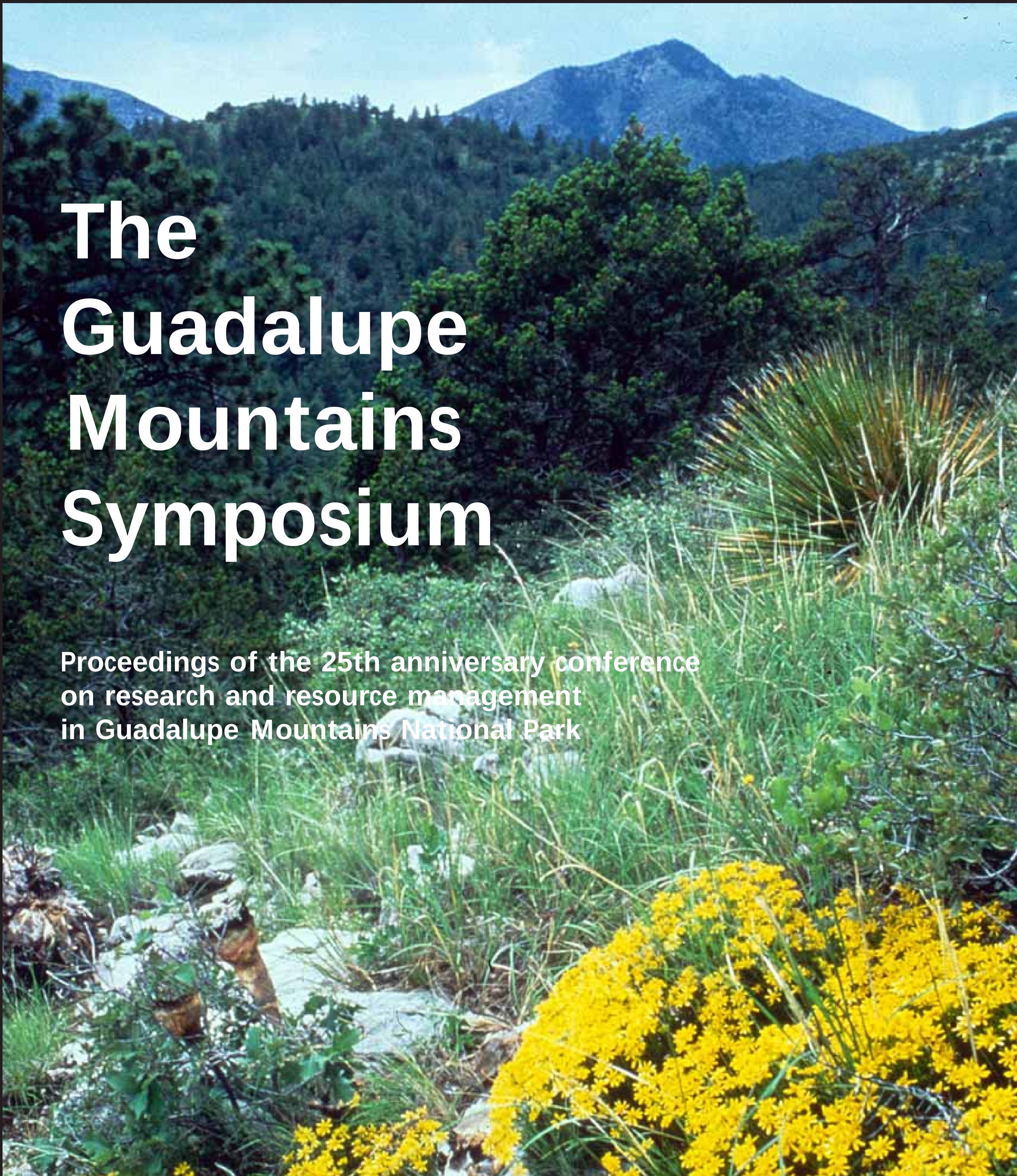
National Park Service
U.S. Department of the Interior

Guadalupe Mountains National Park
Texas



The Guadalupe Mountains Symposium

Proceedings of the 25th anniversary conference on research and resource management in Guadalupe Mountains National Park

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Editor's Message

The first Guadalupe Mountains symposium in 1975 was held primarily to present baseline research results about the new park and to enhance communication between researchers who were unaware of each others' projects. As the time approached to celebrate the park's 25th anniversary, 22 years of additional field studies and scholarly research had taken place. What better way was there to share results of that second wave of studies and, again, to facilitate communication between researchers of varied disciplines than to hold another symposium, this time in conjunction with the park's anniversary.

The 25th anniversary symposium was sponsored by Guadalupe Mountains National Park, the National Park Service, the Carlsbad Caverns Guadalupe Mountains Association, and Texas Tech University. Financial contributions of the National Park Service, universities, private organizations, and independent researchers provided support for the research presented at the symposium.

Readers of this volume will notice a wide range of presentation styles. This is because many presenters shared their knowledge of the Guadalupe Mountains from personal experiences and hand- written notes, and these presentations appear as transcripts in the symposium volume. Other presenters prepared papers, which appear more-or-less in the original form. Regardless of their form, we consider all of the symposium presentations as important summaries and significant documentation about the cultural and natural resources of the Guadalupe Mountains.

The presenters at this conference represent only a fraction of the research that has been accomplished since that earlier symposium and the inception of the park. Many other projects would have been appropriate for this symposium volume, but the investigators were simply not able to attend. However, additional research results and associated bibliographies may be reviewed over the Internet at http://science.nature.nps.gov/permits/.

One of the more important aspects of the gathering was to capitalize on the wealth of collected experience and knowledge, and to hold open forums about potential research, education, and management directions for the park. We encourage you to periodically revisit this volume and evaluate where we stand with the recommendations discussed during the forums. Furthermore, we encourage current and future park employees, researchers, and educators to use the knowledge herein, as we fulfill our roles as the present stewards of Guadalupe Mountains National Park's outstanding natural and cultural resources.

Edited by Fred R. Armstrong and Katie KellerLynn
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The Guadalupe Mountains Symposium

Carlsbad, New Mexico
April 22-25, 1998

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on research and resource management in
Guadalupe Mountains National Park

Preface

The papers included in this volume are part of a research symposium devoted to studies associated with Guadalupe Mountains National Park. The symposium was held in Carlsbad, New Mexico, on April 22–25, 1998. It was the second such research conference and focused on the park since its establishment in 1972. The first conference was presented in April 1975.

This second symposium was organized as a response both to continuing interest in the park's natural and cultural resources and as part of the 25th anniversary of the establishment of the park. Over 50 presentations, nearly 50 poster displays and exhibits, and 11 field trips were included in this conference.

At the time of this conference, each participant was promised a copy of the symposium proceedings. It has now been over five years since the end of this conference. And from nearly the beginning of my tenure as the superintendent of Guadalupe Mountains National Park in 2000, I have been aware of the commitment we made to publish and provide the proceedings to participants. It has been a more difficult undertaking than any of us probably expected. And while none of us on the park staff are happy with how long it has taken us, we are finally able to fulfill our commitment. More importantly, we can now make available the significant work done on behalf of the park by so many researchers, scholars, and employees of the National Park Service. Research, learned thought, and writing will continue to contribute to the management of this park and the preservation of its fragile and increasingly rare natural and cultural heritage for all people to explore and enjoy.

It is also with sadness that we dedicate these proceedings to Dr. Garner Wilde who recently died in a tragic automobile accident. Dr. Wilde's work exemplified the passion many scientists, historians, educators, and artists have had for this park over the years. His work will guide us as we continue to study the natural and cultural history of Guadalupe Mountains National Park. And we hope his example will serve as a model for all those who come after.

—Ellis Richard, Superintendent
Guadalupe Mountains National Park
2000-2004

Welcome

I want to welcome all of you here to the second Guadalupe Mountains symposium. This event is a closeout for our 25th anniversary year and it comes some 23 years after the first symposium was held at Texas Tech University after they had done several years of work after the park was established in 1972. So this has been a long time coming; it has been a dream that Jan and I and several others have had in doing for a number of years, but other things always kept taking precedence. Even this year with our 25th anniversary activities, we had some thoughts about whether or not we'd do this; I said, "Yes, we will do this," and all these other people did all the work and have finally pulled it together. So, we really do appreciate all of you coming, because your presence is what will make this gathering and these proceedings invaluable for now and for the future.

During the next three days we plan to focus on the studies that have been associated with Guadalupe Mountains National Park and adjacent land resources, assimilate ideas and conversations related to future studies, and present the results of the many studies that have occurred in the past 25 years. This is a pretty exciting time to be here, and it's just wonderful that it has all come together. Where the first symposium presented the results of baseline biological studies that were done after the establishment in 1972, this symposium and convocation of scholars, resource managers, and interested public will focus on the much broader ideas of geological, cultural, and biological interest. So we have expanded our horizons over the decades and look forward to you all sharing the results of your studies. I hope that this will also stimulate from you all suggestions, ideas of areas where we need to focus our efforts and resources in the future on different projects and needs, and we will appreciate your suggestions related to things that we are doing in the management of the resources of the park and the surrounding resources. This is a time where if you are ever going to be open and candid, we expect it now so that this can be the most productive gathering that it possibly can.

In assembling this, we will have the presentation of some 49 talks given by 52 speakers, three open forums, 30 posters, 19 exhibits, and 11 field trips. One of the tough parts here during our time will be picking and choosing, because there are some wonderful things being scheduled, and although you would like to be three or four people [so you can attend sessions simultaneously], it's not meant to be. All of you will receive a copy of the talks as the proceedings are published afterward, so you will be able to have everything that has been presented and some presenters who weren't able to make it will also be in the proceedings. We hope you'll take full advantage of this symposium for learning, sharing, and inspiring each other about the important resources of the Guadalupe Mountains and this very special national park. We really do appreciate your coming and look forward to the interface during the next couple of days.

Now I would like to introduce the honorable Mayor Perkowski. Mayor Perkowski will come and welcome you to the City of Carlsbad.

Thank you very much, Larry. It's a pleasure to be here today and it's a pleasure to have all of you in Carlsbad to participate in this symposium. I got the sheets and I found out what was going on, and I am going to apologize to you; I wish I could be here for all three days of it, but in my real life I am an assistant principal at a middle school and they make me be there most of the time because we have all those kids to take care of, but every chance I get I will be over here because I think some of the speeches and some of the presenters and some of the projects that you are going to be working on over these next three days sound so interesting and really neat. I wish there was some way we could get our school children over here to hear some of this and to be part of this. But I know that that's not always possible.

For those of you that aren't from Carlsbad, I just want a few minutes to tell you a little bit about our community. It's a community of people who work together very closely to make things happen for the good of the community and the good of the area. That includes working with the National Park Service. It is a community that is highly dependent upon tourism and for many years was highly dependent upon extractive industries. We have finally diversified our economy enough that the extractive industry part of it has become a smaller section, but we still are very, very reliant upon getting the tourism here and bringing people that come in and go to the national parks and see the sights and do all the things that we have in Carlsbad. To say that this is a community that can work together, a very good example of that is working with Larry and Frank Deckert from the Caverns. When they had the budget crunch a few years ago, Carlsbad was the only community that could work together to get our national park open. It took the community coming up with the money to pay, but more than that it took the national park people that were willing to help us and work with us, and I know Frank and the people at Carlsbad Caverns were called and told them they didn't have to go to work if they didn't want to, even though we were trying to get the Caverns open, and every one of the people out there volunteered to go and volunteered to go out there and get paid and work even though they probably knew in the end they would get paid for this anyway while the budget was getting done. We got the Caverns opened and it saved a whole lot of headache and heartache for the people living in Carlsbad and getting the tourism going.

It's great to see Ron Kerbo back in the audience. I have served with him on a task force on Lechuguilla Cave, and one of the questions we were asking was whether or not we were going to develop it and let people go down and see the cave and what was going to happen. Of course, as you all are probably aware, that committee came back with a report that said we did not want to open the cave to the public and we wanted to maintain the pristine atmosphere or the pristine situation that is there in the cave. One of the things that grew out of that was cooperation of the National Park Service with our congressional delegation, and we are, we hope, a minor step—but as we all know it is a major step—away from being designated as the community that will have the Cave and Karst Research Institute in Carlsbad. That has passed the senate. It's out of the House of Representatives Energy and Natural Resources Committee, and it's up for a vote on the house board in the near future, and then it will go to the president. We hope that we can continue to work and develop that into a major resource for the community and for the National Park Service and for the Guadalupe Mountains, as we look at all of the cave and karst formations in this area.

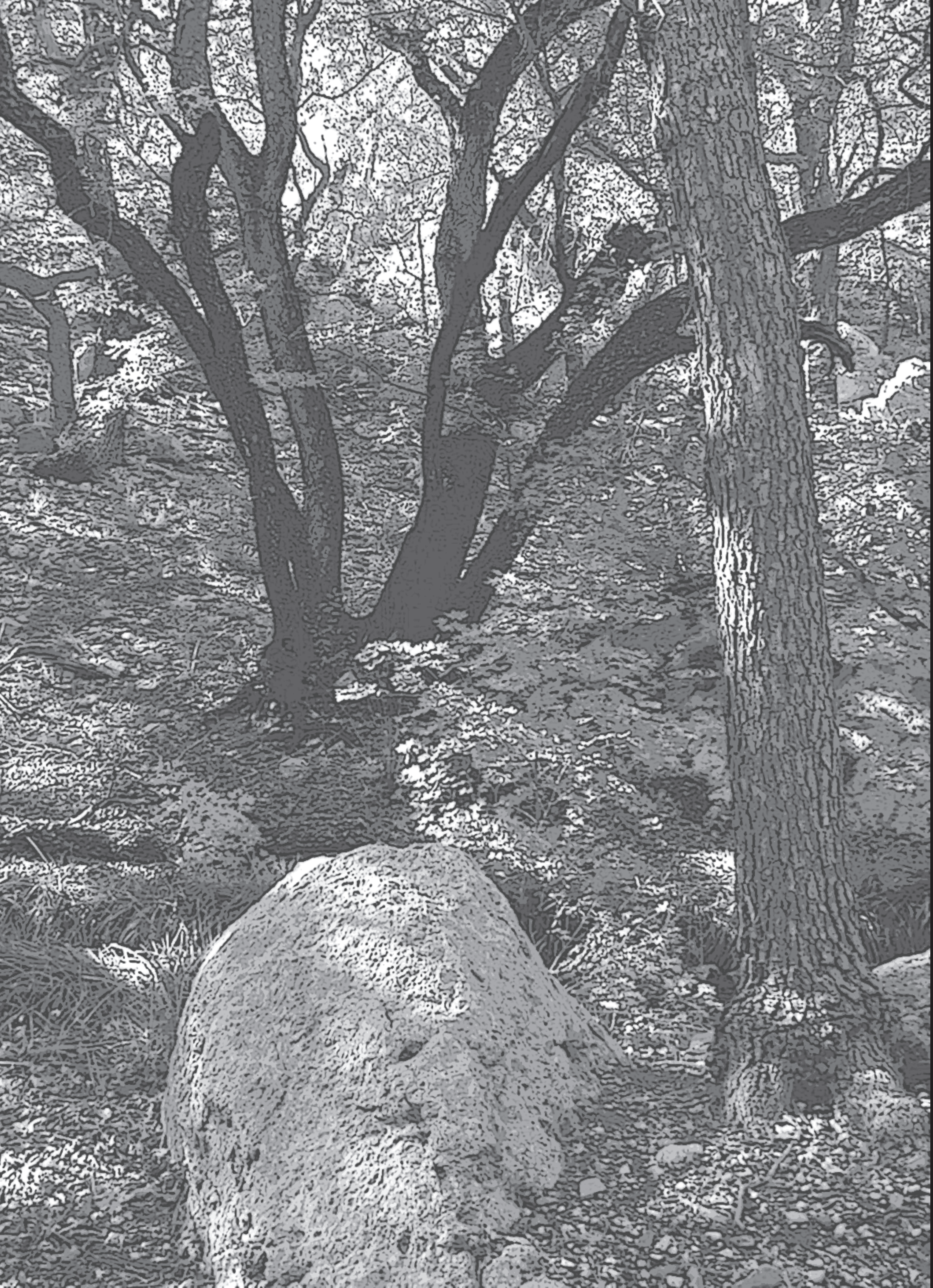
I apologize for the fact that the lake is not up. It's a little prettier when the lake is up, but at this time we are involved in an erosion control project where we have been passing water on to Texas. We have come into a problem with the erosion on the bank over here. We were about to lose our par 3 golf course. Plus we were putting a lot of extra dirt into the river against the dam, and we were afraid we were going to lose it in the end. We didn't know what to do, and it's a project that now has become an erosion control project and recycling project. You may, on one of your breaks or if you get a little time, want to go look at this project because in the process of saving the bank and doing a good job with this the City of Carlsbad, the environment department and the State of New Mexico and a couple of contractors that are doing this, it has become a unique one-of-a-kind project in which we will be taking 300,000 old tires out of the environment and putting them in the bank of the river to stabilize this and make it where we can probably continue to have a par 3 golf course and not lose it to the Pecos River as the water comes down. We are pretty proud of that, and we do apologize for it, but it's something that had to happen.

I thank you again for letting me be part of your program today. I will hope to give back as much as I can and be part of it as we go along. Thank you for being here. I wish you good luck and welcome to Carlsbad.

LARRY HENDERSON: The project out there is quite impressive. They were funded with some equipment that bundles about 25 tires, compresses them all together in a big very heavy bundle, and then they inject that whole thing with cement, and it makes a very permanent way to recycle those tires. It's also going to provide an extension of our multi-mile walkway along the river. It will be a real asset to the local environment.

Note: LARRY HENDERSON was superintendent at Guadalupe Mountains National Park from 1990 to 1999. GARY PERKOWSKI was mayor of Carlsbad, New Mexico, from 1994 to 2002.

Introduction



Chapter 1

The Last Traditional National Park: Guadalupe Mountains

HAL ROTHMAN, Ph.D., is a professor of history at the University of Nevada-Las Vegas and editor of Environmental History. He is currently compiling a history of Carlsbad Caverns and Guadalupe Mountains national parks.

I'm here in an interesting capacity. What I'm trying to do is put some thoughts together for you, not so much about Guadalupe Mountains National Park itself but about its meaning and its place in the history of national parks, as well as in American culture and society. I have become fond of calling Guadalupe Mountains "the last traditional national park," and I do that with my tongue in my cheek. Guadalupe Mountains is really one of three of the last traditional national parks in the lower 48 states. I mean this figuratively. The window during which Guadalupe Mountains National Park was both proclaimed and established, that little six-year period, is a pivotal moment in the history of national parks in the United States. It marks the end of a tremendously long era that began with the establishment of Yellowstone National Park in 1872—the great and enormous Yellowstone National Park—when they just drew a great big line around all that area and said "there ain't gonna be much up there that we can use in commercial economic endeavor, so let's lock it up." With those cool geysers and big waterfalls and wide rivers, not to mention spectacular vistas, we can make a national park out of that land, a place Americans can respect and revere, and not incidentally make some money from. This idea functioned with relative ease throughout the first half of the 20th century; most national parks were scenically spectacular—not necessarily as fantastic as Yellowstone—and they were created mostly from federal land. If you look at the creation of those parks, you get Yellowstone, the transformation of Yosemite from state park to national park, Rocky Mountain, Mount Rainier, and the others; they all share traits with Guadalupe Mountains National Park. First, all are expansive. Yellowstone is of course a great deal bigger than the more than 76,000 acres that Guadalupe Mountains was originally proclaimed to preserve, but Guadalupe Mountains still represents the idea of expansiveness. All such parks were remote or difficult to reach at their time, and it was easy to conceive of them as wilderness.

We can make a national park out of that land, a place Americans can respect and revere.

In a changing society after 1950, park proclamation became a fractured process. By the mid-1960s, the National Park Service had begun to move in many directions. Some of these expanded its reach; others were the result of changing values in American society. The National Park Service had always been among the most supple of federal agencies, the one that had the least trouble responding to the demands of the public—for better and worse—and as its values changed in conjunction with the times, so did the kinds of parks it sought to establish. I have become fond of saying that the Park Service has gone through three basic stages: the first was a long period of landscape architecture and dominance of facilities development, really from the founding of the agency in 1916 until the 1960s. During this time, the agency built a constituency by offering facilities—amenities really—that helped people identify with the national parks and not incidentally with the green of the Park Service uniform. A very short period of science followed in 1963, the year the Leopold report came out, and for a brief instant the Park Service became what some of its constituents thought it should have always been, a preservation-based agency that managed by scientific principles. But the growing demand for national parks and their amenities—the same circumstance that led to Mission 66, the greatest development project in the history of the agency—also forced new realities on the agency. By the time of the famous riot in Stoneman Meadows in Yosemite on July 4, 1969, law enforcement—people management actually—had come to dominate the agency. The first era was about building, then a very brief interlude was about thinking and about science, and since then parks have been about people management. I think that's telling. I believe it has the ring to truth to it. It also clearly indicates the pushes and pulls of park management at time of the establishment of Guadalupe Mountains National Park.

By the 1960s, the United States had become a very different place that had different psychic and cultural needs from its national parks. Thirty years had passed since national parks served the purpose of spiritual enlightenment. In late-19th-century America, national parks came to represent the tripartite meaning of American land: they showed the power of Manifest Destiny, after the rise of especially geology, the empirical knowability of science, and of course, the sublime that so enticed the 19th century. The parks told Americans not only that their quest to conquer was justified, but also that they could know about nature—they could create boxes on which they could put labels that gave them the power of definition—and even more, they could appreciate nature's beauty and feel good about themselves for doing so. This was heady stuff for a young nation, feeling its way to maturity during the years before World War I, a time the American writer John Dos Passos called "the quiet afterglow of the 19th century."

Americans came to national parks to understand themselves and their nation, and they felt better about themselves and their culture as a result.

This cultural impulse dominated at the turn of the 20th century. It far exceeded recreation or any other purpose for national parks. Americans came to national parks by train and were in awe when they looked around. They came to understand themselves and their nation, and they felt better about themselves and their culture as a result. In short their reasons were spiritual. I think they went for uplift, to feel closer to their deities, to appreciate the beauty of nature, and especially to feel the power of American society. They affirmed American culture by their actions. That's clearly not what most people were doing, at least not consciously. By the 1960s a great deal of park visitors were "the young me and my parents." We were people headed out West once again, but in a different kind of way. On some subconscious level we traveled to belong, but the affirmation we sought was less of the nation than of ourselves and our position in it. We were driving around in cars, going to national parks because we thought we should. Nothing revealed this need to belong as much as the once ubiquitous "I visited Carlsbad Caverns" bumper sticker. Everybody in the American middle class grew up with one of those; it was a marker of belonging, of being part of the post-World-War-II middle class. If you had one of those bumper stickers, you were somebody! If you didn't, well, tough. I once met somebody who said the hardest thing about his childhood was that his family didn't have one of these bumper stickers on their car. And so somehow, they were left out. This was a different kind of belonging; it wasn't a cultural uplift as much as it was a form of experience, a counting of events and activities that made you part of the nation.

It is in this context that Guadalupe Mountains National Park enters the picture. It's a park with wilderness attributes in its initial formulation, but it comes about at a time when people are looking for experience. It also coincided with the moment in which national goals and aspirations, in general, especially for national parks, were beginning to change. In the cultural climate of the 1960s, national parks seemed remote from the concerns of many Americans. In fact, by the mid-1960s, it was easy for people who were not far from poverty to point to national parks and say, "These are trophies for a certain class of people in our society, and a certain class of people who get all the perks to begin with." What grew out of the response to that sentiment was nothing less than the latest in a series of reshapings of the boundaries for inclusion in the national park system. Historic sites found their definitions most radically transformed. If you look at, for example, Pipe Springs National Monument on the Arizona-Utah border, you'll find basically a 19th-century Mormon fort set over a well that Paiute people once used, proclaimed in the 1920s as a national monument. It's very typical of the early generation of national monuments. Pipe Spring is an intermediate site, located between Zion National Park and the North Rim of the Grand Canyon, and added to the system because Stephen T. Mather, the first director of the Park Service and the visionary who framed its earliest goals, thought it would be a good place for automobile travelers to stop on the long dusty roads between his crown jewel national parks. Its larger historical significance is minimal, and what significance there is reveals the raw power of Anglo-American society—in this case Mormons—when confronted with the needs and desires of Native Americans.

History in the park system in the 1960s began to mean something far different. It indicated inclusion, belonging, a place at the American table. In some cases, it granted official status, gave specific groups long left out a claim to Americanism. In 1962, the Frederick Douglas home, the property most associated with the famed Abolitionist spokesman who had been born a slave, became a national historic site. In 1980, the Women's Rights National Historic Park came to be. Other areas, commemorating and in some cases sanctifying varieties of American experience, followed. Such places offered categorically different explanations of the past. Their inclusion in the national park system spoke volumes about the broadening of what American history, both officially or unofficially, included. These places told a different story than did Pipe Spring or even what the Civil War battlefields brought into the park system during the New Deal of the 1930s. A place in the park system meant a place in the nation.

Against that backdrop, another kind of national park area began to be created, but these aren't really national parks in the traditional sense, but national recreation areas. A significant percentage of national park areas also experienced local use. Bandelier National Monument, which on some days serves as a city park for Los Alamos, was typical. People from the nearby Los Alamos National Laboratory have a close relationship to the park. They enter for no charge under an agreement; many come down there to eat their lunch and view the archaeological sites, and they engage in an entire range of recreational and cultural activities. That has always been one of the functions, but it's never been even the primary function of any of the more traditional national parks, places like Yellowstone, Yosemite, or Glacier national parks. With the creation of national recreation areas, especially Gateway in New York and the Golden Gate National Recreation Area in the San Francisco Bay area, a new kind of national park developed. Here was a nationally reserved area aimed at day users, at local people, and at regional constituencies that traditional national parks did not always do much to serve. This development represented a broadening of the purpose of national park areas, even more so than did the new historic sites. National recreation areas gave recreation a pre-eminence in the park system, which it had not achieved earlier.

I have become fond of referring to Golden Gate as the first national park of the 21st century. Its goal, its mission, is no less than to be all things to all people all of the time. At Golden Gate National Recreation Area, even dog waste has a constituency; there are people who will battle for the right to take their dogs into the park and accept the responsibility of cleaning up after them. This is a park manger's dream and nightmare rolled into one. Here is a constituency that accepts responsibility for its impact, but simultaneously sees that it is entitled to create an impact that may have deleterious effects beyond what its proponents anticipate. This is truly a

No federal agency can afford to ignore a vocal public.

Wirth saw himself representing tradition in the Park Service, not as a preservationist but as a promoter, extending the reach of the park system.

remarkable situation; it is what happens when parks are created atop prior public and private uses—patterns of usage established over time that give users a proprietary feeling about the land in question. At Golden Gate National Recreation Area, people used the lands that became the park before the Park Service received mandate to administer. Those people—citizens and taxpayers—had to be brought in to the management equation. They were very often vocal representatives of communities in the area and they had—or believed they had—rights. No federal agency can afford to ignore a vocal public. So a different picture of a national park resulted. It is a national park that serves the local-use constituencies, has lots and lots of historic features, has lots of natural features but has some wilderness—but people hang-glide there too. This is not traditionally what the national parks were about.

Now why is this happening? Of course it's one of the many results of the massive cultural changes in the post-war United States, but it is also happening because the National Park Service itself is changing. Between 1916, the founding of the agency, and 1953, one generation of people ran the National Park Service. Of the first five directors, only one, Newton Drury, did not come up through the ranks and was not, at one point or another, Stephen T. Mather's assistant director. Drury was the only exception to that pattern and as the only genuine preservationist to head the agency, he was a most interesting exception. In 1954 Conrad L. Wirth—who had come into the National Park Service as a landscape architect during the New Deal, which served as the first great development program in national park history—ascended to the head of the agency. Wirth's agency offered a very different focus, a very different way to look at the world. What Wirth wanted to do was build park areas, places that people would use and places that people would see largely from their cars. Wirth saw himself representing tradition in the Park Service, not as a preservationist but as a promoter, extending the reach of the park system. The problems of national parks in the 1950s and 1960s were hardly a lack of visitation; the lack of facilities to accommodate visitors topped the list of issues for the agency. This was a move away from national park values of the turn of the century, not its goal of reaching the people but in the way it reached them. George Hartzog, who succeeded Wirth in 1964 and lasted until 1972, was the last director of the agency who was not a political selection, the last person who didn't survive some kind of political loyalty test to get appointed to the top position in the agency. He was also very much a promoter who strongly valued preservation. In this context, the proclamation of Guadalupe Mountains National Park looks pretty remarkable. It is starting to look like an afterthought or somebody's pet project—which is not entirely untrue—or just something that came together despite the dominant currents of its moment.

Now, the traits of these new parks are that they are all things to all people, they are created from prior uses, and they have easy access for day use. It is surprising to find that Guadalupe Mountains actually shares a history of prior uses with such parks. Guadalupe Mountains is the last major national park created not from federal holdings or gifts, but by purchasing land. There weren't any federal lands in Texas, which was a unique arrangement with the United States upon entering the Union in 1845. Guadalupe Mountains also shared initially another dimension, one that generated a bit of controversy for the park. The traditional national parks—e.g., Yosemite, Yellowstone, Glacier—all did a tremendous amount to obliterate human history within their boundaries. One disgruntled former Park Service employee once told me that there is an enormous wall of file cabinets—and this is of course apocryphal—in the Washington Office of the Park Service that details every historic structure of the national park system that has ever been destroyed, and there are thousands of them. I don't know how true this is, but the point is that the Park Service had a tremendous investment in making the wilderness free of people. At Guadalupe Mountains that erasure by and large, did not happen. In fact, human history was included within the park, and I think that is part of its own process of making a national park in this new era. That is, the natural past was sufficient at the turn of the century when people revered nature as spectacle, as scenery, as affirmation of culture. But in this increasing post-industrial world, in this world of service economies, it has become very important to have a human past in natural areas. So you have Frijole Ranch, Williams Ranch, Ship-on-the-Desert, and other vestiges of a human history preserved within the boundaries of a national park.

Another issue that speaks very much to this changing situation at Guadalupe Mountains National Park was the question of the tramway. The proposal for a tramway to the top of Guadalupe Mountains was an enormous fight, and I will try to locate it in the context here. Tramways were not uncommon propositions in the early 1970s. The idea of accessibility gained great sway as an antidote to charges of elitism in the national parks. Not everybody can get to the top of Guadalupe Peak on his or her own, but on a tramway everybody can. The proposal blended different currents in the park system—in particular the oldest challenge that faced the agency, how to preserve and create access simultaneously—and it loomed very large for the Park Service particularly during the 1960s and 1970s. Was access for everyone, everywhere what a national park ought to offer? Was the goal to offer accessibility or was it to preserve a special kind of experience? I don't think we're through with that dialog yet. Ask any superintendent of a national park with a feature that people desire to see but don't want to do the work to reach it. The Park Service handled the situation as well as it could. It commissioned a number of studies and held a bunch of meetings, and eventually personnel stood by and hoped that the project would die, and in fact it did. It died as much as a result of cultural change, as being studied to death. The studies eventually said that fewer than 50% of the people wanted the tramway, but the fact remained that in some cases, the appearance of action as opposed to real action—a passive approach to not getting things done—makes them disappear just as well as an active approach. This is another version of the old adage that there is more than one way to skin a cat.

In every sense, a national park is a reflection of the moment of its creation. The real dance, the real trick, the difficult thing to do is to maintain the integrity of the values of a national park area as the values of the society change around it. In this context, Guadalupe Mountains is part of what I call the "great aberration," the period of time from 1945 to 1973 when more people in this country did better than they had ever dreamed of doing, economically better than any group of people in human history. There was more wealth, and because of that wealth, people were willing to look at putting things aside in a permanent way. They shared a vision of optimism; they could see their way to a better world. In the 1960s Lyndon Johnson used to talk about ending poverty for all time. Now we're happy to settle for holding the line at 13% of the population below the poverty line. During that great aberration it was possible to attempt and sometimes accomplish social, political, and even environmental objectives that could not have been considered during other times. It was possible to say, here's a tract of land with about 100,000 acres that we can hold aside. First of all, we can get it cheaply. Second of all, there aren't a lot of evident ways that it is going to offer us great economic benefit.

The difficult thing to do is to maintain the integrity of the values of a national park area as the values of the society change around it.

Guadalupe Mountains also falls within a category that I call "quality of life maneuvers." This category really begins with the implementation of air and water pollution standards in the late 1940s and 1950s and ends more or less with the Endangered Species Act in the 1970s. It includes the Wilderness Act of 1964, as well as all kinds of legal mechanisms that represent the success of traditional environmentalism in the United States. Why does Guadalupe Mountains fit in here? As in many other places, wilderness became a representation of quality of life, proof of a society that could expand and save at the same time. And of course, with the proclamation of wilderness—first in Guadalupe Mountains, later at Carlsbad, and then finally including the wilderness study area in the adjacent national forest, a large complex of interconnected wilderness, which is really the intellectual province of Guadalupe Mountains National Park, was established.

Wilderness had a very special resonance during this time period, because we were again feeling ourselves over-civilized, again feeling unable to get in sync with ourselves even as the economy seemed to be going well around us. Wilderness became a marker not so much of cultural affirmation as it had at the turn of the century, but of individual experience. Never mind that we were able to accomplish this experience largely with the technological tools created by the space program—the lightweight pack frames and the featherweight hiking shoes, the freeze-dried food, and other technological improvements—that made the wilderness possible for even the most unfit of us. Without those accouterments, we'd have to experience wilderness on its own terms. Many of us might like to think we're Daniel Boone, but we're not.

"This is a harsh, dry, bitter place, lonely as a dream. But I like it. I know I could live here if I wanted to, if I had to." Ed Abbey

As wilderness experiences have been made more palpable, more accessible, it has become available to more people. What has happened, I think, in the 25 years of this special place, is that the park was established for one purpose and now it is gradually acquiring another one. It seems to me that Guadalupe Mountains National Park was invented, was created to preserve itself and to preserve its specialness. This is me waxing eloquent as opposed to being cynical; there are cynical things to point to in the creation of any national park. But what's happened is that national parks have become, and have had to become, more than stored-up scenery to be admired. They are also agents of economic development. The mayor of Carlsbad just got up here and acknowledged the incredible significance of tourism in his town. In Wyoming, where I recently spoke, one of the things they still have a hard time doing is getting tourism out of the shadow economy and into the sun. Very clearly, that process has happened here in the last ten years or so. But in fact, the rise of tourism here has been instrumental in perpetuating Guadalupe Mountains National Park, and in making it far more significant to a wider audience.

The resistance to oil exploration in the vicinity illustrates this point. During the late 1970s and early 1980s, oil companies sought to create access to drill in and near the wilderness areas. Oil prices were sky-high and domestic oil production was an agreed-upon goal. Yet, the people of southeast New Mexico were not only unhappy about this prospect, they battled against it. A local newspaper, the *Carlsbad Current-Argus*, came out against oil drilling in the Guadalupes. It argued that in this case, environmentalists had a significant point: drilling for oil ought to take place first in less environmentally desirable areas. The idea that a local newspaper editor in the American West would say that environmental goals should supersede energy exploration in 1980 is almost beyond comprehension. Tourism—that nebulous invisible source of jobs—over oil exploration, patriotic and industrial? Guadalupe Mountains, as well as Carlsbad Caverns, is part of a revolution that is clearly underway. The service economy has come in incredibly important ways and projects an economic future: the transfer payments of retirees, accepting low-level nuclear waste, and more and more tourism. This is made possible by more and more technology and mitigated by the vast distance from the interstate to the Guadalupe Mountains, in particular, and to Carlsbad Caverns as well. There is no greater barrier for tourism in postmodern America than being more than twenty minutes from the interstate highway.

So this is where we stand at the 25th anniversary. Guadalupe Mountains is a national park with a wilderness that is desirable to a certain constituency. As the wilderness comes to represent the meaning of the national park and as distance from the main arteries of American society becomes even more a marker of group values, the constituency for places like Guadalupe Mountains—which can claim remoteness and wildness—will continue to grow. Here is a park that is bifurcated in complicated ways.

I want to leave you here briefly with two thoughts: one from the iconoclastic writer Edward Abbey, who observed in the 1970s from atop Guadalupe Peak: “This is a harsh, dry, bitter place, lonely as a dream. But I like it. I know I could live here if I wanted to, if I had to.” Then, finally, with Nevada Barr’s Anna Pigeon, the ranger from *The Track of the Cat*, which I know is probably not everybody’s favorite book. But there is a marvelous scene in that book when Anna finds herself on horseback taking water to Pentecostals marching for Jesus to the top of Guadalupe Peak. Of course, they are unprepared; there are pregnant women; there are people who are too overweight to be able to make the trip; they don’t have enough water per person. Yet here they are streaming up the side of the mountain by the thousands in the hot, late-spring sun. They are recklessly endangering themselves, and it’s the ranger’s job to make sure their danger is not too real. I think encapsulated in those two little vignettes are two futures, the two intertwined and largely inseparable futures of Guadalupe Mountains National Park.

Chapter 2

A New National Park: Research Needs and Challenges in the 1970s

DONALD A. DAYTON is a resource consultant. He retired from the National Park Service after 35 years. He was the superintendent of Guadalupe Mountains National Park from 1972–1981.

Welcome to the Guadalupe Mountains Symposium. It is almost like a reunion for me with all the faces that I recognize from the 1970s. My 10-year association with this park was one of the most enjoyable and fulfilling of my 35-year career with the National Park Service.

For better or for worse, the new national park authorized at Guadalupe Mountains was born at the time of controversy and upheaval within the research discipline of the National Park Service. Historically, research had played only a minor role in the functions of the National Park Service prior to the 1960s. In fact some early administrators of the agency, as well as congressional committees, were openly hostile to the need for basic research in the National Park Service.

It was not until Director Hartzog's assumption of office in 1964 that research began to gain recognition. Even then, Director Hartzog had to substitute the designation "resource studies" for "research" and disguise the program in budget requests to get a reluctant congress to appropriate significant funds. However, with recognition and significant funding finally achieved, controversy erupted on who should direct the work of park scientists. This wavered back and forth for several years. Director Hartzog initially placed all research and supervision of the scientists in the National Park Service under the chief scientist in the Washington Office. A division of Natural Science Studies under the director was created.

Centralized management of the National Park Service science program began to fade in 1969 when Hartzog removed the program from under his direct supervision and buried it in a cluster of eight divisions in the Washington Office. Then in 1971 shortly before Guadalupe Mountains National Park was formally established, Hartzog transferred Washington Office staff scientists to regional offices, some to serve as regional chief scientists reporting to the regional directors. This may have been fostered by a perceived need to de-emphasize pure research in favor of research that met resource management needs. The development of the Resource Management Plan program for all field areas was getting under way and with it came the realization of the need for developing large amounts of basic resource data as a foundation for the plans. One issue that developed at Carlsbad Caverns National Park a couple of years earlier may have helped to influence this change. The resident biologist under the direction of the Washington Office chief scientist took deer specimens for research purposes at Carlsbad Caverns National Park in direct defiance of New Mexico requirements for state issued collecting permits. The issue went into court and ultimately to the secretary of the interior. While the court decision confirmed the authority of the federal government in collecting specimens inside federal areas, the secretary nevertheless mandated that henceforth, the National Park Service would cooperate with state agencies in the taking of large mammal specimens for research purposes. The fallout from this created some problems for the Service.

Guadalupe Mountains was born at the time of controversy and upheaval within the research discipline of the National Park Service.

Scientific research in the early years of the National Park Service was minimal.

With the decentralization of the Service's research program, pressures began to mount. The role of the park superintendent increased. While biologists stationed at parks were under the technical supervision of the regional chief scientist, administrative direction came from park superintendents. It took considerable cooperation between the regional chief scientist, park superintendents, and field biologists to make this type of organization work. Success varied from park to park and with the attitudes of the personnel involved. As the first superintendent of the new Guadalupe Mountains National Park, I had the good fortune of having previously been employed as a research parasitologist at the U.S. Department of Agriculture Research Center at Beltsville, Maryland early in my career. As a park manager, this gave me the perspective of looking at issues from the standpoint of a former researcher as well as a manager. Unfortunately, not many superintendents had this advantage.

Having arrived at Carlsbad Caverns National Park in 1971 when the park biologist was still directly under the Washington Office and then being able to compare this experience with the later organization proved to be beneficial. With the reorganization, superintendents were closely involved with the regional chief scientist and field biologists in the coordination of research planning with resource management planning. I recognized the great benefits available in basic research data inventories serving as a valuable tool in developing a complex resource management plan for the new park. Fortunately, Guadalupe Mountains National Park came on line just as the Servicewide emphasis began to be focused on research as well as resource management planning. Regional Scientist Roland Wauer was instrumental in setting up an excellent research program for developing a comprehensive basic resource data inventory plan and cooperatively we were able to get it funded at the rate of $25,000 per year initially for five years. This was later extended. While not a big sum today, it was significant in the early 1970s when research and resource management were just coming into their own. This funded project came at a critical time, and we looked forward to it. Through a contract with Texas Tech University, Ro Wauer was able to get a cadre of highly talented scientists to tackle this ambitious research project. Disciplines deemed to be of top research priority for this project included:

1. Inventory of flora
2. Fire ecology
3. Inventory of fauna
4. Climatological data
5. Inventory of significant geological features
6. Vegetative analysis
7. Faunal factors
8. Data analysis
9. Human intrusion on the ecosystem
10. Soils inventory and analysis
11. Water resource analysis
12. Inventory of microorganisms
13. Ecosystem analysis

The association with these enthusiastic research professionals proved to be one of the more enjoyable parts of my management experience in these early days of the new park. Coordination and cooperation between all parties was excellent.

The arrival of Dr. Gary Ahlstrand as the staff biologist for both Carlsbad Caverns and Guadalupe Mountains was a tremendous asset. He was able to work well with the contract research program and provided much to the great success of the project. He later went to Texas Tech to head up the first CPSU by the Service at that location.

Guadalupe Mountains National Park was probably one of the few new national parks to benefit from such a comprehensive basic resource data inventory in those days and it fell right in sync with the other park planning taking place. It proved to be of immense value in developing the Resource Management Plan, Wilderness Plan, General Management Plan, later Master Plan, Interpretive Plan, Resource Protection Plan, and Development Concept Plans for the new park.

As stated previously, scientific research in the early years of the National Park Service was minimal. Probably some of the earliest research efforts in the Guadalupe Mountains area took place in the late 1920s, when J. Stokely Ligon, a biologist with the U.S. Biological Survey spent two years doing a wildlife survey of the Guadalupes for the State of New Mexico. In 1931, Ben Thompson of the National Park Service and George Wright of the University of California conducted a preliminary wildlife survey and reported on the unique wildlife resources of the Guadalupe Mountains.

October 15, 1966, was a momentous occasion for the Guadalupes of West Texas. With the signature of President Johnson on legislation authorizing Guadalupe Mountains National Park, 32 years of effort by many people in Texas, New Mexico, and the National Park Service came to fruition. However, this was only a step in the process required to create a new national park. It was not until September 30, 1972, after the mineral rights and land acquisition requirements had been met that the new national park was formally established by Federal Register notice.

As a park project under the administration of Carlsbad Caverns National Park from 1967 to 1972, the area received only minimal caretaker staffing and protection. With the formal establishment in 1972, a new park was born and visitors began coming. As superintendent at Carlsbad Caverns, I was given the additional duty of superintendent of this new national park. Initially relying largely on the staff at Carlsbad Caverns, a new organization for joint operation of the two parks was established and headquartered in the town of Carlsbad.

Recognizing that the new park was not only of national geological significance but equally of great ecological and historical importance, the need for many research studies and investigations became critical. Unfortunately, until the park was formally established, significant funding for anything other than land acquisition was hard to come by. Suddenly, we had a new park with fragile ecosystems and little research data with which to develop a Resource Management Plan. To compound the problem, the area was not pristine but had been subject to years of grazing by domestic goats. Fortunately, it had been owned for many years by people with a feel for the environment. Both J. C. Hunter Jr. and Wallace Pratt had preservation utmost in their minds as they ranched the mountainous terrain. Nevertheless, heavy grazing of the high country, the westside desert, and the Dog Canyon area over many years took its toll on the ecology of the area. The accumulation of domestic goat manure in the Bowl area of the high country contributed to an unnatural buildup of a grass and brush understory beneath the relict forest. A tremendous fire potential existed. Without research in fire ecology, particularly in the Bowl and the relict forest area, it was almost impossible to plan a fire management program.

Unfortunately, some of the private land to the north and west of the park boundaries had been heavily grazed—down to bare rock in many places. Huge erosion gullies were prevalent. Some of this erosion extended into the Dog Canyon area of the park. Livestock trespass into portions of the new park was a severe problem. Consequently, one of the priority projects early on was to obtain funding for boundary fencing on the north and west boundaries. Five years later, the comparison of vegetative growth from one side of the fence line to the other was very significant.

Fortunately, the McKittrick Canyon area, one of the most ecologically fragile areas of the park, escaped much grazing activity in the early days because of the rough terrain. Even the reintroduced elk population had been fenced off from a portion of McKittrick Canyon by the early owners. The floor of McKittrick Canyon itself had been available to motorized vehicle travel as far as the Hunter Lodge in the upper canyon. For many years the owners invited overnight guests into the area. Upon acquisition, the Hunter Lodge was removed before it reached historical status. Fortunately, in 1968 a major flood wiped out part of the

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road into the Canyon. This provided the impetus to permanently discontinue public vehicle use of this road. The relict forest of the high country, and accompanying plant associations, needed much study in order to properly manage and interpret this valuable resource.

The Pine Springs-Frijole Ranch area also had received significant grazing over the years. With protection, it has gradually recovered. The west-side low desert land of the park in particular had received very heavy grazing over the years. Because of substantially less rainfall than other parts of the park, this area has been very slow to recover.

Fortunately, some advance knowledge of the ecology of McKittrick Canyon existed because of the extensive and valuable studies by Dr. Barton Warnock of Sul Ross College in the years prior to and during the park authorization period. However, in order to obtain additional knowledge of the interaction of periodic natural flooding of the canyon and natural plant succession, much more needed to be done. This periodic flooding and intervening reestablishment of the travertine seal of the stream bed needed research studies to further identify the effects on the ecology of plant species in the canyon bed and along the canyon walls. It was also crucial for later planning to determine the extent and type of public use that could be permitted in the canyon.

The reintroduction of elk by early owners of the property created management problems for the new park, particularly after the artificial water supply in the high country was removed.

Geology was probably one aspect of resource studies that received the most research prior to the establishment of the park. However, this was concentrated almost entirely on geology related to oil exploration and was carried out by various oil exploration companies trying to find significant oil reserves in the reef formation. These companies were very cooperative in sharing data after the park was authorized. The Guadalupes were also used as a training ground for student oil geologists. Cave resources in the fossil reef had essentially not been inventoried prior to the park establishment. Previous landowners took a dim view of spelunkers and generally prohibited cave exploration. The National Speleological Society and National Park Service cave specialists began extensive studies of the karst resources after the park was established.

Outside of the development and utilization of small springs during ranching days, practically no research had been done on water resources or the watershed of the park. With the semi-desert climate existing in much of the park, knowledge of the water resources was critical in order to properly plan for management of the park. It was essential that utilization of water resources for park facility developments be very limited and selective to cause the least damage to the resource. A very low flow spring at Dog Canyon barely provided for the previous ranch employee residence. The Pine Spring originally with a moderate flow, was almost destroyed when early ranchers tried to increase the flow by the use of dynamite. Frijole Spring was one of the few with a significant flow. The Williams Ranch area on the west-side lowland did have some water. Little was known of climate and watershed effects on the plant ecology. Research was needed. When the land for the park was acquired, it came with an extensive network of old pipes, pumps, and reservoirs distributed over the Bowl area of the high country. An earthen tank had been constructed to store water. This network provided water to large herds of goats that grazed the area. It also provided an unnatural water source for wildlife in the high country, including elk. Research was needed to determine what the wildlife distribution should be without this unnatural water source.

As mentioned earlier, the wildlife resources of the Guadalupes received some of the earliest research attention. The reintroduction of elk by early owners of the property created management problems for the new park, particularly after the artificial water supply in the high country was removed. The deer population and their distribution needed study. The mountain lion population in the northern part of the park and the predator-prey relationships needed further study. The peregrine falcon known to nest in the park needed

significant research to determine causes of population decline. Wild turkey was known to exist in the high country as a result of reintroduction years earlier. A non-native species of trout had been introduced into waters of McKittrick Canyon. The black bear was beginning to make a comeback. University researchers from New Mexico, Texas, and Arizona, and other states joined in accumulating valuable resource data on the fauna of the new park.
In the early efforts for the creation of a park in the Guadalupes, little attention was given to the historical and cultural significance of the area. The remains of the old Butterfield Stage Station at Pine Springs were about the only historical artifacts to receive much recognition. However, early on, rich historical and cultural resources were discovered. Unfortunately, little research on the history of the Guadalupes had ever been performed, and management had little data to use. The importance of research in this field was recognized. There was early Indian history, Spanish involvement, the U.S. Cavalry, early-day ranching history, impacts of the California Gold Rush, the early settling of the West, and the tales of lost treasure—all fascinating elements that needed research.

The availability and emphasis of a comprehensive, basic-data research program early in the planning stages of the new park was of tremendous importance in developing management plans. It was hoped that those plans would protect and preserve the unique and fragile resources in the years to come, as well as providing an interpretive base to make visits by the public more enjoyable.

I want to extend my thanks and gratitude to all the great scientific talent that contributed so much to the knowledge of the natural, historical, and cultural resources in those critical years of the new park.

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Chapter 3

Stewards of the Land: The Role of Discovery, Science, and Research

JANICE A. WOBBENHORST has been with the National Park Service for 27 years and at Guadalupe Mountains National Park for the past 10 years. She is the chief of resource management and visitor protection for the park. Her duties include the overall management, coordination, and supervision of the natural and cultural resource management program. She has a Master's degree in environmental affairs.

We're here today to talk about something that is really special to all of us—the Guadalupe Mountains, a very special place. I'd like all of you to think for a minute about your first experience in the Guadalupes—the first time you went there, or some special time when you were in the Guadalupes that has a meaning for you and a memory for you. When I first got back to Guadalupe Mountains in 1988, I told the staff I had a very special and fond memory of the Guadalupes. I told them the story I'm going to tell you now.

I'm a flatlander out of Nebraska. I grew up in northeast Nebraska and I started working for Carlsbad Caverns in 1970. Every day, I'd look out the window from the Caverns toward the Guadalupe Mountains and there was this big peak there. Finally, in 1971, I had the opportunity to go down and climb that mountain. From a flatlander's point of view, I'd never been in the mountains. I don't know that I'd ever seen one before I saw the Guadalupes. There weren't many trails in those days. I climbed to the top of Guadalupe Peak, the highest point in Texas, and stood there just overwhelmed. I opened up the trail register at the top of the peak, and there in the trail register, somebody had written, "How high are we? I think I hear angels." You know for me, that summarized the feeling I had that day with that absolutely awe-inspiring view from the top of our "island in the sky" and with that desert surrounding where you can see for miles. I bet every one of you have had an experience over the years like that, which has stuck with you and made you come back to the Guadalupes.

Our theme for today's conference is stewardship. We're talking about 25 years of cultural and natural resource stewardship in the park. I'd like to look back at stewardship and the role of resource management—explorers and discoverers—those people that have come to the park over the years. I want to go back quite a ways as I talk about that. Let me first talk about the definition of stewardship. What do we mean by stewardship? Webster says that stewardship is [the practice of] somebody who takes care of something, somebody who manages affairs. From the National Park Service point of view that means that we preserve and protect that resource for future generations while we allow people to come use it.

I climbed to the top of Guadalupe Peak, the highest point in Texas, and stood there just overwhelmed.

So what does that mean about the people that were here in the past? I'm sure that the Mescalero Apache, when they were living here, utilized and occupied the resource, and they thought they were pretty good stewards. Likewise, the ranchers, when they were here, were taking care of the land from their perspective and they were pretty good stewards. Now it's our job—yours and mine—as the current-day people involved in the park to take care of this resource and be stewards.

I'd like to look back at the people who have come to the park: those people on whom we found our research today. The first known writings on the park were

It was kind of like a mecca for all of these geologists.

from 1692—we've just discovered this. Don Diego de Vargas was governor of Mexico at the time and he got a group of people together—they came from El Paso to the salt flats—to harvest salt. We are fortunate because the Vargas Project at the University of New Mexico has been translating some of his early journals. He describes the journey to the salt flats and then he describes a side journey they took into a beautiful canyon. He describes the vegetation and the spring in the canyon and he describes a juniper tree next to that spring to such detail that some people think we even know which juniper tree it was in Guadalupe Canyon today. Those early records give us such valuable information that we can base our research on [them] today, and base management decisions on what the park was like in the past.

The next group of people in the park of which we have records came in the 1850s. In 1850, Marcy led an expedition into the Guadalupe Mountains and he talked about the lush vegetation: the grama grasses growing everywhere. And then in 1855, Captain John Pope came to the Guadalupe Mountains. He brought with him a keystone figure, George G. Shumard. He [Shumard] was a physician for that military group. He was a doctor but he was also a geologist. We have a copy of his journal, published in 1886—published after the war. He talks about leaving San Antonio on April 16, 1855, and he arrived at Guadalupe Pass on September 27—quite a journey! He was probably the first geologist to really look at the Guadalupes and study them, and he is the first geologist that we know of that collected fossils in Pine Spring Canyon during that expedition. His journals give us all kinds of incredible information about the Guadalupes. Shumard Peak, of course, is named after George Shumard.

Other people came through the area like John Russell Bartlett when he was doing the boundary survey. The Butterfield Stagecoach came through from September of 1858 to August of 1859. Bartlett described his trip as he rode through the pass, "winding and turning in every direction, we follow the intricacies of Guadalupe Pass. Before us stood the majestic bluff in all its grandeur—solitary and alone." All of these people give us a rich heritage and all kinds of information of what the mountain was like in those days.

I'm going to jump a few years to 1905. In that year we had the publication by Vernon Bailey, with which many of you are familiar. He was a biologist doing the initial biological surveys for the state of Texas. He came into the Guadalupe Mountains and wrote about the bighorn sheep in Pine Spring Canyon – something we don't have today. Again, this is valuable information that tells us a little bit about what the Guadalupe Mountains were like back then. All of those people from that early period give us references to help us manage the resource today.

Since the early 1900s we've had lots of people do research. In the early years, what is now the park was private land, so not much archaeological work got done, but a little bit of biological work got done. People like Davis and Robertson came in. In 1940, they did a mammal survey of Texas and Culberson County. That's valuable information for us today. But the geologists—they're the ones who really came to the park. It was kind of like a mecca for all these geologists. What I would like to know is: when was the very first geological field trip to the Guadalupe Mountains? I don't mean to Carlsbad Caverns; I'm talking about the Guadalupe Mountains. To be honest, I'm not really sure if I've found a definitive answer. But I can tell you that there was a field trip in 1947 by the West Texas Geological Society, and they published a field trip guide book for that field trip. But I also found reference to an earlier one: Philip B. King visited the Guadalupe Mountains on a field trip in 1932. This gives you an idea of how many years people have been going and studying geology at the Guadalupes. Even though it was private land, those geologists were down there exploring, looking, and doing research in the park.

Then came the 1960s and the 1970s. As the park was created a lot of research was done in the park—the initial inventory. This inventory was done primarily by a large group of people from Texas Tech. The National Park Service had a CPSU, a Cooperative Park Studies Unit, with Texas Tech. That facilitated a cooperative relationship between the park and the university. There were all kinds of people from Texas Tech that came to the park and did research. Twenty-three years ago this month, they had a symposium up in Lubbock at Texas Tech on the biological investigations that were being done. They produced this book, *Biological Investigations in the Guadalupe Mountains National Park, Texas*. It's been out of print for a long time. So today, we have it on sale, reprinted specially for the conference today. We're really proud to be able to put this back on the shelves and provide people with this information, because all those people that did that original biological work in the park are referenced in this book. But it wasn't just them, it was people like the Katzes—all kinds of people doing work in the initial inventory.

Now, what does that mean for us today? We, today, are trying to do the resource stewardship in the park.
We're doing the research, we're looking at the resource and providing management with the information that management needs to guide us into the next century. What is our role? It's to find that balance. We talked about the balance between visitors and the park. There's also a balance between people doing research and collecting in the park and providing the information. In our quest to find information and answer resource management questions, [that is] to have enough information to provide us the detailed information we need to make management decisions, we've also got to look at [researchers] cooperating with us to make sure that we preserve the resource.

I'd like to give you an example from when I worked at Bandelier National Monument. One of the special things that I remember about Bandelier is there was this one little mesa top called Tsankawi. You hiked up the trails to this little mesa top. The ground was covered with pot shards, lithic scatter, and little pieces of obsidian everywhere. In 1974 when I walked up there, you couldn't put your foot on the ground without stepping on a pot shard. That's how prevalent they were. In 1995, I went back - 20 years later.
Now when you stand on top of the mesa at Tsankawi, you have to look hard to see a pot shard. What happened to all of them? All the visitors—thousands of people that visited the park—said, "Oh, I'll just take one little tiny piece. If I take one little tiny piece and slip it into my pocket, nobody will notice it; nobody will miss it." And so after 20 years, impact on the resource has been incredible.

That's our challenge in managing our resource. The National Environmental Policy Act (NEPA) says that we need to consider cumulative impacts of everything we do. So we have to think about all the research, and all the collecting, and the information that we gather. And as we go out and seek information in our quest for gathering information about the park, we also have to remember that our ultimate goal is to preserve and protect this park, and to be good stewards of the land for the next century.

Resource Management

Chapter 4

An Overview of the Resource Management Program at Guadalupe Mountains National Park

FRED R. ARMSTRONG has been employed with the National Park Service for 19 years. As the resource management specialist at Guadalupe Mountains National Park for the past six years, he coordinates and implements the park natural and cultural resource management programs.

With each passing year, the collective bank of human knowledge about the world in which we live increases exponentially. It is phenomenal what we have learned over the past 25 years about the cultural story and natural resources of this parcel of land called the Guadalupe Mountains.

If you consider the collective pool of human knowledge about the world from the time of creation to 0 B.C. as a baseline quantity, it then took from 0 B.C. to 1760 for the information that people knew about their world to double. It took another 120 years, from 1760 to 1880, for that information load to double. From 1880 to 1914, only 34 years, it doubled again. There was another doubling after 27 more years, and again after 11 years which brought us up to 1952. It doubled again by 1959. Only 3 years later, the human knowledge bank had doubled again. Since 1985 information about our world has doubled every 6 months or less. Does anybody's brain feel tired yet? Does anybody wonder why we don't know everything there is to know about these resources?

Advances in technology have us learning more and provide the ability to process relationships about our environment that people never thought possible. Studying the resources of the Guadalupe Mountains is no exception. Since the park was authorized in 1966, nearly 250 research studies have been undertaken. These studies have ranged from microscopic fungi to landscape-scale geologic studies; from the early inhabitants and traces they left behind to current visitors with the ways and reasons they come to our national park.

One goal of this symposium is to exchange information about the past and current resource management program. The program has been accomplished through a variety of means which have included cooperative programs, private or university investigators, and federally-mandated assessments and monitoring. Discussing this program is not an attempt to impress anyone, but to get each of us here us to think about what has been done, what yet needs to be done, and even as a springboard to generate new ideas about how we may learn about and share the knowledge of these resources.

Since 1985 information about our world has doubled every six months or less.

The earliest of recorded baseline studies about this area were conducted by Vernon Bailey in 1905. He documented the presence of bighorn sheep, and the black-tailed prairie-dog for which Dog Canyon is named. U.S. Cavalry records of significant water sources and natural resources extend back to the 1860s. Researchers at Texas Tech, Sul Ross State University, the University of Texas at Austin, New Mexico State, Baylor University, and University of Arizona have carried out baseline studies, which greatly contributed to the proper interpretation and management of this park in the early years. An interagency browse survey was initiated in 1973 between the Bureau of Land Management, U.S.D.A. Forest Service, and the National Park Service which provided a good inventory of regional botany. The results of the survey and condition assessment are still used as a basis for our current vegetative cover map. The 1970 Texas Archeological Society Survey and the Katzes' archeological studies in 1973, 1974, and 1976 through Texas Tech and University of Texas, San Antonio, resulted in documenting 330 cultural resource sites.

The momentum and interest generated by these early studies did not necessarily slow down upon completion of these projects. There are many carry-over activities that exist to this day and continue to follow protocol established by those research projects. Water resources of McKittrick Creek were recognized as being fragile and subject to being easily altered if not managed properly. Owen Lind of Baylor University began surface water quality monitoring in 1967, and Dasher and Fish of Texas Tech continued the data collection into the 1980s. Since 1990, park staff has assumed monthly monitoring of surface water: nitrate, orthophosphate, dissolved oxygen, pH, hardness, sulfate, and chloride levels at selected sites. All of the water quality data for McKittrick Creek and some park springs has recently been copied to and made accessible through the EPA STORET database.

Large-scale fire is the greatest threat to Mexican spotted owl habitat within the park.

From 1982 to 1985, Harvey & Stanley Associates conducted a mountain lion territory and range study for Guadalupe Mountains and Carlsbad Caverns national parks. The study resulted in park staff recording multiple forms of lion sign along repeatable transects which are hiked twice a year. The resulting data is being analyzed statistically to determine the population trend. The two parks have amassed a data set for 13 years of lion sign. To make the most of our field effort at Guadalupe Mountains National Park, we have been collecting data about black bear sign observed along these same transect routes since 1993.

With respect to federally-mandated monitoring programs because of special status and significance, the park monitors resident threatened or endangered species. In 1982, the McKittrick pennyroyal was listed as a threatened species and the park became involved in population monitoring in accordance with the recovery plan. As an added measure of protection, park managers decided to reroute part of the McKittrick Canyon trail to prevent trampling of this plant. The plant was delisted on September 22, 1993, not due to a rebound in the population, but because the monitoring effort revealed a greater than previously known population throughout its range. We now periodically monitor the population to ensure there is no significant decline in the park population. The same area of steep terrain serves as home to the American peregrine falcon which is currently listed as endangered. The park has monitored our peregrine population from March to August every year since 1985 to determine the presence of breeding pairs and to monitor nesting and fledging success. Fortunately, there is little human activity or disturbance in these steep-walled canyon areas, and as best we can tell, young have been successfully reared almost every year.

Another newcomer in the federally-mandated monitoring scheme is the Mexican spotted owl which was listed by the U.S. Fish and Wildlife Service as threatened on March 16, 1993. This owl has habitat present in cool, narrow canyons within both national parks and on the Lincoln National Forest. Guadalupe Mountains National Park holds representation on the interagency Mexican spotted owl work group which is tasked with aiding in the implementation of the recovery plan in the Sacramento and Guadalupe Mountains. For the next two years the park plans to conduct field surveys for the owl in order to move ahead with habitat enhancement through the use of prescribed fire. Large-scale fire is the greatest threat to Mexican spotted owl habitat within the park.

Under Section 110 of the National Historic Preservation Act, federal agencies are required to inventory, assess and manage their cultural resources in a manner that will protect significant features from deterioration or loss. It is not uncommon for us to make previously unrecorded discoveries of fire-cracked rock, pot shards, or other traces of material culture while performing a variety of field work in the park. In addition to the park archeological inventories in the 1970s, the park embarked on a cultural resources inventory 1988 to photograph and document as many known cultural resources as possible. These resources range from prehistoric rock art to recent day rock walls such as the remains of the Pinery Station. The Pinery Station is one of four cultural resources in the park which hold special significance in the telling of local or national history and is listed on the National Register of Historic Places. The three other places in the park on the National Register include the Wallace Pratt Lodge, which is a stone cabin in McKittrick Canyon; the more than century-old Frijole Ranch, which is one of the older continuously-occupied houses in Trans-Pecos Texas; and an assemblage of sites and features that compose the McKittrick Canyon archeological district. The Ship-on-the-Desert, another home of Wallace Pratt, is also eligible for listing on the National Register due to the unique character of the architectural style.

Under our preservation activities, we have park staff who are trained to perform routine maintenance and preservation on historic structures. Sometimes that involves looking for traces of original paint around window frames such as at Williams Ranch, or reproducing a masonry mortar formula to match the original that has weathered away on our stone structures. The park maintains contact with the Texas Historical Commission on a regular basis to keep them informed of any activities that may affect cultural resources such as routine maintenance or modifications to roads, trails, utilities, structures or landscapes of ethnographic or historical significance. A cultural landscape report for the Frijole Ranch area has been completed to aid with management decisions and recommends appropriate future interpretive uses of the historic ranch landscape.

Over the last two years our staff has been working jointly with Carlsbad Caverns National Park on issues related to the Native American Graves Protection and Repatriation Act. We have been in communication and consultation with 13 tribes that have associated themselves with the Guadalupe Mountains to begin the process of proper disposition of funerary items and grave goods. In recent years the two parks have also issued joint contracts to document the area history and regional ethnography.

As we consider the Federal Caves Protection Act, we have 30 documented caves within the park. The majority of them are not open for recreational use as are some of the other caves in the Guadalupe Mountains. This is primarily for two reasons; they are tough to reach, not very extensive, and most people don't want to expend the effort for the limited return. The majority of them have not been completely surveyed and the park does not want to lose valuable data about unique features such as faunal remains contained within them.

The park is active in many cooperative study programs. Our air quality program includes particulate monitoring as part of a national effort under contract with Crocker Nuclear Lab at the University of California, Davis, and our visibility monitoring is coordinated through a Servicewide contractor, Air Quality Specialists, in Fort Collins, Colorado. The Clean Air Act identifies the park as a Class I air quality environment. Since 1982, the park has collected data to establish baseline air quality values under a provision of the "protection of significant deterioration" amendment to the Clean Air Act. Visual range conditions, how far a person can see toward an unobstructed horizon, have been measured as great as193 miles and as low as 37 miles. Sulfates, organics, nitrates and coarse material are some of the measured particulates that affect air clarity and visual range. Sulfates are introduced from urban and industrial areas in the Southwest United States and Northern Mexico. Organics come from natural emissions, smoke, and industrial solvents. Nitrates have their source from automobiles or any combustion source. Wind blown soil from regional playas, vehicles on dirt roads and agricultural areas contribute to suspended solids.

Visual range conditions, how far a person can see toward an unobstructed horizon, have been measured as great as 193 miles and as low as 37 miles.

If we don't know what we have, we don't know what to protect.

The park has been a partner of the National Atmospheric Deposition Program since June of 1984. The equipment collects precipitation samples which are analyzed for acid precipitation. A 10-year analysis has shown acidity of precipitation has decreased by 46% in the park. Although the limestone composition may buffer some aspects of acidic precipitation, it is unknown what contact effect it may have on vegetation and other organisms.

A large share of what we learn about the resources is a result of university research through thesis work and from private investigators. Many field projects have been accomplished on the backs of graduate students. Opportunities exist for continued and future student thesis work as long as it contributes to park management goals. Examples of current and recent studies include geological research related to petroleum applications and paleoecology. Some of the specimens collected as a result of these projects have been placed into a study and teaching collection in the park museum. This makes them available for examination by future researchers and students without the need for duplicate collecting. Recent genetics work has focused on the Texas madrone, yellow columbine, and bladder fern. Other projects have expanded our inventories of moths and butterflies, crickets, scarab beetles, and scorpions.

The National Park Service needs to complete basic inventories of park resources. If we don't know what we have, we don't know what to protect. Over the years the park has made progress on inventorying springs and seeps, with an eye toward periodic monitoring of water flow and quality; conducting a breeding bird survey, which periodically needs to be revisited; and sampling vegetation from fuel load plots to determine potential use of fire as a management tool.

Human activities have had an impact on some park resources. We have established a monitoring program to measure human impacts on vegetation adjacent to campsites, and we have attempted to restore populations of Montezuma quail to Dog Canyon in 1986 and have returned Merriam's turkey to McKittrick Canyon and The Bowl. A joint project between the park and the Texas Railroad Commission in 1996 was to secure openings of abandoned copper mines with bat-compatible gates to provide habitat for these mammals and safety for visitors.

Modern transportation has opened corridors for plant and animal pests to enter the park. In 1987 and 1988 the park began removing and monitoring salt-cedar, *Tamarix ramosissima*, from areas around old stock tanks and arroyos. The last salt-cedar was successfully removed in 1993. From 1995 to the present, we are trying to keep a new invader, Malta starthistle (*Centaurea melitensis*), in check through an education program with our employees, and then we get down and dirty and pull them by hand so that we don't eradicate other sensitive species that are growing alongside them. In the three or four years that we have been working with this, we have reduced the population of this exotic to 25% of what the discovered population was in 1995.

We have established a wildlife observation database that currently includes 4,500 entries for birds (2,852), mammals (1,055), and reptiles (472). The park contributes to a National Park Service natural resource bibliography database that currently includes 1,900 entries representing projects associated with Guadalupe Mountains National Park. The greater Guadalupe Mountains bibliographic records in the database are 3,069 if you include the Carlsbad Caverns data. We have also created a database of large-format maps, specific to park projects over the years, which is up to 506 entries. From 1992 to 1997 we built a botanical database with over 1,000 entries of plants that have been found on the park, many of which are represented in the park herbarium.

We have recently entered the age of Geographic Information Systems (GIS) to store field data collected with Global Positioning System (GPS) equipment. This enables us to represent and see relationships between resources. We are building data themes to represent archeology, vegetation types, soils and geology, sensitive species habitat, fire history, park roads, trails and structures. A large task that lies ahead will be to convert years of paper records into digital, georeferenced form that can be used with this system.

Our museum management program contains more material than is able to be displayed in park visitor centers. This material in the collection is maintained for documentation of natural and cultural resources and for the objects' research value. Our Automated National Catalog System currently helps us manage the collection by keeping track of specimens on loan, and generating an annual random sample inventory so we may be sure of the security and condition of a portion of our collection each year.

All research activity in the park generates data and potentially a collection of specimens. Information gathered about national park resources is to be made available to the public. Many of you are familiar with the Investigator's Annual Report of which you are reminded every year if you have an active research project in the park. Those reports are currently going into a searchable database, so I emphasize the importance of submitting specimen records and associated bibliographies that are generated long after the field work is completed. The database is not currently accessible to the general public due to containing site sensitive information, but if you have a research need or want to determine if other scientists have performed work in your field of interest, park staff can assist you by searching the database.

What do we have for the future? We plan to keep all these programs going and desire to maintain and establish new working relationships with resource-based agencies and universities. One dream is to develop field school programs in geological, biological and cultural resources. We hope to restore black-tailed prairie dogs, desert bighorn sheep and American pronghorn to park habitat from where they were eradicated. We would like to restore a population of native fish to McKittrick Creek. We need to conduct vegetation and cultural resource surveys on the newly acquired land on the west side of the park.

No one has the monopoly on the information that has been gathered through the park resource management program. These features are held in trust by the National Park Service for all. During the concurrent sessions of this symposium, we will highlight but a fraction of what has and is currently taking place in the area of research and resource management. I hope that you will be stimulated to consider how you can help Guadalupe Mountains National Park to close the gap even more quickly on the next doubling of information yet to be discovered about this gem of a park.

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Note: The author also consulted references in park databases and reference files. These included research permit files of various authors, the park wildlife observation database, the National Park Service NRBIB database (Natural Resource Bibliography database), and the investigator's annual report database.

Chapter 5

Research, Resource Management, and Resource Protection at Guadalupe Mountains National Park: the Next 25 years

DAVID SIMON is the southwest regional director of the National Parks Conservation Association based in Albuquerque, New Mexico.

I am with the NPCA, the National Parks Conservation Association. NPCA is the nation's largest citizen organization working to protect and enhance the national parks. However, after my stirring performance yesterday in the Forest Service educational skit, many of you may now know me as the "Tall Stalagmite." Thank you. It certainly was a challenging role for me. Some say it was probably far beyond my ability, but it was probably an appropriate role since essentially my costume yesterday was a dunce cap. If you've seen *Wag the Dog* you know how important Dustin Hoffman says casting is; casting is everything. So they probably got the right guy. Larry Henderson, thank you also very much for that certificate. As long as you have been in the National Park Service, it is an honor to have graduated from anything that you are running, so to speak, so thanks a lot. I want to thank all of your capable and committed staff, really Jan Wobbenhorst, Fred Armstrong and everyone who worked so hard to put this symposium together. Jan, I just say that the lovely gift you just got is an exotic plant [a bouquet of roses], and please do not bring it into the park. This is quite an opportunity to be here with you. NPCA is very committed to science, research, and resources management in the park system. This is a wonderful job by the park and its staff, and when you said I might have a place in the program, little did I realize it was going to be as a stalagmite first, but this is a great honor to be with you.

Seriously, I might ask you, though, what is a non-scientist dunce doing addressing this auspicious group, which I might add is a pretty good-looking group, and in addition to being good-looking, I would say it is a wonderful, great collection of wisdom and wit. I was thinking about looking out at this group over the past day or two also. Many of you, of course, have been involved in the Guadalupe Mountains region from the inception of this park or before, even since the 1975 symposium. I wondered what could I possibly say or do that would be around 25 years from now, aside from my police record, that is. I think the answer probably lies—to carry this drama-illusion probably just a little too far—in this area not too far from drama and a little bit of Steven Speilberg's Hollywood. I think the reason I am probably up here and why I'm a part of the jigsaw puzzle of the entire national park family that is represented here tonight, is in the interface and the intersection of knowledge, research, science, policy, the public and what they desire. And I'd say in one of the most quintessential human traits of our race, that is, the ability we have as human beings to contemplate the future, to have some vision, and yes, to dream a little bit. Birthdays and anniversaries are a time obviously to celebrate, but also to look back fondly and be proud of how far we have come, perhaps even to recognize mistakes. For Guadalupe Mountains National Park is still, I would say, a young adult at the age of 25. Really it is a time primarily to look forward, at age 25.

Its safe future depends on you, on us, on the American people.

I wanted to share with you just a few of my thoughts about looking forward, and not so much to summarize the excellent things that I have heard here over the past two days. I think Dr. Baker may have some of that responsibility, and it

If I had a penny for every gallon of gas that has been sold from some of the companies that have done amazing things in terms of learning about geology in this park, I think we'd have our endowment p.d.q.

will be difficult, I think, to summarize so many of the good things I have heard. To present a slightly different view in a slightly bigger picture to what we are all engaged in, I think Guadalupe is, obviously as you do, a national treasure. Its safe future depends on you, on us, on the American people. And as we celebrate the park's 25th anniversary, this being one of the last events in an excellent year of things the park has done, I think our agenda for the next 25 years really does have to be visionary. So, what I would like to do is present to you, if you will, what I'll call NPCA's silver anniversary agenda for the future of Guadalupe Mountains National Park. This is a ten-point action plan, for those of you who like to think in concrete numbers, and I will run down a few of the things that I have been thinking about over the past year here for the park.

I think we need to establish a research endowment for Guadalupe Mountains National Park. I think that endowment should be one that actually benefits Carlsbad as well, but this idea came up in some conversations I'm sure many of you had. I even heard it this afternoon again. This idea is certainly something that superintendents have thought about and we have talked a little bit about over the past year. A research endowment for this park would create a permanent source of funding for both basic and management-related research. Obviously, we can't manage what we don't understand. That's a trite phrase now, but you know the more you hear it, the more optimistic it makes me, and people are believing it. We need to put research, and by that I mean natural and cultural research, which is what I will be talking about in all of my remarks, on a plane that really makes it possible to do better things. Guadalupe is a library of a million volumes, and I really believe we have only taken a few of them down off the shelf. I think we can fund this endowment through a variety of creative ways, and I don't mean to single out one particular potential source of funding, but I will just say that if I had a penny for every gallon of gas that has been sold from some of the companies that have done amazing things in terms of learning about geology in this park, I think we'd have our endowment p.d.q. In 1975 the symposium proceedings from the previous symposium called for a minimum funding of $25,000 a year for research at this park. Adjusted for inflation, that would be right now a whopping $34,000 a year. We clearly need a lot more than that and I think we can get it.

Secondly, I think we obviously have to dramatically improve inventory, monitoring, and resource management programs at the park. The future of the national parks really does depend on strengthening the agency's commitment to science-based natural and cultural resource management. Baseline data is obviously essential to making good sound management decisions. Guadalupe Mountains has significant gaps in its basic resources inventory; in fact, no national park really has a completed one. We need to be much further down the road in these areas. I think the National Park Service here should establish the goal of having the complete, or as complete as possible, resource inventory in a full-scale operating monitoring program in place in the next five years, that is, by 2003. This is an ambitious goal, but it's one that Great Smoky Mountains National Park is about to embark upon, and there is no reason we can't do it here.

This is not to say that there hasn't been wonderful work done at this park. I think this symposium is just total proof that great things are happening here, and we know a lot. We are still a long way from where we should be. I think that also holds true from the way the National Park Service deals with resources management, if you will, and these comments of course are directed to an agency that I love probably as much as you all do, and I hope they will be taken in that spirit. Resources management still is not the priority that it should be in the National Park Service. Twenty-five years ago, Ro Wauer, whose name is familiar in association with this park—he also happens to sit on NPCA's board now, so I have to answer to Ro a fair amount—he wrote in the preface to the symposium proceedings in 1975 that too often federal bureaucrats (I hate that word) expend energy and great sums of money planning park developments without due regard to the full protection of the area's resources that were the primary reasons for the establishment of the park. Twenty-five years later, we have made a lot of progress, but I'm not sure Ro would be entirely happy with where we are, either.

I know some of you just heard recently, just today, little excerpts from Dwight Pitcaithley about Dick Sellars' book. One of the last things Sellars says in the concluding chapter of that book, *Preserving Nature in the National Parks*, is when and only when the National Park Service thoroughly attunes its own land management and organizational attitudes to ecological principles, can it lay serious claim to leadership in the preservation of the natural environment. So even 25 years after Ro made his comments and Sellars' book has come out, we still have a long way to go. That is not to say that we don't have a lot of great committed people and good work going. We still need to see a change in how the National Park Service prioritizes resources management and research. This park has over $4 million in unfunded research needs for critical natural and cultural projects. I think it is probably time this park had a separate resource management division. These are formed and structured things, but they do say a lot sometimes, and in tight budget times it is hard to reprioritize, stretch and do more with less, I guess as the agency has been asked to do. We are coming down to the nub of the issue here now as we approach the 21st century. I am very optimistic about Director Stanton's proposals for a resource initiative, and it is very exciting, although I will have to say the proof will be in the pudding. It is going to take all of us to help the National Park Service implement this initiative and follow through on what I truly believe many, many good people in the agency want to do. Dick Sellars is not the first person to recommend these things. In fact, there have been 13 reports over the last 20 years that have called for some significant change in science, research, and resource management in parks. We need to get on with it. We need to make it a top priority. There is also legislation in congress that is sponsored by Senator Thomas of Wyoming, a republican, that isn't perfect but it does have some titles in that bill that, if slightly corrected, would help the National Park Service programs dramatically, I think. So we need to rally together and get the bill on its proper course and get it passed.

As part of doing that, I think I would like some time to see in the future a really, truly amazing Guadalupe and Carlsbad science center—geophysical sciences center—here in the Carlsbad area, just contributing to a great array of wonderful scientific and investigative talent that is already here that could make Carlsbad even more of an attraction and world-renown for its endeavors. I think we need to understand our visitors to this park tremendously more than we do now. I heard some nice and very exciting research presented yesterday about a visitors survey. Basically we know that backcountry use has doubled here since the park was established, and the park has embarked on some monitoring efforts to watch that carefully and follow the impacts. This park really needs a full-scale visitor enjoyment resource protection (VERP) program, which is sort of the new version of what we used to call carrying capacity. We have to get on in implementing these things.

I think we need to designate wilderness in and around this park to protect the wild places, and if you will, to protect us from ourselves a little bit.

Now I am going to move into the troublemaking section of the talk because I think you probably all agree with what I have thrown at you so far. As we think about the next 25 years, if we are really going to be truly visionary, we'd better talk about not only just researching and learning about this park but truly protecting its resources, protecting its values, the reason it was established as a park and the reason people love it so much. I think that begins with protecting the resource base a lot better than it is right now. Let's start with something that you all will see tomorrow, at least some of you, the sand dunes. I think we need to protect the salt flats that feed the sand dunes. Those are the source of the gypsum that form those dunes and continue to replenish them. Over time, let's make sure that that natural process continues. I think some permanent protection for the salt flats via acquisition or easements or any kind of cooperative approach—and there could be many—really should be pursued. I think we need to designate wilderness in and around this park to protect the wild places, and if you will, to protect us from ourselves a little bit. Congress could designate just about 90,000 acres of wilderness in and around the park. That includes about 33,000 acres within the park as well as some Forest Service and Bureau of Land Management wilderness study areas that are next to it. These designations, I truly believe, will add an extra layer of protection, and over the long term, be what's right for integrating management. Obviously, over the long term—and this is the long term but I think it has to be said anyway—I don't think we should necessarily rule out the notion of these areas being combined into a single national park that would stretch along the entire Guadalupe escarpment between Guadalupe and Carlsbad Caverns.

Quiet—the ability to hear the sounds of nature free from noisy human intrusions—is really one of the most threatened resources in the park system.

I think we need to protect Guadalupe's scenic views. Lands near the park, some of which you will see tomorrow, including sensitive lands immediately below El Capitan, near Guadalupe Pass, and on the approach to McKittrick Canyon, are vulnerable still to development that could mar some of these vistas or otherwise complicate management. I think we also have to have permanent protection for these approach routes and sensitive vistas; again, cooperation is my preferred tactic there. However we do it, we need to get started. We need to talk about these things in order to accomplish them over this time frame.

Number seven on my list is a simple thing we often take for granted. Air quality in West Texas is increasingly threatened by polluting emissions from sources in both Mexico and the United States. The amazing views from the park must be protected by reducing emissions in both countries. This is not a Mexican problem; this is our problem, too. Air quality, I think, is the next "endangered species" resource, if you will, and if we fail to protect the dramatic scenic vistas of the western United States, I think this is one of the things our children will least forgive us for, if we fail on that score. We have hard work to do on it, but let's identify it as an objective and get going on it.

In that same vein I think we have to think over the long term about protecting the sounds of nature in Guadalupe Mountains. Quiet—the ability to hear the sounds of nature free from noisy human intrusions—is really one of the most threatened resources in the park system. There have been proposals in the last year-and-a-half for increased military jet flights, which could seriously impact this park. Many of these impacts have been reduced—I will not say eliminated—but reduced. But I really think we should be talking in terms of isolating and insulating this park from the effects of noisy over-flight intrusions. On that score, congress needs to move quickly, and you need to help congress to pass legislation that would provide a badly needed structure and process for managing scenic air tours over the national park system, which is a problem in almost one-third of the park units in this county. There is legislation, again sponsored by a republican member of congress, Senator McCain, which would set up that structure, and NPCA is backing that. If we care about the park, we better care about why we better get this law made.

I think over the long haul we obviously have to improve interagency and international cooperation for Guadalupe Mountains, preserving the long-term health and integrity of this area, the whole escarpment region. It depends on this cooperation. I think it is visible in the room tonight, the cooperation between the National Park Service, the Forest Service, Bureau of Land Management, state governments, and many, many other entities including Mexico. I do want to take a moment and recognize the non-Park Service folks who came to this conference and who participated in the conference, and I know who want to continue and improve this cooperation. That is the way we have got to go. I think more of those folks should have been here, honestly, but it is great to see the solid base of cooperation that does exist. That cooperation has to extend all the way across the border. Just taking the bats that inhabit this region, if we don't address habitat issues and organochlorine problems and visitation and education issues that relate to our neighbors in Mexico, we are going to be missing the big picture of this park over the long haul.

Lastly on my list, I think, how do you get all of it done? Well, there's probably a pretty big price tag for some of this stuff. Partnerships and funding—addressing these needs of the National Park Service are really critical. As never before, really, the National Park Service needs new funding for critical programs and additional public and private sector partners. Congress can help provide some of that money through concessions reform and permanent changes to the fee program for the National Park Service, enacting film fee legislation, which might return a little bit more money to the parks, and passing something called a park bonding proposal, which might help generate some more money. NPCA is in favor of all of those things. I also think we need to institute some bioprospecting protocols, because in the next few years we are going to see a dramatic increase in that activity, and I don't want the National Park Service to miss the boat either in terms of protecting the resources from the impacts of bioprospecting or losing out from the potential economic or financial benefits that might accompany some positive prospecting. Partnering with institutions—many of which are represented here, like cooperating associations, academic institutions, civic organizations, public and private sector groups, and in fact, the surrounding communities—is the key to strengthening public involvement and commitment to this park. We are going to need a heck of a lot more of it over the next 25 years.

Everybody knows that if you pick ten things, you are always leaving some things off, so there is an 11th thing on my list, and I will close with this. Obviously none of this is going to work really well unless we develop much more of a conservation ethic in this country. The parks are one of the best places, as you all know, to teach that ethic. We have learned to treat our parks a little bit better than other lands, but we still seem to have a propensity for trashing a lot of the stuff outside parks. Over the long term, we can't survive that sort of division and dichotomy. We have to move toward more sustainable approaches. The National Park Service people are great teachers, all of us are teachers, and I think we all have to help in that effort. I know that virtually everyone in this room is contributing in some way or another to it.

I know I am preaching to the converted here on a lot of this stuff, but we do have a lot of work to do. It goes beyond the work you do in science, it goes into civic responsibility, and I want to remind us of that duty that we all have. I think there is hope. I have seen the future and I am optimistic. Part of that future, part of that hope, is named Dana Cassingham. She is the high school student who won the park's award for student presentation at this symposium. I don't know if Dana is still here tonight at dinner, but if she were I would make us applaud her again. Maybe we should anyway just for the virtue of the fact that we see a passing of the torch, if you will, a little bit, and that gives me hope. If she were here, I would probably say I look forward to seeing her as the conference chairman 25 years from now. That really makes me feel optimistic. We have work to do, but Dana has a lot of work to do also.

In closing, I just want to say that this has been a marvelous event, and it obviously is not over. We still have another great day tomorrow, and we should leave this symposium knowing that the National

Park Service and its supporters and partners must join together to make this agenda (or this agenda plus whatever you think is important) a reality. We must act now; we must get started on it, so that Guadalupe's 50th anniversary will find this place more secure and more cherished than ever before. I look forward to working with a lot of you—I'm sure—on those efforts.

Biology

Chapter 6

Archiving the Future (Keynote Address)

ROBERT J. BAKER, Ph.D., is a Horn Professor of biology and museum science and is director of the Natural Science Research Lab at Texas Tech University, Lubbock, Texas. He has been stationed there for the past 30 years. He and Hugh Genoways directed the initial mammal survey of the Guadalupe Mountains and edited the proceedings of the first Guadalupe Mountains Symposium entitled "Biological Investigations in the Guadalupe Mountains National Park, Texas."

I think the whole concept of a keynote speech is a fairly interesting idea. Certainly at this late hour in this whole array of listening to papers and everything, I know you're tired. They've given me this little thing that says, "keynote speaker," and every one of you, I know, have looked at me several times and thought, "Keep it short, Bucko." And then I chose a title that says, "Archiving the future." Well, if you're into words you know that "archive" is a noun and not a verb. But when we finish, it will be a verb, because it is an active process. And I don't know if you noticed or not, but there were at least two times in these meetings when it was used as a verb.

I should start off by saying that a keynote talk should be several things. It should set the tone; it should be entertaining, certainly if people have had alcohol it certainly should be entertaining; and it certainly should be short. I hope that I will be able to do that. This is a really tough talk to give; it's from my former life. I need to bring some ideas together for you and I hope that you will work with me in developing these ideas because I want to talk about where science has gone. I want to talk about some of the good and some of the bad. I hope I don't burden you too much. I'll try to make it all very simplistic and not in any real details, but if you'll work with me on that, then we'll get to the crown jewel and talk about the Guadalupe Mountains, and we will try to keep it short.

I should tell you that all the things we do at Texas Tech we do as a team. There is very little honor and award for individuals. We work together, and there are a lot of people that have done lots of things. Some of the names that I should mention are Clyde Jones, Kelly Allen, Richard Monk, Anton Nekrutenko, and a whole bunch of other people. I'll be showing some slides of individuals and bring them up as we go along. I love working with other people. I got to thinking about this one day. There are only about 10 papers in my life that I've published by myself. I've only done one thing in my life by myself, and I was wishing somebody else was there, so I know I'm a people person.

I first visited the Guadalupe Mountains in 1968. I cannot find my field notes; we're actually in the process of redoing the building and moving things, so I couldn't find my field notes. But, the first time I climbed up to the Bowl I struggled through the whole idea of finding who could give me permission to go up there. We went up to the Bowl and we stretched the net over this [place], and there were a lot of things that happened that day. I was the same age at that time as the Guadalupe Mountains are today; I was 25 years old. At that time, most of you people, a lot of you people are much younger, and you don't understand how that everything hadn't been on TV at that time. Now when you try to be an educator, everything has already been on TV. They've seen desert-mountain bighorns fight; they've seen lions kill; they've seen everything. There is nothing that hasn't been portrayed on TV. We climbed up there, and we got there late in the afternoon, and two bull elk started bugling at each other. They came down out of the hills breaking trees; this was serious fighting. They came down and they locked horns and they put on one of the most magnificent fights I've ever seen. We were probably about 50 or 60 meters away, and Jim Bull, who is now a professor at the University of Texas at Austin, and I sat there with our mouths open. And there was another little interesting thing about this. There was a little fork-horn that was there with them, and these two big bulls were just knocking the daylights out of each other. This little fork-horn was running around and then it'd leap, then it would run around one side and it'd leap, then it would run around…, and you could just see it saying, "Some day, someday, I'm going to be there and I'm going to be doing this." Of course, they didn't pay any attention to that so they went on about their business. But that was my first. Jan, you asked us to talk about—and that won't be the last time she asks us to talk about—our first experiences or our best experiences in the park.

"Archiving the future"—archive is a noun and it means to hold in trust, so I want to talk about the concept of holding things in trust and where the scientific and the conservation communities associated with this are going. When we published the first *Biological Investigations of the Guadalupe Mountians*, Hugh Genoways and I were very young and we struggled to get this done. I read through it the other day when we reprinted it, or read most of it, and I was pleasantly surprised that there was an awful lot of good work done there. We did the mammal survey, and I want to impress you with where all there are collecting sites. I didn't go to all the collecting sites but I do think we actually earned our spurs for visiting the Guadalupe Mountains. There are a lot of voucher specimens that are in the archives at Texas Tech.

Figures 1-3 are diagrams out of David Schmidly's book, *The Mammals of Texas*, and I want you to look at what this really means about the critical aspect here of this fauna. If you look at the total volume of land that is in these various regions, the post oak savannah, the pineywoods, and then you look over at the extreme right up at the top, the Trans-Pecos of Texas, there are almost 90 species of the mammals that are

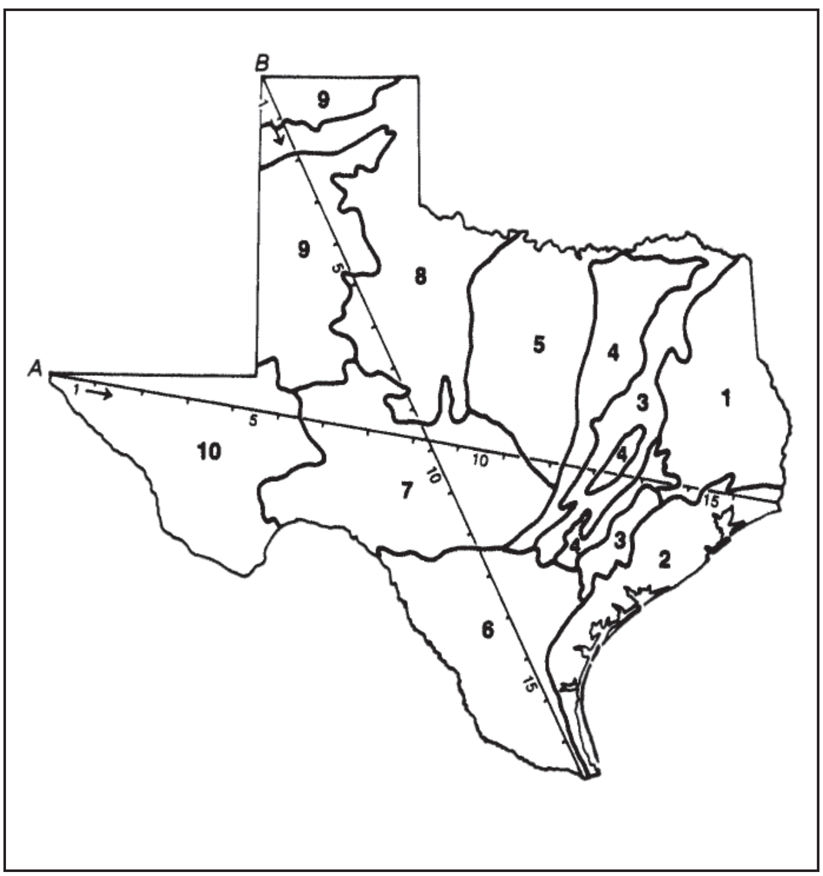

Figure 1. Map of Texas shows major vegetative regions and the location of two transects along which species diversity was analyzed. Transect A stretches from El Paso to Beaumont; Transect B stretches from Dalhart to Brownsville. 1=Pineywoods, 2=Gulf Prairies and Marshes, 3=Post Oak Savannah, 4=Blackland Prairies, 5=Cross Timbers and Prairies, 6=South Texas Plains, 7=Edwards Plateau, 8=Rolling Plains, 9=High Plains, 10=Trans-Pecos, Mountains and Basins. (From *Mammals of Texas* by David J. Schmidly, 1962. Map according to Gould, "Texas Plants: A Checklist and Ecological Summary." Texas Agricultural Experiment Station, MP-585. Used by permission of Texas Parks and Wildlife Press.)

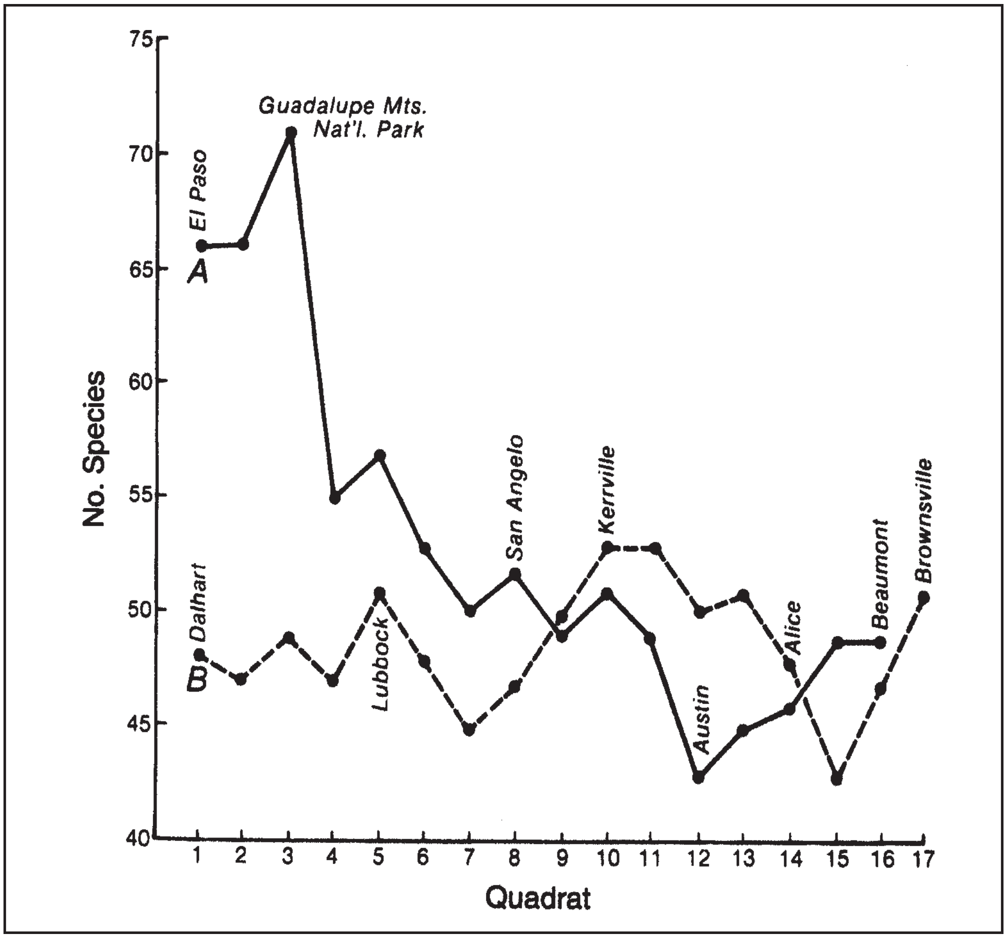

Figure 2. Species diversity plots for the quadrants along the two transects (A and B) shown in Figure 1. (From *Mammals of Texas* by David J. Schmidly. Used by permission of Texas Parks and Wildlife Press.)

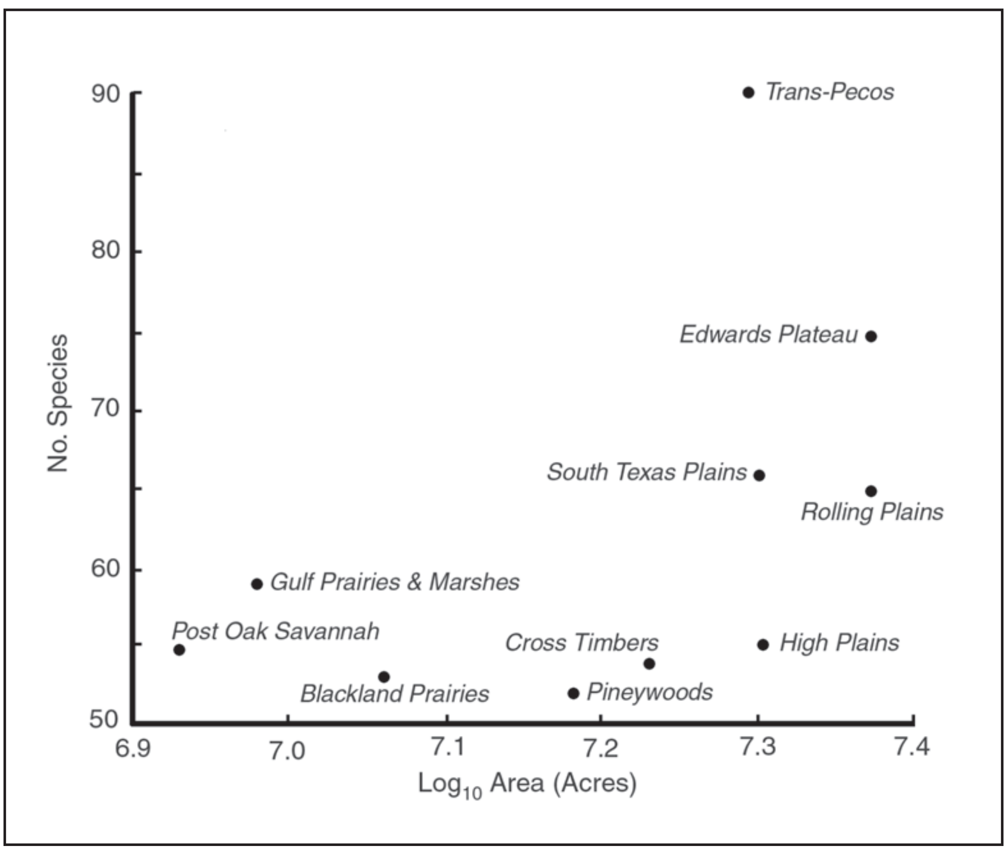

Figure 3. Plot shows the number of species versus the area for each of the vegetative regions of Texas shown in Figure 1. (From *Mammals of Texas* by David J. Schmidly. Used by permission of Texas Parks and Wildlife Press.)

known from Texas, more than half are known from the Trans-Pecos of Texas. The Guadalupe Mountains mammal survey that we did revealed that there are 65 species recorded from the Guadalupe Mountains in the last 150 years, and nine of those have been extirpated. They did not exist at the park at the time that Hugh and I finished our work. I do think prairie dogs should be introduced into Dog Canyon. *Chaetodipus*, a pocket mouse, is a small thing, but it was probably overgrazing that caused this animal to become extinct and we do believe that it doesn't exist here anymore. The wolf has gone, but there is some effort to reintroduce it. The grizzly bear is not going to be back. I doubt we're going to get it back anytime soon. Merriam's elk is an awesome animal. We need to know, "How different was Merriam's elk?" We have elk back here, but they aren't Merriam's elk—that's a biological entity and we really need to know how different that is, and I would certainly like to try to do some of that work sometime. White-tailed deer—I talked to Fred the other day and he does not think it's moved back in. *Antilocapra* was devastated across the whole United States and there are very, very small groups left. Bison—what can I say, bison is making a comeback but the [natural activity of] bison is gone, and *Ovis canadensis*, the desert bighorn. I want you to look at that and think about with me for just a moment what that means for the ecosystem. You're taking nine major [animals out of the ecosystem] with a couple of exceptions. The only animal that doesn't impact the ecosystem in a great fashion is *Chaetodipus*, and it may be really important, too. It has little pouches in its cheeks and carries things around and buries them, and it may really be critical to the survival of certain kinds of ecosystems. So this is a very significant loss, and it's not likely to be fixed anytime soon.

I want to talk for a minute about some of the changes that have taken place. We archived a lot of voucher specimens from here, and those are available to the scientific community. It's really important that we document what was there. Robert Baker may not be able to correctly identify specimens, and whether or not I did, if we leave a specimen there for these people to look at [we have an invaluable record]. We've looked at some of the other Bailey stuff, and so forth. But it really is important and it's going to become [more so in the future]. I'm going to build a case, but it's only [a] beginning. Our mammal collection at Tech, when I got there had about 5,000 specimens, now it has somewhere around 76,000, representing 20 orders of mammals, 94 families, 478 genera, and almost 1,100 species, and they come from all over the world. But certainly, one of our best representations is from the Guadalupe Mountains. Most of them are in [museum storage] cases, and Tech does have a very real commitment to the museum concept. They have a very real commitment to saving the museum stuff. In fact, there are a lot of collections that are being abandoned, and we're working toward being able to take those abandoned collections and to protect and save them for future scientists because we shouldn't lose sight of the fact that this is our record. These are our baseline data.

Another thing we've done is go to the concept of bar codes. When we go to the field now, we do one of two things. We either punch data into a computer—we don't write on any tags, we simply take a computer or we take one hard copy when it's back and we type from that one hard copy—or we simply download global positioning coordinates, and we take photographs. There's a higher standard now. When we get back, we catalog. We simply push a button and it catalogs all those specimens, and we can catalog a thousand specimens with the push of a button. It prints out all the information that goes on the tag. No longer do you have guys writing in there in ways you can't read. All of that is printed out and goes on the tag in a [legible] fashion. We can print out a field catalog; we can print out a catalog for the museum; we can print out a catalog of all frozen tissues. All of that now is pulled together, and we think it has reduced our error rate tremendously. The young man who did this is on our staff, his name is Richard Monk, and he has done an outstanding job. We were trying to do bar codes about 10 years ago, but it was just not the right time. All of these things have a time and place. Right now we're just about where Albertson's and United Supermarket are. I don't know whether I ought to feel secure or whether I ought to be asking why we are so far behind. But, basically what we do is, when we make a loan, we now go out and read the bar code and it prints out what goes on the loan sheet. So no longer is there all this tedium and so forth that goes along with it.

We also save frozen tissues. I want to tell you how important all these things are. We've talked tonight already about libraries, and these are absolute libraries. When we collect a mouse or a bat or a grizzly bear, or whatever you can get your hands on, we save those tissues. We literally save liver and heart and kidney and lung and blood and muscle and everything else that we can save. The reason you do that is every one of those is an absolute wealth of information. Every one of those is a library. Every one of those has all the information about the history of life and the DNA code. There are pieces of DNA in there that unite all of life together, us with arche-bacteria. There are pieces of stuff in there that identify every individual as being totally unique, and we can pull that out and read it now; the book is readable. You also can do systematics; you can do toxicology—how much genetic change has been induced by whatever that mouse had in the way of exposure to toxins. You can do forensics. You can tell something about the animal, where it was from. You can tell multiple paternity, whether or not this pregnant female animal had multiple males inseminating the litter. Medicine—There are genes in there that can be pulled out that are going to be used in making trans-genics. There's disease—hantavirus and all the other diseases that we can look at and see whatever. Right now, the problem is that we just don't have the imagination. The technology has gone far enough and soon it's going to go a lot further and those things are going to be absolutely powerful in helping us make management decisions. Agriculture—Genes are going to be brought out for trans-genic things. Recreating history—There are a lot of things from these animals you're going to be able to do, to recreate a lot of events in history. And then all the other things that I haven't managed to think of yet. Maybe somebody will. We keep all these things in liquid nitrogen. We have a facility where we have 10 ultracolds [refrigerators], and there are back-up ultracolds that aren't plugged in [so] if an ultracold goes down [it can be replaced]. Somebody walks through the building every day; somebody deals with it.

The program is a very international program. We work with Ukrainian, Canadian, and Mexican scientists, and most of our work today deals with international issues, not just simple things. Our frozen tissue collection holds tissue from about 26,000 specimens from 16 orders and 61 families. That's a lot of collecting and saving and a lot of people have spent a lot of time doing it. We have things like wooly mammoth. We were able to get something out of an American wooly mammoth up in the Arctic. We've got gorillas and whooping cranes and all other kinds of endangered species and animals from Chernobyl, Texas resources, and all kinds of baseline data.

We've done a lot of work at Chernobyl. Chernobyl is a very fascinating place. There is a lot of biology to be learned at Chernobyl, and our question, our research effort there is, "what are the biological consequences of this?" The truth is that [the] Chernobyl [nuclear accident] is not as detrimental to life as is normal human activity where there is no contamination. In other words, we went in, we set up grids, and we found the most radioactive spot. This was the ultimate search. Where is there more radioactivity than anywhere else on the face of the earth? It's actually not at Chernobyl; it's at a place called Chelyabinsk in Russia, Siberia. So we went to this place, and we set out the grids, and there's more life because there is no over-grazing or over-farming, and the habitat is deep and good. There are more mice per trap-night there and there is no species of mammal missing. If you were to drive through there, you would see more moose and more roe deer and more Russian wild boar and more foxes and rabbits and everything than you would ever see out where normal people live and they farm and they take care of things. We've written a paper, although no one is really happy about publishing it. It's called, "How to create a wildlife preserve: the world's worst nuclear power plant disaster." In reality, we found a hawk's nest on the ground where the Geiger counter was essentially pegged, and they were hatching on the ground, and we cannot find any evidence of radiation that is doing anything that we can detect and show as effect. There are no monsters. The whole ordeal is blown out of proportion. I'm not telling you that it's not bad. I wouldn't want my kid sleeping on the ground over there. I'm just telling you that it's not as bad. If my kid had to sleep on the ground or smoke, I'd probably let him go there before I'd let him smoke cigarettes.

Here is how we use this. Terry Yates is at the University of New Mexico. He's one of my Ph.D. students. When the Four Corners disease came out, there was a big newspaper release of stories saying that this is probably just a military biological warfare agent that's available and has been turned loose and escaped. What we did is, we took all the *Peromyscus maniculatus* we had in his collection and in our collection—his collection is New Mexico—and we sent them off to CDC, and this was all the stuff that was collected long before the Four Corners disease was described. We could show that this was not something from the military. It was a disease that had killed people in the past, but we just didn't have the medical skills to recognize it. It wasn't in the multiple choice answers that physicians have for, "this is what you died with." So they [said the patient] died with a respiratory ailment.

I have this obsession with collecting. I love animals, but people often ask me, "Do you ever feel guilty?" Let me tell you a story about the time I got talked into not keeping something, and I really regretted it. We took a mammalogy field trip to a place that I owned and there were about 1,000 thousand-pound bales of hay, and it had been there for a couple of years. We were taking a tractor and driving up and picking up those bales and shaking those bales and the mice would just rain out! There was *Peromyscus* and all kind of things. This was mammalogy! We were talking today about how these people love their work, and I'm telling you, this was a party! So, everybody is diving under these bales and catching all these mice, and we took several hundred, maybe thousands, and we brought enough back that each mammalogy student could prepare two specimens. I took them over to the collection and the curator, the assistant that I had then, said, "Robert, we've got"—obviously we've got a lot of *P. maniculatus*—"too many *P. maniculatus* already. Why don't you just not save those things?" I struggled with that, and we saved 10. That was before hantavirus showed up. Once when hantavirus showed up, then the question was—nobody [from that collecting trip] got sick—"In breathing all that mouse excrement and hay and everything else, did these people not catch hantavirus because the mice were not carrying the disease or did they not catch it because it is hard to transmit to people?" The answer was very simple. Six of the 10 mice we saved had hantavirus, had active infections. Today, if we took a class out and did that, and somebody got sick, we'd be sued for a billion dollars; and probably appropriately so. But at that time, we didn't know that and mammalogy was an art form. That was meaningful information. I only wish I'd have saved 20, or 30, or 40, or all the ones that were prepared by those students.

We have a contract with Texas Parks and Wildlife that is funded by the state legislature. What we are supposed to do between now and the year 2000, is to visit all the land that is controlled by Texas Parks and Wildlife. We are to collect and present them with a record of what's there—UTM coordinates and photographs of all the taxa—and we're supposed to save these livers, kidneys, hearts, lungs, and everything else and archive them. The person that's actually doing most of the work is Robert Bradley and he's doing a great job. The other person who is playing a role in all this is Nick Parker. He's always up in the air about something, so I'll have to give him some credit. And, of course, David Schmidly, who we're recycling from Texas A&M. We're certainly glad he's a vice-president at Tech now.

The kind of data we're pulling together gives you a new view. This is something that Kelly Allen did. Today, Nick Parker was pointing out how the habitat is very restricted for *Peromyscus truei* in the Panhandle, and they live on the very steep sides of the canyons there. But more importantly, the Guadalupe Mountains animals, habitat-wise, are absolutely different than the animals up there. Now what that usually means is that you don't have the same species. So what we need to do, we need to pick up on these kinds of things, and probably when it's all said and done, *Peromyscus truei* in the Texas Panhandle will not be recognized as the same species. This is the kind of thing you get from Texas GAP and from doing those kind of animal associations with habitat, but we can test it; we can work on that.

We are committed to putting all the material that we can on the World Wide Web to deal with students. I have an 11-year- old son, and he's a computer nerd. I try to break his arms and everything whenever he goes in there, but so far I haven't been able to keep him away from it. When he was eight-years old, I picked him up from school one day and I asked, "Bobby, do you have any homework?" And he said, "Yes, sir, I do." And I asked him, "Well, what is it?" And he said, "I'm supposed to compare and contrast the public policy and positions of Bill Clinton and Newt Gingrich." And I said, "Just where are you going to find that?" And he said, "Oh, I'll just get it off the Web." So I thought, "I'll just go watch," and I did. My son went in there and he started clicking through this thing, and he started pulling all these things up that Newt Gingrich had said and that Bill Clinton had said. He started highlighting and pasting, and when he walked out of there he had a one-page statement on each of those and would be able to articulate it. I thought, "Holy cow!" We're missing something here. If that kid can go do that, we need to figure out, to get those children using, studying biology, and looking at all the agendas that we have.

The problem is that no longer are the students, the young people, involved outdoors. They're living in cities; there's more and more urbanization, and there's less and less opportunity to interact with nature. We need to fix it so they can interact with nature and they can see the Guadalupe Mountains and all of these things. So, we are about this [work]. We've set about to fix all this. We have *The Mammals of Texas* on the Web, on our home page, and so does Texas Parks and Wildlife. We work with them and when we get one of those things finished we put it on [the Web]. They actually own the copyright, so we have to play on their team, so I won't sound too magnanimous.

One of the things that's going to be exciting is that David Schmidly has looked at every [mammal] specimen that has been collected from the State of Texas, in any museum, anywhere. He said, "I didn't get them all right, I'm sure, but I got most of them right." I would bet money that, absolutely, he got most of them right. Some of the things that are at the Smithsonian, from that 1880 to 1905 (or 1903) biological survey of the State of Texas, are about 1,500 photographs that were made around 1900. Some of them were made by A. H. Howe, and you mammalogists know who that is. Unfortunately, we [at Tech] only have six that are from the Guadalupe Mountains, from Upper Dog Canyon, but there may be a substantial number more. Our plan is to have this so that everybody in the State of Texas can simply go on [the Web] and they can interface them by going to any county, or wherever they are, click on that, and have a list of all the photographs, then be able to pull them up. We hope to be able to go back and get as close as we can to UTM coordinates and other ways to let people be able to look at them. This is part of our history, and having that available, I think, will entertain a lot of people, a lot of ranchers, a lot of naturalists, and a lot of children as well.

One of the things that always worries me is I'm always saying, "Why are we doing this? Who called this meeting? What's the goal here? Where are we trying to get from this point?" I think one of the goals is to get scientists to communicate with each other to make information available. One of the goals is to communicate and have successful communication.

This is what Larry Henderson wrote in the introduction, "…preservation of outstanding ecological, scenic, cultural and other natural values in a place of untrammeled wilderness…." I've edited the beginning and the end of that [statement], but that's a very honorable goal and a very specific goal. That's out of the foreword to the second printing of *Biological Investigations in the Guadalupe Mountains National Park, Texas*. We need to conserve resources. We have just heard from the National Parks Conservation Association how that's really important. We need to avoid unnatural change. And am I uncovering a fight here, because there are people who say, "What is natural?" and the deconstructionists, humans, are just a part of it. I probably would like to take on that group a little bit, because I think that while it is true that the guys with spears and the guys with bows and arrows and perhaps even with rifles played a real role in selection and forcing ecosystems to go, I think the bottom line is that the problem that we are facing today is a different level and a different magnitude. It may still be natural, if you want to just call humans a part of the ecosystem, or whatever.

The other real big issue here is "What is change?" The human mind is an amazing thing. I can go to the women's basketball game playing UT-Austin, and I can thank the referees for the worst they ever were, and every call went against Tech. Everybody who's sitting over on that burnt orange side feels exactly the same way, except every call went against the UT ladies. We're both honest; we both saw the plays. I think it was E. O. Wilson who said that the human brain is made for survival; it's not made for accuracy in science and all that stuff. Here's the problem. What this means is that we have to back off. We have to learn how to work with ranchers. We've got to learn how to work with economic developers. We've got to learn how to work with all these people, and we've got to understand that how they see it is different than how we see it, and we've got to listen. We've got to build, and that's really critical, because we've got to understand that the human brain and the perception of change are different for everybody that sees it.

Here's the thing that really frightens me. There are 5.6 billion people on the face of the earth right now. There'll be 6.0 billion by the year 2000, and I don't know where this is going to end. But you know what? I have followed this for 25 years, and so far we have been very accurate in predicting how many people there are. We might be able to stop some of this. But the problem here is, go back to Chernobyl. At Chernobyl, we have a unique situation where those people are trying to survive, plowing the ground behind their house, growing their radishes and their cucumbers and their small wheat fields. In just the fact that they are trying to survive, they are destroying biodiversity at a level greater than what is the ultimate fear of all humans, and that's being exposed to radiation! We're doing that. We've got NAFTA [the North America Free Trade Agreement] down here. That's going to produce a lot of pollution in here. I think we need to archive—here we go with the verb again—we need to obtain samples from this mountain range to know how much pollution is in various birds and mammals and everything else that's out here so we have baseline data to know what's happening. What do we have to change, that kind of stuff.

This is a recent statement by E. O. Wilson, "To raise the rest of the world to the level of the United States in amount of food and amount of resources, using present-day technology, would require the natural resources of two more planets Earth." We are the very chosen people on Earth right now. This whole deal with Earth's population, I feel just like this. I was walking through a museum the other day, and I thought, "That guy must feel boxed in." I don't know what the solution to it is. I hope there are some people here smarter than I am or whatever.

Donald Dayton talked to us and he pointed out that a few years ago a major problem was, that getting the Guadalupes the magnitude of care that they needed required getting everybody together. I believe his words were, "We've got scientists crawling all over those mountains and they don't even know the other one is there." That's one of the reasons we held that symposium in 1975. I applaud this symposium, because this is doing the same thing. It's getting people to talk to each other; it's bringing new students in. We need that.

The magnitude of data that's out there is just overpowering. There's a whole new field developing. It's called bioinformatics. This is the definition that we dragged out of some home page: "systematic development and application of computing systems and computational solution techniques, analyzing data obtained by experienced modeling, database search and instrumentation regarding biological abstracts." Is that pedantic, or what? Basically, I think it says that we are using models to calculate values and to sort through the data. I decided with Nick Parker that we needed to redo this definition, so I think this is what we're talking about in bioinformatics: "the delivery of all these powerful data sets and its synthesis, and an understanding that they can interpret to decision makers and potential users, including the general public." That's our responsibility as scientists. Now, I agree that there are things that shouldn't be given out to the general public. There is sensitive data. But I think that this is where interpretation of research data needs to go. Bioinformatics is the hottest field in America, according to some of the magazines.

Here's a little breakdown on it. In 1995, the word first appears on the World Wide Web, and then in 1998 we are getting about 500 hits. There are symposia now on bioinformatics and all this kind of stuff, so it is a very rapidly developing field. Let me tell you where most of the application lies. Most of it lies in genomics. We now are sequencing; we are reading the DNA of everybody and his dog; yeast, bacteria, humans, cotton, everything you can think of. We're in there busily reading all of this stuff. An example is from a paper that we published, and it is a bat study. Bats have about 2.7 billion base pairs. That's a lot. What we wanted to know is, can we go in and find the piece of DNA that is unique to this bat that we took it from? Can we find a piece of DNA that identifies the species *Microtus waterhousii*? Can we find a piece of DNA that identifies the genus *Microtus*? Can we identify the family that it's in? Can we identify the suborder of bats? Can we identify the order? Can we go into these 2.7 billion base pairs and find them? So we made a library, which means what we did was we took this bat, isolated its DNA, cut its DNA up into 35,000 base pair pieces. That's still quite a bit of DNA. We put it in a vector, something that we could grow it in, *E. coli*. We grew it all up and then we did a bunch of scanning. This is the result of this thing. We actually were able to find 17 clones that identified *Microtus*, we identified 10 clones that identified Phyllostomidae and seven that identified the family, and 44 that identified Microchiroptera, and then we tested it to see if it would work. We took all the Noctillianoidea and put them all on there and saw that they all had that, and identified other things as well. So—we were trying to see—can we cheap and dirty pull out a piece of DNA that does that? The reason you want to do that is because you might want to identify a taxon, but you also might want to know, is this a mule deer? Is this a deer? Is it an elk? So if you pull out and go through this kind of method, you can have probes that tell you. If you've got a piece of meat or something, you can go through and see where these are. You can use it in forensics, you can use it in taxonomy, and you can use it in a whole bunch of things. We were very successful.

I think also one thing we need to do is to remember economics and the role that economics can play. Now economics can't solve everything, but we've got to remember that economics are really important. I will give you one real easy example. The two countries in Africa that have more elephants than they can stand are the two that prevent hunting. And I know that the people who want to save the elephants are also the people who don't want any hunting of elephants and don't want any sale of ivory and don't want this stuff. But in Zimbabwe, I believe the figures are something like this. They sell an elephant permit for $12,000 and they have sold something like 20,000 permits. The person who bought the permit has to get there and they've got to hire a guide and do whatever. As a result, the country has built schools, they've built hospitals and they've built everything else with this money, and you know what their problem is right now? At this moment, they have more elephants than the environment can handle. And in those countries that don't permit any hunting, people are poaching, trying to get a few pittances for whatever. The goal is to save the elephant, and this is the way that economically we can do that. Now I think they ought to just jack the price up higher to get more money for elephants and all that.

Another problem I think is pointed out by E. O. Wilson in his latest book called *Consilience*. You'll find he defined the word as, "the interlocking of causal explanation to cross disciplines." We do need to really back off and really look at the big picture. We need to not lose sight of the fact that—I know the most important thing to me is to protect my bats and my rats but in reality—the overall pattern is absolutely important. Natural science is moving away from the search for fundamental laws and elemental truths and reduction approaches toward highly organized systems. This is the sixth of seven weekends in a row that I have been away from home going to meetings, and I went to the Texas genetics meetings not long ago, and I sat in on this meeting. So I'm sitting there listening to these people, and they are sequencing genes from the human genome. Now, there are 100,000 genes in the human genome, give or take 5,000 or something, and so they sequence these things and then they look at the promoter. You've got to have something to turn a gene on, and you've got to have something to turn it off. I'm sitting here and this guy's up there talking about the gene for cartilage. Well, you know, you've got cartilage here, and you've got cartilage in all the bones, and you've got to know when to turn it on and make cartilage. You don't want to make cartilage in your eyeballs, you want to make it where you need cartilage. You've got to know how to turn all that stuff on and everything. So this guy's going through it and he sequenced the whole gene, and he sequenced the promoter region, which tells it when to turn on. He has found four protein binding sites in this promoter region. He went over each one of them. He says, "Well this one's used when you develop cartilage; and the precursor for bone, this one binds here; and when you need to do this, this one binds in the ear and the nasal septum; and when you do this...." So he has gone through and he has worked all of this out. Wow! Right? I don't know whether I can stand listening to 100,000 genes or not, you know? I mean, what we have done is we have sequenced less than 7,000 genes. We have 93,000 more to go. I had attention span deficit syndrome long before it was a disorder, and I just wanted to scream and run out of the building. I'm sure it's absolutely important. I'm sure it's perfect, incredible, but you know, God help me, how many of those can I listen to and work with.

What I think I've tried to do is tell you, "Boy! There are a lot of powerful methods out there." There are computers and there are all kinds of things that we can use to address problems like biodiversity in the mountains, to document pollution in the fauna, to ecotoxicology, to capture genes, to do things like go to Chernobyl. Chernobyl has created a stressful environment. The mice that live there probably have genes that, if we can pull them out and use them, we probably can put them in cattle and every other thing and make a better cow that can live on a more stressful environment. We probably can get the plants there and get stuff that cotton can grow where there is more soil with salts and all kinds of things. I mean, everything is the good news and the bad news; you've just got to figure out what the good news and the bad news is. But this is the diamond in it. That's what it's about.

I remember a day when we were doing our survey in the mountains over on the west side, and I was trying to figure out where the limits of woodrats, *Neotoma mexicana* and *Neotoma albigula,* were. I had this idea that if we could figure out where that boundary was, and we could watch the stress on the system, maybe this would be a bioindicator of environmental stress and change, and we could follow this distribution, which one comes right up to the other. The west side is huge, you know. I mean, I was wandering around over there—you can only haul so many traps so long—so in the middle of this after a while I got to looking at these cacti, and I decided I didn't really care much about woodrats. I climbed that mountain all day long and I looked at probably a thousand of these cacti over there, and I got to looking at symmetry and everything else, and that actually was one of the finest days of my life. Then I saw the truth, went back, and started to set traps again.

The Guadalupe Mountains are an archive. Archive means to hold in trust. The Guadalupe Mountains are held in trust by the government and by us. You're the movers and the shakers. We are all a major part of this. What a diamond this lady is. What cake, icing and cake, this lady is. I think we need to not lose sight of the fact that we are in a position where we can impact this, and we need to dedicate ourselves to excellent science. We need to dedicate ourselves to biodiversity and ethics in behavior that will lead to and protect this. We need to dedicate ourselves to trying to spend the money because money is always going to be tight. There is never going to be enough that we can squander any. We need to make sure we spend it correctly and we need to go in with the same philosophy that we have heard so many times here, with the enthusiasm and the love and the pleasure that we get from the lady that is the Guadalupe Mountains. I hope all of this weaves together eventually so that we can do a better job, and I hope the Guadalupe Mountains are there for my children and my grandchildren and for all the other people that can appreciate those aesthetics.

Chapter 7

Interpreting Desert Regions, Deserts, and Regional Indicator Plants

FREDERICK R. GEHLBACH, Ph.D. of Baylor University has been a significant contributor to understanding the vegetation component of the Guadalupe Mountains and other Southwest desert regions. This paper was presented by Larry Henderson, superintendent of Guadalupe Mountains National Park.

I would like to talk about natural history and landscape interpretation in the National Park Service, or for that matter, in any organization committed to educating people about their natural heritage. My message is something I've been pushing for four decades—without much success I should add. It is simple and not entirely original, but traditions die hard and catchy words like "desertscrub" are easy to use even if incorrect. I will keep on trying because I see the public often confused by misleading or obscure terms, and even find educators confused on occasion, especially when it comes to desert plant communities versus desert regions, which is the focus of these remarks.

Because the goal of nature education—any education—is to facilitate self-learning, I advocate using descriptive names that permit easy recognition of Earth's plant cover. This requires common language and easily recognized terms with a long history of use, rather than new jargon. Vegetation is always present on the ground surface and therefore makes the best descriptor of living landscapes. Subjects like desert, grassland, woodland, and forest are easily visualized as are contrasting adjectives like shrub and succulent, lowland and upland, evergreen and deciduous. For example, I suggest speaking of lowland shrub versus upland succulent deserts.

Deserts, grasslands, woodlands, and forests (plant formations) of the United States and Mexico are present in all regions with topographic relief, including places that appear to be mostly comprised of desert. Thus, particular regions have been called deserts—Chihauhuan Desert, for instance—despite the obvious fact that they are not exclusively desert. Certain included areas may not even have desert, and hence the public is readily confused. I heard the Davis Mountains of Texas described as being "in the Chihuahuan Desert." I was with people who didn't see anything but plains grassland and evergreen woodland; they asked where the desert was. I told them that it didn't exist locally.

Chihuahuan is a regional adjective, defined by particular (indicator) plants with ranges centered in Chihuahua, Mexico. But some of these plants are not even desert species! In fact, the two main kinds of deserts present in the Chihuahuan region are identifiable elsewhere, in the Sonoran region, for example (Table 1). In low basins, widely spaced individuals of small-leaved shrubs indicate one kind—the lowland shrub desert; whereas in rocky uplands, clumps of succulent and semisucculent shrubs indicate the upland succulent desert. Soil and togography make the difference, although these deserts grade into one another over relatively smooth transitions in the landscape.

Tarbush in the lowlands and *Agave lechuguilla* in the uplands distinguish the two deserts in and near Chihuahua, just as white bursage and saguaro cactus denote these deserts in and near Sonora, Mexico (see Table 1). Yet, despite the regional differences in indicator species, lowland and upland deserts are structurally similar across regions, because there

	Lower Mountain Slope	Upper Bajada Slope	Lower Bajada-Basin	Arroyo (drainageway)
	4500 feet (1360 m)		3500 feet (1060 m)	
	Rock outcrops, rocks, crevices, little soil	Boulders, rocks, shallow soil	Small rocks, deep soil, caliche	Rocks, deep soil, subsurface water
	EVERGREEN WOODLAND	UPLAND DESERT	LOWLAND DESERT	DECIDUOUS WOODLAND
Life-forms	spaced oaks, junipers, evergreen sumac, basketgrass	clumped succulents, semisucculents, small-leaf shrubs,	spaced resinous or hairy, small-leaf shrubs	adjacent small-leaf, trees, shrubs along water course
CHIHUAHUAN REGION				
Indicators	**gray oak,** redberry juniper, foothill basketgrass	**lechuguilla, candelilla, slimleaf goldeneye,** ocotillo	**tarbush, ceniza,** creosotebush, whitethorn acacia	honey mesquite, desert hackberry, desert willow
SONORAN REGION				
indicators	blue oak, redberry juniper, foothill basketgrass	**saguaro, brittlebush, foothill paloverde,** ocotillo	**white bursage,** creosotebush	**ironwood**, honey mesquite, desert hackberry

Table 1. General vegetation profile on a topographic-edaphic gradient in the Chihuahuan and Sonoran regions. Plant formations in all-uppercase letters are named for structure and topographic position; representative life-forms and selected indicator species are given. Regional endemic indicator species are in boldface type; widespread indicators are in regular type.

are only a few ways of living in such a stressful environment as desert. In the present examples, plants conserve water by living apart from one another and having small protected leaves in low desert basins or by living together and storing water in modified leaves and stems in the rockier uplands.

Because many non-desert plants are also regionally specific, and desert life-forms are recognizable regardless of region, I omit the word "desert" in talking about Chihuahuan, Sonoran, Mohavean, and Great Basin regions. I only employ these adjectives for floristic geography—to specify the locations of particular species. That way I don't have to deal with the confusion of missing deserts and can concentrate on adaptive features (lifestyles) and environments that help to understand particular local vegetation whatever it may be. (Locally, fine resolution is made by naming dominant species or co-dominants in associations, such as creosotebush-tarbush of the lowland shrub desert in the Chihuahuan Region).

Regardless of region, this interpretive scheme stresses the important reoccurring interaction between the distinctive dryness of deserts and plant features. It includes the special adaptation of form—features such as drought deciduousness, and small thick resin- or hair-protected leaves, by contrast to leaves capable of water storage regardless of region. Positioning is equally important to water conservation, hence the inter-regional similarity of spaced lowland plants, whether Chihauhuan regional creosotebush-tarbush or Sonoran regional creosotebush-bursage associations, by contrast to the clumping of upland Chihuahuan family groups of lechuguilla, similar to Sonoran saguaro-foothill paloverde nurse-plant assemblies (see Table 1).

What I'm saying about regions, regional indicator species, and deserts in landscapes with other plant formations is summarized in Table 1, which compares a topographic gradient in the Chihuahuan region with its counterpart in the Sonoran. Representative life- and growth forms typical of each vegetation type and selected regional indicators plus widespread species are given together with general notes on soil conditions and elevations. Table 1 does not mention special plant associations on localized soils, such as gypsum or quartz sand, but these usually represent the lowland shrub desert.

Selected references

I offer a few exemplary references with brief notes on their contents, as they relate to my subject and to the natural history interpretation of Guadalupe Mountains National Park. All of these contain useful and important information, but nearly all use the epithet, "Chihuahuan Desert," to describe one or both interregional deserts without alluding to regional indicators. Some also use the misleading word, desertscrub, which specifies that deserts are scrubby (unable to attain mature stature). This is untrue in undisturbed situations.

Brown, D. E., editor. 1982. Biotic communities of the American Southwest–United States and Mexico. Desert Plants 4:1–342. Useful comprehensive treatment that puts a nice perspective on southwestern and Mexican vegetation patterns. Authors use the misguided term, desertscrub, and Chihuahuan, Sonoran, etc. are employed as adjectives for desert vegetation.

Brown, D. E., F. Reichenbacher, and S. E. Franson. 1998. A classification of North American biotic communities. University of Utah Press. Salt Lake City. An updated reference with nice photographs but employing confusing and misleading terms as in Brown (l982).

Burgess, T. L. and D. K. Northington. 1977. Desert vegetation in the Guadalupe Mountains region. Pages 229–242 in R. H. Wauer and D. H. Riskind, editors. Symposium on the biological resources of the Chihuahuan Desert region, United States and Mexico. Transactions and Proceeding Series number 3. National Park Service, Washington, D.C. Provides a useful breakdown of plant lifeforms on quartz and gypsum sands but does not provide comparisons with other soils. The authors employ Chihuahuan Desert and desert-scrub (note hyphenated).

Dick-Peddie, W. A. 1993. New Mexico vegetation: past, present, and future. University of New Mexico Press. Albuquerque. Fine general area reference but compounds interpretive confusion by employing the novel epithet, Chihuahuan desert scrub. Deserts are mapped in the Guadalupe region, generally occurring at lowest elevations below desert or plains grassland which is below evergreen woodland. If overgrazed and lacking periodic fire, grassland can be desertified as it has been in the Guadalupe region.

Gehlbach, F. R. 1967. Vegetation of the Guadalupe escarpment, New Mexico–Texas. Ecology 48:404–419. Only quantitative study of the Guadalupe Mountains vegetation-types. Describes lowland (small-leaved shrub) and upland (succulent, semisucculent) deserts, and introduces the present system of naming vegetation on the basis of life-forms and/or topographic positions using unbiased quantitative appraisals of measured plant cover.

Gehlbach, F. R. 1979. Biomes of the Guadalupe Escarpment: vegetation, lizards, and human impact. Pages 427–439 in H. H. Genoways and R. J. Baker, editors. Biological investigations in the Guadalupe Mountains National Park, Texas. Proceedings of a symposium held at Texas Tech University, Lubbock, Texas. Transactions and Proceedings Series number 4. National Park Service, Washington, D.C. Why and how landscape may be interpreted to the public based on vegetation, lizards, and human impacts, the sum of which is more comprehensive (ecosystemic) than vegetation alone.

Gehlbach, F. R. 1981. Mountain islands and desert seas: a natural history of the U.S.–Mexican borderlands. 1st edition. Texas A & M University Press, College Station. The first chapter describes the present vegetation and regional interpretive system, which is used throughout the book.

Johnston, M. C. 1977. Brief resume of botanical, including vegetational, features of the Chihuahuan Desert region with special emphasis on their uniqueness. Pages 335–359 in R. H. Wauer and D. H. Riskind, editors. Symposium on the biological resources of the Chihuahuan Desert region, United States and Mexico. Transactions and Proceedings Series number 3. National Park Service. Washington, D.C. Reviews regional indicator species including endemics from vegetation-types besides deserts, yet uses Chihuahuan Desert region.

Johnston, M. C. 1979. The Guadalupe Mountains: a chink in the mosaic of the Chihuahuan Desert? Pages 45–49 in H. H. Genoways and R. J. Baker, editors. Biological investigations in the Guadalupe Mountains National Park, Texas. Proceedings of a symposium held at Texas Tech University, Lubbock, Texas. Transactions and Proceedings Series number 4. National Park Service, Washington, D.C. Despite the misleading title, this text is specifically but briefly about the Chihuahuan regional flora. It is about the only recent unambiguous interpretive treatment of the Chihuahuan regional concept.

Northington, D. K., and T. L. Burgess. 1979. Summary of the vegetative zones of the Guadalupe Mountains National Park, Texas. Pages 51–57 in H. H. Genoways and R. J. Baker, editors. 1979. Biological investigations in the Guadalupe Mountains National Park, Texas. Proceedings of a symposium held at Texas Tech University, Lubbock, Texas. Transactions and Proceedings Series number 4. National Park Service, Washington, D.C. Usefully compares plant ecological terms but uses desertscrub and says the park is transitional between Chihuahuan Desert and plains grassland, confounding interpretation by comparing a region (Chihuahuan) and within-region vegetation (plains grassland).

Chapter 8

Recent Changes in the Breeding Avifauna of Four Southwestern Mountain Ranges in Texas and Coahuila

KELLY B. BRYAN has been the Regional Resource Coordinator for the Texas Parks and Wildlife Department for the past 17 years. He has participated in past Christmas bird counts at the park and is interested in the continued documentation of changes to the breeding avifauna to the park and its relationship to the same of other mountain islands in the southwestern United States.

Today I am going to talk about the changes in the breeding avifauna of four southwestern mountain ranges. This first appeared in the symposium of the Chihuahuan Desert Research Institute back in 1974, in a publication by Ro Wauer and David Ligon that tried to chronicle which birds nested in montane habitat. At that time they defined the montane habitat as elevations over 5,500 feet. I have taken the information that they presented and followed it through today, and I am going to try to chronicle some of the changes. What precipitated my interest in these mountain islands was the fact that in 1990 Steve Howell and Sophie Webb recorded four or five species of birds on a piece of property in the Davis Mountains that were not known to be nesters in Texas. This opened a door of opportunity in 1991 for a survey in June that followed up through about mid- 1992 with some survey work in the Davis Mountains. Most of the information that I am presenting today concerns the Davis Mountains, and I am going to show you a short slide program of what the habitat looks like up there. We will look at the table that Wauer and Ligon presented in 1974 and at the changes that have occurred based on new knowledge, new discoveries, and things that we have located in the Davis Mountains, as well as what we know of some of the changes in the Guadalupe Mountains. So, without any further ado, I will start the slides.

This is the south rim trail in the Chisos Mountains. I thought I would throw in a few slides of the Chisos Mountains, for those of you who don't know these three mountain islands. I'm not going to talk much about the Sierra del Carmen in Mexico, but [these photos of] the Chisos Mountains will show you the habitat and what is up there. This view is from the south rim, looking down toward Santa Elena Canyon, down near Castolon, Boot Canyon. The mountain island there is very restrictive—only about 10 square miles—but the habitat diversity is very broad. The plant diversity is probably greater in the Chisos Mountains than in the Davis Mountains, [and] might rival what diversity there is in the Guadalupes. This is Boot Canyon—the type of montane forests that you would have at elevations of 5,500 feet high and higher in the Chisos Mountains. You have Arizona cypress there, which is one plant represented that is not present in either the Davis or the Guadalupes. Just a few more habitat shots: down in lower Boot Canyon, you get kind of an oak canopy forest, but you have quite a bit of diversity there on the floor of the forest in the form of shrubs. You will see that there is not a heck of a lot of grass coverage on the floor of the forest in the Chisos.

Let's go to the Guadalupe Mountains. The substrate in the Chisos was igneous. The dominant substrate here is obviously limestone. You have heard a lot about the geology. Here are some pictures of the Guadalupe Mountains. Going up McKittrick Canyon, you get a little bit more hardwood diversity, approaching elevations of 5,500 feet. You go a little bit higher, and you get piñon and juniper woodlands, with not very much hardwood diversity, I discovered yesterday. The mountain chain here is very much a linear mountain range. It is a very rugged mountain range with deep canyons; it really differs considerably from the Davis Mountains, which I will show you in just a second. You get fairly well developed grassland for ground cover in these areas, especially areas where fires have been able to burn freely.

Now the Davis Mountains—I know more about the Davis Mountains than I do the Guadalupe Mountains, and we have been able to do some surveys. All of our surveys there have been conducted on lands that we have had permission to go on, private lands prior to this year, and the bulk of the central portion of the mountain range is now owned by the Nature Conservancy of Texas, and is called the Livermore Preserve. In the future we will be making further investigations into the avifauna of that area, especially with an emphasis on the breeding avifauna.

This is a picture from Davis Mountains State Park, near Fort Davis. The elevation where I am standing is about 5,600 feet, so it is above 5,500 feet elevation. This is Limpia Canyon, and you see kind of the southern end of the Davis Mountains range, including the most significant peaks. This is Paradise Ridge here. You see Mount Livermore; it has that little knobby peak on the end, called Old Baldy or Baldy Peak. That is Mount Livermore, and then Madera Canyon would be over the ridge here, and on the other side of that ridge would be the core of the Livermore Preserve in Madera Canyon, and I'll show you that in just a minute. From the air, this is the south slope of Livermore. You'll see that even though it has these nice, rugged igneous outcrops, providing a lot of vertical cliff habitat for things like prairie falcons and white-throated swifts, violet-green swallows, etc., it doesn't have nearly the rugged nature that the Guadalupes do. The south slope of the mountains is fairly dry. There are very few tall pines. There are some pines in these enclaves here, which are wetter [and] more mesic, as you get to the north side. Let's just go to the other side of Livermore and look at it from the north slope. The upper Madera Canyon is very wooded with very thick forest and lots of tall pines, both *Pinus ponderosa* and *Pinus strobiformis*, the southwestern white pine; this is all upper Madera Canyon at this point. From the mountain, this is what Madera Canyon looks like, when you look down. This is a view to the north and northwest from the road leading up to the summit of Mount Livermore. You can still see that the largest pines are found in the more mesic zones, the drainages. The drier slopes are covered with piñon and juniper woodlands only. There are very few ponderosas. The forest is well-developed there and has never been logged, but you will see that the ground cover is still grassland. The shrub component of the forest is basically absent in the Davis Mountains; there is just not very much shrub diversity. The midstory would be alligator juniper and various oaks, but it is a very dynamic woodland, based on the avifauna that are located there, especially in the breeding season. Fire still has a free rein in the mountains and burns through on the ground. It sometimes gets fairly fierce. In 1993 a fire was started by lightning in the canyon, and it burned about 26,000 acres over 12 days; it was suppressed by the Texas Forest Service, local volunteers, etc. There was also a very large fire of about 25,000 acres that occurred in the late 1970s—I think 1977 or 1978. So to a certain extent fire still does control the ecology of the area.

The north slope of Mount Livermore is certainly the most interesting, habitatwise; therefore, from an avifaunal aspect, it is also the most interesting. This is what the north-slope woodlands look like. It is basically on a fairly steep incline—maybe a 30° at the minimum. There is a lot of southwestern white pine and ponderosa pine. Gambel oak is the main oak component of that forest. You can still see on the ground; there are basically grasses and a few minor shrubs.

The mountain snowberry is fairly common in places there. We found a painted redstart nest on this slope right here, which is the first record ever for that species in the Davis Mountains. There was a nest with young. I will show you a picture of a painted redstart in a minute. Just above that slope aspect, there is a real nice stand of quaking aspen. There are probably a half-dozen or so stands of aspen on Livermore; some of them are fairly extensive, but they are usually in the very mesic enclaves, rock breakdown, or talus slope type situations. This August [1997] in this particular woodland, a bird was added to the Texas list. Greg Lasley, John Karges, and a couple other folks were fortunate to be there and get pictures of a slate-throated redstart that was in this aspen stand, which was the first confirmed record for Texas.

This is that north-slope woodland, of which I showed you three pictures earlier. You can see the big pine. There are the aspens—a fairly extensive stand. There is the summit of Livermore right above there, so you're at about 8,000 feet, maybe just below 8,000 feet at this location. And because it's been private land and a working ranch for many, many years, you find a lot of situations like this. You find basically what we call stock ponds up in the forest habitat. Most of these stock ponds have good water resources in them. It is pretty dry right now. In Fort Davis, we have had less than two-tenths of an inch of rain in four months. Livermore and the foothills of the mountains are extremely dry right now. This would be a fairly typical situation on an average year, as far as rainfall. We walked into this woodland and found a pair of common black-hawks sitting on the shore of this particular pond, which is probably up at very near 7,000 feet elevation, or just below. You can see well-developed ponderosa woodland, and nobody has ever located Douglas-fir in the mountains.

Let's talk about some of the birds, just briefly introduce them. Sophie Webb and Steve Howell located a gray flycatcher, *Empidonax wrightii*, in 1990 carrying nesting material. The nearest nesting gray flycatchers were in south-central New Mexico some 250 to 300 miles north of the Davis Mountains; therefore, it was thought to be very improbable that the gray flycatcher might be represented as a breeding bird. Here is a male on territory. Here is a female with food in her mouth headed to a nest. This picture, taken in June 1991, represents the first nesting record for Texas. During the surveys in June 1991 and the follow-up surveys in 1992, we easily documented an excess of 30 pairs or 30 territories of *Empidonax wrightii* in Madera Canyon, which I think is a very significant population of a species that is disjunct from its core population by 250 to 300 [miles]. So the gray flycatcher is a definite addition to the breeding avifauna of the range.

Some other things that we found up there—I don't know how many of you recognize this—is a bird of the Sierra Madre Occidental that just barely gets into the Animas Range in New Mexico and southeastern Arizona mountain islands. That picture really shows well its name "dusky-capped flycatcher." It is a Myiarchus flycatcher that is of Mexican origin, Madrean origin. Here is another picture of it. These pictures were taken on our surveys in 1991, and in 1992 we had no less than seven birds, including three pairs, but were not able to confirm nesting, because of access problems in mid-1992. This would be one species that you will see. I have got a table up here that I have produced for these four mountain islands that you can pick up (see Table 1). This will be one bird that I think will be a target to confirm is nesting in Texas. It is even more disjunct from its core population, maybe by excess of 300 miles in Chihuahua. So the dusky-capped flycatcher will be a bird that will be represented perhaps as a breeding bird there that is not represented in any of the other four mountain islands that were characterized in that treatise by Wauer and Ligon.

Here is a picture of a painted redstart. This is not the pair that nested there, but wanted to throw it in to show you. I think it's pretty significant that we found painted redstart there on the north slope woodland, because it was previously

Table 1. Differences in the breeding avifauna of four southwestern mountain ranges in Texas and Mexico (for elevations above 5,500 ft). ©1995, Kelly B. Bryan and John P. Karges (version 3/1/2001). Based on Wauer and Ligon 1974. Trans. of the symposium on the biological resources of the Chihuahuan Desert region. Shaded blocks indicate species added and/or status changes since 1974. * indicates marginal species normally breeding at lower elevations. ® indicates species normally breeding exclusively above the designated elevation.

	GUAD	DAVIS	CHISOS	CARMEN
TURKEY VULTURE	X	X	X	X
SHARP-SHINNED HAWK®	R	R	R	X
COOPER'S HAWK	X	X		X
NORTHERN GOSHAWK®				X
COMMON BLACK-HAWK*		X		X
ZONE-TAILED HAWK	P	X	X	X
RED-TAILED HAWK*	X	X	X	X
GOLDEN EAGLE	X	X	X	X
AMERICAN KESTREL	X	X	X	X
PRAIRIE FALCON®	R	X	R	
PEREGRINE FALCON	X	H	X	X
MONTEZUMA QUAIL	P	X	H	X
WILD TURKEY	X	X		X
BAND-TAILED PIGEON®	X	X	X	X
WHITE-WINGED DOVE*	P	X	X	X
MOURNING DOVE	X	X	X	X
YELLOW-BILLED CUCKOO*		P		
GREATER ROADRUNNER*	X	X	R	?
FLAMMULATED OWL®	X	X	X	X
WESTERN SCREECH-OWL	X	X	X	X
GREAT HORNED OWL	X	X	X	X
NORTHERN PYGMY OWL®				X
ELF OWL*	R	R	X	X
SPOTTED OWL®	X	R		
NORTHERN SAW-WHET OWL®	X	P		X
COMMON NIGHTHAWK	X	X		X
COMMON POORWILL	X	X	X	X
WHIP-POOR-WILL®	X	X	X	X
WHITE-THROATED SWIFT	X	X	X	X
WHITE-EARED HUMMINGBIRD®		?		P
BLUE-THROATED HUMMINGBIRD®	R	?	X	X
MAGNIFICENT HUMMINGBIRD®	X	X	X	X
LUCIFER HUMMINGBIRD		P	X	X
BLACK-CHINNED HUMMINGBIRD	X	X	X	X
BROAD-TAILED HUMMINGBIRD®	X	X	X	X
ACORN WOODPECKER	X	X	X	X
LADDER-BACKED WOODPECKER	X	X	X	X
HAIRY WOODPECKER®	X			P
NORTHERN FLICKER	X	X	X	X
OLIVE-SIDED FLYCATCHER®	X	?		
WESTERN WOOD-PEWEE	X	X		?
DUSKY FLYCATCHER®	?	X		
GRAY FLYCATCHER®	?	X		
CORDILLERAN FLYCATCHER®	X	X	X	X
BUFF-BREASTED FLYCATCHER		R		
BLACK PHOEBE	X	X	X	X
SAY'S PHOEBE	X	X	X	X
DUSKY-CAPPED FLYCATCHER®		P	R	
ASH-THROATED FLYCATCHER	X	X	X	X
CASSIN'S KINGBIRD	X	X		
VIOLET-GREEN SWALLOW®	X	X	X	X
BARN SWALLOW*	X	X	X	
STELLER'S JAY®	X	X		
WESTERN SCRUB-JAY	X	X	R	
MEXICAN JAY®			X	X

	GUAD	DAVIS	CHISOS	CARMEN
COMMON RAVEN	X	X	X	X
MOUNTAIN CHICKADEE®	X	X		
JUNIPER TITMOUSE*	X			
"BLACK-CRESTED" TITMOUSE		X	X	X
BUSHTIT	X	X	X	X
RED-BREASTED NUTHATCH®	R			
WHITE-BREASTED NUTHATCH	X	X	X	X
PYGMY NUTHATCH®	X	X		X
BROWN CREEPER®	X	?		
CACTUS WREN*	X	X	X	X
ROCK WREN	X	X	X	X
CANYON WREN	X	X	X	X
BEWICK'S WREN	X	X	X	X
HOUSE WREN®	X	X		X
BLUE-GRAY GNATCATCHER	X		X	X
WESTERN BLUEBIRD®	X	X		X
MOUNTAIN BLUEBIRD®		R		
TOWNSEND'S SOLITAIRE®				P
HERMIT THRUSH®	X	X		
AMERICAN ROBIN	X	X		X
NORTHERN MOCKINGBIRD*	X	X	X	X
CURVE-BILLED THRASHER	X	X	R	X
CRISSAL THRASHER*	R	?	X	X
PHAINOPEPLA*	R	X	R	P
LOGGERHEAD SHRIKE*	X	X	?	?
BLACK-CAPPED VIREO*			X	X
GRAY VIREO	X		X	X
PLUMBEOUS VIREO®	X	X	H	X
HUTTON'S VIREO®	X	X	X	X
WARBLING VIREO	X	X	H	
ORANGE-CROWNED WARBLER®	X	X		
VIRGINIA'S WARBLER®	X	X		
COLIMA WARBLER®		P	X	X
"AUDUBON'S" WARBLER®	X	X		
BLACK-THROATED GRAY WARBLER®	H			
GRACE'S WARBLER®	X	X		
MacGILLIVRAY'S WARBLER®		?		
PAINTED REDSTART®		R	R	X
SLATE-THROATED REDSTART®				X
OLIVE WARBLER®				X
HEPATIC TANAGER®	X	X	X	X
WESTERN TANAGER®	X	X		
BLACK-HEADED GROSBEAK	X	X	X	X
BLUE GROSBEAK*	X	X	X	X
GREEN-TAILED TOWHEE®	X	X	H	?
SPOTTED TOWHEE®	X	X	X	X
CANYON TOWHEE*	X	X	X	X
CASSIN'S SPARROW*		X		
RUFOUS-CROWNED SPARROW	X	X	X	X
CHIPPING SPARROW	X	X		
BLACK-CHINNED SPARROW	X	X	X	X
LARK SPARROW*	X	X		?
"GRAY-HEADED" JUNCO®	X			
YELLOW-EYED JUNCO®				X

	GUAD	DAVIS	CHISOS	CARMEN
EASTERN MEADOWLARK	X	X		
BREWER'S BLACKBIRD		R		
BRONZED COWBIRD*		X	?	?
BROWN-HEADED COWBIRD	X	X	X	X
AUDUBON'S ORIOLE				X
SCOTT'S ORIOLE	X	X	X	X
HOUSE FINCH	X	X	X	X
RED CROSSBILL®	X	R		?
PINE SISKIN®	X	R		P
LESSER GOLDFINCH	X	X	X	X
REGULAR NESTER (X)	83	82	57	76
RARE/LOCAL NESTER (R)	7	9	8	0
PROBABLE NESTER (P)	3	5	0	4
POSSIBLE NESTER (?)	2	6	2	7
HISTORICAL NESTER (H: PRIOR TO 1974)	1	1	4	0
TOTAL KNOWN/POTENTIAL BREEDERS	96	103	71	87

thought that the Chisos Mountains represented the northern extent of nesting painted redstarts. In fact, in 1992 when this bird was nesting in the Davis Mountains, there wasn't a single pair documented as nesting in the Chisos. I think that's pretty significant in that the nearest nesting painted redstarts to the pair that were in the Davis Mountains that particular summer had to be in the Sierra del Carmen of Coahuila, Mexico, where it's a very common bird and a regular nester. So the painted redstart was an unexpected discovery for the breeding contingent there.

Another unexpected bird was the northern saw-whet owl. Mark Lockwood photographed this bird in 1991 near the top on Paradise Mountain, and we found it both in 1991 and 1992. We think it's going to be a fairly regular summer component of the breeding avifauna, but we need to confirm it as nesting. Even though we have recorded northern saw-whet owl in the summertime, it will be on the table as a probable nester instead of being confirmed as a nester. David Woolf, by the way, had one here in the Guadalupes, I think about a month and a half ago; it was calling on territory, and he got recordings off of it.

A bird that was not listed previously by Wauer and Ligon was the red crossbill. I photographed this bird along with a second juvenile and a female—both juveniles were begging for food—at the McDonald Observatory in the summer of 1995, I believe. An obvious juvenile red crossbill, mid-July record, indicates that those birds had to have fledged from a nest nearby. So, red crossbill is added as a breeding component of the Davis Mountains. It had always been a component of the Guadalupe Mountains.

One of the biggest surprises we had was the discovery of almost an annual population of white-eared hummingbirds in the Davis Mountains. This particular adult female was at a feeder in 1993 in upper Limpia Canyon, and the birds are present from May through September. It is one of the three birds that were present that particular summer. In June, this bird right here, which is a juvenile male characterized by the sandy color at the lore, but look at the breast; it's not even fully feathered. I have shown this to a lot of folks, and if you want to vote on it, you can. I think this bird had to be reared locally. How could a bird with a not even fully feathered breast, a juvenile white-eared hummingbird, fly approximately 300 miles from the nearest known nesting locality to the Davis Mountains and spend June through September at that location? Birds showed up in May. I think there's a small nesting contingent, but it needs to be confirmed. This would be one of the things we're looking for.

This year we added another bird to the Texas State list. A Berylline hummingbird was present for about three weeks in August at feeders in upper Limpia Canyon; this bird is thought to be an adult female. There had been one previous sight record, but unconfirmed, and so the pictures that you see here, taken in August, were the first confirmed records from Texas.

I have been fortunate to be in the right spot in 1992 on Mount Livermore on another occasion. This spring singing male olive warbler was a first confirmed record for Texas. There had been maybe three or four viable sight records but no confirmation prior to May 1992, and this picture represents the first confirmed record for Texas. So Mount Livermore and the Davis Mountains have a lot of discoveries yet to be made, and we would be real fortunate to be a part of looking at some of the avifaunal components year round.

Here's a pretty picture of Montezuma quail. There's still a very strong, viable population in the Davis Mountains, but it has totally disappeared from the Chisos, and now I understand it has probably disappeared from the Guadalupes. It used to be a native component of the avifauna here in the Guadalupes, and it was subject to reintroduction programs, I think both in the Chisos Mountains and in the Guadalupe Mountains, and it doesn't look like these populations are going to hang on. [Note: Montezuma quail have been periodically but infrequently seen in the Dog Canyon area almost every year since the 1986 reintroduction project.] I can say one thing, that studies on the Montezuma quail have indicated that they are not a bird of short grasslands, and they must have medium to tall grasslands and a fairly good coverage on the land in order to have a good viable population. So if grazing is a problem, such as on federal lands, it might reduce the grassland to an extent of coverage that the Montezuma quail cannot tolerate. There are still good viable grasslands in the Davis Mountains, and I think that's the reason the population is so viable there.

This will end the slides, and I will go into some more detail. I just want to show a nice sunset in the ponderosas of Ridge Gap near Mount Livermore, and even though the sun sets every day, we are just beginning, I think, the chapter of bird discoveries in the Davis Mountains. Now that private lands have been purchased by the Nature Conservatory of Texas, there may be some opportunities at some point in the future to do further studies. I would be really pleased to be a part of that study team, and we have a lot more discoveries to make. We've got a lot of things to fill in from our brief surveys in 1991 and 1992. I don't know the Guadalupes really well, but I want to present some information based on Wauer and Ligon's table for the Davis Mountains and the Guadalupe Mountains.

It's been about 25 years since Wauer and Ligon did their study. At that time their publication in 1974 listed 83 species for the Guadalupe Mountains as birds breeding, above 5,500 feet of elevation. They had 81 regular nesters and two probable nesters. The Davis Mountains were listed as having 72 species regular and two probable. The Chisos Mountains had 64 regular nesters. They didn't list any birds at that time that were just probable in occurrence as a nesting bird. Sierra del Carmen in Mexico listed 73 regular breeding species with two probable. I thought I'd go over some of the comparisons of the mountain islands so that you would understand a little bit of the differences there. Maximum elevation of the Guadalupe Mountains is around 8,750 feet. The area of the mountain island that exists above 5,500 feet is listed by Wauer and Ligon as 65 square miles. Now, I think that needs to be defined, because I don't know whether they included all of the [Guadalupe Mountains] area in New Mexico. The title of the presentation should include the state of New Mexico, because the Guadalupe Mountains don't stop at the political boundary of the national park or the state line of Texas. Therefore, it needs to be extended north into New Mexico, and it certainly would encompass, I think, some diversity of habitats that aren't well represented in the park. I am going to reflect on that in just a minute. Again, the substrate is limestone.

The Davis Mountains maximum elevation is about 8,350 feet above sea level. Now, here's a big thing. Wauer and Ligon listed the area above 5,500 feet as being 70 square miles. Now, think about that. It's the most massive mountain range in Texas. I got to thinking about that myself and I pulled out topographic maps and started looking at it, and Jeff Davis County is 2,254 square miles. If the Davis Mountains with elevations in excess of 5,500 feet covered only 70 square miles, that would be less than 3% of the area of Jeff Davis County. No way. So we got to looking at the information. Fort Davis itself is right at 5,000 feet elevation, and the state park has a lot of elevation in it in excess of 5,500 feet. I discovered there was probably a decimal place there in the calculation, and instead of being 70 square miles it was likely 700 square miles. I confirmed that by examining the 5,500-foot line on the topographic map. I think it's actually closer to 650 square miles in excess of 5,500 feet of elevation, which would make it right at one-third of Jeff Davis County. All of that 5,500-foot elevation contour line is in Jeff Davis County except for a small contingent in northwestern Brewster County. None of it lies in Presidio County whatsoever. So it's 650 square miles, which changes things quite a bit. You're going to see that reflected in the numbers in just a minute.

The Chisos Mountains remain at a maximum elevation of about 7,835 feet with 10 square miles above 5,500. Their basic substrate is igneous. In the del Carmen Mountains in Mexico, you get two [substrates]. You get the northern Sierra del Carmen, which are all a limestone substrate with several peaks in the neighborhood of 8,000 feet, but the southern section of the mountain known as the Sierra de la Encantata, is going to be all the way up to 8,960 in elevation, Lumas Peak, and it has an igneous substrate. So the Sierra del Carmen is kind of a dual type of mountain there. Both are listed as having elevations covering an area of 115 square miles above 5,500 feet elevation. I don't know what the exact breakdown is between the igneous part of the mountain and the limestone part of the mountain, but that's what is listed.

Before we analyze some of the changes in the birds, I thought it might be interesting for you to learn some of the vegetation changes that have been applied to these ranges. Just dealing with the dominant woody species: ponderosa pines were previously listed for all four mountains, but now it's on the Davis and Guadalupe mountains only. Ponderosa pine is not found in the Chisos and not found in the del Carmen. In the Chisos, the pine is described as being *Pinus arizonica* var. *stormiae*, and it's called the Arizona pine, which is different now taxonomically than the ponderosa. In the del Carmen you have both Apache pine, *Pinus engelmanni*, and the Chihuahua pine, *Pinus leiophylla*. So there are no ponderosas in the del Carmen, either. You have southwestern white pine in the Davis Mountains, basically no change from the previous table that's listed for Guadalupes, Davis, and del Carmen mountains. There is no change in firs. You have a couple of firs, I think, in the del Carmen; Douglas-fir is in the Guadalupes and a little bit in the Chisos. It's just a very minor component of the woodland. There are absolutely no fir whatsoever in the Davis Mountains. There is no change in Arizona cypress. It's only found in the Chisos and the del Carmen. With the junipers you have some changes. No change with respect to alligator juniper found in all four, but you now have Rocky Mountain juniper, *Juniperus scopulorum*, in the Guadalupes, and the juniper in the Davis Mountains is now known as *Juniperus erythrocarpa*, rose-fruited juniper. It's only represented in the Davis Mountains of these four mountain islands, I think. It may be in the del Carmen, though. *Juniperus monosperma*, or one-seed juniper, which was previously listed for all four, is now just found in the Guadalupes. Oaks: there are basically four oaks in the Guadalupes, eight oaks in the Davis Mountains, eight oaks in the Chisos Mountains, and nine oaks in the del Carmens.

What have we found in the Davis Mountains? First of all, from [Wauer and Ligon's] table, I deleted yellow-billed cuckoo, because I do not believe it occurs anywhere in any of these mountain islands and in elevations in excess of 5,500 feet. Birds that were listed as probable previously in the Davis Mountains, which are now confirmed as regular nesters, would include magnificent hummingbird and western tanager. Birds that were not listed previously which are now considered regular nesters include common black-hawk, white-winged dove, greater roadrunner in the inner montane and montane islands of grassland, the gray flycatcher, black phoebe which nests up high as well, and barn swallow. Anywhere you have a ranch up high, above 5,500 feet in elevation, you're going to get barn swallows. I suspect that they are probably here in the Guadalupes in that same respect. House wren was not listed previously for the Davis Mountains. It's common in rock outcrops and downed timber areas at elevations in excess of 7,800 feet. American robin was not listed previously. It's found in Madera Canyon, all up and down the canyon, and has also nested in Fort Davis itself; that's not above 5,500 feet, though. Loggerhead shrike is up there in the high mountain meadows. Near the summit of Livermore, we found orange-crowned warblers on nest and Virginia's warbler, which is the second most abundant warbler to Grace's. Grace's is the most common warbler up there as a nesting bird. Also, Audubon's warbler, of which I think there was some previous information that should have had them listed as probable, but Audubon's warbler is there as well. Green-tailed towhee and black-chinned sparrows both nest in stunted oaks at the summit of Livermore, so green-tailed towhee is new to the list. Lark sparrow in the inner montane meadows and bronze cowbird now has been found up high in the mountains.

Birds changed from those not listed to those that would be historical are those for which we don't have any definitive evidence in the last 25 years still nest in the Davis Mountains. Spotted owl: Steve Runnels of the Dallas Museum documented nesting spotted owls in the late 1970s in the Davis Mountains, and we do have one recent record which would indicate probably resident birds and the probability that they are still there as nesters. Mountain bluebird: the first nesting record for Texas was obtained by me, Barry Zimmer, and Victor Emanuel two years ago on the south end of the Davis Mountains, so mountain bluebird has been added. Others include painted redstart and red crossbill.

The birds that were previously not listed that are probable nesters are the birds that we will need to work on. These are the northern saw-whet owl, the olive-sided flycatcher, which is a probable nester up high as well, and the dusky-capped flycatcher.

Those birds changed from not listed to possible nesters are the birds that have been present, and we need to look at. We don't know what the exact extent for sharp-shinned hawk, northern pygmy owl, white-eared hummingbird, and blue-throated hummingbird. Lucifer hummingbird is there every year now and probably is nesting. Brown creeper and MacGillivray's warbler are possible nesters.

Birds on the table changed from regular to historical are those birds that we don't have any evidence in 25 years that they've nested: peregrine falcon and Brewer's blackbird. There's only one [Brewer's blackbird] nesting record, and Pansy Espey found that in Madera Canyon about 25 years ago.

We downgraded some birds from a regular nester to a rare and local nester including elf owl and pine siskin. Also, birds I suspect that are not in the mountains would be blue-gray gnatcatcher, which we can't find anywhere in the range; crissal thrasher as a nester, it's a winter bird but not a nester; and gray vireo. Also, we're close to deleting summer tanager from the birds that nest in the Davis Mountains.

I compared the [table with the current] checklist of the Guadalupe Mountains, which really doesn't include the area in New Mexico, a portion of the Guadalupe Mountains range. You will see some of the discrepancies there that probably need to be confirmed and checked. I think the breeding avifauna is the most important aspect of the birds that occur in any location, especially in parks. Therefore, it behooves us as resource managers to really get a handle on those birds that breed or nest within the boundaries of your jurisdiction. So you'll see some discrepancies there. I'm probably going to downgrade sharp-shinned hawk to rare in the Guadalupes. Zone-tailed hawk is not listed as a nester in the checklist, but it's probably a rare and local nester. There are some Montezuma quail. Also, northern pygmy owl is not listed as a nester. Common nighthawk is not listed as a nester, but it was listed previously by Wauer and Ligon and is probably present. You will see some others. Dusky and gray flycatchers are two Empidonax flycatchers that need to be really investigated. So these would be two species that should be looked at in further detail if they are present in the summertime. Again, common raven is not listed as a nester; I don't know why. I think some of these birds that I listed as "Elevation?" after seeing the New Mexico section of the Guadalupe Mountains and up in Dog Canyon, we can easily put on the list because some of those inner mountain grassland species like Lillian's or eastern meadowlark, lark sparrow, roadrunner, loggerhead shrike are all there, and they're all above 5,500 feet as nesters.

Thank you very much.

Chapter 9

Avifaunal changes in the Guadalupe Mountains of New Mexico and Texas

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The Guadalupe Mountains of west Texas and southeastern New Mexico are one of the many "sky islands" located in the American Southwest and northern Mexico. Sky islands are isolated mountain ranges surrounded by hot, dry lowlands, usually desert grassland or scrub areas. The uniqueness and importance of these areas have long been recognized, and they usually have a higher degree of biodiversity than surrounding areas. This richer flora and fauna can be attributed to three factors. One is the sky islands have a variety of habitats. Another factor is that many of them are isolated biologically from similar areas, and endemic species develop. A final factor is that relict populations are often found from pre-Holocene times when climates were different and isolation occurred to a lesser degree. The biodiversity of the Guadalupe Mountains is a result of all these factors.

This paper examines the avifauna of the Guadalupes, starting with what we know of populations around the turn of the 20th century, changes during the 20th century, and what we might expect over the next century.

The Guadalupe Mountains extend in a general southeast to northwest direction, losing elevation as one proceeds to the northwest. The general area at its greatest length is about 55 miles (80 km) and at its widest is a little less than 36 miles (60 km). The mountain range occurs across several political boundaries and occupies parts of two states and five counties. In part because of this, land management schemes have differed widely in the Guadalupes, ranging from high to low degrees of protection and activity.

The high point in the mountains is Guadalupe Peak at 8,749 feet (2,667 m). The low point is not as easy to determine because of defining where in the transition area the Guadalupes stop and start. For the purposes of this paper, the low point would be around 3,500 feet (1,067 m) along the eastern edge of the escarpment in the area of Carlsbad. In this paper all of the land within the Guadalupe Mountains unit of the Lincoln National Forest, Carlsbad Caverns National Park, and Guadalupe Mountains National Park is included. This is a large area of about 408,840 acres (164,455 ha). Compared with other areas, it is a little more than half the size of Big Bend National Park in west Texas, an area long recognized for a very diverse avifauna with about 450 species.

Currently about 363 species representing 55 different families have been reported from the Guadalupes. Carlsbad Caverns National Park with 337 species has the richest list followed by Guadalupe Mountains National Park with 295. The Lincoln National Forest unit has 166 species. The low number of species recorded from the forest is more a reflection of a lack of field work there than an indication of species paucity. While much of the Lincoln National Forest may appear to differ little, there are places such as Big Canyon which are probably as rich biologically as anyplace in the range. The numbers listed for each of the units differs somewhat from checklists currently in use because of recent taxonomic revisions. In addition, species which are considered hypothetical are not included. Included on all three checklists, however, are species which are reported to have occurred or are possible but for which documentation is poor. A more important measure of the richness of the Guadalupes might be of nesting species, which currently would include about 125 species, historical and current.

The earliest literature available is from the Pope survey which passed along the southern flank of the Guadalupe Mountains during February 28 to March 2, 1854. No specific mention is made on birds from that part of the journey, which is unfortunate, but they did comment on bird life to the west in the Cornudas Mountains and along the Delaware River to the south and east (Bailey 1928).

Florence Merriam Bailey (1928), author of *Birds of New Mexico*, produced some of the earliest literature on birds of the Guadalupes and also one of the finest state bird books, even today, 70 years after publication. She and Vernon Bailey worked in the southern part of the Guadalupes in the late summer of 1901 in the Queen, Dog Canyon, and Salt Flat areas. Her book also contains information on other work done in the mountains up until about 1915 and during some of the initial Carlsbad Cavern surveys in the early 1920s.

Also in 1928, Vernon Bailey published a work entitled *Animal Life of the Carlsbad Cavern*. This was the result of work he had done in conjunction with an initial survey of the Carlsbad Cavern area to see if the area merited national monument status. Although many of the locations mentioned in the text are vague, he did add at least 30 species to the overall Guadalupe Mountains list. Stokely Ligon (1961) authored *New Mexico Birds and Where to Find Them* in which much additional information was provided on the Guadalupes.

On December 24, 1957, the first Christmas count in the area was held at Carlsbad Caverns National Park. These volunteer winter surveys of bird populations within a 7.5 mile radius have served to provide a great deal of information on status and distribution. The first count in Guadalupe Mountains National Park was held in 1964. Over the years, 35 counts have been held at Carlsbad Caverns and 21 at Guadalupe Mountains. One-hundred-sixty-eight species have been recorded at Carlsbad Cavern and over 120 have been found at Guadalupe Mountains National Park. The number of hours in the field has been impressive with over 1,400 party-hours in the field at Carlsbad Caverns. Party-hours reflect the number of hours a party spent in the field (one-to-many people) and not the actual hours of field observations.

Other sources of information have been banding studies which were initiated at Carlsbad Caverns in the 1940s, followed by cave swallow (*Petrochelidon fulva*) work done by Ken Baker in the early 1960s. Additional banding work was done primarily at Rattlesnake Springs, starting in 1979 to the present, and a continuing cave swallow banding and status study at Carlsbad Caverns National Park starting in 1980.

Rattlesnake Springs and the Guadalupe Mountains in general have long been recognized as one of the prime birding spots in the United States (Pettingill 1981, Zimmer 1985). These areas are visited by hundreds if not thousands of birders over the course of a year. Rattlesnake Springs serves as one of the best vagrant traps in the American Southwest. McKittrick and Dog canyons are also visited by many birders with some species there being found easier than anyplace else in the state of Texas. All of this adds up to a growing and valuable accumulation of data on bird distribution—much of it provided by volunteers, birding enthusiasts, photographers, and other visitors.

Because of the general lack of information on bird status from 100 or more years ago, it is difficult to comprehend all the changes that have occurred. Still there are changes that have occurred and have become clearer with time with all the recent information that has been collected. Several of these species are mentioned below in different categories which include "recent changes in status" and "declining species and species of concern."

Recent changes in status
Numerous species have undergone recent population increases. Some of these are recovering populations, some are species that have gradually moved into the area, and others represent recent discoveries of forms that may have been overlooked by earlier researchers.

Turkey vulture (*Cathartes aura*). V. Bailey (1928) reported that the species was "abundant" and that "sometimes two or three hundred were seen together on the roosting grounds." He reported young in the nest before the first of May, and cliffs and canyon walls were reported as nesting and roosting sites. Since Bailey's time the species has abandoned the large roosts in Walnut Canyon and similar spots, although roosts of 50+ birds are known from Last Chance Canyon (Lincoln National Forest) and Big Canyon (Lincoln National Forest). The largest roosts in the area have developed since the mid 1980s at Rattlesnake Springs in the deciduous trees with the maximum count of 400 birds on September 17, 1997 (G. Garber, personal communication). Bailey implied that this species was probably a common nesting species although nests are very rarely reported from anyplace in the area anymore.

White-winged dove (*Zenaida asiatica*). The first report of this species is from Ligon (1961) who reported that it occurred "occasionally on the east side of the Guadalupe Mountains near the Texas line, and in the Pecos Valley about Carlsbad." The species was rare for many years after that until 1970 when 16 were found at Rattlesnake Springs including a nest with well-developed young (Hubbard 1970). The general population in the area gradually grew with the biggest increases and most stable populations being in Carlsbad where large numbers of birds would winter. Birds that occurred during the summer and presumably nested in Big, Walnut, and McKittrick canyons generally left the area during the winter. By the mid 1980s, bird occurred in many of the canyon bottoms and wintered throughout in low numbers. The spread increased and a small population colonized the Queen area (Lincoln National Forest) in 1994 (Snider 1997). This species has spread to most of the Guadalupe Mountains highlands from Robinson Draw to north of Queen and may have even been a minor factor in the decline of band-tailed pigeons.

Inca dove (*Scardafella inca*). The recent arrival was first recorded in the Guadalupes in 1979 (Hubbard and West 1979) at Rattlesnake Springs. Small populations have become established in Carlsbad and other residential areas. Interestingly, this species has yet to be recorded at Guadalupe Mountains National Park and is not known elsewhere in the Guadalupes area except in the area around Rattlesnake Springs and Washington Ranch.

Elf owl (*Micrathene whitneyi*). F. M. Bailey (1928), V. Bailey (1928), and Ligon (1961) did not report this species from the Guadalupe Mountains area. Two to three pairs were reported from the Guadalupe Mountains (probably the lower parts of McKittrick Canyon) by F. R. Gehlbach in 1969 (Oberholser and Kincaid 1974). A small population continues to persist in that area. It was first recorded in Lincoln National Forest in 1997 when a pair was found in upper Dark Canyon on June 16 (Williams 1997) and later in the summer to the north in the lower reaches of Last Chance Canyon (Hibbitts 1997).

Cave swallow *(Petrochelidon fulva)*. This species was first found in Slaughter Canyon in 1930 (Johnson 1960) although the initial specimens were misidentified as Cliff swallows (*Petrochelidon pyrrhonota*). It is likely that the species was actually recorded in 1924 when V. Bailey visited the Guadalupes but was again misidentified (West 1995). A "rediscovery" occurred when a colony was found in Goat Cave in Slaughter Canyon, Carlsbad Caverns National Park in June 1952 (Ligon 1961). Since then cave swallows were monitored sporadically until 1980 when a banding program was initiated which continues to this day. Ligon (1961) reported that in 1959 the species was known from four sites at Carlsbad Caverns National Park involving about 200 birds. By 1966 this had expanded to five sites with 213 adults and 319 young (Snider 1966). In 1966 the species first occurred at Carlsbad Caverns and the population there has expanded to approximately 2,000+ birds. The most recent estimate for this species in the Guadalupes (West 1991) recorded the species from 18 caves and 4,720 to 5,220 individuals. Two additional sites were no longer in use. One of the sites was on Bureau of Land Management land, three were in the Lincoln National Forest, and the rest were at Carlsbad Caverns National Park. The species is known to occur at Guadalupe Mountains National Park and probably will eventually be found to nest in the park.

Tufted (black-crested) titmouse (*Baeolophus bicolor*). This species has been reported in recent years in McKittrick Canyon. The closest population occurs in the Davis Mountains, about 100 miles (160 km) to the southeast of McKittrick Canyon (Oberholser and Kincaid 1974). This species either is a recent arrival, a species with a low population base that was overlooked until recently, or no more than a vagrant from the Davis Mountains. This species has never been recorded in New Mexico.

Bronzed cowbird (*Molothrus aeneus*). Apparently the first record for the area was a male at Rattlesnake Springs on May 28, 1983 (Goodman 1983). Since that time the species has occurred sporadically at Rattlesnake Springs and more regularly at feeders in Carlsbad. While it has been reported farther north and east with some regularity, the numbers of this species are still very low and apparently this species has not colonized this northern area well.

Declining species and species of concern

A number of species reported from the Guadalupe Mountains by earlier authors have either declined or may have become extirpated from the mountains. This section includes species that formerly were widespread and now are largely gone.

Zone-tailed hawk (*Buteo albonotatus*). There were few early reports, but F. M. Bailey (1928) reported this species as early at 1901 from Turkey Canyon (Lincoln National Forest). Ligon additionally reported it from Sitting Bull Falls (Lincoln National Forest). Zone-tailed hawk was first reported from Guadalupe Mountains National Park in 1972 (Newman 1974), and the first nest was recorded from Turkey Canyon in 1947 (Ross 1973). Nesting was not recorded again until June 1997 when another nest was discovered in the same canyon (Williams 1997). It probably breeds elsewhere in the mountains, but currently only one nesting pair is known. It is only known as a migrant and vagrant summer visitor at Carlsbad Caverns National Park.

Golden eagle (*Aquila chrysaetos*). F. M. Bailey (1928) reported this species as "very abundant," but now it certainly cannot be regarded as common. A wide variety of factors including legal and illegal persecution, changes in land management strategies, and increased human activity in the area have caused declines in this species. Formerly nested almost annually in Walnut Canyon (Carlsbad Caverns National Park) where five historic nesting sites are located but has not nested since the mid 1980s. Nests elsewhere in Guadalupe Mountains National Park and Lincoln National Forest are low in number. Northern migrants augment winter populations.

Peregrine falcon (*Falco peregrinus*). This species nests in the Guadalupes in very low numbers. Populations were very low in the 1970s and early 1980s but may be slowly recovering. It formerly nested in Lincoln National Forest, but an active nest [in Lincoln National Forest] has not been reported since 1980. They are an uncommon to rare migrant throughout.

Montezuma quail (*Cyrtonyx montezumae*). This species was formerly widespread in the Guadalupes to as low as the entrance of Carlsbad Cavern (V. Bailey 1928). Apparently it became extirpated from the Guadalupes during the mid-1950s (Ross 1973) due to a combination of drought and overgrazing. Ross reported that overgrazing, especially during the growing season, was detrimental to the survival of this species. An intensive wildlife survey of over 2,500 man-hours was conducted on Carlsbad Caverns National Park and Lincoln National Forest lands during the summers of 1971 and 1972 and Montezuma quail were not found. Although secretive and often difficult to locate, it was assumed that the species was extirpated from the Guadalupes. The National Park Service acclimated and released two groups in 1985 totaling about 50 birds, which were originally taken in southern Arizona. Small groups were seen on several occasions, even in the adjacent New Mexico–portion of Dog Canyon, and a pair with young was seen one time. None have been recorded in almost 10 years, although they may still occur.

Yellow-billed cuckoo (*Coccyzum americanus*). Formerly reported as "very common" in the general area (F. M. Bailey 1928) this species is now largely restricted to lowland mesic canyons and riparian areas. It is most common at Rattlesnake Springs (Carlsbad Caverns National Park) with smaller numbers in McKittrick Canyon (Guadalupe Mountains National Park), Big Canyon (Lincoln National Forest), Walnut Canyon (Carlsbad Caverns National Park) and the Sitting Bull Falls–Last Chance Canyon drainages (Lincoln National Forest). Preservation of stands of deciduous trees is a requirement for the continued presence of this species.

Spotted owl (*Strix occidentalis*). This species was probably never common in the Guadalupe Mountains and occurs in only selected areas at this time. It nests in several canyons in the southern part of the Guadalupes and although numbers seem stable, the population is small and the habitat is limited. The species is a permanent resident in the Guadalupe Mountains. The Guadalupes make up the easternmost range for this species, and it is known to occur in all three areas but is not known to nest at Carlsbad Caverns National Park.

Acorn woodpecker (*Melanerpes formicivorus*). Once reported as "abundant" by F. M. Bailey (1928), this species is now very local in the Guadalupes. Currently only very small populations of just a few individuals are known from Dog and McKittrick canyons (Guadalupe Mountains National Park) and Turkey Canyon and possibly upper Dark Canyon (Lincoln National Forest). Birds are rarely seen elsewhere in the mountains. This species requires stands of dead timber; the removal of most of the large ponderosa pines and dead timber has been a factor in their decline.

Scissor-tailed flycatcher (*Tyrannus forficatus*). This species was formerly common at Rattlesnake Springs (Standiford 1965) and probably as a nesting species. Scissor-tailed flycatcher is now rarely found and only in migration. This decline follows the same decline in the species of the Carlsbad area, probably as a result of changes in agriculture as alfalfa gradually replaced cotton. They are common farther east of the Guadalupe Mountains area.

Horned lark (*Eremophila alpestris*). This is a widespread species across much of the Great Plains and western states. It is not rare in the general area and is often recorded in the lowland areas of Carlsbad Caverns and Guadalupe Mountains national parks. V. Bailey (1928) reported that the species breeds "and on top of the Guadalupe Mountains." Since Bailey made that observation, based on his 1924 field work, West has made the only report of horned larks in the area, i.e., from Lincoln National Forest, in the fall of 1997. This species probably occurs as an uncommon migrant and may even breed on the far northern edge of the forest; there is no known breeding since 1924 and only the one sight record. As juniper and scrub has replaced more open grassland with scattered ponderosa pine, this species has apparently been gradually eliminated from the forest portion of the Guadalupes.

Common raven (*Corvus corax*). The common raven is an adaptable, widespread species found across the northern hemisphere (American Ornithologists' Union Checklist 1983). It generally persists except under the most vigorous persecution. F. M. Bailey (1928) reported that it "breeds east at least to the Guadalupe Mountains" and that it was fairly common around Carlsbad during the winters of 1915 and 1916. Oberholser and Kincaid (1974) also reported it as rare in the northern trans-Pecos. The status of this species at the turn of the 20th century is not clear although it was certainly present and was probably widespread in at least low numbers and nested in the Guadalupe Mountains. Since that time, records have been very rare and limited primarily to Guadalupe Mountains National Park. During recent forest surveys some birds have been found in the area of Robinson Draw–Hammwell and along the western escarpment of Lincoln National Forest in Otero County. The first recent record for Lincoln National Forest was of a pair feeding four fledged young at Robinson Draw on July 9, 1994 (Snider 1998). Since that time there have been half-a-dozen records in the areas, usually of pairs.

Bell's vireo (*Vireo bellii*). Virtually the entire population of this species in southeast New Mexico is located in the Rattlesnake Springs area. While heavily impacted by brown-headed cowbirds (*Molothrus ater*), the population seems stable. The existence of this species in southeastern New Mexico is contingent on good habitat management at Rattlesnake Springs. Alteration of the limited native riparian habitat could eliminate Bell's vireo as a breeding species.

Varied bunting (*Passerina versicolor*). Varied buntings are considered rare to uncommon in the two parks and have not yet been found on Lincoln National Forest land. In the 1960s and early 1970s they were found with some regularity at Carlsbad Caverns National Park but have since become somewhat rare and difficult to find. The Guadalupes are at the northeastern extremity of range for this species. It is possible that it is overlooked and not all canyons have been checked for breeding territories. Precipitation may be an important factor on the presence of birds in canyons in the area.

Orchard oriole (*Icterus spurius*). This species is often common at Rattlesnake Springs and also occurs in surrounding areas in low numbers. The presence of native riparian vegetation, particularly large deciduous trees, is necessary for this species to nest in the area. Without such trees, this species would decline and eventually disappear. The almost total destruction of native riparian vegetation along surrounding rivers has made Rattlesnake Springs even more important for a growing number of species.

Hooded oriole (*Icterus cucullatus*). This species may be one of the rarest of breeding species in the Guadalupes area. Occasionally a pair or two are found at Rattlesnake Springs, but it is unreported some years. As with the orchard oriole, maintenance of riparian woodland is necessary if this species is to persist in the area.

Birds and all other species must be taken into account when devising management plans. What effect will new trails and campsites, fuelwood areas, grazing and extended waterlines, prescribed fire or lack of prescribed fire have on these populations? Some current populations are restricted and declining because of natural forces; others have been lost or will be lost in the future because of land policy and management decisions. There can be little doubt that human activities have accelerated many of these changes and made others possible. If there is a desire to maintain a native balance in the Guadalupe Mountains, avifauna that occupies this sky island will have to be considered.

Composite species list for the Guadalupe Mountains of New Mexico and Texas

Table 1 is a composite of three checklists for the three major political entities in the Guadalupes; Carlsbad Caverns National Park, Guadalupe Mountains National Park, and Lincoln National Forest. It has been difficult to illustrate the status of each species in each area without at least a moderate amount of confusion. Every attempt has been made to reflect the true status of each species and with only a few exceptions, the checklists have been followed without deviation (Carlsbad Caverns Guadalupe Mountains Association 1997).

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Table 1. Each species is followed by a status designation and then seasonal status. If it occurs in only one season it is noted in that manner. Species known to occur as both spring and fall migrants are recorded as migrant. Some species are known to occur in only one migration season. Some species (mostly breeding species) occur spring through fall (sp-fa).

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
PODICIPEDIDAE			
pied-billed grebe	r-uc, fa-sp	r, fa	acc, fa
eared grebe	r, m	o, fa	
western grebe	acc, w		
PELECANIDAE			
American white pelican	acc, sp	acc, m	acc, fa
brown pelican		acc, su	
PHALACROCORACIDAE			
double-crested cormorant	acc, fa		
ARDEIDAE			
American bittern	r, m		
least bittern	acc, sp		
great blue heron	uc-o, pr	r-o, pr	
great egret	r, sp	o, m	
snowy egret	uc, m	o, sp	
tricolored heron	acc, su	acc, su	
cattle egret	o, m	o, sp-fa	
green heron	fc-r, sp-fa	o, sp	acc, fa
black-crowned night-heron	r-o, sp-fa	acc, su	acc, su
THRESKIORNITHIDAE: ibises and spoonbills			
white ibis	acc, sp	acc, su	
white-faced ibis	uc-m	acc, su	
CATHARTIDAE: American vultures			
black vulture		acc, su	
turkey vulture	c, sp-fa	c, sp-fa	c, sp-fa
ANATIDAE: swans, geese, and ducks			
black-bellied whistling-duck	acc, sp		acc, fa
snow goose	r, f-sp	o, fa	
Canada goose	r, wi	o, sp	
tundra swan	acc, sp		
wood duck	r-o, m	o, fa-sp	
gadwall	c-uc, fa-sp	uc, fa-sp	r, fa
american wigeon	uc, fa-sp	uc, fa-sp	
mallard	fc-r, pr	r, fa-w	r, w
blue-winged teal	fc-r, fa-sp	occ, sp-fa	uc, fa
cinnamon teal	fc-r, fa-sp	o, sp-fa	r, fa
northern shoveler	c-fc, fa-sp	o, sp-fa	
northern pintail	c-uc, fa-sp	o, fa-w	
green-winged teal	c, fa-sp	r, sp-fa	r, fa-w
canvasback	r-o, fa-sp	o, sp-fa	
redhead	uc-r, fa-sp	o, sp-fa	
ring-necked duck	fc-uc, fa-sp	uc, fa-sp	acc, sp, w
lesser scaup	r-c, pr	o-w	
bufflehead	uc-r, fa-sp	o, sp	
common goldeneye	uc-r, fa-sp		
hooded merganser	acc, m		
common merganser	r, w	o, fa-w	
ruddy duck	uc-r, fa-sp	o, fa	acc, w
ACCIPITRIDAE: kites, eagles, hawks and allies			
osprey	r, m	o, sp-su	
white-tailed kite	acc, w	acc, w	
Mississippi kite	r-acc, m	acc, p-su	
bald eagle	acc, w	o-acc, pr	r, fa-sp
northern harrier	c-uc, pr	fc-r, pr	
sharp-shinned hawk	fc-uc, fa-sp	fc-r, pr	uc, fa-sp
Cooper's hawk	uc, pr	fc-uc, pr	uc, pr
northern goshawk	o, f-w	o, m	acc, fa
common black-hawk	acc, sp	o, m	
Harris' hawk	r, pr	o, w-sp	
red-shouldered hawk	acc, sp		
broad-winged hawk	acc, m	acc, sp	

Status	**Season**
acc- accidental	sp - spring
o - occasional	su - summer
r- rare	fa- fall
uc- uncommon	w- winter
fc- fairly common	m - migrant (spring and fall)
c- common	pr- permanent resident
extir-extirpated	

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
ferruginous hawk	fc-r, pr	r-acc, pr	r, w
rough-legged hawk	uc-r, w-sp	o, fa-w	
golden eagle	fc-uc, pr	fc, pr	uc, pr
FALCONIDAE: caracaras and falcons			
crested caracara		acc, fa	
American kestrel	c-uc, pr	c-uc, pr	uc, pr
merlin	acc-w	o,fa	acc,fa
prairie falcon	fc-r, pr	uc-r, pr	
peregrine falcon	r, m	r, pr	r, sp-fa
PHASIANIDAE: pheasants, grouse, and turkeys			
ring-necked pheasant	r, pr	o, fa-sp	
lesser prairie chicken	acc, fa		
wild turkey	fc, pr	uc, pr	uc, pr
ODONTOPHORIDAE: quail			
Montezuma quail	extir	r, pr	extir
northern bobwhite	r, pr	o, pr	
scaled quail	c, pr	c, pr	r, pr
Gambel's quail		acc, sp	
RALLIDAE: rails, gallinules, and coots			
Virginia rail	uc-r, fa-sp	acc, sp	
sora	r, fa-w	acc, fa	
common moorhen	r-acc, w-sp		
American coot	c-r, pr	r, fa-sp	
GRUIDAE: cranes			
Sandhill crane	fc-uc, fa-sp	uc-o, fa-sp	r, sp
whooping crane		acc, m	
CHARADRIIDAE: plovers			
killdeer	c, pr	uc-r, pr	r, fa-sp
RECURVIROSTRIDAE: avocets and stilts			
black-necked stilt	r, m		
American avocet	r, m	acc, fa	acc, sp-su
SCOLOPACIDAE: sandpipers, phalaropes, and allies			
greater yellowlegs	uc, m		acc, fa
lesser yellowlegs	uc, m	acc, fa	acc, fa
solitary sandpiper	uc-r, m	o,fa	acc,fa
willet	o, sp		
spotted sandpiper	uc, m	o, sp-su	uc, fa
upland sandpiper	fc, fa		
long-billed curlew	r, m	acc, fa	
sanderling		acc, fa	
western sandpiper	fc, m	o, fa	
least sandpiper	fc-o, fa-sp	acc, fa	
Baird's sandpiper	r, m	acc, fa	
stilt sandpiper		o, fa	
long-billed dowitcher	uc, m		
common snipe	c-acc, pr	r, fa-w	
American woodcock	acc, w		
Wilson's phalarope	fc, m		
red-necked phalarope	r, fa		
LARIDAE: skuas, gulls, terns, and skimmer			
Franklin's gull	acc, sp		
ring-billed gull	o, w	r, fa-w	
herring gull		o, w	
black tern	uc, m		
COLUMBIDAE: pigeons and doves			
rock dove	o, pr	o, sp-fa	
band-tailed pigeon	r, pr	r, sp-fa	r, sp-fa
white-winged dove	c-fc, pr	c, pr	fc, sp-fa
mourning dove	c-fc, pr	c-uc, pr	fc, pr
inca dove	uc-r, pr		

Status

acc- accidental
o-occasional
r- rare
uc-uncommon
fc- fairly common
c- common
extir-extirpated

Season

sp-spring
su-summer
fa- fall
w- winter
m-migrant (spring and fall)
pr-permanent resident

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
yellow-billed cuckoo greater roadrunner groove-billed ani	fc-r, sp-fa fc, pr acc, fa	r, su-fa fc, pr	uc, sp-su r, r
TYTONIDAE: barn owls			
barn owl	r, pr	o, sp-su	
STRIGIDAE: owls			
flammulated owl western screech owl great horned owl	o, su-fa r, pr fc, pr	uc, sp-fa uc, pr c, pr	acc, su uc, su fc, pr
northern pygmy-owl elf owl burrowing owl	 o, pr	r, sp-fa acc, sp-su r, pr	acc, m r, su
spotted owl long-eared owl	o, w-sp acc, w	r, pr o, w-sp	uc, pr
short-eared owl northern saw-whet owl	r-acc, w-sp	acc, fa o, sp-su	 acc, su
CAPRIMULGIDAE: nighthawks and nightjars			
lesser nighthawk common nighthawk	c-acc, pr c, p-fa	r, sp-fa c-fc, sp-fa	 c, su
common poorwill whip-poor-will	c-r,pr r, sp-su	c-uc, sp-fa uc-r, sp-fa	c, p-fa r, su
APODIDAE: swifts			
chimney swift white-throated swift	acc, fa uc-r, pr	 c-acc, pr	 c, sp-fa
TROCHILIDAE: hummingbirds			
broad-billed hummingbird white-eared hummingbird blue-throated hummingbird	acc, sp o, su	 acc, su r, sp-fa	
magnificent hummingbird ruby-throated hummingbird black-chinned hummingbird	acc, su c, sp-fa	r, sp-fa acc,su c, sp-fa	acc, su uc, sp-su
Anna's hummingbird calliope hummingbird	acc, sp acc, fa	 r, su-fa	
broad-tailed hummingbird Rufous hummingbird	fc, m c-fc, su-fa	c, sp-fa fc, su-fa	fc, sp-fa uc, su-fa
TROGONIDAE: trogons			
elegant trogon			acc,su
ALCEDINIDAE: kingfishers			
belted kingfisher	fc, fa-sp	uc-r, sp-fa	acc, sp
PICIDAE: woodpeckers			
Lewis' woodpecker red-headed woodpecker acorn woodpecker	 acc, sp uc, pr	o-acc, fa-sp acc, fa-w c, pr	acc, w uc, pr
red-bellied woodpecker yellow-bellied sapsucker red-naped sapsucker	o, fa-w o, fa-w uc, fa-sp	 r, w fc, fa-w	 r, fa-sp
Williamson's sapsucker ladder-backed woodpecker downy woodpecker	acc, fa-w c, pr r, fa-sp	r-o, fa-sp c, pr r, fa-sp	 c, pr
hairy woodpecker northern flicker	uc-r, a-sp c-fc, pr	fc, pr c-uc, pr	uc, pr uc, pr
TYRANNIDAE: tyrant flycatchers, becards			
olive-sided flycatcher western wood-pewee eastern wood-pewee	uc-r, m c-r, sp-fa acc, fa	uc, sp-fa c, sp-fa	uc, fa c, sp-fa
willow flycatcher least flycatcher hammond's flycatcher	uc, m acc, sp-su uc, m	acc, su r, fa-sp	r, m
dusky flycatcher gray flycatcher cordilleran flycatcher	fc, m o, m fc, m	fc, r-sp-fa acc, sp-su c, sp-fa	 uc, sp-su uc, sp-su

Status	Season
acc- accidental	sp-spring
o-occasional	su-summer
r- rare	fa- fall
uc-uncommon	w- winter
fc- fairly common	m-migrant (spring and fall)
c- common	pr-permanent resident
extir-extirpated	

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
vermilion flycatcher	c-r ,pr	o, sp-fa	
ash-throated flycatcher	c, sp-fa	c, sp-fa	c, sp-fa
great crested flycatcher	o, m		
brown-crested flycatcher		acc, sp-su	
great kiskadee	acc, sp-su		
piratic flycatcher	acc, fa		
Cassin's kingbird	c-uc, sp-fa	fc, sp-su	c, sp-fa
western kingbird	c, sp-fa	uc-sp-fa	r, m
eastern kingbird	acc, sp-fa		
scissor-tailed flycatcher	uc-r, sp-fa	acc, su	
LANIIDAE: shrikes			
northern shrike		acc, w	
loggerhead shrike	c-fc, pr	fc, pr	r, fa
VIREONIDAE: vireos			
white-eyed vireo	acc, sp	acc, su	
Bell's vireo	c-uc, sp-fa	r, sp-su	
gray vireo	fc, sp-fa	fc-uc, sp-fa	uc, sp-su
blue-headed vireo	acc, fa		
plumbeous vireo	fc-uc, sp-fa	c-o, pr	c, sp-su
yellow-throated vireo	acc, fa	acc, su	
Hutton's vireo		r-sp-fa	acc, w
warbling vireo	fc-uc, sp-fa	c-uc, su-fa	r, m
Philadelphia vireo	acc, fa	acc,sp	
red-eyed vireo	o, m	acc, sp-su	
yellow-green vireo	acc,su		
CORVIDAE: jays, magpies, crows			
Steller's jay	r, fa-sp	fc, pr	uc, pr
blue jay	acc, m	acc, su	
western scrub-jay	fc-r, pr	c-uc, pr	c, pr
pinyon jay	r, fa-wi	uc-r, pr	c-r, pr
Clark's nutcracker	acc, su & wi	acc, fa-sp	
black-billed magpie	acc, sp		acc, fa
American crow	acc, w	acc, w	
Chihuahuan raven	r, pr	r, fa-sp	acc, sp
common raven		r, fa-sp	r, pr
ALAUDIDAE: larks			
horned lark	pr, c	uc, pr	acc, fa
HIRUNDINIDAE: swallows			
purple martin	acc, su-fa	acc, su	acc, su
tree swallow	uc, m	r, m	
violet-green swallow	fc-uc, sp-fa	c, sp-fa	fc, sp-su
northern rough-winged swallow	fc, m	uc, m	
bank swallow	r, sp		
barn swallow	c, sp-fa	uc, sp-fa	uc, sp-su
cliff swallow	fc, sp-fa	c, sp-fa	c, sp-fa
cave swallow	c, sp-fa	o, su	fc, sp-fa
PARIDAE: titmice			
mountain chickadee	uc-r, pr	c, pr	fc, pr
juniper titmouse	uc-r, pr	uc, pr	uc, pr
tufted titmouse		o, sp-su	
REMIZIDAE: penduline tits, verdins			
verdin	uc, pr	uc, pr	
AEGITHALIDAE: long-tailed tits, bushtits			
bushtit	fc-uc, pr	c, pr	fc, pr
SITTIDAE: nuthatches			
red-breasted nuthatch	o, fa-wi	uc-o, pr	uc, fa-sp
white-breasted nuthatch	uc, fa-sp	c, pr	fc, pr
pygmy nuthatch	r, pr	fc, pr	uc, pr
CERTHIIDAE: creepers			
brown creeper	r, fa-w	uc, pr	
TROGLODYTIDAE: wrens			

Status

acc- accidental
o-occasional
r- rare
uc-uncommon
fc- fairly common
c- common
extir-extirpated

Season

sp-spring
su-summer
fa- fall
w- winter
m-migrant (spring and fall)
pr-permanent resident

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
carolina wren	o, fa		
Bewick's wren	c-fc, pr	c, pr	c, sp-fa
house wren	c-o, fa-sp	uc, pr	r,m
winter wren	o, w-sp	occ, fa-sp	
sedge wren	acc, w		
marsh wren	fc-fa-sp	acc, m	acc, fa
CINCLIDAE: dippers			
American dipper	acc, w	occ, fa-sp	acc, fa
REGULIDAE: kinglets			
golden-crowned kinglet	uc-o, w-sp	uc, fa-sp	
ruby-crowned kinglet	c-fc, fa-sp	c-r, pr	uc, fa-sp
SYLVIIDAE: Old World warblers			
blue-gray gnatcatcher	uc-o, pr	c-fc, pr	fc, sp-su
black-tailed gnatcatcher	o, pr	r, w-su	r, su
TURDIDAE: thrushes			
eastern bluebird	uc, pr	r, fa-w	
western bluebird	fr-r, pr	c-uc, pr	fc, pr
mountain bluebird	uc-r, fa-sp	c-o, pr	uc, fa-sp
Townsend's solitaire	fc, fa-sp	c-o, pr	fc, fa-sp
Swainson's thrush	uc, m	r, m	
hermit thrush	fc, fa-sp	c, pr	uc, m
wood thrush		acc, sp	
American robin	c-fc, fa-sp	c-o, pr	fc, pr
varied thrush	acc, fa	acc, m	
MIMIDAE: mockingbirds, thrashers			
gray catbird	occ-fa-sp	acc, w-sp	
northern mockingbird	c-fc, pr	c-uc, pr	c, sp-fa
sage thrasher	c-uc, fa-sp	fc-uc, fa-w	
brown thrasher	fc, fa-sp	r, fa-sp	
long-billed thrasher	acc-fa-sp		
curve-billed thrasher	fc-pr	fc-uc, pr	pr, uc
Crissal thrasher	uc, pr	uc, pr	r, su-fa
STURNIDAE: starlings			
European starling	fc-uc, pr	o, fa-sp	
MOTACILLIDAE: pipits			
American pipit	fc-uc, fa-wi	r, fa-sp	
Sprague's pipit	acc, fa		
BOMBYCILLIDAE: waxwings			
Bohemian waxwing		acc, fa-w	
cedar waxwing	uc, fa-sp	fc, fa-sp	
PTILOGONATIDAE: silky flycatchers			
phainopepla	o, pr	fc-r, pr	uc, sp-su
PARULIDAE: wood warblers			
blue-winged warbler	acc, fa		
golden-winged warbler	acc, sp		
Tennessee warbler	o, m		
orange-crowned warbler	fc-o, fa-sp	fc, sp-fa	
Nashville warbler	uc-r, m	o, m	
Virginia's warbler	fc, m	fc-uc, sp-fa	r, su
Lucy's warbler	acc, sp-su		
northern parula	acc, m	acc, su-fa	
yellow warbler	fc, m	uc, m	uc,m
chestnut-sided warbler	acc, sp	acc, su	
magnolia warbler	acc, sp		
Cape May warbler	acc, sp		
black-throated blue warbler	acc, fa	acc, m	
yellow-rumped warbler	c-uc, fa-sp	c-r, pr	c, m
black-throated gray warbler	fc-uc, m	uc-r, sp-fa	uc, sp-su
Townsend's warbler	r, fa	c, m	uc, fa
hermit warbler	acc, m		
black-throated green warbler	r, fa	acc, su	

Status	Season
acc- accidental	sp - spring
o-occasional	su - summer
r- rare	fa- fall
uc- uncommon	w- winter
fc- fairly common	m - migrant (spring and fall)
c- common	pr- permanent resident
extir-extirpated	

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
pine warbler	acc, w	acc, fa	
bay-breasted warbler	acc, m		
blackpoll warbler	acc, m		
Cerulean warbler	acc, sp		
black-and-white warbler	r-o, sp-fa	acc, sp	
American redstart	r-o, sp-fa	r, m	
prothonotary warbler	acc, sp		
worm-eating warbler	acc, m	acc, su	
Swainson's warbler	acc, fa		
ovenbird	acc, sp	acc, sp-fa	
northern waterthrush	uc, m	acc, su-fa	
Louisiana waterthrush	acc, fa		
Kentucky warbler	acc, sp	acc, sp	
Connecticut warbler	acc, fa		
MacGillivray's warbler	fc, m	fc-o, sp-fa	fc, fa
common yellowthroat	fc-uc, sp-fa	r, sp	
hooded warbler	acc, sp	acc, sp	
Wilson's warbler	c-acc, fa-sp	c-o, sp-fa	c, m
Canada warbler	acc, sp		
painted redstart	acc, sp	c-acc, sp-fa	
yellow-breasted chat	c-uc, sp-fa		r, su
THRAUPIDAE: tanagers			
hepatic tanager	uc-r, sp-fa	fc, sp-fa	fc, sp-su
summer tanager	c, sp-fa	r, sp-su	uc, sp-su
scarlet tanager	acc, fa	acc, su	
western tanager	fc, m	c, sp-fa	fc, sp-su
EMBERIZIDAE: sparrows			
green-tailed towhee	fc-uc, fa-sp	uc, pr	uc, fa
eastern towhee	acc, w		
spotted towhee	c-fc, fa-w	c-uc, pr	fc, sp-fa
canyon towhee	c, pr	c, pr	c, pr
Cassin's sparrow	c-acc, pr	uc-r, pr	r, su
Rufous-crowned sparrow	c, pr	c, pr	fc, pr
American tree sparrow	acc, w-sp	o, w	
chipping sparrow	c-fc, fa-sp	c, pr	c, pr
clay-colored sparrow	uc, m	r, sp-su	
Brewer's sparrow	c-uc, fa-sp	fc, fa-sp	fc, fa
field sparrow	r, fa-sp	r, w	
black-chinned sparrow	fc-uc, pr	c-uc, pr	fc, sp-fa
vesper sparrow	fc, fa-sp	uc, m	fc, fa
lark sparrow	c-o, pr	fc-r, pr	fc, sp-su
black-throated sparrow	c, pr	c, pr	r, sp-fa
sage sparrow	uc, fa-w	uc, w	
lark bunting	c-fc, fa-sp	uc-r, sp-fa	r, fa
savannah sparrow	fc-r, fa-sp	occ, fa-w	uc, fa
Baird's sparrow	acc, sp	acc, fa	acc, fa
grasshopper sparrow	o, fa-sp	acc, sp	
LeConte's sparrow	acc, fa		
fox sparrow	uc, fa-sp	r-acc, w-sp	
song sparrow	c, fa-sp	r, fa-sp	r, w
Lincoln's sparrow	c-fc, fa-sp	uc, fa-sp	
swamp sparrow	c-fc, fa-sp	acc, fa-w	
white-throated sparrow	fc-uc, fa-sp	r, w-sp	r, w
Harris' sparrow	o, w-sp		
white-crowned sparrow	fc-uc, fa-sp	c-fc, fa-sp	uc, fa-sp
golden-crowned sparrow	acc, m		
dark-eyed junco	c-uc, fa-sp	c, fa-sp	fc, pr
yellow-eyed junco		acc, m	
McCown's longspur	acc, w	acc, w-sp	
chestnut-collared longspur	r, w	acc, sp	
CARDINALIDAE: cardinals and grosbeaks			
northern cardinal	fc, pr	occ, su & wi	

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fc- fairly common	m-migrant (spring and fall)
c- common	pr-permanent resident
extir-extirpated	

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
black-headed grosbeak	fc, mi	c-fc, sp-fa	fc, sp-su
blue grosbeak	c, sp-fa	c-fc, sp-f	fc, sp-su
lazuli bunting	r, m	uc, m	
indigo bunting	uc-occ, sp-fa	uc, mi	acc, su
varied bunting	r, sp-su	acc, su	
painted bunting	c-fc, sp-fa	acc, fa	acc, fa
dickcissel	r-o, sp-fa		acc, sp
ICTERIDAE: blackbirds and orioles			
bobolink	o, fa		
red-winged blackbird	c-fc, pr	r, sp-fa	r, sp-su
eastern meadowlark	c-uc, pr	c, pr	uc, su
western meadowlark	c, pr	c-r, pr	
yellow-headed blackbird	uc-oc, pr	r-o, fa-sp	r, su
rusty blackbird	o, fa-w		
Brewer's blackbird	c, fa-sp	uc, m	uc, fa
common grackle	o, sp	o, sp-su	
great-tailed grackle	r, pr	o, pr	r, sp
bronzed cowbird	r, sp-su	acc, su	
brown-headed cowbird	c, pr	c, sp-fa	c, sp-fa
orchard oriole	c-fc, sp-su		
hooded oriole	r, sp-su	acc, sp-su	
Baltimore oriole	r, m		
Bullock's oriole	c, sp-fa	r, sp-su	r, sp-su
Scott's oriole	c, sp-fa	c, sp-su	fc, sp-su
FRINGILLIDAE: finches			
purple finch	acc, w	acc, sp-su	
Cassin's finch	uc, w	uc, fa-sp	r, sp
house finch	c, pr	c, pr	c-uc, pr
red crossbill	acc, su	uc, pr	uc, w-su
pine siskin	c-fc, fa-sp	uc, pr	uc-r, pr
lesser goldfinch	c-fc, pr	c, pr	uc, sp-su
American goldfinch	fc-o, pr	uc-o, pr	uc, fa
evening grosbeak	o-acc, w-sp	r-o, pr	
PASSERIDAE: weaver finches			
house sparrow	c, pr	c, pr	r, sp-su

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Season

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Chapter 10

The Texas GAP Project: Status and Potential

NICK C. PARKER, Ph. D., has been a professor and unit leader for the U.S. Geological Survey, Texas Cooperative Fish and Wildlife Research Unit for the past 27 years. He has completed projects associated with Guadalupe Mountains National Park on vegetation cover, vertebrate distribution, and land use. He is currently involved with the Texas GAP Analysis Program, Rio Grande GAP Analysis Program, and the Texas Natural Resource Database. Other authors: CARLOS GONZALEZ-REBELES, T. SCOTT SCHRADER, ANDREA E. ERNST, YONGLUN LAN, KELLY E. ALLEN, ERIC HOLT, and SHERI HASKELL.

It's a pleasure for me to be here. I have certainly enjoyed the presentations I have heard up until this point, and I am sure that the rest of the presentations, perhaps with this one exception, will be very good. What I would like to do is give you a broad overview on what the gap analysis program (GAP) is, how it ties in with the Museum at Texas Tech University, and how this effort is unique among GAP projects. I would like to show you the reason we need a cooperative effort, the importance of the Guadalupe Mountains and how all of these pieces are fitting together in the big picture. To give you that view, I would like to start with the slides, with the big picture approach, and let's see if we can bring it back to what really applies right here.

First of all, the title has my name on it. However, I am just representing all these students sitting in the front row, many others back in the lab, and others who are working on this cooperative project. Whatever I present, these students and staff have produced it; however, when the student made the title, he put my name on it.

We have the opportunity to step back and look at the world from afar, from space. We see it as a very different place than our ancestors did. Today, we can look at the entire United States in one view. We can see detail with satellite imagery that we have never before been able to see. We can zoom in and look at not only the detail of Texas, as this soil map indicates, but with Landsat and satellite imagery, we can look at details that we have not been able to envision previously. From the Landsat scene containing the Guadalupe Mountains, we can now develop maps depicting vegetation and land use. We can use the information that we gather remotely to help us understand the world around us and to help us make decisions necessary to preserve and maintain the unique ecosystem of the Guadalupe Mountains. To do that, I would like for us to see how the Guadalupe Mountains fit into the big picture. We are the first civilization that has ever had this power. Every civilization before us has collapsed, arguably, because they exhausted their local natural resources and changed the world in which they lived to the extent that it could no longer support their societies. This has been true through time. If we look at the Mediterranean hills and valleys of today, they are quite different than those seen by earlier societies. At one time all of those hills were forested. Consider the Nile Valley—it was a forest at one time. Ancient people exploited the resources but did not have the management tools that we have to work with today. We are all familiar with the large-scale problems that we have in the world today. We recognize the problems of water shortage, soil erosion, pollutants, an expanding human population, and the loss of natural habitat. However, we typically see these problems as somewhere else; it's difficult to see them in our own backyard. Yet, these problems influence what we do. If we look at the

Every civilization before us has collapsed, arguably, because they exhausted their local natural resources and changed the world in which they lived to the extent that it could no longer support their societies.

human population, the world is growing at such a rate that we don't really have a problem with resources, habitat, and animals; we have a problem with people. It is difficult for us to focus on the human population problem so we therefore focus on these other problems of resources, habitat, and animals. We try to manage the habitat that we have left.

Let's consider the way we are changing the environment around us. Just in the last few years up until 1950 we were annually using about three million tons of nitrogen fertilizer. By 1990 fertilizer use was up to 50 million tons and increasing. The yield of corn per hectare from 1866 to 1993 has increased rapidly and even exponentially in recent years. This increased use of fertilizers, production of corn and other food and fiber products is impacting the world in which we live. To the southwest of the Guadalupe Mountains, west of El Paso, there is a concentration of dairies with thousands of cows and each dairy cow requires about 22 gallons (83 L) of water per day. Throughout the Texas panhandle we have cattle feedlots and large swine production facilities. Each steer requires about 8 gallons (30 L) of water per day and sows require about 4 gallons (15 L) each. All of these industries are needed to support our society. Modern industries tax our society and our natural resources; however, for our society to exist we must have these industries. Our society requires energy and most energy production involves carbon emissions. In the 100 years from 1860 to 1960 carbon emissions into the atmosphere were about a billion tons per year. From 1960 to 1990, 2.7 billion tons of carbon were released annually into the atmosphere. Not only does our modern society affect the atmosphere, it also impacts the world's oceans. For example, an aerial photograph of a coastal bay in southeast Alaska showed 29 boats with nets capturing salmon. There are captains of these vessels that tell you when they started fishing with their fathers they used a stone and string to determine the depth of the water. Today with the equipment these fishermen have on board, they can tell you with 95% confidence that they will take 98% of the fish in a school they find, and they can find them all. Fishermen today can capture essentially all of the fish. Today, man and modern society has the capability to manipulate the world's environment. When one stands on the shore at Galveston, Corpus Christi, or any other coastal city and looks out to sea, the sea appears so large we easily believe that man could never impact it. Now we find that 29% of the fish are over-exploited, 45% fully-exploited, 22% moderately-exploited, and only 4% are under-exploited. As we critically examine our world it's easy to see that modern society has changed the natural environment. We are very quickly changing the world we love into something that may no longer meet our needs or be satisfactory to us or our children. We have to find ways that we can address these issues.

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In this part of the country, we are very concerned and very aware of the precious value of water, the quality of the water, and the price we are paying for it. In west Texas we have about 3,500 cubic meters of water per person per year. Israel has about 480 cubic meters and Saudi Arabia about 300 cubic meters of water per person, and life goes on. So no matter how difficult or how hard it is to acquire water, we can and will adjust to life with a limited supply of water. A degraded quality of life is our future unless we take measures today to preserve our natural resources and protect our environment. What I wish to present to you is a planning tool to help us maintain a quality environment and biodiversity. Biodiversity—the high diversity of life forms, a species-rich biological system—is something we must maintain. Tools such as the National Gap Analysis Program can help us maintain the biological diversity of the world by providing the information needed for natural resource managers, developers, landowners, and all factions of society to make better decisions.

Scientists today have described about 1.4 million species, but it is estimated that there are 25 to 50 million species living today, and we are annually losing to extinction an estimated 30 to 300,000 species. We don't really know how many species exist and we will not know until we survey and inventory our biological world. That we need to keep conducting inventories, is a difficult thing for us to sell to the public. In a 21 square meter area of the North Atlantic, scientists found 898 species, 100 families, and 12 phyla. Of the 898 species, 460 (51%) were not described, and 200 repetitive samples continued to yield new species at the same rate. We have heard a great deal about the rain forest and the large number of species living there. This is the world on which we live and we don't even know what treasures of life it contains. Therefore, programs like gap analysis and geographical information systems (GIS) provide the tools necessary to organize data and help us understand the complexity of our world. The GIS layers and associated databases can help us make wiser decisions. The tools available to us today include computer software, hardware, relational databases, image analysis, electronic exchange of museum collections, and GIS GAP analysis. All of these tools are giving us the power to make decisions based on science. Our predecessors and earlier civilizations did not have the opportunity to use the powerful analytical tools available to us today.

There are 47 Landsat scenes covering the state of Texas. These scenes have been used to map vegetation and land use based on interpretation of the satellite imagery. We have the potential to meld different interests and the expertise of groups such as the mammalogists of the museum, staff of Texas Parks and Wildlife Department, and the Texas Health Department. Professionals from these organizations are in the field daily. They are collecting data. They are answering questions for their agency. When they're finished, field biologists usually produce a narrowly focused report to answer immediate questions and then it is buried in some agency file. We now have the opportunity to pull all these data together, to build relational databases so that a large body of information about a species, a place, or an ecoregion can be linked together and used to make better decisions. As one example, the museum collection of mammals includes species of great concern to federal and state agencies. The swift fox, or kit fox, is a species of concern and has been discussed as a species that might be listed as threatened or endangered by the U.S. Fish and Wildlife Service. When we examine the biological data, what do we have? We find that the mammal collection of the Museum of Texas Tech University (one of the largest collections of mammals in the Southwest) contains only 10 specimens of swift foxes. We have one specimen from four counties and two specimens from three counties. How can we make sound biological decisions based on such sparse data? We need data in a database that provides enough information to support valid and wise decisions. Many people look at museum collections as history. They often naively argue that we don't need to add to museum collections because they view the museum collections as static history. Contrarily, museum collections provide a dynamic reflection of our world and can be used by resource managers to make better decisions.

Many people look at museum collections as history. They often naively argue that we don't need to add to museum collections because they view the museum collections as static history.

As another example, Dr. Robert Baker and fellow scientists in the museum have been able to work with the Texas Department of Health to examine the incidence of rabies in bats. The number of rabid bats collected annually in Texas has been pretty stable. However, when the spatial distribution of rabid bats is examined over time we find that one year the bats with rabies were in the middle of the state and the next year they were in the eastern part of the state. The third year rabid bats were found primarily along the Gulf Coast. People who understand bat biology, bat behavior, where bats spend winters, and where they feed have only a partial understanding of bat ecology. We must bring in people from the agricultural community to know what has happened to the habitat. For example we know that in south Texas a large part of the cotton producing area was sprayed with pesticides to control cotton boll weevils. When we poison boll weevils, do we poison non-target organisms on which bats feed? Do those bats now shift to a different place to feed? These are very complex ques-

Quality decisions begin in the field when data are collected with specimens, properly prepared, and moved back into museums.

tions and cannot be answered without valid data. It is these broad- scale questions that we are now trying to address. The value of data based on tissues and in museum collections is far greater than that of data produced without voucher specimens. Voucher specimens provide positive proof that the species collected was properly identified by a curator. When we have voucher specimens and tissue samples from which DNA can be analyzed, we can provide positive identification of species, gender, and a myriad of other information encoded in the DNA. Museums can provide the irrefutable data necessary for society to make decisions that are really solid and valuable.

Good decisions are based on very good field data. We can prepare no models, no maps, and no information that is any better than the data upon which those products are based. Quality decisions begin in the field when data are collected with specimens, properly prepared, and moved back into the museums. Once in the museum, specimens are properly identified using advanced techniques as required. The Museum of Texas Tech University has about 75,000 mammals, 15,000 reptiles-amphibians, 10,000 fishes, and 4,500 birds as curatorial specimens, plus about 70,000+ cryogenically preserved tissue samples. These voucher specimens, tissues, and their allied databases allow Dr. Baker and other scientists to answer questions about the distribution of hantavirus and know that it is found in a specific location, in a specific species. When we link these data to a GIS and GAP, we can begin to ask questions about how rainfall, crops, and El Niño change the rodent population in which hantavirus is found. Would full knowledge of hantavirus change the way we manage natural resources? Would this knowledge help us reduce health risks to people? It is important to know that when tourists are out backpacking and exploring remote trails, they are aware of areas with a high susceptibility for exposure to hantavirus. Field collections of small mammals and screening surveys for viruses provide the kinds of data needed to make decisions affecting natural resources and human health.

In the museum at Texas Tech bar code tags are used to mark and identify all mammal and tissue specimens. The bar codes can quickly be converted into electronic information, put into GIS layers in maps, and overlaid with other data so that we can link maps of habitat with the distribution of species. There are 47 Landsat scenes covering the state of Texas. Each scene covers an area about 115 x 115 miles (185 x 185 km), or about nine counties in the Texas panhandle. To classify land cover in each scene, we traveled to the area covered by the scene and identified the vegetation at 50 to 200 sites. The location of each site was determined with global positioning system (GPS) units by recording Universal Transverse Mercator (UTM) coordinates. The UTMs were entered into a database and incorporated into a GIS for presentation in a graphical form. The dominant plant communities at each site were classified using The Nature Conservancy's description of North American vegetation.

Texas GAP has over 10,000 miles of aerial videography flown in a north-south pattern from the Texas northern border to the Texas southern border at 1,000 feet elevation. These north-south flight lines are about 30 miles apart east to west and provide a low level, aerial view of land cover. We used the low level aerial videography and data collected on the ground to interpret the satellite scenes and classify the vegetation. Texas GAP is really large; however, it becomes even larger when linked to a project that spills over into Mexico. This project in Mexico, the Rio Grande or Rio Bravo GAP, covers the North American Free Trade Agreement (NAFTA). The 20 Landsat scenes necessary to cover the NAFTA area south of the border are larger than the state of California. When we put the Texas and Mexico projects together, they form a pretty significant project. The Rio Grande GAP is the first international GAP project and is being conducted hand in hand with Mexican agencies such as CONABIO and colleagues in Mexico. We are collaborating on the field work, the data analysis, and production of vegetation maps to be used in a GIS to build distribution maps for the vertebrate species.

Spectrum software, from Khoral, Inc., Albuquerque, New Mexico, is used to classify the hyperclustered Landsat scenes. The vegetation, represented by a particular pixel or group of pixels, is identified in the field, and the Spectrum program classifies all other pixels with that same spectral signature. We are certainly not able to go to every point in Texas, but we do go to selected points, and with Spectrum we extend our field identification of vegetation to all similar pixels and strive for 80% accuracy for classification of vegetation. We can get to about 80% with a fairly low cost; however, to get it from 80% to 100% the cost becomes prohibitively high. The goal of national GAP is to achieve 80% accuracy in classification of vegetation.

The successes of the national GAP and Texas GAP depend upon partnerships. Multiple partnerships, such as our partnerships with the Texas Parks and Wildlife Department and the Museum of Texas Tech University, allow us to acquire information on genetic biodiversity—details that go far beyond this program. Together, we are developing data including DNA libraries. Dr. Baker, his colleagues and students are collecting the museum specimens and developing the DNA libraries. We establish computer databases, containing DNA fingerprints and profiles, and link these databases to Texas GAP. Texas GAP benefits from these partnerships. The data points will be used to develop vertebrate models with site specific details and species specific projects, such as for scaled quail or mountain lions. For example, to answer questions about scaled quail distribution, graduate student, Raquel Leyva has prepared the 100-year average of precipitation in the state. These data were gleaned from 3,860 weather stations in Texas, some of which have records going back over 100 years. She placed all of these records into a database, a process which took about 18 months, and now she is able to produce maps depicting average rainfall, maximum temperature or minimum temperature for any year or series of years. With the historical precipitation, the maximum temperature, the minimum temperature available for any time frame, weather patterns can be examined for possible correlations with the abundance of scaled quail.

These databases and GIS layers can also be used to more precisely model distribution of vertebrates. For example, the piñon mouse, *Peromyscus truei*, is found in about six counties in the panhandle and in the Guadalupe Mountains. If you were to look at any earlier map showing distribution of *P. truei*, you would find the entire county, the political boundary, depicted as the range. As part of GAP, we develop models to delimit vertebrate distribution by specific information developed for each species. Is the species found in association with a certain plant, in a certain soil type, at a certain elevation, on a certain slope or aspect? These types of data are used to develop a habitat profile for each species and the habitat profile is used to build a model to predict where the species could be found. The model is used to develop a habitat specific map for each species, and then scientists knowledgeable of a particular species distribution verify accuracy of the predicted range. In an interactive process of adjustment and feedback we refine models to develop the most acceptable range map. The habitat restricted models can be quite valuable to society. People in these six counties would be concerned about how their land could be used if the piñon mouse were listed as threatened or endangered. They would be concerned about the red tape and permitting processes. Habitat-based distribution models can now be very specific; we can limit the areas of concern.

Habitat-based distribution models can now be very specific; we can limit the areas of concern.

As another example, consider the tremendous economic activity of birders all over the country as they build their life list of birds identified in the field. They want to go where the birds are, and they will spend money to get a new entry on their lists. If they have a bird distribution map that has the whole county in it, they might have to look throughout the whole county to find a specific species of bird. However, a habitat specific distribution map for a species is a far more precise product than is a county map. Elevation is an important delimiter in distribution models for many species. For example, the model for *P. truei* was limited to juniper habitat on steep slopes by including elevation in the model. To help us better view elevational changes on the southern high plains, we have prepared maps in which the vertical elevation has been highly exaggerated. Even with vertical exaggeration, the plains appear as flat as a table top. It is this type of information that we build into vertebrate distribution models that lets us draw a fine line and say this is where we find *P. truei*.

Our common goal is to place information into databases so that it may be used as tools to support decisions.

When I discussed this model for *P. truei* with Dr. Baker, he told me that some people have argued that animals collected from the Guadalupe Mountains and the panhandle may not be one and the same species. There may be two species. We don't really know the genetic diversity; we don't know how closely the two populations are related. It may take DNA probes and a DNA analysis to really have a definitive answer on this species. Building distribution models based on habitat profiles is an interactive process, and it takes both the field work and the field biologists working with GIS and GAP to develop an acceptable product. At Texas Tech University we have the most tightly linked museum and gap analysis program in the nation. We put this information into the hands of users: the professionals making natural resource management decisions, the public, school teachers, and school children. There are several products now on the Web: the Coop Unit Web page at <http://www.tcru.ttu.edu/tcru/> and the Natural Science Research Laboratory of the Museum <http://www.nsrl.ttu.edu/tmot/>. *The Mammals of Texas* by Dr. Schmidly is now on the Web. We also have the *Manual of Fish Culture*, published in 1897, on the Web. This century-old book contains 80 wonderful plates and 36 figures of various sites all over the country. The biological survey of Texas, conducted from 1895 to 1906 by Vernon Bailey, is being prepared for release on the Web. Dr. Schmidly has visited the Smithsonian and has personally examined every specimen collected by Vernon Bailey in the *Biological Survey of Texas*.

Schmidly has copies of all 1,038 photographs taken during the 1895–1906 survey. He also has copies of all of the field notes. One of those early photographs was taken in Santa Elena Canyon in Big Bend National Park. Today, the vegetation that exists in Santa Elena Canyon is quite different from that of 100 years ago. I haven't seen all of the early photographs, but undoubtedly there are pictures of the Guadalupe Mountains taken as Vernon Bailey passed through this area. When these data and photographs are placed on the Web, they will be available to everyone who has an interest. These are the types of information products we are developing. We expect these products to really make mountain islands, such as the Guadalupe Mountains, of greater value to those who live and study here and to those who will only be able to visit through the Web. We view this process as ongoing, not just another report to be filed. The information will only get better as more data are added to the databases. These electronic databases will link information resources such as geology, cultural areas, gap analysis, and vegetation. These different data layers exist today, but only in obscure reports filed away in some even more obscure bureaucratic office. Our common goal is to place information into databases so that it may be used as tools to support decisions. By placing data synthesis products into GIS layers and providing them through the Internet, people can use them to make better decisions.

If our society can accomplish that goal, we may be able to avoid the problems that ancient civilizations faced, and we are the first civilization to have the tools to make that opportunity available. As a society, we face some big problems in maintaining biodiversity and a biologically rich environment. The Guadalupe Mountains National Park is one very critical point protecting and preserving biodiversity and our quality of life. I thank you for the opportunity to share these thoughts with you.

Chapter 11

Distribution of Aquatic Invertebrates in McKittrick Creek

TIMOTHY M. GREEN, Ph.D., is a section manager for the Water Permitting and Compliance Program, Pantex Plant, Battelle Memorial Institute. He inventoried the distribution of aquatic invertebrates in McKittrick Creek and provided recommendations on the use and probable effects of rotenone in McKittrick Creek.

Introduction

McKittrick Creek in the Guadalupe Mountains National Park, Texas is a semi-isolated, perennially-flowing, discontinuous, desert-mountain stream. It flows over solid calcareous rock, cobbles, gravel, and sand. The creek is divided into three branches: North McKittrick Creek, South McKittrick Creek and Lower McKittrick Creek. North McKittrick originates in the Lincoln National Forrest of New Mexico, while South McKittrick originates high in the center of the Guadalupe Mountains. North and South McKittrick join to form Lower McKittrick Creek about 2.3 miles into McKittrick Canyon from the McKittrick Canyon Visitor Center. North McKittrick and South McKittrick flow through pine and maple forests. Lower McKittrick flows mostly through desert shrubs and shrub oak. Terrain through which McKittrick Creek flows varies from steep in North and upper South McKittrick to a gentle incline in lower South and Lower McKittrick. The creek itself is somewhat unique in that it is discontinuous and flows both above and below ground as it winds its way to the desert east of the mountains. Because of the uniqueness of this stream system it becomes an ideal location to study benthic invertebrate distributions that can be used in comparison to existing hypotheses.

At the time this study was done there had been few studies conducted on desert-mountain streams (Bane and Lind 1978; Bruns and Minckley 1980; Lind, 1969, 1971, 1979, 1982; Meyerhoff and Lind 1987a, 1987b). Only the studies by Lind and, Meyerhoff and Lind, dealt with McKittrick Creek. The study by Meyerhoff and Lind (1987b) was the only study to detail invertebrate distributions in McKittrick Creek. Meyerhoff and Lind simply discussed the relationships between substrate and detritus and continuous versus discontinuous flow. The present study investigated the effects of other factors such as habitat, current velocity, and physical and chemical aspects of the creek that might affect invertebrate distributions.

Many works have dealt with aquatic invertebrate distributions. These studies have investigated distributions in relation to habitat (McCulloch 1986, Reisen 1975); substrate and sediments (Brusven and Prather 1974, Crisp and Crisp 1974, Cummins and Lauff 1969, Egglishaw 1964, Hunt 1930, Linduska 1942, Minshall and Minshall 1977, Percival and Whitehead 1929, Rabeni and Minshall 1977, Reice 1980, Williams 1980, Williams and Mundi 1978); and current velocity, silt, detritus, and other factors (Rabeni and Minshall 1977, Minshall and Minshall 1977). Merritt and Cummins (1984) hypothesized that the ultimate factors affecting invertebrate distributions are the physical-chemical tolerance of the invertebrates to their environment. Competition and/or predation probably also play roles in invertebrate distributions (Hart and Resh 1980, Peckarsky 1980, Peckarsky and Dodson 1980, Allan 1982). All of these factors together may determine the major constraints on the distribution of aquatic invertebrates.

The concept of the river continuum was proposed by Vannote and others (1980). They noted that a downstream invertebrate community is affected by factors and conditions that exist upstream from the community. In McKittrick Creek the nature of the creek precludes the river continuum concept (Meyerhoff and Lind 1987b). McKittrick Creek's discontinuous nature, typified by stretches of above ground flow separated by areas of submerged flow, does not allow the continuous flow of material from upstream sources to down stream locations. Therefore, upstream factors should seldom have affect on down stream populations in McKittrick Creek. Meyerhoff and Lind theorized that coarse detritus would ultimately determine invertebrate distributions and are also temporal in nature (1987b).

Previous studies of McKittrick invertebrates were based on small samples. Lind (1979) collected data over a five-year period from 1967 to 1972 that resulted in approximately 11,000 individuals from 41 taxa found in three habitats during two seasons (spring and fall). Meyerhoff and Lind (1987b) obtained only 60 samples containing 16,600 individuals from 13 taxa, one habitat (pools), and one season (summer). This recent study resulted in approximately 300,000 individuals from more than 80 taxa, three habitats (riffles, runs, pools), and four seasons over a two-year period. This large number of individuals resulted in full analysis of 24 taxa and partial analysis of 44 taxa. Several taxa identified had numbers less than 0.5% of the entire population, too low a number for statistical analysis.

There is a difference in the number and type of taxa present between the three studies that have been done. McKittrick Creek undergoes periodic flash floods that alter the creek bottom and very probably the faunal composition. After Lind's study, flash floods have occurred in the late 1970s and mid-1980s, and since completion of the field work for this study floods have occurred in 1990 and 1991. Comparing the taxonomic information of the three studies reveals the differences in the taxa found (Table 1). These variations may in part be the result of flash floods. Other differences are probably more a result of the level of sampling that occurred.

Table 1. Comparison of taxonomic make-up of collections between previous studies and the present study of McKittrick Creek

Lind, 1979	Meyerhoff and Lind, 1987	Green, 1993
Cnidaria		
Chlorohydra sp.		Hydra sp.
Turbellaria		
Dugesia tigrina		Dugesia tigrina
Nematomorpha		
Gordius sp.		Gordius sp.
		Nematoda
Annelida		
Oligochaeta		
		Pristina sp.
		Lumbricus sp.
		Naididae
Mollusca		
Physidae		
		Physa sp.
		Pisidium sp.
Crustacea		
Ostracoda		
		Cytheridae
Amphipoda		
Hyallela azteca		Hyallela azteca
Copepoda		
Ectocyclops phaleratus		Cylopoida
Cladocera		
Daphnia pulex		Alona sp.
Ceriodaphnia quadrangula		

Lind, 1979	Meyerhoff and Lind, 1987	Green, 1993
Acarina		
		Acarina 1
		Acarina 2
		Acarina 3
		Acarina 4
		Acarina 5
		Acarina 6
		Acarina 7
		Collembola
Diptera		
		Dixidae
Tipulidae		
		Tipula sp.
		Hexatoma sp.
		Pedicia sp.
Heleidae		
Simulidae		
Simulium sp.		
Tendipedidae	Chironomidae	
Genus A	Psectrocladius sp.	Chironomid 1
Genus B	Nilotanypus sp.	Chironomid 2
Genus C	Conchapelopia sp.	Chironomid 3
Genus D	Microtendipes cf. caducus Townes	Chironomid 4
Genus E	Stictochironomus sp.	Chironomid 5
	Stenochironomus hilaris (?) (Walker)	Chironomid 6
	Pseudochironomus nr. richardsoni Malloch	Chironomid 8
		Chironomid 9
Tabanidae		
Tabanus sp.		Tabanus sp.
Stratiomyidae		
Euparyphus sp.		Euparyphus sp.
		Caloparyphus sp.
Ceratopogonidae		
Probezzia sp.		Ceratopogonidae
		Empedidae
		Haemerodromia sp.
Trichoptera		
Calamoceratidae		
Notiomyxia sp.	Phylloicus sp.	Phylloicus sp.
Psychomyiidae		
Odontoceridae		
Genus A (Ross)	Marilia sp.	Marilia sp.
Helicopsychidae		
Helicopsyche sp.	Helicopsyche mexicana Banks	Helicopsyche sp.
Limnephilidae		
Hesperophylax sp.	Hesperophylax sp.	Hesperophylax sp.
	Limnephilus sp.	Limnephilus sp.
Hydroptilidae		
Agraylea sp.	Hydroptila sp.	Hydroptila sp.
	Oxyethira sp.	Oxyethira sp.
	Genus A	Neotrichia sp.
		Neotrichia A
		Ochrotrichia sp.
Hydropsychidae		
Hydropsychae sp.	Hydropsychae sp.	Hydropsychae sp.
Leptoceridae		
Athripsodes sp.		Oecetis sp.
	Lepidostomatidae	
	Lepidostoma sp.	Lepidostoma sp.
	Philopotamidae	
	Wormaldia sp.	Wormaldia sp.
		Polycentropodidae
		Cernotina sp.
		Lepidoptera
		Petrophila sp.

Lind, 1979	Meyerhoff and Lind, 1987	Green, 1993
Odonata		
Zygoptera		
Agrionidae		
Argia sp.	Argia lugens	Argia lugens
	Argia plana	Argia plana
Coenagrionidae		
Archilestes sp.	Archilestes grandis (Rambur)	Archilestes sp.
Anisoptera		
Libellulidae		
	Paltothemis lineatipes Karsch	Paltothemis sp.
	Aeshnidae	
	Aeshna umbrosa Walker	Aeshna sp.
Hemiptera		
Belostomatidae		
Belostoma sp.		
	Gerridae	
	Gerris remigis Say	Gerris sp.
		Trepobates sp.
		Limnoporus sp.
	Veliidae	
	Rhagovelia distincta (?) Champion	Rhagovelia sp.
	Microvelia sp.	Microvelia sp.
	Naucoridae	
	Ambryssus buenoi Usinger	Ambryssus sp.
		Cryphocricos sp.
	Corixidae	
	Graptocorixa abdominalis (Say)	
	Notonectidae	
	Notonecta lobata Hungerford	Notonecta sp.
Ephemeroptera		
Baetidae		
Baetis sp.		Baetis sp.
Leptophlebiidae		
Choroterpes sp.		Choroterpes sp.
		Caenidae
		Caenis sp.
Coleoptera		
Psephenidae		
Psephenus sp.		
Chrysomelidae		
Neohaemonia sp.		
Elmidae		
	Dubiraphia sp.	Heterelmis sp.
	Macrelmis sp.	Elsianus sp.
	Neoelmis sp.	Neoelmis sp.
		Stenelmis sp.
		Microcylloepus sp.
		Ordobrevia sp.
		Hexacylloepus sp.
Curculionidae		
		Hyperodes sp.
		Lixus sp.
Georyssidae		
Georyssus sp.		
	Dytiscidae	
	Hydroporus pseudovilis (?) Young	Hydroporus sp.
	Hydroporus dimidiatus Geminger and Harold	Neoclypeodytes sp.
	Neoclypeodytes discretus Sharp	Laccophilus sp.
	Laccophilus horni Van Den Branden	Liodessus sp.
	Thermonectes marmoratus marmoratus Hope	Thermonectes sp.
		Derovatellus sp.
	Hydrophilidae	
	Tropisternus sp.	Berosus sp.
	Dryopidae	
	Helichus triangularis Musgrave	Helichus sp.
	Helichus confluentus Hinton	

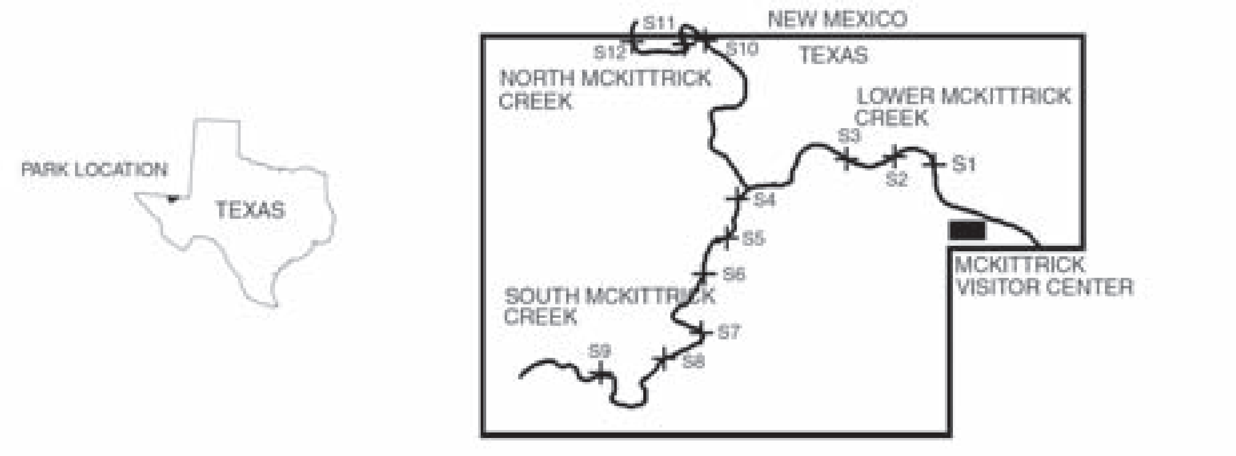

Figure 1. Location of sampling sites along McKittrick Creek.

Materials and methods

Twelve sampling sites were chosen along North, South, and Lower McKittrick creeks. Each site was chosen for its location along the creek for its accessibility (Figure 1). All sites were sampled approximately every two months (weather permitting) over a two-year period with a shift of one month after the first year of collecting. This shift resulted in collections during every month of the year.

Three sampling sites were located along Lower McKittrick Creek (S1, S2, and S3), six sites along South McKittrick Creek (S4, S5, S6, S7, S8, and S9), and three sites along North McKittrick Creek (S10, S11, and S12). Trout are present at all three sites in Lower McKittrick.

Vegetation along Lower McKittrick varies from desert shrub and shrub oak (*Quercus* sp.) at S1, to bigtooth maple (*Acer grandidentatum*) and juniper (*Juniperus* sp.) at S2, to sawgrass (*Cladium jamaicense*), juniper, and deciduous trees at S3. Trout are present at all three sites in Lower McKittrick. The creek bottom varies from cobble, sand, and gravel at S1; to gravel, cobbles and coarse detritus at S2; to gravel and cobble in riffles and runs, and sand and fine particulate matter in ponds at S3.

Trout are also present from S4 to S8 but are absent from S9. Vegetation varies from pine and maple at S4 (away from the creek) and S5, to maple, pine, horsetail (*Equisetum laevigatum*) and watercress (*Rorippa nasturtium-aquaticum*) at S6, to sawgrass and pines at S7 and S8. S9 is located high in South McKittrick and is lined with boulders. Vegetation at this point tends to be pine forest and maple located on the mountain slopes. The creek flows over travertine at S4, cobble, gravel, and sand at S5 and S6. S6 is located at the spring of the lower portion of South McKittrick Creek. The creek bottom at S7 is composed of cobble, gravel, and sand, but large quantities of seeds and other organic matter is present. S8 has an area of solid rock with the remainder of the area being cobble and gravel. The creek at S9 flows over solid rock to a cobble-lined pool.

Sunfish were present at S10 in 1987 but were absent in 1988. No fish were present at S11 or S12. Vegetation in North McKittrick generally consisted of sawgrass, maple, and pine trees. The creek flows over cobble and gravel at S10 and contains large quantities of coarse organic matter. At S11 the creek flows over cobble, gravel, and sand. The creek flows over solid rock into gravel-lined pools at S12.

Physical and chemical characteristics of the creek were sampled at each location during each visit. Water temperature was measured with a centigrade thermometer at each location and with a semi-permanent maximum-minimum thermometer at S1, S3, S4, S6, S7, S9, S10, and S12. Conductivity and pH were recorded using pocket mini-meters, and dissolved oxygen was recorded using a portable oxygen-meter adjusted for altitude, temperature, and conductivity. Water samples were taken and analyzed for total alkalinity, total hardness, calcium hardness, magnesium hardness, sulfate, nitrate-nitrogen, and total phosphates. Surface water velocities were measured using a neutrally buoyant vial in each of the three habitats (riffle, run, and pool). This method of measuring water velocity was necessary because of the shallowness of the creek in most locations.

Invertebrate samples were taken by combining two 929-square-centimeter samples taken from each habitat using a Surber stream bottom sampler. Although this method is not the most accurate (Usinger and Needham 1954, Needham and Usinger 1956), it was preferred for this study because of the nature of the substrate and transport requirements. Samples were stored in plastic bottles and fixed with a 10% formalin solution containing rose bengal. In the laboratory, samples were washed through a standard soil sieve set to remove detritus. Material left on sieves with mesh sizes 230, 120, and 60 was placed in a gridded pan and subsampled using rapid bioassessment protocols established by the Environmental Protection Agency (EPA) (Plafkin et al. 1989). This usually resulted in between 90 and 300 individuals being sampled. Subsamples were placed under a dissecting microscope and individuals identified to lowest taxonomic level possible using available taxonomic keys (Merritt and Cummins 1984, Pennak 1978, Burch 1975). Total number/taxon was estimated using the formula:

T = t x n / N

Where T is the total numbers/taxon, t is the number/taxon counted, n is the number of cells sampled in the gridded pan, and N is the number of cells in the sampling pan. Single individuals of any species were quickly picked from the sample by scanning the pan. Specimens were then preserved by taxon in vials using 70% ethanol.

Statistical analysis included analysis of variance (ANOVA), multiple linear regression, Chi-square, cluster analysis, principle components analysis, diversity, and evenness. These analyses were completed using BioCalc2, True Epistat, and Systat.

Cluster analysis was used to determine distributional classification of sites and the 44 most common species. Taxonomic classification was based on taxon distribution among the 12 sites, and site classification was based on the taxonomic make up of the sites using the 44 most common species. Distributional analyses, by means of ANOVA, were done for each of the 24 major taxa and on diversity indices for sites. Principal components determined from physical-chemical data were used in multiple linear regression to determine factors affecting invertebrate distributions. Multiple linear regression was also performed using raw physical-chemical data and Log10 taxonomic data to determine which physical-chemical factors had effects on invertebrate distributions.

Results

A total of 87 taxa were identified and quantified in this study. Of the 87 taxa only 24 were present in sufficient numbers to complete statistical analysis. The other taxa were used either in cluster analysis or were simply reported as being present.

Individual species or taxonomic groups showed variable distributions depending on the group and relationships with other invertebrates, habitat, physical-chemical factors, and stream segment (Green 1993). When data for all 24 taxa were combined and analyzed using ANOVA, significant distribution among the three habitat types is seen. There is also significant spatial variation between stream segments. They are most abundant in Lower and South McKittrick with S4, S5, S6, and S7 having the largest groupings of taxa.

Shannon-Weiner diversity was calculated for each site and each habitat at each site. Site diversity varied between sites and between habitats at sites. Highest site diversity was seen at S5 with H = 2.7398. Diversity in riffles indicated that the riffles at S5 had the highest value of 2.3170. S3 had the highest diversity in run habitat with a value of 2.4333. Pool diversity was highest at S5 with a value of 2.4957. Runs were more diverse than either pools or riffles. The lower South McKittrick section of the creek was more diverse than the other sections with an index of 2.5763. This section contains S5. Evenness values indicate that Lower and South McKittrick have significantly higher mean evenness values than North McKittrick.

Cluster analysis was performed on the taxonomic data in two ways. The first was using the 44 most common taxa to determine their distribution within the 12 sites. The second way was to cluster the 12 sites based on distributions of the taxa among the sites. Species clustering resulted in 11 cluster groups, three of which contained the majority of the 24 major taxa. Site clustering resulted in three clusters that included S5 and S6 in the first cluster, S2, S3, S4, S7, S8, and S9 in the second cluster, and S1, S10, S11, and S12 in the third cluster (Table 2).

Distribution of 13 taxa was somewhat affected by physical-chemical factors as shown by regression analysis. Of the various physical-chemical variables water velocity was important in the distribution of 11 groups. Four taxa had a temperature variable and six taxa had a chemical component included in their regression

Discussion

Invertebrate distributions continue to intrigue biologists. The river continuum concept proposed by Vannote and others (1980) has resulted in numerous papers concerning the validity of the concept, including the present paper. The river continuum concept suggests that distributions of aquatic invertebrates are determined for the most part by the physical and chemical conditions that exist in the upper portions of a stream system. Materials and processes are graded from upstream to downstream, which would result in variations in invertebrate distributions. The present study suggests that the river continuum concept is not valid in discontinuous desert streams, such as McKittrick Creek.

In discontinuous streams the accumulation of materials due to downstream flow does not occur to the extent that it does in continuous streams. Stream sections are too short for transport of sufficient quantities of organic material that would result in varying microhabitats, which would cause variations in invertebrate communities. The subsurface flow that occurs in McKittrick Creek prevents the continual downstream transport of organic material and results in uniformity within the physical and chemical variables. In McKittrick Creek the detritus tends to accumulate within the pools of each stream section and may play a role in distributions within pools (Meyerhoff and Lind 1987b). Distributions within McKittrick Creek appear to be influenced more by habitat, location, biotic interactions, and to a lesser extent, physical and chemical variables (Green 1993).

Substrate and detritus as shown by Meyerhoff and Lind (1987b) influence distributions. Habitat plays a major influence in distributions. Differences among habitats are largely a measure of water velocity and the ability of the stream to carry organic matter. In this study various groups are distributed based on habitat preferences. Twelve taxa were found in riffles with three of these limited to the riffle habitat. Sixteen groups were found in runs with three being primarily found in this habitat. Pools tend to be more diverse with 18 groups being abundant of which six are primarily found in pools.

Interspecific interactions play a somewhat major role in invertebrate distributions. Regression analysis consistently included two or more taxa within the regression more often than other variables. Interactions appeared to be due to many different reasons including parasitism, niche separation within the same habitat, exclusion, competition, and preda-

Table 2. Classification of taxa and sites. Horizontal classification is by species composition of sites. Vertical classification is by distribution among sites. * = 1 of 24 common taxa. Similar sites are clustered together across the top of the table with a space between clusters. The clustered taxa are shown down the left side of the table with blank rows separating the clusters.

SPECIES	S6	S5		S4	S2	S3	S7	S8	S9		S1	S10	S11	S12
Ochrotrichia	127	8		27	27	0	0	0	8		5	23	13	33
Lepidostoma	533	292		32	18	33	129	2	7		0	0	2	2
Hydra	601	441		59	8	5	76	34	34		1	1	0	1
Naididae	5	53		86	19	51	9	39	135		17	0	2	0
Cyclopoida	167	213		100	52	62	129	71	94		9	0	16	8
Chironomid 5*	113	670		289	59	323	206	45	28		2	3	13	0
Oxyethira*	219	2242		634	73	379	377	81	121		19	6	18	0
Stenelmis	8	50		0	6	2	35	87	361		36	39	71	7
Elsianus	12	28		4	6	11	31	99	315		27	94	31	10
Helichus	14	30		26	5	30	44	9	100		13	32	7	1
Wormaldia	22	127		14	122	264	184	35	15		34	36	10	1
Tabanus	53	44		35	84	129	100	21	28		38	14	3	24
Haemerodromia	8	62		33	96	71	103	33	5		65	7	29	18
Paltothemis	9	29		64	73	30	13	121	43		14	37	29	13
Acarina 4	7	31		41	15	38	167	122	54		37	27	34	15
Marilia	4	78		56	66	34	329	112	224		41	89	80	109
Neoelmis	1	87		3	535	24	184	61	136		17	10	19	1
Microcylloepus	0	14		1	10	15	94	19	37		2	17	92	2
Neotrichia A	0	3		27	17	21	78	36	146		5	28	15	2
Argia lugens*	20	0		120	119	170	411	284	116		38	58	58	53
Euparyphus	1	3		132	164	5	4	5	15		23	71	22	47
Liodessus	1	0		14	39	0	4	21	57		5	14	50	29
Caloparyphus*	1	38		2291	2064	123	100	570	434		155	682	276	1982
Hexatoma	13	266		586	83	275	74	108	307		368	13	6	18
Alona*	72	417		432	188	113	343	1023	352		40	27	6	19
Pristina*	126	343		155	499	299	390	333	229		63	35	45	31
Hydropsychae*	119	443		92	128	219	191	36	75		18	31	60	6
Physa*	475	618		837	195	156	76	126	43		17	54	32	93
Chironomid 6*	653	636		196	288	484	199	201	55		110	143	213	143
Acarina 1*	1189	452		82	105	158	208	76	217		119	63	45	24
Cytheridae*	4992	2138		103	556	874	345	49	194		242	203	43	51
Caenis*	143	972		751	76	132	1705	208	668		4	95	337	186
Hyallela azteca*	3773	2878		1874	512	3725	1235	289	129		309	10	30	110
Chironomid 3*	4273	3056		564	338	250	1239	351	413		71	69	260	166
Dugesia tigrina*	1943	1284		551	581	946	1130	724	685		293	246	267	252
Argia plana*	3367	2108		647	1072	1384	1495	881	224		549	402	272	86
Chironomid 2*	1533	2261		1388	495	712	963	963	737		293	275	183	40
Choroterpes*	1164	3702		321	474	1128	3301	2247	1737		2958	305	418	142
Chironomid 1*	885	3806		3097	2080	1920	3233	1656	2804		717	517	606	710
Chironomid 4	3107	5464		7565	2983	1957	2894	1646	2328		817	1373	729	634
Baetis	7032	7536		2211	2258	3666	3274	2784	2129		439	1915	2814	1459
Simulium	4357	4534		1645	1342	1759	3476	1549	674		332	499	1737	921
Hydroptila	714	764		1756	1489	963	1093	2267	266		1042	2786	1965	1246
Ceratopogonidae	179	3004		1327	2444	1384	5570	2335	872		1693	2337	1525	8712

tor-prey relationships. These relationships result in multiple taxa being consistently present together in samples.

Physical and chemical variables such as water velocity, temperature, conductivity, and pH play minor roles in determining the distribution of some aquatic species. Thirteen taxa had physical and chemical variables within their regression, but the included components were not as important as other variables.

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Chapter 12

Forensic Entomology Meets the Guadalupe Mountains

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Introduction

Forensic entomology is the application of arthropod evidence to legal investigations (Keh 1985, Hall 1990, Catts and Goff 1992, Goff 1993), and has been divided into three main categories: urban entomology, stored products entomology, and medicolegal entomology (Lord and Stevenson 1986). The focus of this article is medicolegal entomology, which deals with entomological evidence recovered from crime scenes, usually involving a felony homicide or other violent crime, and the application of this evidence to a criminal or civil investigation (Hall 1990, Catts and Goff 1992). Medicolegal entomology has become the most widely recognized category and is synonymous with forensic entomology throughout the scientific community and the public in general (Goff 1993).

The earliest written record of the use of insects to solve a homicide is cited in a 13th-century Chinese manual on forensic medicine (Keh 1985). This manual, *The Washing Away of Wrongs*, was written by Sung Tzu in A.D. 1235 (McKnight 1981, Smith 1986, Turner 1991, Catts and Goff 1992, Goff 1993). In this account, the victim died of wounds inflicted by a farmer's sickle. The inquest officer ordered each farmer to place his sickle on the ground in the center of the village. Flies were attracted to only one sickle, the one where traces of blood remained. The owner of the sickle subsequently confessed his crime.

The beginning of the modern era of forensic entomology is marked by the works of several European scientists, including Berget, Broudel, and Yovanovitch (Catts and Goff 1992). Their contributions were made in the late 19th century and were followed by Megnin in 1894, with the publication of *La Faune des Cadavres: Application L'Entomologie a la Medicine Legale* (Turner 1991, Catts and Goff 1992, Goff 1993). Megnin was the first to demonstrate the importance of entomological data in legal investigations. Megnin also proposed that corpses undergo a series of stages of decay and that each stage is characterized by a unique arthropod assemblage (Hall 1990). This was quite a novel concept at the time, and even today researchers are still conducting decomposition studies in order to document the succession of arthropods at a corpse (Tantawi et al. 1996, Richards and Goff 1997).

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Decomposition research: collecting baseline data

Decomposing remains provide a unique resource to many organisms, including bacteria and fungi, arthropods, and vertebrate scavengers (Goff 1993). A thorough knowledge of the ecology of the fauna associated with remains is an essential foundation of forensic entomology. Arthropods compose the greatest proportion of this fauna, and insects are the most abundant component of the arthropod group, both in species diversity and absolute number of individuals (Goff 1993). Arthropods play several roles at the carcass, and generally four groups are recognized (Smith 1986, Turner 1991, Catts and Goff 1992, Goff 1993):

Necrophagous species. This group includes taxa which feed directly on the remains. This group is primarily composed of Diptera (flies in the families Calliphoridae, Sarcophagidae, and Muscidae) and Coleoptera (beetles in the families Silphidae and Dermestidae). This group is by far the most important in establishing a time of death or postmortem interval.

Predators and parasites of necrophagous species. This group has been identified as second in importance to forensic entomology. This group includes the Hymenoptera, wasps which parasitize immature stages of Diptera. Also included in this group are the larvae of Calliphoridae, which are facultative predators and will prey on the larval stages of other species present at the carcass. Another major group is beetles in the families Stayphilynidae, Silphidae, and Histeridae. These beetles prey on dipteran larvae.

Omnivorous species. This group contains species that feed on both the carcass and on the arthropods present. Hymenoptera (wasps and ants) are a major component of this group. Ants often feed on dipteran eggs and first instar larvae, and on the liquids and soft tissues of the carcass. Wasps also consume liquid and soft tissues of the carcass and in addition, prey on adult flies associated with the carcass. Although this group is not recognized to be as important as the two groups previously discussed, the presence of such species can deplete the population of necrophagous species present at the carcass and thus delay the decomposition process (Early and Goff 1986, Richards and Goff 1997) and/or alter arthropod succession patterns (Stoker et al. 1995). This may have serious implications in determining a postmortem interval, and a forensic entomologist should be aware of the presence and impact of such species.

The history of carrion research involves documenting arthropods associated with decomposition, describing the ecology of the carrion community and understanding the biology of these arthropods.

Adventive or incidental species. This category includes arthropods found using the carcass as an extension of their normal habitat, such as spiders, centipedes, mites (Acari) or springtails (Collembola). They may opportunistically use the carcass as shelter or as a resting place. The forensic importance of such species at a carcass is low but is always documented during decomposition studies.

The history of carrion research involves documenting arthropods associated with decomposition, describing the ecology of the carrion community, and understanding the biology of these arthropods (Doube 1987, Catts and Goff 1992). Two excellent reviews of the ecology of the carrion habitat as an ephemeral resource have been published (Beaver 1984, Doube 1987). Many studies have documented varying stages of decomposition and the fauna associated with each stage (Bornemissza 1957, Reed 1958, Payne 1965, Coe 1978, Early and Goff 1986, Tullis and Goff 1987, Tantawi et al. 1996), faunal differences in this community among contrasting habitats in desert, tropical, and temperate regions (Bornemissza 1957, Walker 1957, Reed 1958, Payne 1965, Cornaby 1974, Johnson 1974, Mckinnerney 1978, Rodriguez and Bass 1983, Early and Goff 1986, Braack 1987, Tullis and Goff 1987, Richards and Goff 1997), and seasonal changes in the carrion arthropod community within a single habitat (Braack 1987, Putman 1978a, 1978b).

The collection of baseline data is the foundation of forensic entomology. The community of arthropods that colonizes remains is quite diverse and requires meticulous investigation. Numerous baseline decomposition studies have been conducted and various types of animal carcasses have been used, including guinea pigs (Bornemissza 1957), lizards and toads (Cornaby 1974), rabbits (Denno and Cothran 1975, Tantawi et al. 1996), cats (Early and Goff 1986), dogs (Reed 1958), pigs (Payne 1965, Tullis and Goff 1987, Hewadikaram and Goff 1991, Richards and Goff 1997), sheep (Denno and Cothran 1975), impala rams (Braack 1987), and elephants (Coe 1978). Although some of these studies were conducted in the interest of ecology and not for forensic purposes, a major concern in structuring most decomposition studies is the choice of animal used as a surrogate model for humans. The domestic pig, *Sus scrofa* L., provides the most accurate extrapolation from field studies to human remains and has been used extensively in such studies (Goff 1993). The size, skin, and hair of the domestic pig approximate that of a human, as does the chemical composition of the muscle tissue (Erzinclioglu 1986). However, many have used other animals out of practical considerations.

The spectrum of topics addressed in forensic entomology has grown in recent years. The assumption that Diptera arrive immediately to the corpse and begin depositing eggs or larvae is specious. Forensic entomologists must bear in mind that the estimate they establish is the duration of arthropod activity and not necessarily the time since death (Catts and Goff 1992). There are a number of situations that occur which delay arthropod access to a corpse, and this has been the focus of many studies. For example, Goff (1992) determined that the wrapping of a corpse in two layers of blankets delayed invasion by flies in the family Calliphoridae by 2.5 days. Others studies are currently examining the effects of hanging, burning, submergence, and/or burying of a carcass on arthropod colonization, succession, and developmental patterns. Any of which can cause these patterns to deviate from those observed during baseline decomposition studies. A forensic entomologist must know what impact such situations have on the estimation of a postmortem interval.

Applications of arthropod evidence

There are many ways in which entomological evidence can be applied to a legal investigation. For example, arthropods have been used in criminal and civil investigations to: (1) determine time of death, (2) serve as evidence of relocation of a corpse, and (3) serve as toxicological specimens (Greenberg 1991, Catts and Goff 1992, Goff 1993).

The challenge a forensic entomologist is most likely to encounter is to determine a time of death or postmortem interval for human remains. There are two main reasons why insect evidence is so useful when determining a postmortem interval. First, the insects, usually blow flies in the family Calliphoridae, are the first to arrive at a corpse and will usually lay their eggs or deposit their larvae within a few hours, sometimes within even a few minutes after arrival (Catts and Goff 1992, Goff 1993). A biological clock is started at the time the eggs are laid and is interrupted when the body is found and the forensic entomologist collects specimens from the body or surrounding area. It is now the forensic entomologist's job to determine how long the clock has been running; in other words, to determine the age of the specimens found at the crime scene, whether they are eggs, larvae, or pupae. Developmental rates vary among species associated with carrion and there have been numerous studies conducted in order to establish such baseline data at controlled temperatures and humidities (Kamal 1958, Zumpt 1965, Nuorteva 1972, Nuorteva 1977, Busvine 1980, Goodbrod and Goff 1990, Greenberg and Tantawi 1993, Wells and Kurahashi 1994, Byrd and Butler 1996).

Arthropods have been used in criminal and civil investigations to: 1) determine time of death, 2) serve as evidence of relocation of a corpse, and 3) serve as toxicological specimens.

Temperature is a key element controlling decomposition. There are two aspects of temperature which must be considered. Ambient environmental temperature is crucial in determining the activity of adult flies. The flies will not deposit eggs or larvae if the temperature is not above 20°C (Goff 1993). Therefore, a forensic entomologist must obtain weather data at the crime scene—and from several days prior to and following the discovery of the crime scene (Turner 1991). The second aspect to be considered is the internal temperature of the maggot mass if present on the corpse. This is the temperature at which the larvae develop and will determine the rate at which they grow. There is an increase in temperature even with small (>4 larvae/gram of substrate) maggot feeding masses (Goodbrod and Goff 1990). However, there is little evidence indicating a direct relationship between ambient environmental temperatures and the actual temperature experienced by large masses of developing maggots (Turner and Howard 1992, Goff 1993). Richards and Goff (1997) found that the temperature in the core of a maggot mass can exceed the ambient temperature by 26°C. Both aspects must be considered when the forensic entomologist processes the crime scene.

Several considerations and techniques have been put forth to estimate the age of Diptera larvae (Williams 1984, Erzinclioglu 1990, Goff 1993, Wells and LaMotte 1995). Killing and preservative solutions can affect larval size. It has been documented that the various solutions used in collecting and preserving insect specimens can cause varying degrees of shrinkage, resulting in an underage error from 9.7 hours up to 28.8 hours (Tantawi and Greenberg 1993).

Insects or other arthropods impact forensic science in that they may serve as alternate toxicological specimens when tissues that are taken normally for such analyses are not available or have decomposed to an unsuitable state.

The second way arthropod evidence is used to determine a postmortem interval is based on the succession pattern of the arthropods which colonize the remains. This sequential colonization has been documented to be predictable (Catts and Goff 1992). The utility of colonization studies is dependent on rigorous baseline decomposition studies. During each decomposition study, the arrival and departure dates are noted for each species that visits the carcass. This information may vary dramatically among habitats even though the same species are involved. This stresses the need for decomposition studies to be conducted in a variety of habitats.

The presence of drugs or other toxins or contaminants in the tissues of human remains impact forensic entomology and forensic science in general, and this area of forensic entomology has been termed entomotoxicology (Goff and Lord 1994). As mentioned previously, one way a postmortem interval is established is based on the life cycle of the arthropod, especially those in the order Diptera, families Calliphoridae, Sarcophagidae, and Muscidae (Goff and Lord 1994). The larvae feed on the tissues of decomposing remains and ingest the drugs or toxins contained in these tissues as they feed. Nuorteva and Nuorteva (1982) recovered mercury from maggots of various species of Calliphoridae which fed upon fish containing varying amounts of mercury. The mercury was retained throughout the larval stage and was detectable in the adult forms. The experiment was carried one step further when staphylinid beetles were fed maggots which had fed upon fish contaminated with mercury. Staphlylinid beetles frequent carrion and commonly feed on immature Diptera, and a bioaccumulation of mercury was observed in these predatory beetles. Other studies have documented the effect of various drugs on the developmental rate of the immature insects feeding on the contaminated tissues, including malathion (an organophosphate) (Gunatilake and Goff 1989), cocaine and benzoylecognine (Goff et al. 1989), heroin (as morphine) (Goff et al. 1991), amitriptyline (Goff et al. 1993), phencyclidine (Goff et al. 1994), and ecstasy (3,4-Methylenedioxymethamphetamine) (Goff et al. 1997). All of the above studies indicate that different drugs either accelerate or retard different stages of development and confound a determination of a postmortem interval.

Insects or other arthropods impact forensic science in that they may serve as alternate toxicological specimens when tissues taken normally for such analyses (blood, organs or urine) are not available or have decomposed to an unsuitable state (Goff and Lord 1994). There have been numerous studies conducted to determine the presence of drugs in fly larvae, pupae, pupal cases and adults (Beyer et al. 1980, Nuorteva and Nuorteva 1982, Introna et al. 1990, Kintz et al. 1990, Nolte et al. 1992, Goff et al. 1993, Goff et al. 1994, Goff et al. 1997) as well as beetle exuviae (Miller et al. 1994). Documentation of the presence of drugs can provide evidence of suicide or accidental overdose for a badly decomposed body (Beyer et al. 1980, Gunatilake and Goff 1989, Lord 1990) or even provide information on the geographic origin of a body by examining varying levels of mercury poisoning based on where a person lives (Nuorteva 1972). Current research areas include further basic studies documenting the effects of drugs on the developmental rates of various insect species associated with carrion and quantitative techniques to determine concentrations in the original tissues based on the levels measured in the insect specimens.

Arthropod evidence also has been used to associate suspects with a crime scene. For example, a team of investigators from Ventura County, California, visited a crime scene and nearly all of the personnel processing the scene received bites characteristic of a chigger in the genus *Eutrombicula* (Webb et al. 1983, Prichard et al. 1986). Interestingly enough, the suspect which was apprehended also had present on his body the characteristic lesions produced by bites of the same chigger. It was previously presumed that chiggers did not occur in southern California, so a team of entomologists conducted an extensive survey of the area surrounding the crime scene and recovered specimens of *Eutrombicula belkini*. The suspect denied having been anywhere near the crime scene, denied even having left the city limits, and claimed the last time he was in contact with the victim was at her home on the night she disappeared. It just so happened that the suspect chose to dispose of the body in the only area infested with this species of chigger in approximately 100 miles. He was convicted and sentenced to life in prison without the possibility of parole.

Blood- feeding, or hematophagous, arthropods also can be used to associate suspects with a crime scene. Replogle et al. (1994) were able to recover human DNA from louse excreta. They allowed crab lice, *Pthirus pubis* (L.), to feed on either the inner thigh or calve of several volunteers. Lice fecal pellets were collected from each volunteer and analyzed via the application of amplified fragment polymorphism (AMP-FLP) to amplified products of polymerase chain reaction (PCR). They used two human DNA markers and compared the results from the fecal pellet analysis to a saliva sample taken from each volunteer. They were able to identify each individual host of this blood feeding arthropod. The above research was prompted by an actual rape-murder case, where the perpetrator, infested with crab lice, left behind a valuable clue, a sample of his DNA.

Current research in Guadalupe Mountains National Park

Entomological evidence has provided information regarding the postmortem relocation of human remains. Law enforcement personnel cannot assume that the place in which the body is discovered is the same as the place of death. Blow flies are frequently the first insects to arrive at a corpse and deposit eggs or larvae, and this acquired arthropod fauna is often transported along with the corpse (Byrne et al. 1995). Information regarding relocation of human remains may lead investigators to the primary crime scene, where additional evidence can be recovered, providing a critical link between victim and perpetrator.

Currently, there are three methods proposed to detect relocation of a corpse. Goff (1991) reviewed 35 cases of human remains recovered in both indoor and outdoor settings on the island of Oahu in the Hawaiian Islands. He demonstrated there are specific arthropod taxa which are restricted to each setting. For example, if an arthropod species known to colonize remains in an indoor setting is recovered from a corpse found outdoors, this will indicate to law enforcement personnel that the body was transported from an indoor setting to an outdoor setting. Another method used to determine relocation following death is based on the natural geographic range of insect species associated with carrion (Smith 1986, Hall 1990, Lord 1990, Goff 1993). If the corpse has been transported across a natural boundary, specimens collected from the remains may be foreign to the area where the body was discovered. The third, and most recently proposed technique, involves the use of insect cuticular hydrocarbons. Cuticular hydrocarbons are lipids found on the outer surface of insects, and function to reduce water loss and serve in chemical communication (Chapman 1982). Cuticular hydrocarbons have been demonstrated to be species-specific and have shown that populations of the same species, inhabiting distinct geographic regions, have unique cuticular hydrocarbon profiles (Kruger and Pappas 1993). Studies of the individual components of the cuticular hydrocarbons and their variation with age, sex, or diet in various Diptera have been conducted

Entomological evidence has provided information regarding the postmortem relocation of human remains.

(Louloudes et al. 1962, Tyndale-Biscoe and Kitching 1974, Trabalon et al. 1990). Byrne and others (1995) extracted cuticular hydrocarbons from individual *Phormia regina*, the black blow fly, from three geographic locations in the United States. They found they could discriminate among populations and sexes using this technique and suggest it as a potential tool for use in forensic entomology.

Current research within Guadalupe Mountains National Park is designed to investigate the potential of a fourth method to detect postmortem relocation of human remains, using geographic variation in morphology among populations of carrion blow flies. Nearly all blow fly species used in forensic investigations are cosmopolitan in distribution. In such cases, indication of relocation may go undetected and critical evidence may not be recovered from the primary crime scene. Therefore, if significant morphological variation can be detected among populations of cosmopolitan species, then evidence may be recovered, which suggests that individual flies associated with the remains originated elsewhere, and thereby, indicating movement of the corpse.

Evidence may be recovered, which suggests that individual flies associated with the remains originated elsewhere, and thereby, indicating movement of the corpse.

The objectives of the current ongoing research are to determine the amount of intraspecific variation among populations of blow fly species in Texas and to determine which characteristics most contribute to morphological discrimination. Research will continue within Guadalupe Mountains National Park over the next three years to investigate temporal or year-to-year variation in morphology. The data collected from Guadalupe Mountains National Park will be joined together with data collected from other locations in west and central Texas in order to understand geographic variation among populations of blow fly species associated with carrion.

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Chapter 13

The Native Bees of Guadalupe Mountains National Park: a Preliminary Assessment

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Mention bees and the first thing likely to come to mind are honeybees. But honeybees are not typical of North American bees. They are not native, having been brought over by early European colonists. Furthermore, most North American bees are solitary, not social. They are not perennial and they do not produce honey. Yet they play a vital role as mediators of pollen across a wide array of natural landscapes (Paxton 1995, Neff and Simpson 1993). Our best estimate is that there are nearly 4,000 species of bees in the United States. And, while we have a rough idea of overall bee diversity, we have only a limited idea of distribution and behavior patterns. To ensure conservation of this rich pollinator heritage we need to know the bee fauna. We need to inventory the species and determine their distributions and habits.

Just as early cartographers were forced to leave large areas on their maps blank, so there remain uncharted regions on the entomological map. One such area is west Texas, including Guadalupe Mountains National Park. Here I present preliminary results, which though based on limited data, suggest a rich bee fauna for this uncharted region. Our knowledge of bees in the park is based on only three collections made in three separate years, once each in April, May, and in September, for a total of only seven collecting days. This is admittedly a very limited and inadequate sample. Here I present the results from this preliminary data that hint at a very rich and diverse fauna, give some sense of the biological and historical factors that might contribute to this diversity, suggest directions for future research, make predictions about the fauna, and briefly address the importance of bees in natural ecosystems.

The known bee fauna of Guadalupe Mountains National Park includes five of the six families of bees found in North America. Only Melittidae is so far undetected; I would expect it to be found with more systematic sampling. Thirty-nine genera are presently recorded from the park (Table 1), more genera than are present in all of New England, with 30 additional genera likely to occur within its boundaries. The species diversity (145) is likewise substantial. As a further indication of the richness of the fauna, 13 of these species are new. Some of these new species have been found elsewhere; others are presently known only from the park. Finally, the presence of *Dufourea boharti*, a species that was previously only known from central Mexico, is a great surprise.

Bees possess a great diversity in size and color, and this is certainly true of the Guadalupe fauna. They range from diminutive pollinators only three-millimeters long, to the highly visible carpenter bees at more than three-centimeters long, which are common in the canyons of the region. Black is the dominant ground plan, but some bees have a red abdomen, others are variously marked with white on yellow, or may be partly to entirely bright green or blue.

What are the factors that might foster this rich array of bees? The first of these is different lifestyle patterns. The majority of the bees are solitary; that is, a female makes a nest and provides for her offspring without any assistance from other individuals. Social species—repre-

Family Colletidae

Colletes bryanti
Colletes gilensis
Colletes kincaidii
Colletes sphaeralceae
Hylaeus asininus
Hylaeus episcoplais coquiletti
Hylaeus n. sp. aff. cookii
Hylaeus personatellus
Hylaeus wootoni

Family Halictidae

Agapostemon texanus
Agapostemon tyleri
Augochlorella neglectula
Augochlorella striata
Dufourea boharti
Dufourea pulchricornis
Halictus ligatus
Halictus tripartitus
Lasioglossum (Dialictus) sp. 10
Lasioglossum (Dialictus) sp. 23
Lasioglossum (Dialictus) sp. 29
Lasioglossum (Dialictus) sp. A
Lasioglossum (Dialictus) sp. B
Lasioglossum (Dialictus) sp. F
Lasioglossum (Dialictus) sp. G
Lasioglossum (Dialictus) sp. T1
Lasioglossum (Dialictus) sp. T2
Lasioglossum (Evylaeus) sp. A
Lasioglossum (Evylaeus) sp. B
Lasioglossum clematisellum
Lasioglossum comulum
Lasioglossum lampronotum?
Lasioglossum morrilli
Lasioglossum petrellum
Lasioglossum pictum
Lasioglossum pruinosiformis
Lasioglossum ruidosensis
Lasioglossum sisymbrii
Lasioglossum tegulariformis
Sphecodes (Arctosphecodes)asclepiadis gr.

Family Andrenidae

Andrena imitatrix
Andrena jessicae
Andrena pecosana
Andrena prunorum
Andrena simulata?
Andrena sp. A
Andrena sp. C
Andrena sp. D
Calliopsis coloradensis
Calliopsis rozeni
Perdita aperta
Perdita ignota ignota
Perdita lepachidis
Perdita opuntiae
Protandrena (Heterosarus) n. sp. 1
Protandrena albitarsis
Protandrena n. sp. aff. sublevis
Protandrena n. sp. aff. leucoptera
Protandrena n. sp. aff. rudbeckiae
Protandrena n. sp. aff. subglaber
Protandrena neomexicana
Protandrena renimaculata?
Protandrena towsendi

Table 1. Native Bee and Wasp Fauna of Guadalupe Mountains National Park

sented by bumble bees, some sweat bees, and the exotic honey bee—are a minor component. Other bees are cleptoparasites—bees that locate the nests of other bees, usually specific genera, and enter the nest while the host is out and lay an egg in the cell. These are not true parasites in the sense that they do not consume the host, rather they destroy the egg or young larva and then consume the provisions designed for the host. Solitary bees are expected to comprise the majority of the park's bees as they do in other faunas.

A second factor that affects diversity is diverse nesting sites. Although the nesting biologies of most of Guadalupe's residents remain unknown, based on known patterns for the North American fauna the majority will be found to nest in the ground. Arid lands prove to be preferred nesting habitat for many ground-nesting bees (Cane 1991). These nests are frequently inconspicuous. Often the only indication is a small diameter hole in the ground. But if you arrive during the active phase of nesting, you may find little volcanoes of soil, or a mud turret that has been created by the

Family Megachilidae

Anthidium maculosum
Ashmeadiella aff. dimalla
Ashmeadiella bucconis
Ashmeadiella cactorum
Ashmeadiella erema
Ashmeadiella gilletei
Ashmeadiella meliloti
Ashmeadiella n. sp. aff. micheneri
Ashmeadiella prosopidis
Ashmeadiella rubrella
Atoposmia daleae
Atoposmia n. sp.
Coelioxys hirsutissima
Coelioxys mitchelli
Coelioxys rufitarsis
Coelioxys texana
Dioxys productus
Heriades gracilior
Heriades micropthalma
Hoplitis grinnelli
Hoplitis producta
Lithurge apicalis
Megachile (Phaeosarus) n. sp.?
Megachile comata
Megachile inimica sayi
Megachile parallela
Megachile policaris
Megachile spinotulata
Megachile subanograe
Megachile sublaurita?
Megachile texana
Osmia (Acanth.) aff. watsoni
Osmia (Acanth.) n. sp. aff. enixa
Osmia cordata
Osmia gaudiosa
Osmia latisulcata
Osmia lignaria
Osmia prunorum
Osmia ribifloris
Osmia subfasciata
Stelis (Stelidina) n. sp.

Family Apiadae

Anthrophora affabilis
Anthrophora californica
Anthrophora lesquerellae
Anthrophora montana
Anthrophora n. sp. aff. californica
Anthrophora petrophila
Anthrophora sp. porterae gr.
Anthrophora squammulosa
Apis mellifera
Ceratina aff. acantha
Ceratina aff. apacheorum
Ceratina nanula
Ceratina neomexicana
Diadasia australis
Diadasia diminuata
Diadasia sphaeralcearum
Doeringiella sp. 1
Doeringiella sp. 2
Doeringiella sp. 3
Epeolus compactus
Habropoda salviarum
Melecta pacifica fulvida
Melissodes confuse?
Melissodes coreopsis
Melissodes montana
Melissodes sp. 1
Melissodes sp. 2
Melissodes tristis
Nomada (Nomada) sp. A
Nomada (Nomada) sp. B
Nomada (Nomada) sp. C
Nomada n. sp.? aff. zebrata
Nomada sophiarum
Syastra sabinensis laterufa
Syntrichalonia exquisita
Tetraloniella sp. 1
Tetraloniella sp. 2
Xeromelecta californica
Xylocopa californica arizonensis

bee as part of the architecture of the nest. In some instances these turrets are built up and then run along the ground, reminiscent of an entrance to an igloo. Below ground nest architecture is even more varied. All nests have two basic elements: (1) a tunnel, often branched, going down into the ground at the end of which or along which are; (2) cells, oblong pockets in the soil, sometimes lined, in which a mass provision of pollen, usually mixed with nectar is placed, an egg laid, and the cell sealed off. The nest architecture is usually distinctive, at least at the generic level. In some, individual cells are constructed on laterals off of the main tunnel; in others, there is a vaulted chamber with vertical cells in its floor. Cells may be in series or they may be solitary. Most ground-nesting bees nest shallowly. In sandy substrates, however, they may go to extraordinary depths. The deepest recorded nest in North America reached a depth of almost three meters (Parker and Griswold 1982). The preponderance of shallow nesters has management implications. Mechanical impacts, whether they are vehicular or pedestrian, could have a significant impact on populations that nest shallowly, both by interrupting nesting activity and by destroying completed nests.

Ground nesting is the most common nesting strategy but is certainly not the only one. A number of bees nest in cavities either existing or created by the female. Some bees, carpenter bees included, drill into yucca stalks or other pithy stems. Some nest in wood, in old beetle burrows. Other cavities used include snail shells and emergence holes in galls. A variety of materials are used in cell construction by these cavity nesters: leaf pieces, masticated leaves, plant fibers, resin, mud, gravel, and glandular secretions. A few bees, including most resin bees, build exposed nests. Such a nest constructed by an unknown species of *Dianthidium* was found on a stem of a creosote bush (*Larrea tridentata*) in the park. The nest consists of a cluster of cells formed of resin with pebbles adhered across the entire exterior.

A third factor in diversity is specialization in larval diet. While some bees, such as the exotic honey bee, are catholic in their taste, most native bees are much more limited in the scope of their floral visitation. Specialization is typically for pollen, not nectar. Bees may collect nectar from a variety of floral sources for their own energy needs, but the larval pollen diet is often quite specific, often at the level of plant genera (Linsley 1958, Wcislo and Cane 1996). Pollen specialization may lead to restricted temporal activity tied to pollen presentation. Most bees are active during the hottest time of the day from midmorning to midafternoon, but some such as *Andrena* (*Onagandrena*) will only be found at dawn when the flowers of evening primrose (*Oenothera*) are open. Flight times for *Perdita* that specialize on blazing stars (*Mentzelia*) are timed to coincide with their late afternoon flowering. Some evening primrose open at dusk and specialist *Sphecodogastra* can be observed waiting for the flowers to open and even forcing their way in as the bud unfolds.

Commonly, a large suite of both specialists and generalists visit a given flowering plant. One-to-one correspondence of pollinator with plant is rare. Data on bee plant relationships in the park are largely lacking, but specialists have been recorded for creosote bush (*Larrea*), cactus (*Opuntia*), and globe mallow (*Sphaeralcea*), and specialists can be expected on a wide variety of other plants including evening primrose (*Oenothera* and *Cammisonia*), mint (*Salvia*), beardstongue (*Penstemon*), and various composites.

The fourth factor to diversity is phenology. Most bees appear as ephemerals on the landscape in the same way that splashy shows of annuals occasionally grace the desert with their transient beauty. Adult bees of many species are active for at most two to four weeks, during which the female actively nests. After provisioning a cell with pollen and nectar, the female lays an egg then seals the cell. The egg hatches shortly thereafter and a succession of larval instars feed on the provision. A period of dormancy follows completion of the provision. After pupation, the adult emerges, to repeat the cycle. In many bees this is an annual cycle, but some bees have multiple generations within a year. Many bees are strongly seasonal, linked with their floral hosts. This strong seasonality, coupled with a short adult life span, results in a rapid turnover of the fauna. This is evidenced in the three samples from the park. Despite the relatively large number of species in each sample, there is very little overlap between months (Figure 1).

The final factor that can affect bee diversity is faunal affinities, a reflection of historical influences on the bee fauna from diverse source areas. We would expect an enriched fauna for Guadalupe Mountain National Park, lying as it does at the juncture of two biomes, the Rocky Mountains and the Chihuahan Desert. The North American deserts are considered one of the richest areas for bees in the world (Michener 1979). A strong representation of hot-desert-restricted bees is evident here. Over half of the presently known fauna are from the Southwest. So far we lack similar evidence for a northern, montane element. I suspect this is an artifact of our collect-

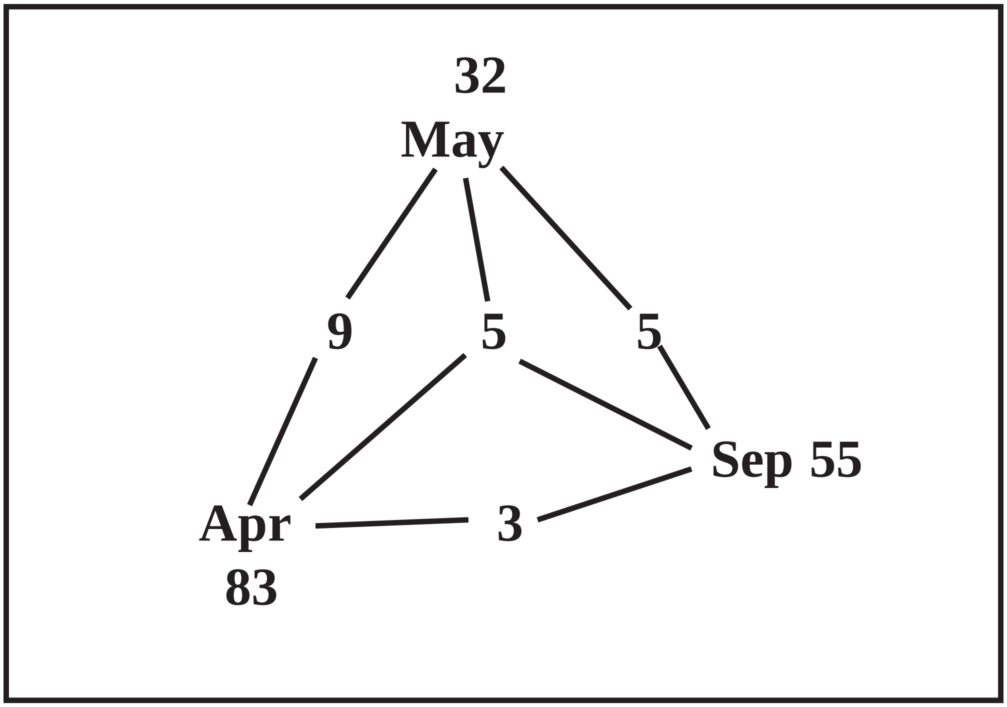

Figure 1. Seasonal turnover in the bee fauna of Guadalupe Mountains National Park. Number of species recorded for each month and numbers in common between months.

ing effort; almost all of our collecting has been at lower elevations. This probably explains why we have not picked up such largely montane groups as bumble bees (*Bombus*). Other bees of the Guadalupes are more wide ranging. Nearly a fourth are widespread in the West, a further eighth are transcontinental. A few Great Plains species are present. A couple of Eastern bees appear to reach their western limit here in the Guadalupes. And *Dufourea boharti* is a representative of an austral element little documented in the United States. There are other hints of this southern influence. One of the new species discovered belongs to the genus *Atoposmia*. Known United States representatives of *Atoposmia* have all been active only in the spring, while those of Mexico are all fall flyers. This new species was found in the fall.

It is likely that there is also an endemic component. This is much more difficult to determine because of the limited collecting in the region. Systematic sampling both inside the park and in surrounding areas is needed to answer this question.

I would predict that a full census of the park will demonstrate a wealth of bee diversity well in excess of 350 species. That prediction is based first on the spatial and phenological limitations of our sampling effort thus far. We have only sampled at three limited times during the year. Due to the strong seasonality of most bees, sampling at other periods of the year should add a significant number of species.

Spatially, our sampling is not representative of the diversity of habitats in the park. Samples are limited to roads and lower stretches of the trails along the southeast side of the park. No collections have been made on the west or in the bulk of the highlands. We have not sampled in burned areas. Work in Pinnacles National Monument (Messinger and Griswold, unpublished data) suggests that bees are diverse in burned areas, perhaps both because there is increased diversity of flora, at least in some situations, and because nest sites are made available. Dunes remain unsampled. Elsewhere, dune systems have been found to be very rich reservoirs for bees, with some species restricted to this substrate (Griswold, et al., 1998). Whether this is true for gypsum dunes is unknown since all the dunes studied thus far have been siliceous.

A systematic multi-year sampling in the park and surrounding areas of all habitats across the entire flowering season would provide the only comprehensive bee study for both the southern Rocky Mountains and the Chihuahuan Desert and would provide valuable data for comparing bee diversity patterns across North America. Such a study would determine the extent of the endemic component and the importance of the park in bee conservation. Study of the gypsum dunes would be of particular value in determining whether they, like siliceous dunes, are repositories of unique faunas. Systematic sampling on all flowering plants would address the importance of floral specialization in bee-plant interactions in the park.

Why survey for bees? Bees can be indicators of the importance of habitats not flagged by more obvious components of the biota. They are part of that "uncharismatic microfauna," as a friend of mine calls it, that shows richness in places like sand dunes, where there are no glamorous vertebrates to speak to their importance. Secondly, bees are vital in the maintenance of floral diversity, a function which may be in jeopardy (Buchmann and Nabhan1996). Two thirds of flowering plants require pollinators. These services are most commonly provided by bees. This includes many rare plants. Studies of the pollination and reproductive biology of 35 rare plants, most of them federally listed, have shown that most, including the local endemic McKittrick pennyroyal (*Hedeoma apiculatum*), require pollinators to vector their pollen (Tepedino, personal communication).

Beyond these considerations, perhaps biodiversity is wonderful in its own right. To know that when you walk along one of the trails in the Guadalupes or just wander across the desert, you will meet 20 to 40 kinds of bees, even if you are unable to call them by name, is to know a bit more about the incredible wealth of life that is our heritage.

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Chapter 14

An Update on the Status of the Rare Plants in Guadalupe Mountains National Park

JACKIE POOLE has been a botanist for the Endangered Resources Branch, Wildlife Division of the Texas Parks and Wildlife Department for the past ten years. She performed several status reports during the 1980s on sand sacahuiste (*Nolina arenicola*), Guadalue Mountains fescue (*Festuca ligulata*), McKittrick snowberry (*Symphoricarpos guadalupensis*), and others.

Introduction: the history of rare plant classification in Texas and the rest of the world

In Texas the delineation of rare plants formally began in the 1970s with the inception of the Texas Organization for Endangered Species (TOES) and the Rare Plant Study Center at the University of Texas in Austin. These two organizations produced the first lists of rare Texas plants (Gould 1973; Rare Plant Study Center 1974). By the late 1970s the U.S. Fish and Wildlife Service (USFWS) had also produced the first assemblage of endangered and threatened plants as well as a group of potential candidates (USFWS 1975, 1976). The initiation of the Texas Natural Heritage Program (TxNHP) by The Nature Conservancy (TNC) and the General Land Office in 1983 provided yet another list of rare plants, based on TNC ranking methodology (TxNHP 1984). Heightened awareness has led to increased investigation of these species. Additional locations have been found, threats have been managed for or otherwise alleviated, and in general more information has been acquired about many of these species.

Concurrently there has been much thought given to the concept and types of rarity. Early rare plant lists relied on knowledgeable individuals to identify such species, and were often biased toward species that the specialist liked or knew well. Also the spatial and temporal aspects of rarity were often overlooked. Every species is rare somewhere or at some point in time. For example, an annual species may be quite rare or absent in some seasons. Likewise most species are quite uncommon at the limits of their range. However either type of species may be quite abundant in the proper season or in the main part of its range. Some species are rare in both space and time. Rabinowitz (1981) produced a classic study of rare plants, known as the seven forms of rarity. Using three variables with two character states each (geographic range: wide vs. narrow, habitat specificity: broad vs. restricted, and local population size: somewhere large vs. everywhere small), Rabinowitz constructed a table showing that seven of the eight combinations produced species considered rare. Aside from the application of this model to the British flora (Rabinowitz 1986), it has not been widely used and certainly not in Texas. Two widely used classifications of rarity include those of the International Union for the Conservation of Nature (IUCN) and TNC. The several categories employed by the IUCN rely on subjective criteria and thus are open to interpretation. The global, national, and state rankings developed by TNC are based primarily on number of populations with adjustments for abundance, range size, population trends, level of protection, threats, and fragility. Most of these criteria are tied to numerical values. Thus the knowledgeable individual must quantify rarity through a standardized format. Although the final rank is at the discretion of the author of the ranking form, the rank and form are subject to review by other stakeholders and interested parties.

Current rare plant classification in Texas

By the early 1980s, the Rare Plant Study Center was inactive. The Texas Organization for Endangered Species had thrown out their original rare plant list, and began a nominating process to place plants on the rare list. The U.S. Fish and Wildlife Service dropped their category 2 status and relies instead on other agencies and organizations to provide lists of sensitive species. The Texas Natural Heritage Program, although no longer extant, still functions through the Biological Conservation Database (within the Endangered Resources Branch of the Wildlife Division at Texas Parks and Wildlife) and the Conservation Data Center of the Nature Conservancy of Texas. A state list of rare plants was recently produced by these two groups (Poole and Carr 1997). This list used by the Texas Parks and Wildlife Department (TPWD), the state agency with authority for endangered species in Texas to allocate priorities to the state flora, is based on the TNC ranking system. This latest list of rare plants (Poole and Carr 1997) includes 235 G1 (five or fewer populations on a worldwide basis), G2 (20 or fewer populations worldwide), or G3 (100 or less populations globally) species. A "watch" list of S1 or S2 (five or fewer, or 20 or fewer populations, respectively, on a statewide scale) species is also kept by TPWD (Carr 1995), but little additional information aside from name and county of occurrence has been acquired.

Lists of rare plants for Guadalupe Mountains National Park

There have been several floristic studies in the Guadalupe Mountains National Park (Gehlbach et al. 1969, Burgess and Northington 1981) including three studies of rare and endangered plants (Riskind 1974a, 1974b; Burgess and Northington 1981; Higgins 1989). The Riskind list and supplement (1974a, 1974b) were conservative, being composed primarily of globally rare endemics (or near endemics), and disjuncts or peripherals. Two relatively rare species, *Cirsium turneri* and *Senna (Cassia) orcuttii*, reported by Riskind, were not found by Burgess and Northington, nor have any herbarium specimens been observed. Burgess and Northington (1981) conducted a significant study of the flora of Guadalupe Mountains National Park, and uncovered many more disjuncts, peripherals, endemics, and other species rare to the park. Burgess and Northington produced the most exhaustive list of rare plants of the park. Many of the species included in their list are rare within the boundaries of Guadalupe Mountains National Park, but are common or even abundant outside the park. Higgins (1989) did not compose his own list of rare species for the park, but he did conduct survey work and make listing and management recommendations for the category 2 species reported from the park.

Much has changed in the last 25 years. Of the three federally listed plants reported in the Guadalupe Mountains National Park, one has been delisted, another is proposed for delisting, and the third turned out to be a new species. McKittrick pennyroyal (*Hedeoma apiculatum*) was delisted in 1993 due to discovery of additional populations, thus alleviating of the threat of extinction (USFWS 1993). Lloyd's hedgehog cactus (*Echinocereus lloydii*) was proposed for delisting in 1996 because the species was found to be a hybrid, and thus did not qualify for protection under the Endangered Species Act (USFWS 1996, Powell et al. 1991, Zimmerman 1993). Burgess and Northington (1981) found Sneed pincushion cactus (*Coryphantha* or *Escobaria sneedii* var. *sneedii*) at one location in the park. However when Heil and Brack (1985) found *C. sneedii* in the park, they decided that the cactus was a new variety. When they published the entity later, they described it as a new species, *Escobaria guadalupensis* (Heil and Brack 1986). While the park is on the verge of having no listed species, there is a candidate species (formerly referred to as category 1, that is, Guadalupe Mountains fescue (*Festuca ligulata*). This species was collected in upper McKittrick Canyon in 1952. Even though the species has not been relocated in the park, it probably occurs as a small population (as it does in Big Bend National Park) and will require intensive surveys to relocate. Other species of federal concern in the park are the 12 taxa formerly labeled category 2. At present there is not enough information about these plants to make a listing decision.

Guadalupe Mountains National Park has developed its own list of rare plants (Armstrong 1996). The park has several categories: listed species, federal candidate species, National Park Service sensitive species (the former federal category 2 taxa), other species of concern, historically present species, and species of possible occurrence. Most of the taxa on the list are federally listed, federal candidates, former candidates, or taxa formerly or currently tracked by the TxNHP.

A table comparing the lists of Riskind (1974a, 1974b), Burgess and Northington (1981), and the Guadalupe Mountains National Park (Armstrong 1996), with the categories and ranks assigned by the U.S. Fish and Wildlife Service (USFWS 1993), the Texas Organization for Endangered Species (1993), and The Nature Conservancy (1998), has been prepared (Table 1). Nomenclature is drawn from various sources: Correll and Johnston 1970, Johnston 1990, Hatch et al. 1990, Jones et al. 1997, and Kartesz 1994.

Conclusions

For the most part, there is fairly good concurrence among the lists of USFWS, TOES, Guadalupe Mountains National Park, and the ranked taxa of TNC. The lists of Burgess and Northington, and Riskind are more similar because of their identification of peripherals and disjuncts as rare plants of Guadalupe Mountains National Park. It is somewhat inequitable to compare the lists of Burgess and Northington and Riskind with the others. Burgess and Northington recorded any species that was rare within the boundaries of Guadalupe Mountains National Park, and Riskind concentrated on peripherals. Also both lists are dated. The U.S. Fish and Wildlife Service considers only those taxa rare on a worldwide basis. Although both TOES and TNC have provisions to cover statewide rarity, neither group has acted on it, at least in west Texas. Guadalupe Mountains National Park has taken a more USFWS approach, but still retains some peripheral or disjunct elements.

What types of rarity and which species should be of conservation concern to Guadalupe Mountains National Park? For management purposes, an agency such as the National Park Service may be highly interested in preserving what is rare or unique within the boundaries of various units. However, globally rare species that occur only, or primarily within, a political unit should be given first priority over species of local concern. Certainly any taxa endemic to the park, or with the majority of their range within the park, or ranked G1 or T1, should receive the highest protection and management priority. However, federal regulations may also require other species—such as those federally listed, recently delisted, or candidates—to receive high protection regardless of their global distribution or rank. All first priority taxa should have regularly monitored populations to assess population health and demographic trends. Threats should be assessed and managed or alleviated. This group of plants represents the top rare plant conservation priorities of the park. A second tier of species receiving less attention would be species ranked G2, T2, G3, or T3. Populations of these species should be identified and checked on a regular basis. A third level would be comprised of those plants which are peripheral or disjunct in the Guadalupe Mountains. While these species are not rare globally, they are quite rare on a state level. Guadalupe Mountains National Park has for the most part excluded such taxa from its rare plant list. However, these species are unique within Texas. They may also serve as indicator species of plant communities unique or rare to Texas. Occasional checks for the presence of these species and management of their habitat should be sufficient for their continued survival.

Before such priorities and management tasks can be assigned, preliminary work needs to be done. For example, the exact locations of many of the species need to be verified (i.e., *Festuca ligulata*, *Agave glomeruliflora*, *Scutellaria laevis*). Determining the portion of the species' range within Guadalupe Mountains National Park would help in assigning management and research tasks (i.e., *Chaetopappa hersheyi*, *Aquilegia chaplinei*, *Polygala rimulicola* var. *rimulicola*). Much of the knowledge to allow such prioritization is lacking. The present list of Guadalupe Mountains National Park is an excellent start, but would benefit from an assessment according to rarity (and federal regulatory requirements) and the addition of peripherals and disjuncts.

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Table 1. Comparison of rare plant lists of Guadalupe Mountains National Park with selected organizational and agency classifications of rarity

1(Burgess and Northington 1981; Northington and Burgess 1979)
I–endemic to a relatively limited area in and or around the Guadalupe Mountains
II–widespread in other states, but known in Texas from very few localities, usually known only from the Guadalupe Mountains
III–of distributional interest; includes species with relatively small ranges and those near the limits of their known occurrence in the park
IV–rare within the park, but may be common elsewhere in Texas
V–not seen by Burgess and Northington, but previously recorded for the park

2Riskind 1974a, 1974b

3(U.S. Fish and Wildlife Service (1980, 1983, 1985, 1990, 1993)
LE–federally listed as endangered
PDL–proposed to be delisted
DL–delisted
C1–federal candidate with enough information for listing
C2–federal species of concern
3B–no longer considered a valid taxonomic entity
3C–no longer under federal review for listing

4(Texas Organization for Endangered Species 1993)
I–federally listed endangered species
II–federally listed threatened species
V–watch list species
*–species needing more research

5(Armstrong 1996)
FL–federally listed as endangered
CS–federal candidate or category 1 species
NPSSS–NPS sensitive species (formerly federal category 2)
SOC–species of concern without special status within the mountainous Trans-Pecos region
H-NRR–historically present species with no recent records

6The global ranks are primarily from the Biological Conservation Database of The Nature Conservancy (The Nature Conservancy 1998), with some global and all state ranks being assigned by the author and the Texas Conservation Center of The Nature Conservancy of Texas.
G1 (S1)–less than six occurrences known globally (statewide), critically imperiled (in the state), especially vulnerable to extinction (extirpation from the state)
G2 (S2)–6-20 occurrences known globally (statewide), imperiled and very vulnerable to extinction throughout its range (extirpation throughout the state)
G3 (S3)–21-100 occurrences known globally (statewide), either rare and local globally (statewide) or vulnerable to extinction throughout its range
G4 (S4)–more than 100 occurrences known, apparently secure globally (statewide)
G5 (S5)–demonstrably secure globally (statewide)
GH (SH)–of historical occurrence throughout its global (statewide) range, i.e., not observed in the last 50 years
Q–denotes taxonomic uncertainty
?–indicates that the rank is not certain
T–a subrank indicating the global rank for a subspecific taxon
U–a rank has not been assigned

	B&N$_1$	RISK$_2$	FWS$_3$	TOES$_4$	GUMO$_5$	TNC$_6$
Acacia roemeriana	IV					G5S5
Agave glomeruliflora			C2		NPSSS	G2S2
Aletes filifolius	III		3C			G4S2
Allium geyeri	II	x				G4G5S1
Allium perdulce var. *sperryi*	IV		3C		H-NRR	G4T4S2
Amelanchier utahensis	II	x				G5S1
Andropogon hallii	IV					G4S4
Anthericum torreyi	III(IV?)					G5S3
Aquilegia chrysantha var. *chaplinei*	I	x	3C	V	SOC	G4T1S1
Arceuthobium douglasii	II					G5S1
Argyrochosma limitanea ssp. mexicana	II					G4G5T4
Asclepias tuberosa	III					G5S5
Aster hesperius (=A. lanceolatus ssp. hesperius)	II	x				G5T5?S1
Aster laevis var. *guadalupensis*			C2	V	NPSSS	G5T1QS1
Arbutus xalapensis	II					G5S4
Astragalus albulus	II					G3G4S1
Astragalus gypsodes	I		3C	V	H-NRR	G3S2
Astragalus pictiformis	III					G5S1
Berberis repens	II	x				G5S1
Berlandiera lyrata var. *macrophylla (= B. lyrata)*	III				SOC	G5S5
Bouteloua warnockii	III					G4S2
Brickellia parvula	V?	x				G3?S1
Caesalpinia jamesii	IV					G5S5
Campanula rotundifolia	II					G5S3
Carex eburnea	II	x				G5S1
Carex geophila	II					G5S1
Cassia orcuttii (=Senna orcuttii)		x				G2S2
Castilleja latebracteata (=C. nervata)	IV					G3S2
Celastrus scandens	II	x				G5S1
Centaurea americana	IV					G5S5
Cevallia sinuata	IV					G5S5
Chaetopappa hersheyi	I	x	C2	V	NPSSS	G3S2
Chamaesaracha edwardsiana	IV					G4S3
Choisya dumosa	III	x				G5?S2
Chrysothamnus nauseosus ssp. texensis (C. nauseosus ssp. bigelovii in part)	I(V)	x	C2	V	NPSSS	G5T2S1
Chrysothamnus pulchellus	IV					G4G5S4
Chrysothamnus spathulatus	II	x				G3S2
Cirsium turneri		x	3C			G3S3
Cologania pallida	II					G4S1
Corallorhiza striata	III,IV					G5S2
Coreopsis lanceolata	II,III					G5S4
Coryphantha dasyacantha (misidentification of C. strobiliformis)	III					
Coryphantha macromeris	IV					G5S4
Coryphantha scheeri	IV					G4S3
Croton suaveolens				V		G3S3
Cryptantha paysonii	III			V	SOC	G3S1
Cystopteris bulbifera ssp. bulbifera	II,IV	x				G5T5S1
Cystopteris fragilis var. *simulans*	III					G5T4S2
Dalea bicolor var. *argyrea*	IV					G4G5T4S4
Dalea frutescens	IV					G5S5
Dalea scoparia	III					G4S4
Delphinium virescens (=D. carolinianum ssp. virescens)	IV					G5T5S4
Dicranocarpus parviflorus	III					G4S3
Echinocereus lloydii			PDL	I	FL	G2QS2
Epipactis gigantea	IV					G4S3
Epithelantha micromeris	III					G4S3
Equisetum kansanum (= E. laevigatum)	III	x				G5S3
Erigeron rusbyi (=E. arizonicus)	II					G3G4QS1

	B&N₁	RISK₂	FWS₃	TOES₄	GUMO₅	TNC₆
Escobaria guadalupensis (misidentified as Coryphantha sneedii var. *sneedii)*	I		C2	V	NPSSS	G1S1
Festuca ligulata	II		C1	V	CS	G1S1
Forestiera pubescens? or neomexicana?	III	x				G5S5
Fragaria bracteata (= F. vesca ssp. bracteata)	II	x				G5T?S1
Gaillardia multiceps	III					G4S1
Galium fendleri	II					G3G4S1
Glyceria striata	II	x				G5S1
Grindelia havardii	III	x				G4S2
Hackelia besseyi (syn. H. grisea)	III,IV	x				G3?S2
Hedeoma apiculatum	I	x	DL	II	SOC	G3S2
Heterotheca viscida	V	x				G3S2
Hexalectris nitida	IV		C2		H-NRR	G3S3
Hexalectris revoluta			C2	V	NPSSS	G1S1
Hymenopappus biennis	V	x		V	SOC	G2S2
Hymenopappus flavescens	IV					G5S5
Hymenoxys richardsonii var. *floribunda*	II	x				G4T4S2
Ipomoea lindheimeri	III					G4S4
Ipomopsis arizonica	III,IV					G3G4S3
Jatropha dioica var. *graminea*	III,IV					G5T5S5
Juniperus deppeana forma sperryi	I	x				G5T1S1
Juniperus scopulorum	(I?)III	x				G5S2
Lactuca graminifolia	II	x				G5?S2
Lathyrus leucanthus (= L. lanszwertii var. *leucanthus)*	II					G4G5S1
Lepidospartum burgessii			C2	V	NPSSS	G2S1
Lesquerella valida	I	x	3C		SOC	G2S1
Lilium philadelphicum var. *andinum*	II	x				G5T?S1
Linum schiedeanum	IV					G4G5S3
Lithospermum multiflorum	III					G4S2
Lithospermum parksii var. *rugulosum*	II-III,IV	x				G3G4T2S2
Lithospermum viride	III					G4S3
Lobelia cardinalis	III	x				G5S4
Lonicera arizonica	II	x				G4S1
Machaeranthera blephariphylla	III					G3?S2
Mammillaria lasiacantha	III					G4S3
Mentzelia humilis	III					G4S2
Monotropa latisquama (= M. hypopithys)	III	x				G5S3
Nama carnosum	III					G4S2
Nama xylopodum	I	x	3C		SOC	G4?S3
Neolloydia intertexta	IV					G4G5S4
Nolina arenicola	III?		C2	V	H-NRR	G2QS2
Oenothera caespitosa ssp. eximia	II	x				G5TUS1
Opuntia schottii	IV					G5S5
Oryzopsis hymenoides	III					G5S3
Ostrya knowltonii	II					G4S2
Panicum ramisetum (= Setaria ramiseta)	IV					G5S5
Penstemon ambiguus	IV					G5S5
Penstemon brevibarbatus	III,IV					G3S3
Penstemon cardinalis ssp. regalis	I	x		V	SOC	G3T2S2
Penstemon dasyphyllus	III					G4S2
Penstemon fendleri	IV					G5S3
Perityle quinqueflora	I				SOC	G3S3
Peteria scoparia	V(IV?)					G4S2
Phanoerophlebia auriculata	III,IV					G4S2
Philadelphus hitchcockianus	II	x				G4S1
Physocarpus monogynus	II	x				G4S1
Physostegia virginiana var. *praemorsa*	IV					G5T4S3
Pinaropappus parvus	I	x			SOC	G3S3
Poa occidentalis	II					G4S1
Polygala rimulicola var. *rimulicola*	I	x	3C		SOC	G2T2S2

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T–a subrank indicating the global rank for a subspecific taxon
U–a rank has not been assigned

	B&N$_1$	RISK$_2$	FWS$_3$	TOES$_4$	GUMO$_5$	TNC$_6$
Polygonatum cobrense	II	x				G4S1
Populus angustifolia				V		G5S2
Populus tremuloides	II,IV					G5S2
Potentilla pensylvanica	II					G5S1
Prosopis pubescens	IV	x				G4G5S3
Prunus murrayana			3C	V*		G2QS2
Pterospora andromeda		x				G5S1
Rafinesquia neomexicana	II					G5?S1
Rhamnus smithii	(IV?)V					G4?S2
Rhus toxicodendron	IV					G5S5
Robinia neomexicana	II	x				G4S2
Rosa stellata ssp. mirifica var. *erlansoniae*	III	x		V	SOC	G4T1S1
Rosa woodsii	III,IV					G5S2
Salvia farinacea	III					G5S5
Salvia summa	I	x			SOC	G3?S2
Scutellaria drummondii	IV					G5S5
Scutellaria laevis			C2	V	NPSSS	G1S1
Selinocarpus lanceolatus	III					G4?S3
Senecio neomexicanus var. *neomexicanus*	II	x				G5T?S1
Senecio douglasii var. *douglasii (syn. S. warnockii)*	I	x	(3B)		SOC	G5T5S5 (G3S3)
Sibara grisea	III?		3C			G3?S1
Sisyrinchium demissum	II	x				G5S1
Smilacina racemosa (= Maianthemum racemosum ssp. amplexicaule)	III,IV					G5T2S2
Solanum jamesii	IV	x				G4S2
Solanum leptosepalum (misidentification of S. fendleri)	III					
Sophora gypsophila var. *guadalupensis*	I	x	3C		SOC	G2G3T2S1
Sophora secundiflora	III					G5S5
Stephanomeria wrightii	III	x				G3S2
Stipa curvifolia	I		3C		SOC	G4S1
Streptanthus carinatus	III		3C		SOC	G3S3
Streptanthus sparsiflorus	I	x	C2	V	NPSSS	G2S2
Swertia radiata (= Frasera radiata)	II	x				G4G5S1
Symphoricarpos guadalupensis	I	x	C2	V	NPSSS	GHQSH
Trichostema arizonicum	V					G4S1
Ungnadia speciosa	IV					G5S5
Valeriana arizonica	II	x				G5?S1
Valeriana texana	I	x	3C	V	SOC	G3S2
Verbena macdougalii	II					G5?S1
Viguiera cordifolia	II					G5?S1
Viguiera multiflora (= Heliomeris multiflora var. *multiflora)*	II					G4G5T?S1
Viola guadalupensis				V	NPSSS	G1S1
Viola missouriensis	II					G5?S4
Yucca faxoniana	III,IV					G4S4
Zigadenus elegans	II	x				G5S1

1(Burgess and Northington 1981; Northington and Burgess 1979)
I–endemic to a relatively limited area in and or around the Guadalupe Mountains
II–widespread in other states, but known in Texas from very few localities, usually known only from the Guadalupe Mountains
III–of distributional interest; includes species with relatively small ranges and those near the limits of their known occurrence in the park
IV–rare within the park, but may be common elsewhere in Texas
V–not seen by Burgess and Northington, but previously recorded for the park

2Riskind 1974a, 1974b

3(U.S. Fish and Wildlife Service (1980, 1983, 1985, 1990, 1993)
LE–federally listed as endangered
PDL–proposed to be delisted
DL–delisted
C1–federal candidate with enough information for listing
C2–federal species of concern
3B–no longer considered a valid taxonomic entity
3C–no longer under federal review for listing

4(Texas Organization for Endangered Species 1993)
I–federally listed endangered species
II–federally listed threatened species
V–watch list species
*–species needing more research

5(Armstrong 1996)
FL–federally listed as endangered
CS–federal candidate or category 1 species
NPSSS–NPS sensitive species (formerly federal category 2)
SOC–species of concern without special status within the mountainous Trans-Pecos region
H-NRR–historically present species with no recent records

6The global ranks are primarily from the Biological Conservation Database of The Nature Conservancy (The Nature Conservancy 1998), with some global and all state ranks being assigned by the author and the Texas Conservation Center of The Nature Conservancy of Texas.
G1 (S1)–less than six occurrences known globally (statewide), critically imperiled (in the state), especially vulnerable to extinction (extirpation from the state)
G2 (S2)–6-20 occurrences known globally (statewide), imperiled and very vulnerable to extinction throughout its range (extirpation throughout the state)
G3 (S3)–21-100 occurrences known globally (statewide), either rare and local globally (statewide) or vulnerable to extinction throughout its range
G4 (S4)–more than 100 occurrences known, apparently secure globally (statewide)
G5 (S5)–demonstrably secure globally (statewide)
GH (SH)–of historical occurrence throughout its global (statewide) range, i.e., not observed in the last 50 years
Q–denotes taxonomic uncertainty
?–indicates that the rank is not certain
T–a subrank indicating the global rank for a subspecific taxon
U–a rank has not been assigned

Chapter 15

Are Small Populations of Columbines More Vulnerable to Inbreeding Depression?

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Introduction

Pattern versus process-based assessment of rarity. Historically, the main criterion for identifying threatened and endangered species has been the scarcity of individuals or populations. Recently, however, scientists have recognized the need to assess rarity and vulnerability based on biological processes in addition to patterns of geographic distribution (Holsinger and Gottlieb 1991). Patterns of populations of reduced distribution, or of a relatively few number of individuals, could be the result of and are potentially affected by two important processes. One process involves the performance of individuals derived from the mating of two related individuals, i.e., inbreeding (Roff 1997), the probability of which increases as population size decreases. A possible consequence is inbreeding depression, a decline in the value of a trait such as fitness (Barrett and Kohn 1991, Hedrick and Miller 1992, Milligan et al. 1994, Ritland 1996b). In addition to the process of inbreeding depression, a second process affecting population fitness is the long-term evolutionary response of populations to natural selection, quantified either by heritability or additive genetic variance of phenotypic traits (Ridley 1993). Collectively, increased inbreeding depression and reduced heritability, both conditions that indicate increased vulnerability and influence rarity, are expected in small relative to large populations; this expectation is the fundamental basis of conservation biology.

Classic estimates of inbreeding depression and heritability. Quantitative trait heritability and the degree of inbreeding depression are classically estimated from phenotypic covariances between individuals of known relatedness or from known pedigrees usually manipulated by controlled crosses in the laboratory or greenhouse (Falconer 1989, Riska et al. 1989). Although these methods are useful for estimating the degree of inbreeding depression and for estimating heritabilities, quantitative traits are highly dependent upon the environment for their expression. Consequently, traditional methods are restrictive in that the estimates of inbreeding depression and heritability obtained under artificial environmental conditions or under manipulative matings may not reflect the natural situation in the field (Lande and Arnold 1983). Field-based measurements from individuals in situ would be especially useful because estimates would not be subject to the same limitations. However, doing so requires an innovative technique to estimate relatedness. We propose to utilize molecular marker data to estimate relatedness between pairs of individuals within a native population. Together, with phenotypic data, this will allow us to estimate levels of heritability and inbreeding depression of quantitative traits phenotypically expressed in their native environment.

Specific objectives to assess processes. Ritland (1996a, 1996c), Ritland and Ritland (1996), and Lynch and Ritland (1998) have developed mathematical and statistical models to estimate relatedness, subsequently yielding field-based estimates of the components of genetic variation for complex traits that determine inbreeding depression and heritability. Phenotypic similarity among pairs of individuals in a given population are due to environmental effects that decline with increasing distance, additive effects of genes, dominant effects of genes, and inbreeding. These causal determinants of phenotypic variation of a particular trait were incorporated into a multiple regression model (Ritland 1996a). Ritland's innovation is that phenotypic similarities and molecular marker data can be obtained for a variety of traits on individuals in their native environment, thereby enabling field-based measurements of inbreeding depression and heritability.

We propose to utilize this model to quantify both the magnitude of inbreeding depression and heritability for a number of morphological, fitness, and life-history traits in populations of *Aquilegia* species, a plant in the Southwest that occurs in small, isolated populations. As a result of comparing estimates of inbreeding depression and heritability across populations of varying size, we will be able to determine, not only the importance of the genetic mechanisms leading to vulnerability of these populations, but also the effect of population size on those processes. Therefore, the system we have chosen to study is an ideal system in which to make associations between inbreeding depression, heritability, and population size.

***Aquilegia* as a model organism.** The genus *Aquilegia* (Ranunculaceae) is composed of at least 70 north temperate herbaceous perennials (Munz 1946). The habitat associated with many of the Southwest *Aquilegia* includes rocky places in canyons, mostly along streams and dripping cliffs; therefore, the biogeographical range of *Aquilegia* is among montane "islands." *Aquilegia chrysantha* Gray var. *chaplinei* (Standl. Ex Payson) *Lott*, commonly referred to as Chapline's columbine, is currently protected from unauthorized collection under the New Mexico Endangered Plant Species Act. The auspices of this act stipulate maintenance of native plant diversity, and species in eminent danger of becoming extinct in the state of New Mexico are categorized as list 1 species. *Aquilegia chrysantha* var. *chaplinei* is currently in the list 1B category because "the taxon is so rare across its entire range and of such limited distribution and population size that unregulated collection could jeopardize its survival in New Mexico" (Sivinski and Lightfoot 1994). The known, limited distribution of Chapline's columbine is endemic to the Guadalupe Mountains, within Eddy County, New Mexico, and adjacent Texas. Chapline's columbine is also considered a U.S.D.A. Forest Service sensitive species; these are rare plant species which the U.S.D.A. Forest Service considers sensitive to land use practices within national forests. Plant species listed in the state of New Mexico are further categorized by three components of rarity, endangerment, and distribution, and given an R-E-D code. Therefore, based on the R-E-D classification, Chapline's columbine is considered to be endangered in a portion of its range (E-2 status) and rare outside New Mexico (D-2 status) (Sivinski and Lightfoot 1994).

Expansion of prior studies. Previous work on Chapline's columbine includes studies involving the amount of historical gene flow inferred from chloroplast DNA data among populations of *Aquilegia chrysantha* var. *chaplinei*, as well as gathering data on populations of *Aquilegia chrysantha* var. *rydbergii*, and *Aquilegia longissima* (Strand et al. 1996, Strand and Milligan 1996, Milligan 1993). Previous genetic analyses of closely-related southwestern *Aquilegia* suggest limited, among-population gene flow within and among mountain ranges in the Southwest (Hodges and Arnold 1994, Strand et al. 1996, Strand 1997). As a result, the population structure of *Aquilegia* enables comparisons among geographically and genetically isolated populations. Further, principal components analysis (PCA) for several floral traits of southwestern *Aquilegia* implies indistinguishable taxonomic boundaries (unpublished data). This understanding of population isolation and relatively recent divergence of southwestern *Aquilegia*, regardless of historical taxonomic treatment, is fundamental for investigating the interplay of quantitative genetics and population size.

Methods

Phenotypic and life history traits. During the summer of 1997, traits on individual plants were measured. Floral morphological traits included length and width of specialized petals (spurs and laminae) and of sepals for up to three flowers per individual. Vegetative morphological traits included plant height, plant diameter, rosette number and leaf number; petiole, petiolule, and leaflet lengths; and widths for both uppermost and lowermost of the basal leaves. Fitness characteristics included the number of flowers and fruit produced, fruit length and width, and seed number for up to three fruits per individual. The methods of collecting morphological data on each tagged plant were repeated in the summer of 1998 to collect individual life history data. Some studies (e.g., Husband and Schemske 1996) suggest that the deleterious effects of inbreeding depression may not affect perennial plant individuals until later stages of their life history. Therefore, morphological data collected over sequential years will provide life history information that could have a heritable basis.

Environmental conditions. At least two components of environmental similarity between individuals could be attributed to phenotypic resemblance of individuals within a population. One component of environmental similarity could be a function of spatial distribution; individuals that are in close, physical proximity to one another are presumed to share comparable microhabitats and, therefore, will resemble one another. To measure this first component, the spatial location of individuals was accurately mapped. This was accomplished by recording locations of each labeled and sampled individual relative to every other labeled and sampled individual and relative to existing landmarks.

A second component of environmental similarity could be a function of similarity in light availability (Child et a1. 1979). Casual observation of *Aquilegia* individuals and other empirical studies (e.g., Pigliucci and Schlichting 1995, Sultan 1996, VanTienderen and VanHinsberg 1996) suggest that phenotypic plasticity in vegetative characters could be attributed to varying light availability—either directly, via affecting photosynthesis, or indirectly, via affecting transpiration—within a given population. We propose to account for these influences by incorporating estimates of light availability into the model. To obtain environmental data that would suffice as an indirect assessment of the effect of the light environment on plant phenotypes, we wish to quantify similarities in light availability from the view each plant has of the sky. Above each sampled plant, sky and canopy photographs were taken with an Olympus OM camera, a 28 mm, wide-angle lens, and Fuji 400 ASA black-and-white film. A blue filter was used to increase the contrast between foliage and sky. For each photograph, the camera was aligned with true north, and a level was used to ensure the camera was positioned on a horizontal plane. Following film development, a Hewlett Packard Scan Jet IIcx was used to scan each image. The scanned images were manipulated with Micrographix Picture Publisher to enhance the contrast between sky and foliage. Subsequently, each image was analyzed with a computer program written by Milligan (unpublished) to calculate the fraction of open sky per image. Overall, these ecological assessments will complement our spatial distribution data and help expand on our understanding of the environmental influences of phenotypic similarity.

Genetic estimates of relatedness. Assessment of relatedness between pairs of individuals depends on availability of genetic information for each individual. Tissue samples from the labeled individuals were collected for laboratory genetic analyses currently being conducted at New Mexico State University. Nuclear DNA was extracted according to the protocols of Strand and others (1996) and slightly modified from the protocols of Milligan (1997). Previous genetic work has been completed on other *Aquilegia* populations (Strand et al. 1996, Strand and Milligan 1996, Milligan 1993), providing 10, polymorphic, single-gene nuclear markers. Following gene amplification via the polymerase chain reaction (PCR), sequence variation of a single nucleotide can be adequately detected using denaturing gradient gel electrophoresis (DGGE) (Dean and Milligan 1998).

To provide an additional set of loci for estimating relatedness, we have surveyed numbers of inter-simple-sequence repeats (ISSR) within the nuclear genome. These regions are hypervariable in many plant species (e.g., Rus-Kortekaas et al. 1993, Roder et al. 1995, Rongwen et al. 1995, Chase et al. 1996, Kelly and Willis 1998); therefore, microsatellite primers are effective in assessing fine-scale variation (Morgante and Olivieri 1993, Wolfe and Liston in press). We have found that polyacrylamide gel electrophoresis of *Aquilegia* DNA amplified with seven ISSR primers provide considerable variation among individuals. This substantial genetic variation visualized on gel images can be accurately detected with an automatic band-detection program, DNA Graphical User Interface (DNA/GUI, Version 2.0). To date, we have acquired genetic data for one entire *Aquilegia* population; the coupled utilization of single-gene and ISSR markers has yielded roughly 110 polymorphic loci. Upon acquisition of the molecular data, we will estimate relatedness via both codominant (Ritland 1996b, Lynch and Ritland 1998) and dominant (Lynch and Milligan 1994) marker-based methods in order to be able to assess the dependence on population size of quantitative genetic parameters.

Synthesis of fitness data, environmental conditions, and genetic architecture. The specific aims are to combine morphological and life history with environmental and genetic relatedness data in order to ascertain quantitative inheritance according to the mathematical and statistical procedures outlined by Ritland (1996a, 1996c). Ritland's (1996a) general model is a regression-based estimator of heritability, inbreeding depression, and environmental effects based on data regarding phenotypic similarities, genetic relatedness, and environmental comparability between pairs of individuals within a population (Equation 1). Genetic determinants of phenotypic similarity (Z_i) for the i[th] pair of individuals in a given population are additive effects of genes ($2r_i h^2$), dominant effects of genes [$2r_{2i}(H - h^2)$], and inbreeding ($f_{2i}b_f^2$). Environmental determinants of phenotypic similarity (Z_i) for the i[th] pair of individuals in a given population decline with increasing distance ($a_e - d_i b_d$) and correlate with degree of canopy cover ($c_i b_c$). The complete model then, with an error term (e_i) and with our additional canopy cover term discussed below, is a multiple regression of the causal elements of phenotypic variation:

(Equation 1)

$$Z_i = a_e - d_i b_d + c_i b_c + 2r_i h^2 + 2r_{2i} (H - h^2) + f_{2i} b^2_f + e_i$$

Phenotypic and life history traits. Phenotypic similarity between members of the i[th] pair (Z_i) will be based on individual phenotypes obtained for each (Z_{i1} and Z_{i2}):

(Equation 2)

$$Z_i = \frac{(Z_{i1} - Z)(Z_{i2} - Z)}{V}$$

where Z and V represent the population mean and variance, respectively, of a particular trait.

Environmental conditions. Pairwise distances and fraction of open sky determine environmental similarity. Similarity in open sky viewed by each plant will be calculated in an analogous manner:

(Equation 3)

$$c_i = \frac{(C_{i1} - C)(C_{i2} - C)}{V}$$

where C_{i1} and C_{i2} and are the percent sky view for a given pair of individuals and C and V represent the population mean and variance, respectively, of percent sky view.

Genetic estimates of relatedness. Molecular genetic techniques provide commensurate resolution to estimate the distribution and variation of relatedness within populations. These quantitative measures of relationships among pairs of individuals will be subdivided into components (refer to Equation 1) reflecting one (r_i) and two (r_{2i}) shared alleles across all loci and shared levels of inbreeding (f_2) between both members of the i^{th} pair.

Our foremost objective is to ascertain quantitative inheritance for the aforementioned fitness traits potentially affecting *Aquilegia* population persistence. The compiled data can be applied to the multiple regression analysis (Equation 1) to associate life-history and morphological traits affecting fitness with the effects of genetic influences, namely the degree of inbreeding depression (b_f^2) and the magnitude of narrow sense (h^2) and broad sense (H) heritability. Our second objective is to associate both types of environmental influences (b_d and b_c) on phenotypic traits. Our third and ultimate objective is to determine if the degree of heritable fitness is due to the effects of small population size. To achieve this goal, we must have a set of comparable estimates of inbreeding depression and heritability across populations of different sizes.

Quantifying population size. To empirically test the prediction that population size affects inbreeding depression and heritability, our motive was to sample from populations exhibiting a range of numbers of individuals. During 1997, data were collected from *Aquilegia* populations varying in the number of individuals (Table 1). Population size estimates entailed counting the number of adult plants and estimating numbers of seedlings and juveniles. Sample sizes range from 20 to 160 individuals, depending upon the population, totaling 419 individuals for all seven populations. The spread of sizes among the seven sampled populations are within the theoretical framework that has clearly established the expected relationship between population size and population

Aquilegia population	Estimated population size
Caballero Canyon, Sacramento Mountains, New Mexico	75
Pine Canyon, Chisos Mountains., Texas	100
Cattail Falls, Chisos Mountains., Texas	200
Dripping Springs, Organ Mountains, New Mexico	235
McKittrick Canyon, Guadalupe Mountains, New Mexico	375
Maple Canyon, Chisos Mountains., Texas	500
Ash Springs, San Andres Mountains, New Mexico	3,000

Table 1. Sampled populations and estimates of population size.

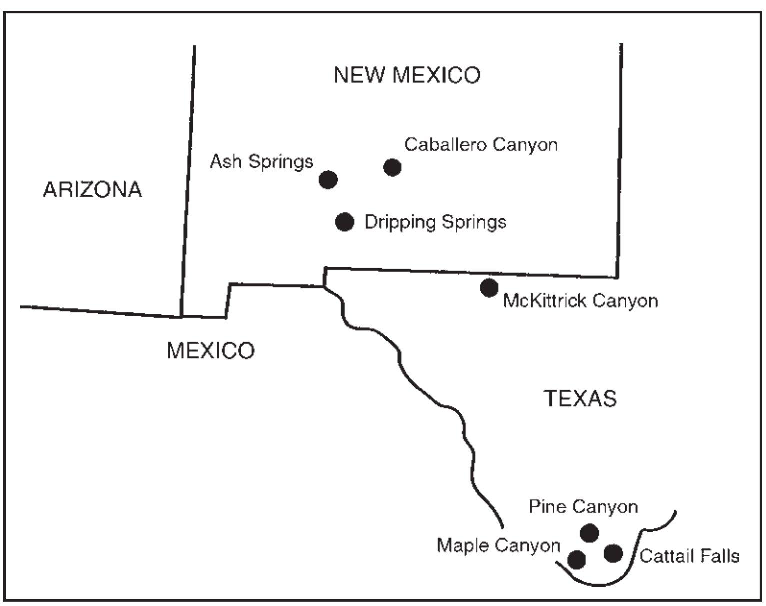

Figure 1. Locations of the seven sampled populations.

performance (Lande 1994, Lande 1995, Lynch et al. 1995). Furthermore, because we are confident of the accuracy in our enumerations of adult, reproductive plants, our knowledge of these counts coupled with data from previous, yet ongoing demographic studies on *Aquilegia* populations (Strand, 1997) translate into a wide range in effective population size (Nunney and Elam 1994, Nunney 1995). Therefore, we hold the potential to assess not only the association of population size with inbreeding depression and heritability estimates, but the association of effective population size with these estimates.

Relationship of quantitative inheritance to population size. Our ultimate goal is the appraisal of whether relatively small populations are characterized by immediate reduction in performance (increased inbreeding depression) and/or a lack of ability to respond to selection (decreased heritability). Because we have selected isolated populations of disparate numbers of individuals, the appropriate statistical analysis is a linear regression of the degrees of inbreeding depression and heritability on population size (Sokal and Rohlf, 1981). These relationships will allow us to determine if quantitative genetic parameters are determined by the number of individuals within populations, as is assumed by many conservation biologists.

Significance to conservation biology. The scientific foundation of conservation genetics has been swayed with evidence of patterns of genetic variability in natural populations and has been influenced by the distribution of neutral, molecular markers to distinguish intraspecific units for preservation. The assumption that genetic variability and diversity as measured at neutral markers shapes the evolutionary fate of taxa remains to be verified (Lynch 1996). Moreover, to understand genetic variation in regard to adaptive differentiation, evolutionary potential, and resistance to selection and threat of extinction, we must concentrate our conservation efforts on understanding the genetic basis of adaptive phenotypes (Hard 1995, Waples 1995). Furthermore, the doctrine of conservation biology builds on certain expectations with respect to relationships—smaller populations associated with an increase in inbreeding depression and a decrease in heritability relative to larger populations—yet the empirical basis of this is not strongly established. Our conservation-oriented study addresses and empirically tests these focal themes of conservation biology and conservation genetics.

The importance of this project ranges from utilization of genetic analyses to provide a powerful tool to clarify the genetic distribution of relatedness within a population, to innovative methods of decomposing phenotypic similarity into classical environmental and genetic components of quantitative genetics. In essence, this study possesses a three-fold significance. First, estimates will be obtained under the environmental conditions encountered by natural populations for a variety of life-history and morphological traits. Second, this nonmanipulative methodology is widely applicable to a variety of taxa. Third, and of utmost significance, this study provides model circumstances in which to investigate whether or not the central tenet of conservation biology—the association of small population size with increased inbreeding depression or decreased heritability—does in fact have an empirical basis in natural plant populations. This knowledge will contribute to our comprehension of the degree to which morphological, fitness, and life-history traits of adaptive importance are heritable and this will, in turn, aid our understanding and implementation of effective conservation strategies.

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Chapter 16

Integrating Genetic Information Into Natural Resource Stewardship

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As stewards of our biological resources, we focus attention on what controls the distribution and abundance of species throughout the landscape. One of the approaches to understanding distribution and abundance is through our long-term monitoring efforts. Typical monitoring for this purpose involves identifying where populations are located and how large they are. Long-term monitoring, by repeatedly obtaining that information, provides a time dimension as well. Such an approach has served us well as a means of inventorying our biological resources. However, this approach is also passive and largely documents changes in abundance or distribution as they unfold through time. Stewardship based on it necessarily remains reactive.

Clearly, the goal for informed natural resource stewardship is that it should involve a proactive strategy, that is, one based on being able to predict future responses to current or anticipated conditions. Rather than merely documenting changes in abundance or distribution, we need to anticipate them and adjust our management plans accordingly in advance. Thus, we must understand the processes involved rather than merely document the patterns.

In the case of anticipating the abundance or distribution of biological resources across the landscape, the processes of prime importance are demographic: growth, survival, reproduction, dispersal, and recolonization. Strategic stewardship must be based on clear understandings and quantification of these processes so that their action can be projected to inform future decisions.

The greatest difficulty faced when trying to understand demography is that often several wildly different processes, with wildly different management implications, can produce similar patterns of abundance or distribution. As a result, monitoring alone cannot distinguish among the possibilities, and therefore, cannot inform management decisions. One of the main points of this paper is to illustrate one case study that integrates genetic and demographic information in a way that successfully distinguishes between competing possible demographic processes. In the process the study illustrates an important role for genetic information in guiding biological resource stewardship.

Aquilegia biology

While focusing attention on the broad importance of proactive stewardship based on explicitly differentiating among competing hypotheses of the demographic processes, which directly influence species distribution and abundance, this paper develops a specific case history involving *Aquilegia* (Ranunculaceae) species in the southwestern United States and adjacent Mexico. *Aquilegia* is an excellent model illustrating many of the important features characteristic of the most endangered resources in this region. For example, the geographic distribution of these plants typifies that of many other plants and animals dispersed throughout the region. These plants require mesic habitats in an otherwise arid landscape and are therefore only found scattered among Springs Canyon, Box Canyon, Dripping Cliffs, and other isolated locations. Furthermore, each local population is generally quite small; typical population sizes range from 20 to 1,000. This is well within the range of sizes subject to genetic problems (Lande 1994a, Lande 1995a, Lynch 1995a, Lynch 1995b) and is not large enough to be immune from stochastic extinction.

Thus, *Aquilegia* populations provide a useful model for understanding how one might obtain information about the demographic properties of biological resources. Our approach to obtaining that information illustrates the need to differentiate between possible biological scenarios with very different demographies. As such it provides insight into how one might proceed in other situations requiring a proactive stewardship strategy based on clear understanding of the underlying demographic processes that determine abundance and distribution of species.

Alternative biological scenarios

From the point of view of understanding, and ideally managing, biological resources distributed among habitat islands, it is important to distinguish between two fundamentally different biological processes responsible for that distribution. First, the populations may be linked by ongoing gene flow and even by periodic recolonization should a local population go extinct. In such a situation, careful management of each individual population may not be required in the long run, because natural recolonization will maintain a set of populations distributed across the landscape. In contrast, the populations may be completely isolated currently, existing only as isolated relicts of a past, more widespread, distribution. In this situation, individual populations may very much warrant specific attention because of the absence of natural recolonization. Indeed, perhaps the most likely outcome in such a case is eventual extinction as each individual population is lost one by one.

The importance of distinguishing between these two situations lies in the implications concerning how one might wish to manage the populations. Unfortunately, information on current location and abundance—the data obtained from typical inventorying activity—cannot distinguish between these two situations. They differ in the processes that have given rise to the current distribution, not in the pattern directly observable by monitoring. Together genetic and demographic data are able to distinguish between the alternatives, though neither alone is sufficient.

The island model. The first scenario—populations interacting in an ongoing manner—has been studied extensively (Wright 1943, Wright 1951, Hartl 1989) since Wright (1931) first formally described it. The fundamental outcome of these studies is that in this situation individual populations achieve equilibrium between loss of genetic variation due to random drift and gain of genetic variation due to introduction from other populations via migration. If the entire suite of populations is considered, equilibrium is between differentiation among populations due to drift in isolation, and homogenization of the populations due to ongoing gene flow or colonization.

Common means of quantifying the degree of differentiation among populations is Wright's F_{st} (Hartl 1989a) which increases with degree of differentiation and $N_e m$, a measure of effective migration, which decreases with degree of differentiation. With ongoing gene flow or colonization, however, either of these quantities reaches equilibrium and thereafter assumes constant values. The specific equilibrium value (whether $N_e m$ is 0.1 or 0.9, for example) depends on the demography of the populations and the rate of interaction via migration or colonization.

The historical subdivision model. The contrasting scenario—isolated, relictual populations exhibiting no current gene flow or colonization—has also been studied (Slatkin 1995a). In this situation the fundamental outcome is individual populations are initially very similar to

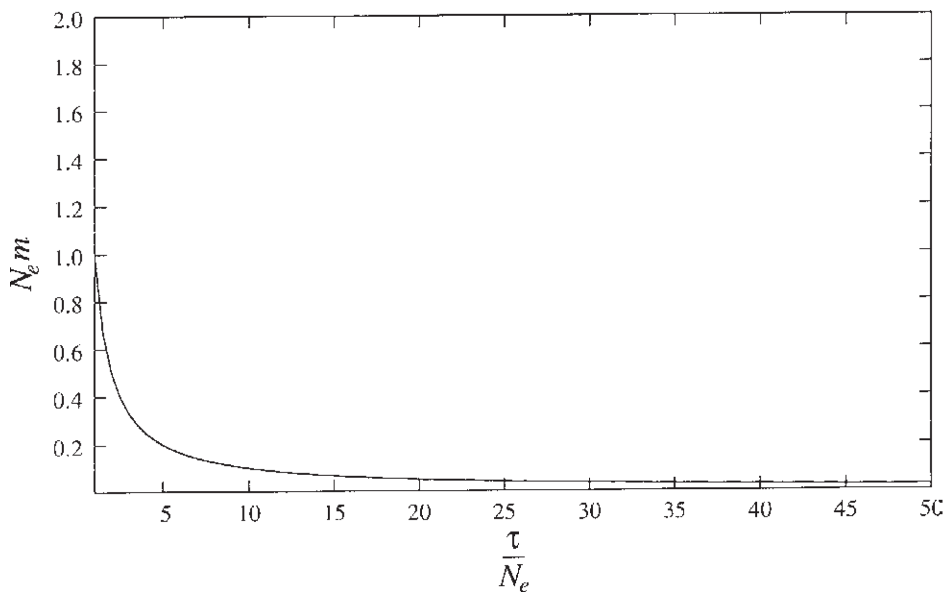

Figure 1. Decay of genetic similarity as a function of time in a set of isolated populations. Time is measured as the number of generations (τ) divided by the effective size of the populations (N_e).

each other immediately following their isolation, yet as time progresses they become increasingly differentiated due to random drift. Eventually all traces of similarity are lost.

The same two quantities—F_{st} which increases and N_e m which decreases—can be used to describe the changing composition of the populations through time. The rate of change depends on the demography of the populations, specifically on the effective population size N_e and on the generation time (Figure 1).

Insufficiency of genetics. Clearly these two biological scenarios make very different predictions about the degree of similarity observable in a set of apparently isolated populations: in one case measures of similarity will remain constant, while in the other they will decay. The difference, however, is entirely in the temporal dynamics, not in the observations available at any single instant in time. Thus, an observation of $N_e m = 0.1$ could be obtained under either scenario, just as could the observation of populations scattered among habitat islands throughout the landscape. Observations of genetic similarity, from which the quantities F_{st} or N_e m are estimated (Nei 1987a), are insufficient alone to distinguish between the two scenarios, just as observations obtained from monitoring are insufficient.

Demography and genetics

If either monitoring or genetic information is insufficient for understanding the processes responsible for a suite of populations limited to habitat islands, the combination of demography and genetics is not. As suggested by Figure 1, given information on the effective size of populations, their generation length, and the amount of time since isolation, one can predict the degree of isolation observed genetically. If the genetic observations do not match those predictions, one can reject the notion that populations are purely relictual. Thus, demographic information provides a crucial means, lacking in purely snapshot monitoring or genetic studies, of investigating the temporal dimension.

***Aquilegia* life cycle.** *Aquilegia* is a long-lived perennial plant. As a result, it exhibits a complex life cycle that must be studied over many years by marking individual plants and following their success. Life cycle diagrams and matrix projection models (Caswell 1989a) are the most appropriate means of organizing such demographic information.

Analysis of this life cycle (Orive 1993, Strand 1997) yields a mean effective size across six populations of 74.1 and a mean generation time of 3.5 years. For *Aquile-*

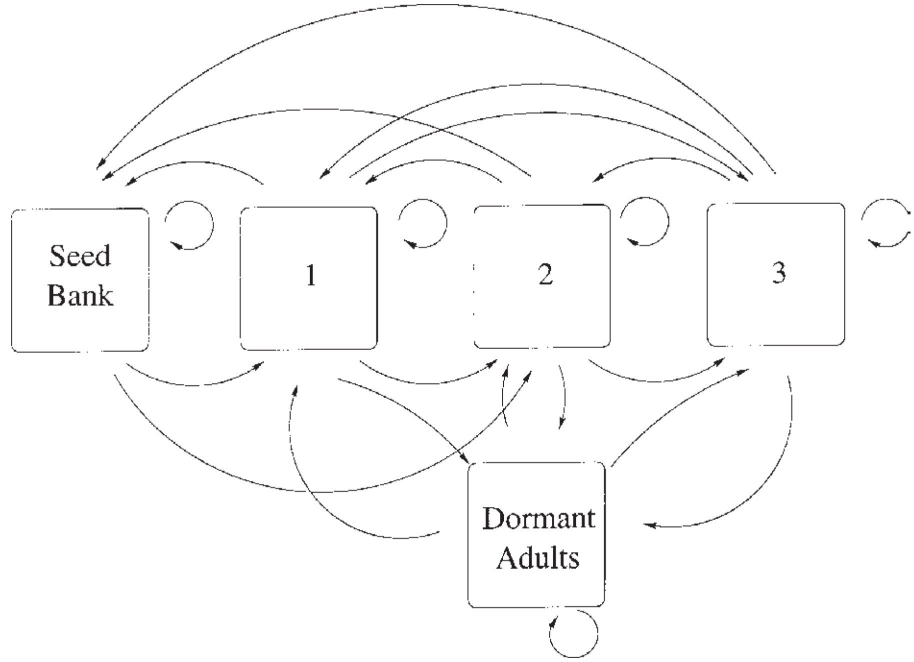

Figure 2. *Aquilegia* life cycle. Stages 1–3 represent progressively larger individuals as determined by the number of leaves produced during the growing season prior to fruiting. Arrows represent transitions, from one stage to another, which are possible during the period of a single year.

gia therefore, the abscissa of Figure 1 reflects values of t / (3.5 • 74.1), where t is the time in years since isolation.

Biogeographical isolation. Although it is highly unlikely that the landscape was ever a continuous expanse of *Aquilegia*, the climatic conditions during the Pleiostocene were much more favorable for *Aquilegia*, and populations were almost certainly more widespread, larger, and interconnected to a much greater degree than they are today. For example, fossil plant debris recovered from packrat middens indicates that a major shift in vegetation occurred between 8,000 and 12,000 years ago (Van Devender and Spaulding 1979, Van Devender 1987). In particular, vegetation typical of cool, high altitude sites dominated low elevation sites prior to that time; afterwards that vegetation was replaced by the dominant desert vegetation present today. The distribution of *Aquilegia* likely followed this same sequence.

Based on this biogeographical evidence, the decay of genetic similarity expected among extant populations of *Aquilegia* corresponds to that illustrated in Figure 1 for 30.9 = t/N_e = 46.2.

Relict *Aquilegia* populations. Genetic studies of one chloroplast DNA locus (Strand et al. 1996, Strand 1997) and three nuclear loci (Strand 1997) provide measures of genetic similarity of $N_e m$= 0.01–0.12 and $N_e m$ = 1.67–1.75, respectively. Together with the time information, this is plotted in Figure 3 as shaded regions indicating the possible ranges of each set of parameters. Evidently the chloroplast DNA data are in agreement with the notion that these are relict populations resulting from long-term isolation, whereas the nuclear DNA data are not.

The differences between the chloroplast and nuclear DNA data reflect the basic differences between dispersal of seeds and pollen. Chloroplast DNA is maternally inherited in *Aquilegia* (Corriveau 1988) and therefore is dispersed only with seeds. The high degree of isolation indicated by the chloroplast DNA reflects the fact that *Aquilegia* populations are not interacting via seed dispersal. Consequently, there is little or no chance of an extinct *Aquilegia* population being recolonized by seed dispersal.

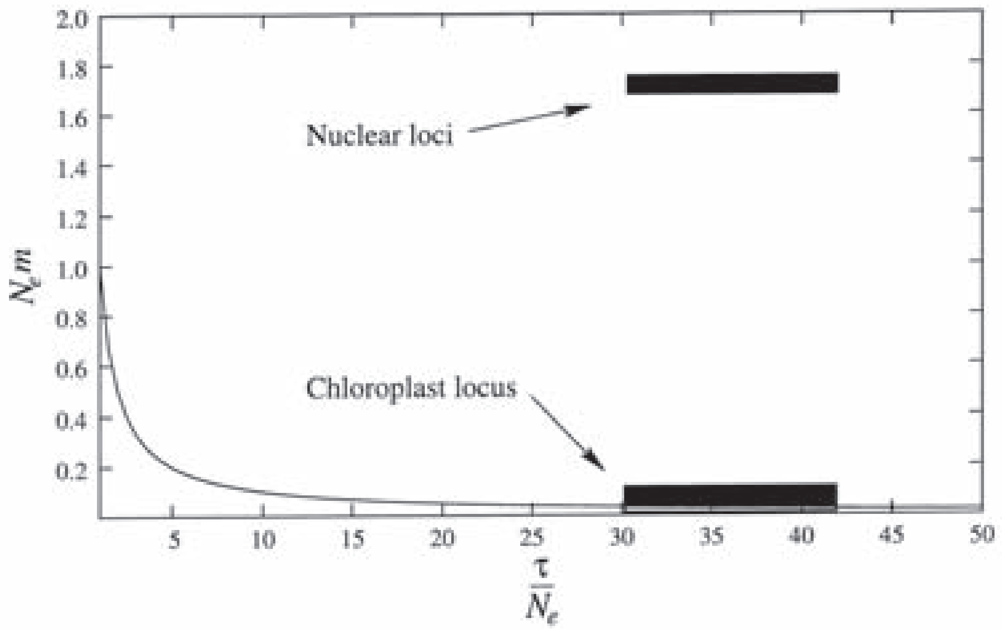

Figure 3. Genetic similarity: chloroplast and nuclear data.

In contrast, nuclear DNA is dispersed by both seeds and pollen. Consequently, the low degree of isolation apparent in the nuclear DNA data reflects the fact that pollen, which is carried by strong flyers such as hummingbirds and hawk moths, is dispersed over much greater distances, at least on the long-term time scales reflected in the genetic data.

Persistence of *Aquilegia* populations

If *Aquilegia* populations in the southwestern United States and adjacent Mexico are isolated relicts—the remainder of more widespread and numerous populations that existed during the Pleistocene—then the current distribution must be a result only of periodic extinction of past populations; once extinct they cannot be recolonized in the absence of seed dispersal. Long-term persistence of *Aquilegia*, therefore, depends entirely on the demographic properties of individual populations and their likelihood of extinction.

Like many riparian plants in southwestern deserts, the performance of *Aquilegia* depends largely on incident rainfall. Figure 4 illustrates the seasonal rainfall patterns adjacent to our demography plots in the Organ Mountains of southern New Mexico. The spring growing season is characterized by highly variable rainfall. Corresponding to that variation in rainfall is also variation in the intrinsic rate of population growth, determined from the projection matrices derived from our demography data (Strand 1997). The relationship between spring precipitation and growth rate based on data for the 1995–1996 and 1996–1997 transitions is ? = 0.0554 x precipitation + 0.3164. This can be used to extrapolate the 12-year precipitation record available for Dripping Springs into a distribution of population growth rate (Figure 5).

This distribution of population growth rates for *Aquilegia* indicates several important points. First, it should be expected that individual populations will do very poorly in some years; ? = 0.33 means that a typical population will decline to one-third its size over a single year and go extinct after only a few years and do very well in others; ? = 1.5 means that a typical population will expand to

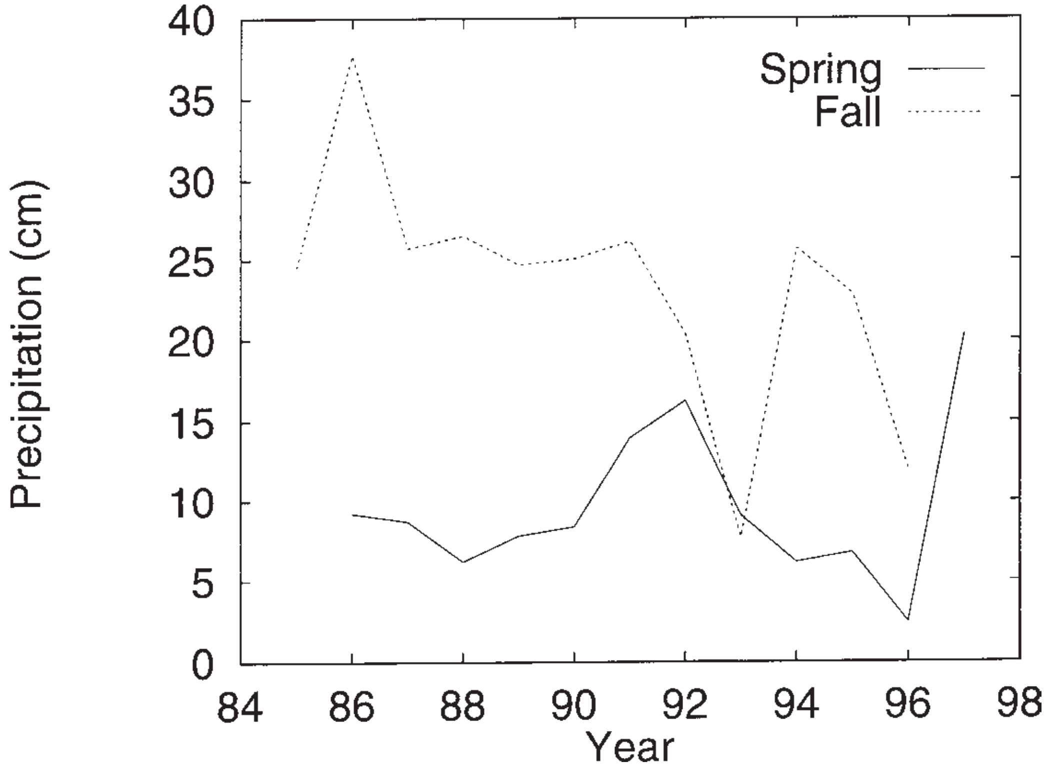

Figure 4. Dripping Springs precipitation record. The spring season represents the period December 16–June 15, while the fall season represents the period June 16–December 15.

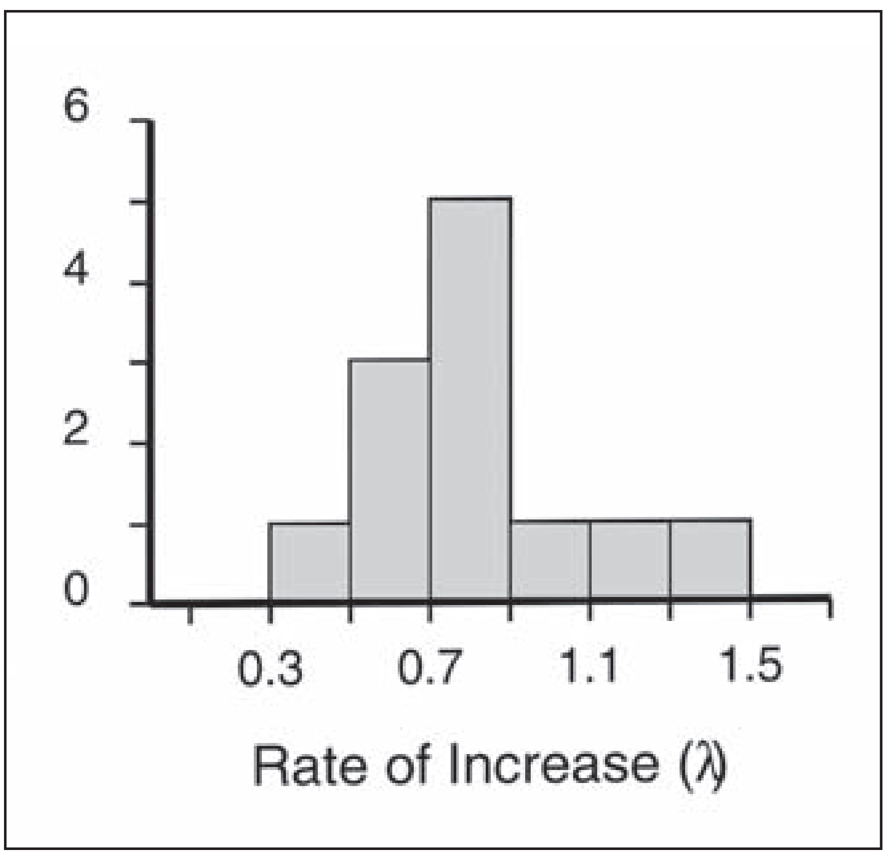

Figure 5: Distribution intrinsic rate of increase. Each value of λ is predicted from the quantity of spring precipitation at Dripping Springs and the relationship between λ and precipitation.

1.5 times its size in a single year. Dramatic fluctuations in performance are to be expected. Conclusions from short-term monitoring may, therefore, be misleading.

More importantly for the issue of long-term persistence, however, is the fact that the mean of the distribution depicted in Figure 5 is 0.8483 (st. dev. = 0.2727). This mean is the long-term growth rate of the population, averaging over annual fluctuations in precipitation, and hence demographic performance. The fact that the mean is less than one indicates that in the long term at least this *Aquilegia* population is likely to decline.

Interplay of genetics and demography
This study clearly illustrates the value of integrating genetic and demographic information to obtain a unified understanding of the processes responsible for the distribution and abundance of *Aquilegia* in the southwestern United States and adjacent Mexico. Basic survey and monitoring activities made it clear that *Aquilegia* existed in small populations scattered about mesic habitat islands in the otherwise arid landscape. However, it provided little more than a snapshot of the current distributional pattern, one of little use for understanding the long-term processes that must inform management decisions. Likewise, genetic data alone could only quantify the apparent degree of similarity among populations, not differentiate between the two major scenarios potentially responsible for the current distribution. Additional demographic and historical information, however, yielded a clear understanding—unattainable from genetic or demographic data alone—of the important ecological processes responsible for shaping the distributional patterns.

As a result of this interplay of genetics and demography, a clearer picture of *Aquilegia* population biology is now available. Clearly populations are restricted to suitable and isolated habitat islands: mesic locations such as springs, box canyons, and dripping cliffs. It is likely, however, that the isolation of these habitat islands translates directly into isolation of populations from the point of view of seed dispersal and recolonization. It is unlikely that should a population go extinct it will be naturally recolonized from another one. Depending on the long-term distribution of precipitation during the growing season, and hence on the long-term population growth rate, it is also likely that individual populations will go extinct. Thus, we may be witnessing the slow elimination of *Aquilegia* from this region.

In contrast, the isolation of the habitat islands does not translate into isolation from an evolutionary point of view. Pollen, and hence nuclear genes, is apparently dispersed among populations. This will tend to reduce genetic problems (e.g., inbreeding depression and loss of heritability) that might be present in these *Aquilegia* populations and in turn reduce the possibility that genetic erosion exacerbates the demographic causes of extinction. Additionally, interaction via pollen dispersal will tend to reduce the possibility of morphological differentiation due to genetic drift. Thus, while pollen dispersal may not enable *Aquilegia* populations to persist in the landscape in the face of periodic local extinction, it can have significant effects on other aspects of the biology of these plants.

Conclusion

While a great deal of attention has been given to this study of *Aquilegia* populations in the southwestern United States and adjacent Mexico, the main point is much broader. Indeed, this study serves primarily to illustrate how we might obtain some critical information needed to act as informed stewards of biological resources. As stewards we can either adopt a reactive response or a proactive strategy. If we focus our attention solely on inventorying and monitoring, that is characterizing the pattern of species distributions as it unfolds over time, of necessity we must be reactive because we lack the understanding of the underlying processes responsible for creating the unfolding patterns. Unless we understand the processes, we cannot predict what the patterns will be in the future, and therefore, cannot adopt a proactive management strategy.

Processes are notoriously difficult to understand, however, because often several (or many) can lead to the same observable pattern. Such was the case with *Aquilegia*. Two extremely different processes with different management implications—one involving the possibility of recolonization of extinct populations and one lacking that possibility—could lead to the same biogeographical pattern and even to the same pattern of genetic similarity. Only the careful quantification of the outcomes of these processes and the deliberate interplay of genetic and demographic information was able to differentiate between these two contrasting biological scenarios. Now, however, we have arrived at a better understanding of the underlying processes and are in a position to make long-term predictions; we are able to adopt a proactive and strategic approach.

Rather than viewing this as a study specifically about the biology of *Aquilegia* in southwestern deserts, regard it as a case study of how one might carefully differentiate among alternative biological scenarios, each with different management implications. Regard it as an illustration of how our understanding can progress from describing the ecological patterns of distribution and abundance to predictive understanding of the processes responsible for those patterns. Regard it as a means of enabling a strategic approach to biological resource stewardship. It is my hope that future studies will follow this lead and directly assess alternative biological processes so that management can be fully informed and as predictive as possible.

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Chapter 17

Mountain Lion Ecology and Population Trends in the Trans-Pecos Region of Texas

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Mountain lions occur in low densities throughout their distribution in the western United States. Small scale radio-telemetry studies provide valuable information on ecology of mountain lions including home ranges, food habits, and densities. Logan and others (1996) studied the dynamics of a population of mountain lions in the Chihuahuan Desert of southern New Mexico, and Harveson and others (1997) provided a review of their ecology in the Trans-Pecos region of west Texas. However, most ecological studies of mountain lions have not provided information on population changes through time.

Previous studies have investigated the use of track counts to index population trends of mountain lions. There is a positive correlation between densities of mountain lions and the number of tracks observed on roads (Van Dyke et al. 1986). Using probability sampling from a helicopter, Van Sickle and Lindzey (1991) estimated densities as a function of number of tracks observed in snow. Smallwood (1994) reported results of a statewide survey of mountain lions in California using track counts. Most recently, Beier and Cunningham (1996) used computer simulations to estimate the statistical power of track counts used by Cunningham and others (1995). Despite the various applications of track counts to index populations of mountain lions, there are no data sets that continuously span more than four years. Beier and Cunningham (1996) reviewed the shortcomings of other methods used to assess changes in densities of mountain lions, such as sightings, depredation rates, and surveys on hunters. Most track surveys rely on implicit assumptions regarding the ability to detect tracks of mountain lions and the quality of the substrate. These assumptions are rarely met consistently throughout a survey route. Scat, scrapes, and kills, as well as tracks, however, are indicators of the presence of mountain lion. The purpose of this paper is to provide data on long-term population trends of mountain lions as indexed by surveys for more than one type of sign.

Material and methods

Data were collected from two national parks within the Chihuahuan Desert ecosystem. Carlsbad Caverns National Park and Guadalupe Mountains National Park were established by in 1930 and 1972 respectively. Carlsbad Caverns National Park is located within Eddy County, southern New Mexico, and encompasses 189 square kilometers. Guadalupe Mountains National Park is located in Culberson and Hudspeth counties of west Texas and is 310 square kilometers. Carlsbad Caverns National Park contains desert shrub and mountain shrub vegetation types (Glass et al. 1974). Typical vegetation on Carlsbad Caverns National Park includes lechuguilla (*Agave lechuguilla*), scrub juniper (*Juniperus pinchotti*), and mountain mahogany (*Cercocarpus breviflorus*). Vegetation types on Guadalupe Mountains National Park are

Carlsbad Caverns National Park		Guadalupe Mountains National Park	
Watershed (km increments)	**Length (km)**	**Watershed (km increments)**	**Length (km)**
East Walnut	13	Upper Dog	13
West Walnut	13	Manzanita	11
North Rattlesnake	10	Southwest McKittrick	11
South Rattlesnake	9	Southeast McKittrick	12
East Slaughter	10	Mid McKittrick	14
West Slaughter	10	El Capitan	13
South Slaughter	11		
Total	76	**Total**	74

Table 1. Multiple-sign mountain lion transects surveyed for Carlsbad Caverns National Park and Guadalupe Mountains National Park, fall 1987 to spring 1996.

similar to Carlsbad Caverns National Park but include creosotebush (*Larrea tridentata*) and conifer communities (Glass et al. 1974), and oaks (*Quercus* spp.) and pines (*Pinus* spp.) occur at higher elevations. Average annual precipitation (1986–1995) for Carlsbad Caverns National Park and Guadalupe Mountains National Park is 41.0 centimeters and 45.3 centimeters, respectively (NOAA 1986–1995).

The National Park Service initiated a program monitoring populations of mountain lions (Smith et al. 1988) in fall 1987 at the conclusion of an ecological study of the felids (Smith et al. 1986). On Carlsbad Caverns National Park, 76 kilometers of permanent curvilinear transects were established within park boundaries. Average (± SD) transect length for Carlsbad Caverns National Park was 10.9 (± 1.57) kilometers (Table 1). An additional 74 kilometers of transects were established within Guadalupe Mountains. Average (± SD) transect length for Guadalupe Mountains National Park was 12.3 (± 1.21) kilometers. Transects were distributed along canyons, ridges, and park trails throughout seven watersheds within Carlsbad Caverns National Park and six watersheds in Guadalupe Mountains National Park. Telemetry data (Smith et al. 1986) and other information on mountain lion patterns were used to establish permanent transects (Smith et al. 1988).

Transects were walked each spring (April to May) and fall (October to November) from fall 1987 to spring 1996. Using compass and maps, two to five observers traveled between 8 to 15 kilometers/day along transects. Observers, trained in the identification of sign of mountain lions, recorded the location (km increment), type, and identifying characteristics of sign. Sign was defined as tracks, scat, scrapes, or kills of mountain lions.

Tracks were recorded as mountain lion only if they had characteristic features such as three-lobed heel pads, rounded toes, and width of the heel pad greater than 42 millimeters (Belden 1978, Fjelline and Mansfield 1989). A set of tracks was defined as continuous if the tracks were in the same direction and of similar size (Smallwood 1994) and were only counted once. Scat of mountain lion was distinguished from other carnivores by diameter and shape. Only scat that was segmented, contained mammal hair, and was greater than 29 millimeters in width was recorded (Johnson et al. 1984). Mountain lion frequently scrape to mark their territory (Seidensticker et al. 1973). Only scrapes greater than 15-millimeters wide (Seidensticker et al. 1973) were distinguished as mountain lion. Canine punctures, feeding pattern, and the presence of mountain lion tracks, scrapes, and scat were used to assess whether mountain lion were involved at carcasses along the transects.

Because of inherent problems with independence of sign of mountain lion, we weighted each type equally and reduced the data to a presence-absence format for each kilometer along the transect (Beier and Cunningham 1996). For example, a kilometer segment of transect containing a kill site that contained mountain lion tracks, scat, and scrapes would be assigned a value of one. Data from Carlsbad Caverns National Park and Guadalupe Mountains National Park were analyzed separately. We expressed the amount of sign found (season-year) as the mean number of kilometers within a watershed with sign of mountain lion. We used Chi-square to test for independence of the amount of sign detected and the number of observers.

Data were analyzed for each park by splitting the data in half (location of the missing data). Carlsbad Caverns National Park was separated into fall 1987 to fall 1991 (n = 9) and from spring 1992 to spring 1996 (n = 9). Data were not collected on Guadalupe Mountains National Park for fall 1992, thus data were separated from fall 1987 to fall 1991 (n = 9) and from spring 1992 to spring 1996 (n = 8). We used simple linear regression (Ott 1993) on halves of data from Carlsbad Caverns National Park and Guadalupe Mountains National Park to test for linear trends in sign. We applied Kendall's tau (T) and Spearman's rho test for trends (Conover 1980) to each half of the data for each area.

Results

On Carlsbad Caverns National Park, a cumulative total of 1,368 kilometers of transects were walked by observers from fall 1987 to spring 1996. A total of 115 mountain lion scats, 40 sets of mountain lion tracks, 29 mountain lion scrapes, and 6 mountain lion kills was identified along the transects. The mean (± SD) number of kilometers/watershed with sign for Carlsbad Caverns National Park from fall 1987 to spring 1996 was 1.50 (± 0.53) and was highest in spring 1994 (2.29) and lowest in fall 1991 (0.43). Data were not recorded for all watersheds in Guadalupe Mountains National Park. On Guadalupe Mountains National Park, 1,103 kilometers of transects were walked during the nine-year period. Fifty-three mountain lion scats, 43 mountain lion scrapes, 4 sets of mountain lion tracks, and 3 mountain lion kill were recorded along transects on Guadalupe Mountains National Park. The mean (± SD) number of kilometers/watershed with sign for Guadalupe Mountains National Park from fall 1987 to spring 1996 was 1.10 (± 0.95) and

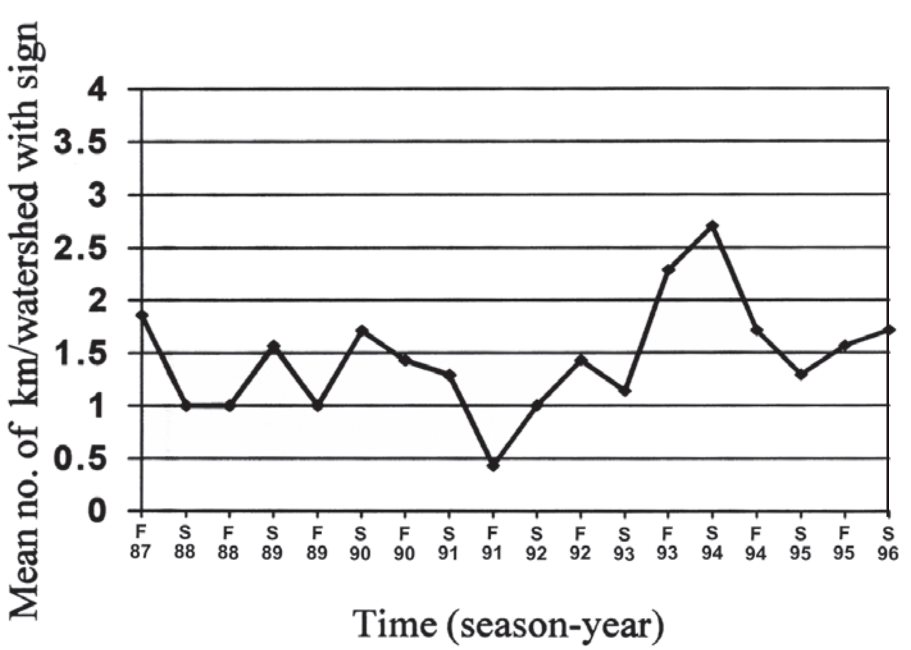

Figure 1. Changes in mean number of kilometers/watershed with mountain lion sign on Carlsbad Caverns National Park from fall 1987 to spring 1996.

ranged from 0.17 (fall 1989, fall 1993) to 3.80 (fall 1987). The type of sign located for the two parks was different (X^2 = 177.65, 3 d.f., $P < 0.001$). For both parks, the amount of sign recorded was independent of the number of observers (X^2 = 0.13, 1 d.f., $P = 0.716$).

No linear trends were detected (Figure 1) for either the first ($F = 1.30$; d.f. = 1, 7; $R^2 = 0.16$, $P = 0.29$) or second half ($F = 0.46$; d.f. = 1, 7; $R^2 = 0.06$, $P = 0.52$) of the data on Carlsbad Caverns National Park. No trend was detected for Carlsbad Caverns from fall 1987 to fall 1991 (Spearman's $R^2 = -0.32$, $P = 0.40$; $T = 156$, $P > 0.20$) or for Carlsbad Caverns National Park from spring 1992 to spring 1996 (Spearman's $R^2 = 0.43$, $P = 0.25$; $T = 68.5$, $P > 0.20$).

There was a negative trend (Figure 2) using both linear regression ($F = 4.38$; d.f. = 1, 7; $R^2 = 0.38$, $P = 0.07$) and nonparametric tests (Spearman's $R^2 = -0.62$, $P = 0.07$; $T = 176$, $P < 0.05$) for Guadalupe Mountains National Park from fall 1987 to fall 1991. Conversely, there was a positive linear trend using both linear regression ($F = 13.91$; d.f. = 1, 6; $R^2 = 0.70$, $P = 0.01$) and nonparametric tests (Spearman's $R^2 = 0.81$, $P = 0.01$; $T = 16$, $P < 0.05$) for Guadalupe Mountains National Park from spring 1992 to spring 1996.

Discussion

The difference in proportion of sign on the two areas was attributed to the dominant substrates. In Carlsbad Caverns National Park, the transects contain a greater amount of sandy areas on Carlsbad Caverns National Park and tracks of mountain lions were observed there more frequently. By contrast, transects on Guadalupe Mountains National Park are dominated by rocky trails. By definition, an index is a measure comparable only to itself (Davis and Winstead 1980) and therefore comparisons were not made between areas.

Our implicit assumption in this study is that the detection of sign is consistent from year to year. This assumption differs from previous studies (Smallwood 1994, Beier and Cunningham 1996) in that detection does not need to be consistent within the sampling periods (i.e., from transect to transect). The long-term nature of these data minimizes violations to the assumption of detection.

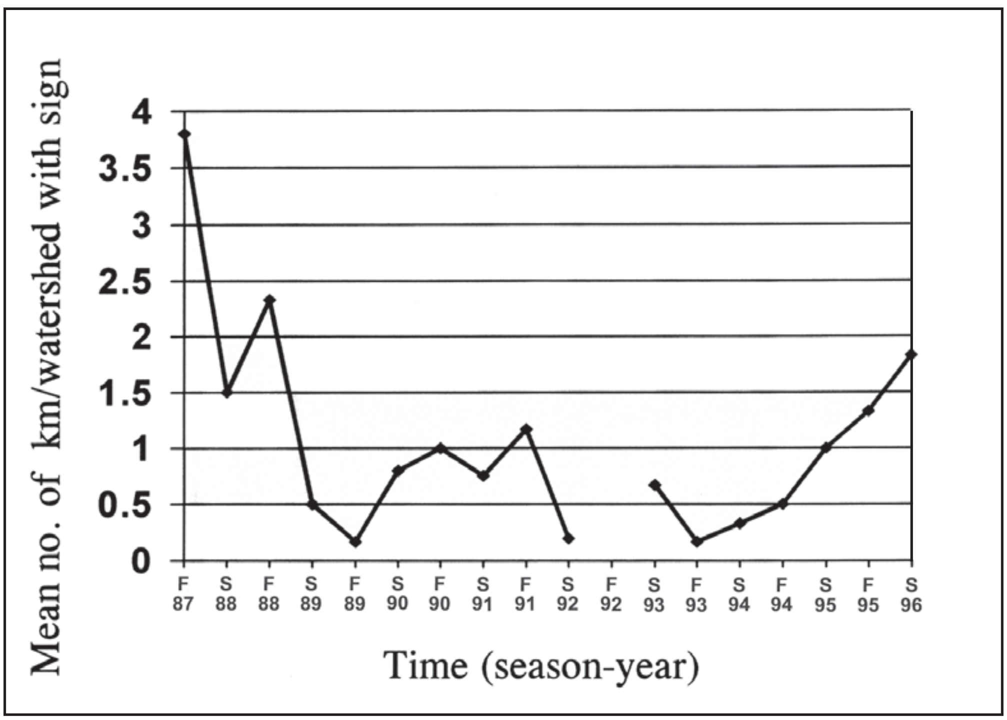

Figure 2. Changes in mean number of kilometers/watershed with mountain lion sign on Guadalupe Mountains National Park from fall 1987 to spring 1996.

The applicability and cost-effectiveness of surveys of multiple signs is greater than surveys of single signs (i.e., tracks). Van Dyke and others (1986) reported an average distance of 80 kilometers between sets of tracks in their evaluation of a roadside count. Van Sickle and Lindzey (1991) required adequate snowfall and a helicopter to monitor populations of mountain lions using track counts in snow. Neither method is realistic for monitoring mountain lion populations in the Southwest. Furthermore, with the incorporation of scat, scrapes, and kills in multiple-sign counts and the reduction of these data to a presence-absence format, the variation between novice observers and experienced trackers is reduced. In addition, the conservative criteria used in this study (Smith et al. 1988) decreases the subjectivity associated with identifying sign of mountain lions.

The decline in numbers on Guadalupe Mountains National Park may be attributed to either precipitation related variables (e.g., declining prey numbers), habitat loss, high mountain lion mortalities, or a combination of factors. Smallwood (1994) attributed changes in mountain lion numbers in California to habitat degradation. Because our study was conducted in national parks, habitats remained unchanged. The primary mountain lion prey on Carlsbad Caverns National Park and Guadalupe Mountains National Park include deer (*Odocoileus* spp.) and collared peccary (*Tayassu tajacu*) (Smith et al. 1986). However, deer and collared peccary populations have remained unchanged during this period (unpublished data). Average annual precipitation during this study varied from 66% to 189% and is considered normal compared to long-term patterns.

A reduction in numbers of mountain lions may have affected our results. Mortalities in the area surrounding Guadalupe Mountains National Park and Carlsbad Caverns National Park are high. From 1982 to 1984, six of eight and four of seven radio-collared mountain lions died as a result of predator control (Smith et al. 1986) on or near Guadalupe Mountains National Park and Carlsbad Caverns National Park, respectively. The Guadalupe Mountains National Park is

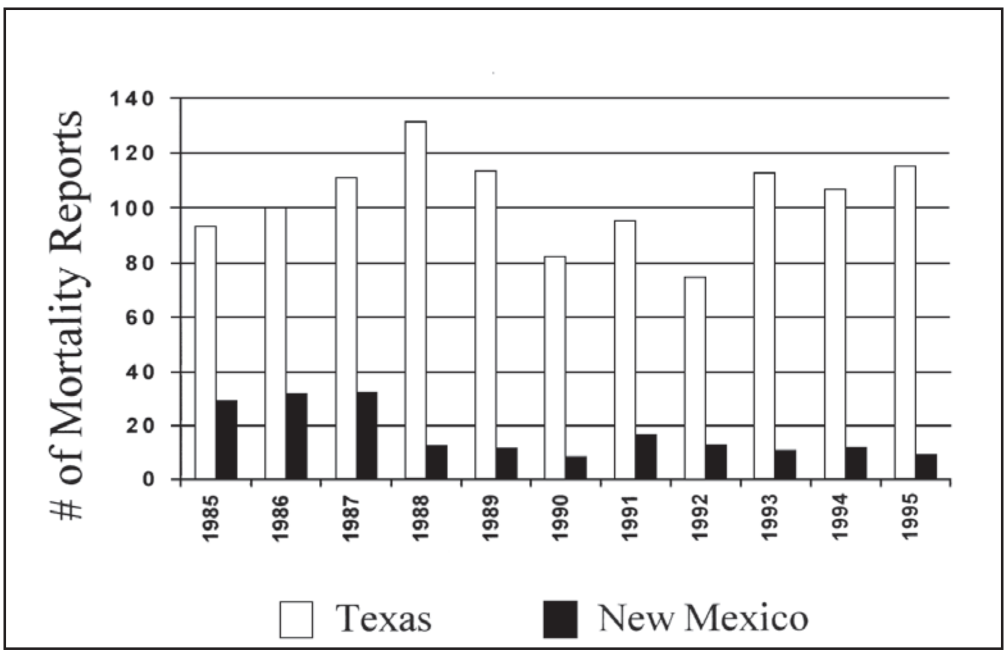

Figure 3. Number of reported mountain lion mortalities in the Trans-Pecos region (7.3 million hectares) of Texas (Russ 1996) and Unit 30 (0.61 million hectares) of southeastern New Mexico, 1985–1995 (Game and Fish Commission, unpublished data).

primarily surrounded by private Texas ranches where the harvest of mountain lions is unrestricted. Russ (1996) reported that the number of annual mortalities from the Trans-Pecos region were consistent and ranged from 70 to 130 individuals from 1986 to 1995 (Figure 3). Although area-specific data are not available, a peak in mountain lion mortalities occurred between 1986 and 1989, which corresponds to a decline in mountain lions we observed during the same period.

Carlsbad Caverns National Park is bordered primarily by private ranches and Lincoln National Forest. Depredation permits are occasionally granted by the New Mexico Department of Game and Fish Commission for the areas surrounding Carlsbad Caverns National Park (see Figure 3). The unregulated harvest of mountain lions in the Trans-Pecos region of Texas and the depredation efforts in southeastern New Mexico appears to have negatively affected their numbers in Carlsbad Caverns National Park and Guadalupe Mountains National Park. Research efforts should focus on validating the indices of mountain lions reported herein with known densities (i.e., radio-telemetry).

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Chapter 18

The Reproductive Biology of McKittrick Pennyroyal, *Hedeoma apiculatum* (Lamiaceae)

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Introduction

Flowering plants may reproduce by apomixis (i.e., vegetatively or by parthenogenesis), by sexual means, or by some combination of the two. For all species, genetic variation in progeny, and the attendant ability of some progeny to successfully respond to changed environmental circumstances, can only be engendered by sexual reproduction. Outcrossing in particular will promote genetically diverse progeny. Thus, the vast majority of angiosperms reproduces sexually either regularly or at some time during their lives and many have evolved self-incompatibility mechanisms to increase their chances of successful outcrossing (Nettancourt 1977).

In this report we will describe the breeding system of a rare mint, *Hedeoma apiculatum*, listed under the Endangered Species Act, which is restricted to the Guadalupe Mountains of Texas and New Mexico (U.S. Fish & Wildlife Service 1985, Anonymous 1988). Members of the mint family (Lamiaceae) are mostly cross-pollinated although some taxa commonly self-pollinate, either automatically or with the assistance of flower visitors (Huck 1992). Indeed, Irving (1980) has reported that some members of the genus *Hedeoma* are commonly self-pollinating. One might predict that sexual reproduction is likely to be especially important for rare plants such as *H. apiculatum* because phenomena such as genetic drift and inbreeding depression tend to genetically impoverish small, fragmented populations (Hamrick and Godt 1996). In particular, we might expect McKittrick pennyroyal to be self-incompatible and obligately outcrossed. However, an alternative hypothesis is also available. Many biologists reason that there is a positive relation between a plant's abundance and its attractiveness to pollinators and as a plant becomes rare it experiences increasing selection for self-compatibility and automatic self-pollination (Levin 1971, Jain 1976). We will examine these competing hypotheses for McKittrick pennyroyal.

Sexual reproduction begins with pollination—the movement of viable pollen grains from dehiscing anthers to a receptive stigma. Pollen may be moved to stigma(s) in the same flower, but more often it is moved to other flowers of the species, either on the same plant or on a different one. Such movement typically requires the cooperation of animals, usually insects, which visit the flowers for nectar and/or pollen and unwittingly serve as agents of pollen transport. A variety of animal taxa affects pollination in the large and diversified mint family (Lamiaceae), including lepidopterans (butterflies and moths), dipterans (flies), hymenopterans (aculeate wasps and, especially, bees) and birds (Huck 1992). Such a variety of visitors to the flowers of a rare plant might be advantageous to successful fruit and seed production. Here, we report on the insect visitors and likely pollinators of *H. apiculatum*.

A recent review suggests that sexual reproduction by flowering plants is frequently limited by inadequate pollination (Burd 1994). Rare plants are especially likely to be ignored by pollinators because of their low numbers

(Levin and Anderson 1970). Thus, although inadequate pollination is unlikely to initiate a common plant's descent into rarity, it may very well hasten a rare plant's descent towards extinction. Thus, we ask whether fruit and/or seed production by *H. apiculatum* gives any indication of being pollinator limited.

Materials and methods

Our studies of the breeding system, and most of the insect collections were conducted on the McKittrick Ridge population in Culberson County, Guadalupe Mountains National Park, Texas. Insect collections were also made over a few days on the Hunter Peak population in Guadalupe Mountains National Park. Geology, soils, habitat, and vegetation associated with McKittrick pennyroyal are described in U.S. Fish and Wildlife Service (1985) and Anonymous (1988).

Breeding system. Thirty-three plants, each with at least five unopened flower buds, were selected for study. One flower per plant was assigned to each of four breeding system treatments: autogamy (A), xenogamy (X), geitonogamy (G), and open-pollinated (O). The additional flower was used to test for stigma receptivity (SR) in flowers whose anthers had not yet dehisced. Treated flowers were permanently marked on the sepals with a distinctive color dot, and with a colored thread tied loosely around the petiole that varied with treatment. Flowers in the A, X, G, and SR treatments were individually bagged from the bud stage through treatment and until seed was counted two to three weeks later. For the X and G treatments, freshly dehiscing anthers from pollen-donor flowers on a plant at least 15 meters away were plucked with forceps on the first day of anthesis and used to hand pollinate flowers whose stigmas had recurved. To minimize impact on reproduction of this rare plant, seeds were counted by cutting mature fruits open while they remained attached to the plant. Data were analyzed using non-parametric statistics including contingency tables with planned comparisons, and Kruskal-Wallis and Mann-Whitney rank sum tests (Conover 1971).

Day vs. night pollination. To compare fruit and seed production of flowers open primarily during night or day, 15 plants were selected and three buds of about the same age on each were chosen and marked. Each plant had one flower in each of three treatments. Buds for the night pollinator treatment were bagged during the day and unbagged at night (1900 to 0700) continuously throughout flowering and until fruit set. Buds for the day pollinator treatment were bagged at night and unbaggged during the day (0700 to1900). Buds for the control treatment were unbagged throughout the comparison. Seeds were counted on the plants as previously described.

Pollinators. Frequent inclement weather prevented systematic collection of pollinators. Instead, insects were observed and collected from *Hedeoma apiculatum* flowers opportunistically over a period of about four weeks in July and August at Wilderness Ridge in McKittrick Canyon in the northeast section of the Park. Insects were also collected from *Hedeoma apiculatum* on Hunter Peak for two days. The insects were pinned, labeled, and identified by comparison with the collection maintained at the U.S. Department of Agriculture ARS Bee Biology and Systematics Laboratory in Logan, Utah.

Treatment	SR	AUT	GEI	XEN	OPE
N	25	33	32	32	33
# fruits produced	2	6	18	24	16
seeds/fruit		1.67	2.44	2.83	2.71
± SD		0.82	1.10	1.17	1.21

Table 1. Number of fruits produced and mean number of seeds/fruit for five breeding system treatments of flowers of *Hedeoma apiculatum*. SR= stigma receptivity, AUT=autogamy, GEI=geitonogamy, XEN=xenogamy, OPE= open-pollinated control, N=sample size.

Results

Breeding system. Flowers of McKittrick pennyroyal follow the protandrous developmental sequence found in other gullet blossoms in the Lamiaceae (Faegri and van der Pijl 1971; Proctor, Yeo, and Lack 1996). Pollen is dehisced from the two functional anthers a few hours after the flowers open. The style does not recurve, and the stigmatic surface does not bifurcate, until late in the second or early in the third day of anthesis. Flowers that cross-pollinated shortly after they opened before either the anthers dehisced or the style had recurved rarely set fruit (Table 1). Pollen adhered poorly to the unbifurcated stigmas of such young flowers as compared to adherence to the sticky stigmas present after bifurcation. Fruit set of flowers receiving this early pollination treatment set significantly fewer fruit than did open-pollinated control flowers on the same plant ($?^2$ = 10.9, d.f. = 1, P = 0.001).

Evidence from the experimental pollination treatments showed that *H. apiculatum* flowers must be visited by insects to produce fruits and seeds. There was a significant difference in fruit set among the three experimental breeding system treatments (Table 1) ($?^2$ = 22.0, d.f. = 2, P < 0.001). Flowers in the autogamy treatment produced significantly fewer fruits than did those in the xenogamy and geitonogamy treatments (χ^2 = 20.0, d.f. = 1, P < 0.001). There was no significant difference between the xenogamy and geitonogamy treatments. For flowers that produced fruit, those in the autogamy treatment produced fewer seeds than those in the xenogamy or geitonogamy treatments (Table 1), but the difference missed significance (Kruskal-Wallis test, P = 0.076). Thus in contrast to many other species of *Hedeoma* (Irving 1980), *H. apiculatum* is not automatically self-pollinating to any great degree: only 18% of the flowers in the autogamy treatment set fruit. The plants are self-compatible but require agents to move pollen between flowers either on the same or different plants.

We found evidence to suggest that fruit set by *H. apiculatum* flowers is limited by inadequate pollen deposition at least sometimes: open-pollinated control flowers produced significantly fewer fruits than did xenogamy flowers (Table 1) (χ^2 = 4.8, P < 0.05). There was no difference between control and xenogamy treatments in the number of seeds/fruit for flowers that produced fruit (Mann-Whitney rank sum test, P > 0.50).

Day vs. night pollination. Night visitors, presumably hawkmoths, were as effective at pollinating flowers as were day, or combined night and day, visitors (Table 2). There were no significant differences among treatments in the number of flowers setting fruit (χ2 = 0.62, d.f. = 2, P > 0.50). For those flowers that set fruit, there were no significant differences among treatments in the number of seeds/fruit (Kruskal-Wallis test, P > 0.90).

Flower visitors. Frequent and prolonged periods of rain made it impossible to follow strict schedules of insect collection and observation. Thus, our information on diurnal and seasonal changes in the flower visitor fauna is incomplete. Nevertheless, we were able to obtain what we think is a representative sample of flower visitors that are potential pollinators. The flowers of McKittrick pennyroyal are visited by a variety of insects including bees, butterflies, moths, flies and beetles but the most abundant and important appear to be butterflies in the genus *Vanessa* (the

Treatment	Day	Night	Control
N	14	14	15
# fruits produced	7	9	9
? seeds/fruit	2.86	2.89	3.11
± SD	1.46	1.36	1.05

Table 2. Number of fruits produced and mean number of seeds/fruit for day, night, and control bagging treatments.

	WR	HP
Halictidae		
Dialictus petrellus (Ckll.)	x	x
Dialictus pruinosiformis (Crfd.)	x	
Dialictus ruidosensis (Ckll.)		x
Dialictus sp. 29	x	x
Dialictus sp. 30	x	
Megachilidae		
Ashmeadiella cactorum (Ckll.)	x	
Ashmeadiella new species	x	
Apidae		
Anthophora montana Cr.	x	
Nymphalidae		
Vanessa sp.	x	x

Table 3. Important flower visitors of *Hedeoma apiculatum* collected at two sites in Guadalupe Mountains National Park, Texas. WR = Wilderness Ridge (7/14–8/6), HP = Hunter Peak (7/28–8/2).

painted lady), hawkmoths (Sphingidae) of unknown identity, and halictid bees in the genus *Dialictus* (Table 3).

Vanessa butterflies were the most abundant insect group seen on the flowers. Their frequent contact with anthers and stigma as they probed the flowers for nectar assures that they are important pollinators. Hawkmoths were seen visiting the flowers on several occasions when night observations were attempted and are likely responsible for nocturnal pollinations. The abundance of dull metallic bees of the genus Dialictus was somewhat surprising because of their small size (5–7 millimeters), short mouthparts, and the depth of the corolla of McKittrick pennyroyal (20 millimeters). Apparently these bees can gain access to the nectar that accumulates at the base of the corolla (sometimes increased and diluted by the frequent rains) by crawling down the tube through the distal, flared part of the corolla. Dialictus females were also frequently seen collecting and depositing pollen as they crawled over the anthers and stigma.

Discussion

We set out to answer three questions about sexual reproduction in the rare mint, McKittrick pennyroyal: (1) Does the breeding system give any indication of selection for self- compatibility or automatic self-pollination? (2) If the flowers of this species require pollination, what are those pollinators? (3) Is there any evidence that the rarity of this species is related to low reproduction caused by insufficient pollinator attention?

In contrast to expectations (Levin and Anderson 1970), we found no compelling evidence that the breeding system of *H. apiculatum* has been influenced by its rarity. While this species is both self-compatible and slightly autogamous, it is less so than many other members of the genus. Indeed, some annual species of *Hedeoma* are even cleistogamous (Irving 1980). McKittrick pennyroyal fits quite well into Irving's (1980) generalizations that larger flowered species exhibit higher levels of outcrossing than smaller flowered species. Thus, McKittrick pennyroyal is yet another example that belies the conventional assertion that rarity in plants engenders traits that make selfing possible and even inevitable (Tepedino 1999). Indeed, the opposite may well be the case.

McKittrick pennyroyal apparently has not gone the expected way towards increased selfing because, despite its global rarity, local populations still attract a variety of insect visitors. Nymphalid butterflies, as well as several species of bees, particularly those in the genus Dialictus, were important at both sites where diurnal pollinators were collected. Nocturnal pollination, likely by hawkmoths, was also an important contributor to fruit and seed production. This diversity of day and night pollinators undoubtedly decreases the likelihood of both complete reproductive failure in any given year, and reproductive failure sustained over a period of years because of the temporary extinction of a particular pollinator at one site. Such "redundancy" of pollinators is important to encourage.

Although *H. apiculatum* was visited frequently by a variety of pollinators, we nonetheless detected evidence for pollinator limitation: there was a significant increase in fruit production of experimentally outcrossed plants compared to open-pollinated controls. There are at least two explanations for this finding. First, although pollinators were frequently sighted visiting the flowers, they may have been inefficient at transferring viable pollen to receptive conspecific stigmas. Based on their movement on and between flowers and plants, we think this explanation unlikely. It is far more likely that fruit set was reduced in open flowers not because of the inefficiency of pollinators but because frequent precipitation forced pollinators to be inactive. This is not the first study to link inclement weather and reproductive diminishment via pollinator inactivity (e. g., McCall and Primack 1987, Bertin and Sholes 1993). Indeed, such microclimatic connections are likely to be far more common than we suspect (Corbet 1990).

We conclude that there is presently little evidence that the pollination system of McKittrick pennyroyal has either influenced, or been influenced by, the rarity of this species. Of course this is not to say that land managers charged with conserving this species should completely ignore the role played by pollinators in its reproduction, only that there may be more pressing threats such those due to sheep grazing, hikers, and climbers on the limestone rock surfaces where this plant is found (U.S. Fish and Wildlife Service 1985).

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Chapter 19

Methods for Estimating Colony Size and Evaluating Long-term Trends of Mexican Free-tailed Bats (*Tadarida brasiliensis mexicana*) Roosting in Carlsbad Cavern, New Mexico

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Introduction

Mexican free-tailed bats roost in colonies that can exceed several million (Altenbach et al. 1979, McCraken 1984, Wilkins 1989). These large colonies usually occupy caves, although bridges and buildings are also used (Wilkins 1989). Investigators have estimated colony size using a variety of methods ranging from gross ocular counts, to video and still photography (Altenbach et al. 1979, Thomas and LaVal 1988). However, few methods have provided a measure of statistical precision. Colony size, roost geography, repeatability of methods, and cost efficiency are all concerns when determining appropriate methods for estimating abundance. Investigators and managers need a variety of procedures from which to choose so that consistent and useable data can be obtained. Herein, we present progress toward developing reflective infrared photography (RIP) as a means of estimating colony size and assessing long-term trends in large colonies of Mexican free-tailed bats.

Background

Carlsbad Caverns National Park hosts a colony of Mexican free-tailed bats that reportedly reached 3 million in the late 1920s (V. Bailey personal communication with V. C. Allison, see Allison 1937). Another estimate of 8.7 million in June 1936 (Allison 1937) was revised down to 3.6 million by D. M. Roemer and W. T. Route (unpublished data). Both Bailey and Allison (Allison 1937) made their estimates from visual approximations and rough calculations of the volume of air filled with bats during the evening exodus. The accuracy and precision of these point estimates cannot be evaluated.

Investigators at Carlsbad Caverns National Park have documented a series of large-scale die-offs and a population decline beginning in 1955 (Ahlstrand 1974). Similar declines were noted throughout the southwestern United States and Mexico. Residues of organochlorine pesticides, primarily DDT and its metabolite DDE, likely contributed to this decline (Clark 1988, Geluso et al. 1976, Geluso et al. 1981). Despite the ban on DDT in the United States in 1972, DDT may still be causing harmful effects to wildlife in the Pecos Valley and the Guadalupe Mountains (Clark and Krynitsky 1983).

Prompted by this decline, Constantine (1967) used ceiling counts to estimate that there were 66,700 bats in the colony in June of 1957. Sixteen years later, in September 1973, Altenbach and others (1979) employed moving and still photography to estimate there were 218,153 bats in the colony. Most recently, Carlsbad Caverns National Park staff used computer counts of video footage taken during the evening exodus to estimate there were 147,418 bats on September 20, 1987 and 142,386 bats on October 1, 1987 (Roth 1987). Each of these estimates was obtained using different methods and at various times of the year. Ocular counts are highly dependent on observer experience. The use of moving and still photography was complex and not easily repeatable (K. Geluso, personal communication). Computer counts of video footage held promise, but as much as 60% of the flight was missed because of poor camera field-of-view and darkness (Roth 1987). None of the investigators provided a measure of precision, and thus, statistical comparisons between years are inappropriate.

To better understand how this colony reacts to disturbance and environmental change, we attempted to develop a monitoring technique that would provide a consistent and statistically robust estimate of abundance both before young were born and again just prior to migration each year. This would provide insights into over-winter survival and emigration as well as over-summer survival and recruitment. Both are critical for developing management strategies. We also wanted a method that was user-friendly, relatively inexpensive, and comparable with data collected elsewhere in the region.

Study area

Carlsbad Caverns National Park is a 46,766 acre (18,926 ha) park situated in the Chihuahuan Desert of southeastern New Mexico. It was first established as a unit of the National Park System in 1923 to protect Carlsbad Cavern, as well as other caves and portions of the surrounding desert. Carlsbad Cavern itself has approximately 30 miles (48 km) of cave passage and is 1,037 feet (316 m) deep. The cave was created by water percolating through an exposed limestone reef that formed along an ancient inland sea during the Permian period some 280 to 250 million years ago. The cavern receives more than 500,000 visitors per year with the highest visitation occurring from June through August when 2,000 to 6,000 visitors walk through the cave each day (National Park Service 1996). The two visitor access points are through a large natural entrance or by an elevator, which goes from the surface to a depth of 750 feet (229 m).

The large natural entrance measures about 21 x 12 meters and is the primary flight route of bats using the cavern. A second, smaller natural entrance (6.4 x 3.4 m) is used to a lesser degree by bats, likely because of its combined small size and steep incline. As far back as the 1950s and up to the 1980s, the roosting site of the Mexican free-tailed bat colony was centered 69 feet (21 m) west of this small natural entrance. Currently, the colony roosts about 722 feet (220 m) east of the small natural entrance. The historic and current roost areas are in a portion of Carlsbad Cavern known as Bat Cave. Bat Cave extends approximately 1,950 feet (594 m) to the northeast from the large natural entrance.

In addition to Mexican free-tailed bats, 12 other species of bats are known to occur in Carlsbad Cavern, but their numbers are small compared to the free-tail colony. A population of about 3,000 cave swallows (*Hirundo fulva*) began using the cave in the mid 1960s for nesting (West 1991).

Methods

During the winter of 1996, 15 permanent photo-points were placed at strategic locations in Bat Cave (Hildreth-Werker et al. unpublished data). Each photo-point consists of a stainless-steel receiving-pin drilled and fastened with epoxy to bedrock. A stainless steel monorod with camera mount and flash mount (patent pending) provided fast and precise photographs at each point. For complete overlap of photographs, two additional photo points were installed during the winter of 1997, bringing the total to 17. In addition, an articulating monorod was developed and used in 1997, enabling angled photographs for bats roosting low on cave walls.

Photographs were taken with a Nikon FM2 camera and a Nikon 28mm fixed-focal point lens (mention of product name does not constitute endorsement). We mounted an infrared flash unit (Sunpack 622 with TriPak II batteries) along side of the camera to illuminate the cave ceiling. Kodak HIE black-and-white infrared film was exposed by remote control with F-stop set at 5.6, focus set on the infrared setting for infinity, and the shutter left open while one to 10 flashes were fired depending on ceiling height. Negatives were processed and enlarged to 11-by-14-inch, black-and-white paper prints. The negatives were scanned and the resulting digital images placed onto CD-ROM for archival, digital enhancement, and future evaluation with GIS technology.

Gridded transparencies were developed to correspond to the ceiling at each of the permanent photo-points. Grid cell size was calculated from the average ceiling height at each point. Average ceiling height was estimated when bats were not present by raising a helium-filled balloon at three arbitrarily selected locations within the area encompassed by each photograph.

Complete sets of photographs were taken each day for five consecutive days in spring and fall 1996 and 1997. Gridded transparencies were overlaid onto the 11-by-14-inch photographs and grid cells containing bats were counted independently by three observers. Counts by observers were averaged over each five day session to provide an estimate of the area of ceiling covered with bats.

Roosting density can be highly variable depending on factors such as bat physiology and cave temperature. To estimate abundance we multiplied roost area by 200 bats/square feet (2,153 bats/m^2), a conservative estimate of roosting density for Mexican free-tailed bats (Constantine 1967, McCraken 1984, B. Keeley unpublished data). Final estimates were rounded to the nearest 1,000 bats because we considered accuracy beyond that to be impractical. Estimates should be considered conservative. All significance levels and confidence intervals were set at the 0.05 level.

To calculate a minimum population estimate we necessarily made the following assumptions: (1) the entire resident colony, and only the resident colony, was present during the photo sessions

	Daily area estimates (m^2)					Observer summary[a]		
Observer	5/29/96	5/30/96	5/31/96	6/1/96	6/2/96	Avg.	Std.	CV_d
JW	71.35	84.17	77.76	70.61	121.61	85.10	21.14	25
BR	72.37	86.77	78.50	73.11	147.16	91.58	31.59	34
JL	74.88	86.77	79.99	77.11	142.05	92.16	28.24	31
Daily summary[b]								
Avg.	72.87	85.90	78.75	73.61	136.94			
Std.	1.82	1.50	1.14	3.28	13.52			
CV_o	2	2	1	4	10			
Final estimated area calculation =						89.61	26.96	30
a = Observer summary provides a measure of daily variability								
b = Daily summary provides a measure of observer variability								

Table 1. 1996 spring estimates of ceiling area (m^2) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

	Daily area estimates (m^2)					Observer summary[a]		
Observer	8/30/96	8/31/96	9/1/96	9/2/96	9/3/96	Avg.	Std.	CV_d
JW	163.42	155.43	180.04	182.74	157.00	167.73	12.86	8
BR	173.17	156.82	171.03	171.03	145.67	163.55	11.93	7
JL	158.68	157.28	170.20	170.01	140.75	159.38	12.06	8
Daily summary[b]								
Avg.	165.09	156.51	173.76	174.59	147.81			
Std.	7.39	0.97	5.46	7.07	8.34			
CV_o	4	1	3	4	6			
Final estimated area calculation =						163.55	11.47	7
a = Observer summary provides a measure of daily variability								
b = Daily summary provides a measure of observer variability								

Table 2. 1996 fall estimates of ceiling area (m^2) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

	Daily area estimates (m²)					Observer summary[a]		
Observer	5/27/97	5/28/97	5/29/97	5/30/97	5/31/97	Avg.	Std.	CV_d
BR	14.96	38.74	44.41	28.06	58.44	36.92	16.46	45
DR	14.21	37.72	40.97	27.31	56.76	35.40	15.87	45
JW	17.56	39.67	43.11	28.06	57.32	37.14	15.13	41
Daily summary[b]								
Avg.	15.58	38.71	42.83	27.81	57.51			
Std.	1.76	0.98	1.74	0.43	0.85			
CV_o	11	3	4	2	1			
Final estimated area calculation =						36.49	15.81	43
a = Observer summary provides a measure of daily variability b = Daily summary provides a measure of observer variability								

Table 3. 1997 spring estimates of ceiling area (m²) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

	Daily area estimates (m²)					Observer summary[a]		
Observer	8/29/97	8/30/97	8/31/97	9/1/97	9/2/97	Avg.	Std.	CV_d
BR	134.24	99.96	101.64	61.59	42.46	87.98	36.19	41
DR	136.57	94.11	106.65	62.24	47.66	89.45	35.44	40
JW	135.92	101.36	105.17	61.69	39.58	88.74	38.09	43
Daily summary[b]								
Avg.	135.58	98.48	104.48	61.84	43.23			
Std.	1.20	3.85	2.58	0.35	4.10			
CV_o	1	4	2	1	9			
Final estimated area calculation =						88.72	36.51	41
a = Observer summary provides a measure of daily variability b = Daily summary provides a measure of observer variability								

Table 4. 1997 fall estimates of ceiling area (m²) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

(i.e., the population was closed to immigration and emigration); (2) all bats could be photographed during the photo sessions; (3) our methods did not disturb the colony; (4) measurements of ceiling height were accurate and provided unbiased estimates of ceiling area; (5) grid counts were accurate and the resulting estimates of roost area were unbiased; and (6) the roosting density estimate of 200 bats/ square feet (2,153 bats/ m²) is conservative and remained constant during the photo sessions.

Results

Spring and fall photo sessions occurred in late-May–early-June, and late-August–early-September, respectively. Photography normally began about 9:00 a.m. (time of first photograph) and ended about 11:00 a.m. (time of last photograph). Each five-day session required approximately 15 hours in the cave to set up and photograph the colony and about eight hours in the darkroom to develop and print film. An additional two hours were required for each of three observers to tally ceiling grids filled with bats. Thus a total of 29 hours were expended to complete each five-day photo session. Our methods resulted in minimal disturbance to the colony. Occasionally a bat would fly, but we noticed only minor and short-lived changes in colony noise during sessions.

During both years the colony roosted at the far end of Bat Cave about 220 meters east of the small natural entrance above photo-points 1–4. Ceiling geography varied from vertical walls to gradually sloping ceiling domes. Most bats were found along the uppermost portions of three natural domes and a closed mine shaft where ceiling heights ranged from 78 to 95 feet (24 to 30 m) above the cave floor. Small numbers of bats were found low on the cave walls during fall sessions both years. We were unable to photograph these bats in 1996, but a new camera mount in 1997 allowed angled photography of these areas. On days one and two of the 1997 fall session we took photographs at angles between 15° and 30° to record bats occupying low positions on the cave walls. These bats comprised 11.8% of the total area calculation for the 1997 fall session.

In the spring of 1996, we estimate bats occupied 89.6 square meters (± 23.6 m^2) of cave ceiling (Table 1), but by fall this nearly doubled to 163.5 square meters (± 10.0 m^2) (Table 2). In 1997 bats occupied an estimated 36.5 square meters (± 13.9 m^2) in spring (Table 3) and 88.7 square meters (± 32.0 m^2) by fall (Table 4). Each year the area covered by bats expanded by fall, and each year this expansion was further into Bat Cave.

Day-observer estimates were similar for all sessions as illustrated by the consistently low coefficient of variation (CV_o < 11%, Tables 1–4). Estimates between days were more variable (CV_d 7: 45%), due to increasing trends in area of ceiling covered with bats during the spring of 1996 and 1997 and the decreasing trend in the fall of 1997 (Figure 1, Figure 3, Figure 4). Only the fall of 1996 provided consistent daily estimates (Figure 2).

Using the roosting density of 200 bats/ square feet (2,153 bats/ m^2) and the mean area of ceiling covered with bats, we estimate that in the spring of 1996 there were about 193,000 bats (± 51,000) in Bat Cave and by fall this nearly doubled to 353,000 (± 22,000). In the spring of 1997 we estimate there were 79,000 bats (± 30,000) increasing to 191,000 (± 69,000) by fall. However, we believe only the fall 1996 estimate of 350,000 bats was representative of the resident colony. This is because the increasing trends in area estimates both springs and the decreasing trend in the fall of 1997 suggests that the population was not closed to emigration and immigration.

Discussion

We conducted our spring photo sessions at the end of May to limit disturbance to pregnant females, which give birth in mid-June to mid-July. Unfortunately, our spring sessions were probably too early. Daily area estimates for both years generally increased (Figure 2, Figure 4). From our data we could not determine whether this ingress was due to returning residents or merely transients moving through on their way to other caves. Constantine (1967) documented bats banded from Bat Cave in early spring being found over 400 straight-line miles

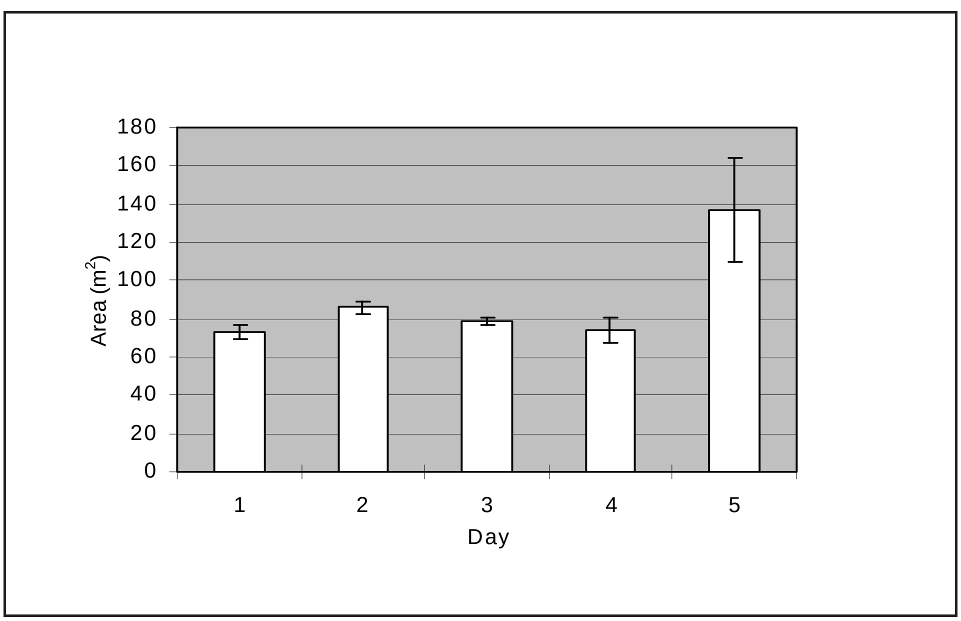

Figure 1. Spring 1996: estimates of roost area. Error bars depict two standard deviations from the mean.

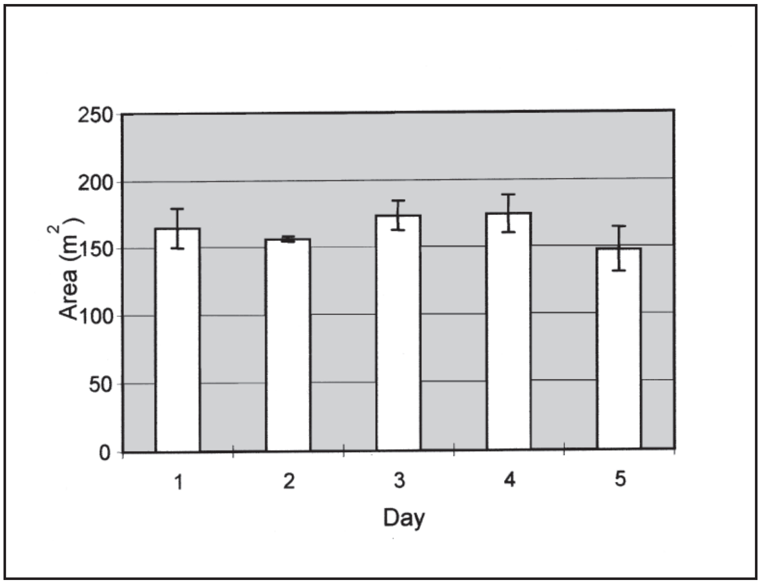

Figure 2. Fall 1996: estimates of roost area. Error bars depict two standard deviations from the mean.

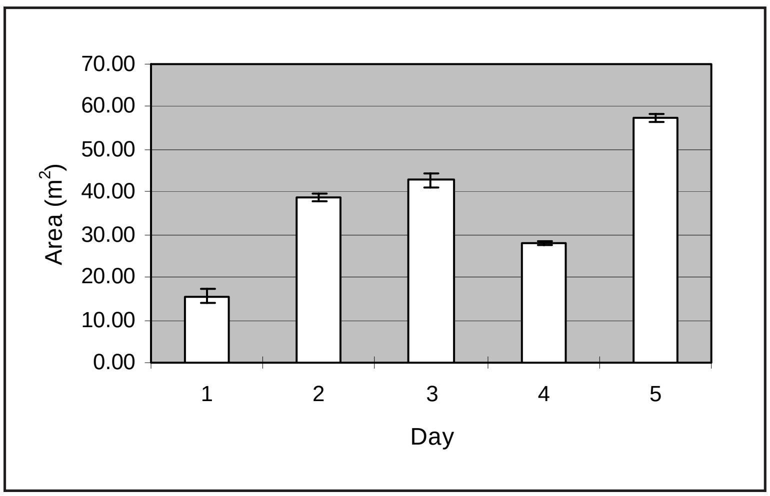

Figure 3. Spring 1997: estimates of roost area. Error bars depict two standard deviations from the mean.

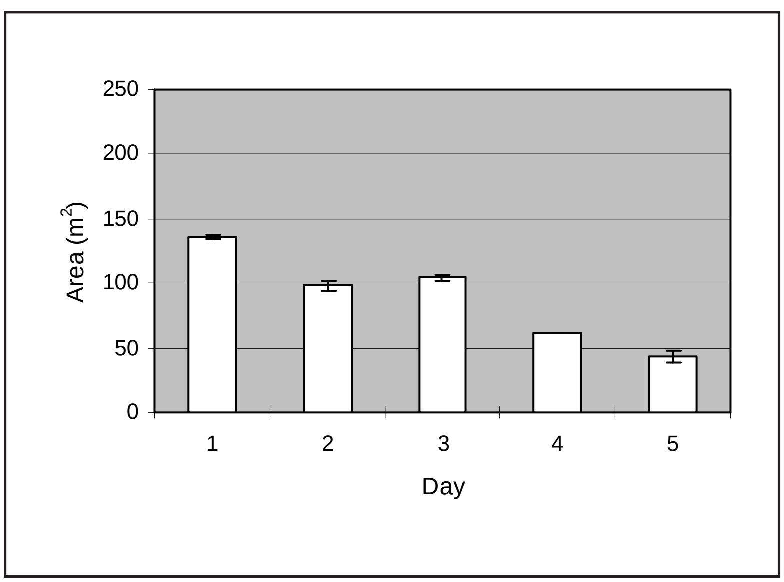

Figure 4. Fall 1997: estimates of roost area. Error bars depict two standard deviations from the mean.

distant within days. Similarly, bats banded 400 miles away in other roosts were found in Bat Cave.

The opposite occurred during the fall of 1997 when daily estimates generally decreased (Figure 4); we believe fall migration was already in progress. Personal observations (all authors), and those of park naturalists, suggested that the resident colony appeared larger in 1997 than in 1996, although our area estimates indicate otherwise.

The fall 1996 session provided consistent estimates between observers and days ($CV_o < 6\%$, $CV_d < 8\%$) with no trends evident (Figure 2). This photo session is believed to be representative of the resident colony at that time and the data show the potential for the RIP technique. Repeated within season, the technique has the distinct advantage of providing confidence intervals and thus statistical comparisons between years. This makes it a good tool for evaluating long-term trends.

The timing of photo sessions is critical in order to avoid migratory movements that could severely misrepresent abundance. Our data indicate that the time between arrival of the entire colony from Mexico and when females give birth is extremely short.

Shadows on some photographs may have resulted in greater estimates when observers counted them as a patch of bats. In 1997 we added a second flash unit to reduce shadowing. In the future we can further decrease the potential for this error by using reference photographs of the ceiling without bats. Fortunately, the potential to overestimate is balanced somewhat by bats that roost in cracks which are not photographed and thus not counted.

Individual ceiling height measurements were accurate; however, the nonrandom selection of few measurements (n = 3 for each photo-point) may have resulted in biases. This is potentially our greatest source of error. The degree of bias would depend on ceiling geography and colony arrangement. We believe this to be minimal during 1996 and 1997 because of the similarity in colony arrangement between years, but we recognize this as a concern. We are currently creating contour maps of the ceiling using laser survey technology. These contour maps will be digitized to form a base map in a Geographic Information System (GIS). Photographs of the ceiling will be referenced to the base map in order to calculate area estimates of bats more accurately.

There are few data on roosting densities of Mexican free-tailed bats, and there are no data specific to Carlsbad Caverns. We attempted to use a telephoto lens to evaluate roosting density in Bat Cave, but the 24 to 30 meter high ceilings and complete dark prevented us from obtaining usable images. The density estimate we used—2,153 bats/square meters—is conservative, although it was probably not constant during the photo sessions. Further research is necessary to estimate roosting density specific to Bat Cave.

Accurate estimates are seldom attainable for large populations of free-ranging wildlife. For monitoring, investigators often resort to techniques which may be inaccurate, but are unbiased, repeatable, and provide a measure of statistical precision (e.g., confidence intervals) so that year-to-year trends can be determined. Furthermore, given that accuracy is a problem, investigators strive to underestimate rather than overestimate abundance. This reduces the chance of careless management that could lead to population declines. The RIP method is reasonably unbiased and provides a conservative estimate of abundance. We demonstrated the repeatability of the method with consistent estimates between observers. Additionally, the photographs are permanent records of the colony, and if more reliable estimates of roosting density are obtained, our estimates can be adjusted.

The method is easy to apply and the camera mount system assures consistent photographs for each point. Processing photographs requires experience, but professional services are available. The method is relatively inexpensive so that it can be done every year. Similar techniques are currently being developed at other caves (e.g., Bracken Cave, B. Keeley personal communication) so that regional comparisons may be obtainable in the future.

Recommendations

Carlsbad Caverns National Park should continue to refine the RIP technique. Specifically, we recommend the following improvements:

1. Contour maps of the cave ceiling should be completed to reduce error associated with inaccurate ceiling area measurements. These maps should be digitized and used with digitized photographs of bats for accurate coverage estimates.
2. A photo session should be conducted from July 15th through July 30th. Possibly, this is the best time to get a single estimate of abundance for the resident colony. Pre-birth and pre-migration estimates would be ideal; however, it is likely that timing will always be a problem. Estimates in the spring and fall could always be subject to migratory individuals from other roosts and from early or late migration of the resident colony. A late July session would include all adults and young-of-the-year just as they are beginning to fly.
3. If time and money allow, the spring and fall sessions should be continued, but photo sessions should be conducted later in the spring and earlier in the fall. During normal years, birthing begins about mid-June and ends by mid-July. Few bats flew during our photo-sessions, and we are confident disturbance was not a problem; thus, a photo-session from June 10th through June 15th might provide good estimates of pre-birth abundance without adversely affecting pregnant females. A fall session could be completed in early August.
4. Reference photographs of the cave ceiling without bats should be available for observers counting grid squares. This would eliminate any potential for shadows being counted as bats.
5. Further research should be conducted to look into the roosting density of Mexican free-tailed bats at Carlsbad Caverns during different times of the year. If differences are found from those we used, past estimates could be recalculated.
6. Staff at Carlsbad Caverns National Park has been testing the use of flight noise recording (FNR) as an index to population trends and this should be continued. A remote microphone and data logger allow continuous recording of flight noise over a 24-hour period. The data are then graphed and the area under the curve serves as an index to abundance. Over the next four years the RIP and FNR techniques should be done simultaneously to correlate the two techniques.

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Cultural Resources

Chapter 20

Archaeological Resources of Guadalupe Mountains National Park

SUSANA R. KATZ, Ph.D., is a principal investigator for Prehistoric Resources Identification, Assessment and Management (PRIAM). She has spent the last twelve years in private cultural resources work. She has conducted archaeological surveys in park environs, a Texas Tech University Archaeological Field School in Pine Spring Canyon, and dissertation research on late prehistoric sites, economy, and environment throughout Guadalupe Mountains National Park.
PAUL KATZ, Ph.D., has been the director for the Square House Museum in Panhandle, Texas for the past eight years. He served as project archaeologist for the Texas Tech archaeological survey. He directed the high country survey of the park in 1976.

Once around the park
We assume that these mountains were named for the Virgin of Guadalupe, but the Saint Hubert Mountains would have been far more appropriate. Saint Hubert is the patron of hunters and gatherers, and success in these most basic forms of human survival has been the mainstay of this area for at least 10,000 years. Further, the Aztec word HUA-TA-LO-PE, from which the word Guadalupe is thought to derive, means "one who treads on snakes." We know the National Park Service frowns on that kind of thing.

Our travels through the park began in September 1973. The Department of Anthropology at Texas Tech University hired us to conduct an inventory of the new park. There were 2.5 scientists starting projects on the same day. Full-time National Park Service Fire Biologist Gary Ahlstrand got in his Scout and drove it into an arroyo on the west side. Full-time Archaeologist Paul Katz and his half-time assistant Susana Katz climbed up the west wall of McKittrick Canyon to look at a "cave" that turned out to be a shadow. The descent was "easy," consisting of a several hundred foot slide down a ravine, tearing our clothes and ourselves to shreds.

The 2.5 of us met at the end of the day at the Pine Springs Café and pondered the wisdom of our actions. Bertha Glover took one look at Paul, declared that he reminded her of her late husband Walter, the "Little Giant of West Texas," hugged him, and told him to come back as often as he could. Her Chihuahua dog looked up at me, lifted his leg, and peed on my ankle. We learned some important lessons that day: things change appearance with light and distance; a straight line may not be the shortest route from one place to another; and, if you're going near Bertha's dog, wear socks. Thus began our love affair with the Guadalupe Mountains.

The descent was "easy", consisting of a several hundred foot slide down a ravine, tearing our clothes and ourselves to shreds.

We were not the first people to conduct archaeological work in the Southern Guadalupe Mountains, but we were nonetheless data-poor. In 1930, E. B. Howard, noted archaeologist from the University of Pennsylvania, came to the Guadalupes at the request of local residents Livingston and Burnet to search for the remains of "early man." Although he excavated several hearths and a Folsom-like projectile point in Burnet Cave, the associations of man-made materials with extinct animals eluded him. So he went to look at another nearby location, Blackwater Draw. He left behind a student, Mary Ayer, who excavated Williams Cave. This cave produced both Pleistocene fauna and cultural remains, but they were not in association and were not early man. Henry Mera joined the Laboratory of Anthropology in 1930, and soon after he surveyed, described, *We took what came naturally to us—every day with our undependable ambulance was an exercise in survival.*

and tested sites throughout southeastern New Mexico (and west Texas), including caves on the western escarpment of the Guadalupe Mountains. He named several of our common pottery types and conducted a study of ring midden features.

That's practically all the published on-the-ground work that took place in this locality until the 1960s. Suddenly, there were small surveys, John Greer's ring midden typology, small excavations in caves in the Lincoln, and an honor's thesis updating Mera's overview written by Barney Burns as an undergraduate at the University of Arizona. (Coincidentally, Barney and Susana were undergraduates together, and Susana actually got to see this rare manuscript, archived in Barney's Mom's garage).

And then the southern Guadalupe Mountains became a national park. Between June 10 and June 20, 1970, the Texas Archaeological Society (TAS) held a field school there. About 10 square miles of the park were investigated by 200 people, recording 150 sites. Harry Shafer, a principal investigator of the field school, along with Dessamae Lorrain provided us with copies of the TAS site forms.

We had other excellent sources of information: Isobel Gilmore, an avid arrowhead hunter and our neighbor in Salt Flat; Bill Balgemann of Carlsbad, an avocational archaeologist who had excavated caves on the New Mexico side; and National Park Service personnel from Guadalupe Mountains and Carlsbad Caverns.

After a few days of putting our limited information together, we sat in our official Texas Tech vehicle and made plans. The truck was a 1954 Dodge power wagon, which saw action as an ambulance in Korea; helicopters from Fort Bliss would hover overhead when they noticed the red cross painted on the vehicle's roof. We took what came naturally to us—every day with our undependable ambulance was an exercise in survival. When the vehicle died, and it did with alarming frequency, we had to know where we could find shelter and water, what to eat, and how to prepare it. Thus, the "intimate ecological approach" to archaeological survey was born.

We were fortunate because although archaeological information was limited, environmental data were not. We had the resources of the Living Desert Museum in Carlsbad, the Carlsbad Caverns research library, and the input from those natural science types from Texas Tech who were all over the park at the same time as us. We became hunters and gatherers. We put together lists of all known plants and animals (living and extinct) in the park, and then compared these with ethnographic accounts of how the same resources were used by native peoples and historical residents of the Chihuahuan Desert and beyond. (Much of this work appears in the Susana's dissertation from the University of Kansas, and the plant data has been incorporated into a volume produced by Human Systems Research of Tularosa, New Mexico.)

Data and definitions

For this discussion, we have taken data from the TAS field school and from three projects that we directed. The latter include the four-month survey conducted by the 1.5 of us in 1973; a field school we taught in the summer of 1974; and the completion of the park inventory in 1976, which concentrated on the high country. We were associated with Texas Tech University for the first two projects and with the University of Texas at San Antonio for the third. In all, we will use data from 261 prehistoric open sites. But wait—caves, rock shelters, and historic sites were recorded, too. However, since the National Park Service distinguishes caves from other sites, and history from prehistory, we have chosen to focus on prehistoric campsites. Nonetheless, we did live in or use historic structures (the Hauser House at upper Pine Spring and Williams Ranch on the west side); we excavated the Pinery in Guadalupe Pass; we examined military activity west of Frijole Ranch; and we recorded prehistoric rock art.

We need to define some terms at this point. The prehistoric chronology for southeastern New Mexico and western Texas is more precise and sophisticated today than it was 25 years ago. Back then, only general time periods were available. That's the way the data were recorded, and so we'll stick with it here.

Paleo-Indian is the earliest stage, with a range from 10,000 to 6,200 B.C. It consists of three periods, Early, Middle, and Late. This is followed, after a hiatus of about a millennium, by the Archaic stage, which dates from 5,200 B.C. to A.D. 500. There are four Archaic periods, Early, Middle, Late, and Terminal. Next comes the Formative stage, from A.D. 500 through 1500, and there are Early and Late Formative periods, followed by the Protohistoric. The Historic stage begins with the arrival of the Europeans.

Artifacts most commonly recognized at prehistoric activity locations in the park include those made of stone (lithics) and clay (ceramics). Some can be used to assign an associated feature or location to a chronological period. Pottery dates to the Formative stage, and painted pottery usually signifies the Late Formative. Plain pottery occurs throughout this stage, but if it is found by itself, it may imply the Early Formative. Arrowpoints are also from the Formative stage, but the larger dart points are generally pre-Formative. Each style or type of point can usually be assigned to a period; for instance, broad, notched points are Middle and Late Archaic, whereas fluted points are Early and Middle Paleo-Indian. Other tools commonly recovered include knives or choppers (bifaces); scraping tools (unifaces); cores, which are left over from making stone tools; and handstones, used to grind something on a grinding slab.

Types of features

We are going to start by looking at the types and distributions of features rather than sites. The site is the place on the ground where the archaeologist locates the features and artifacts associated with the features. Sites are useful, we can't get away from them; but features are fundamental. One other term we'll use is the "component," which refers to the occupation at a site during a specific time period. Single component sites have only one occupation; multicomponent sites have been reoccupied at least once. The most popular feature in the park is the ring midden, or burned rock ring; 75 locations are characterized by one or more rings. This represents 29%, almost one-third, of the 261 site records in our database.

Based on ethnographic analogy, experimental archaeology, and scientific analysis, the ring midden is interpreted as a feature for baking succulent plants. The rocks used in the process are discarded in all directions away from the processing location, thus forming a stone circle. Burned rock rings will conform to their physical setting with respect to three variables: (1) available space, (2) topography, and (3) soil or ground conditions. This conformity applies to both the plan and the profile of the feature.

Concerning available space, it is possible to have either a full circular or oval ring, or a partial ring or crescent. Abbreviated or partial rings are best known on the ledges in front of rock shelters or overhangs.

The most popular feature in the park is the ring midden, or burned rock ring; 75 locations are characterized by one or more rings.

If the surface of the ground is too hard for the excavation of a baking pit, it is possible to build a "supersurface pit" out of rock. This is common on rocky ledges in the Guadalupe Mountains. Remember, what is integral to the process is a baking chamber; it does not have to be in a subsurface pit.

Another variable which affects the plan of the feature is the degree of concentration or dispersion of the burned rock ring. This is a factor that applies primarily to rings which have been reused many times and have accumulated a considerable quantity of burned rock. If adequate space is available, such as on a broad terrace, the ring may be large and low. If the feature is situated on a small ridge saddle, however, its configuration is more likely to be small and high. The same volume of rock may occur in both features, but the morphology will be quite different.

The burned rock ring is the kind of feature that grows old gracefully. Reuse results in a gradual but constant increase in the diameter of the feature and the height of the ring wall, as well as the volume of burned earth and charcoal in the central chamber.

One interesting aspect of burned rock rings is their intersection. In one sense this automatically implies time depth, in that a ring which is intersected by another is probably older than the one that intersected it. There can be several processes that result in intersection, however. One is a function of topography or available space, in that there may simply be insufficient room for multiple features to fully develop. Two central pits may be initially established some distance apart, but over time the intervening space is filled with their respective burned rock debris. Another situation is the use of the exterior ring wall of an existing ring in the construction of a new baking feature.

Burned rock rings have been recorded throughout a range of 5,000 feet—from 3,000 to 8,000 feet elevation. This corresponds to the range of *Agave lechuguilla* in the northern Chihuahuan Desert. The feature has also been recorded in all topographic situations, but its distribution is not even. Furthermore, the associated cultural activities, as indicated by other types of features and by artifacts such as the distinctive chipped stone "agave knife," are not the same at every site that is characterized by a burned rock ring.

Almost all the hearths are located in the lowlands.

A hearth is defined as a tight concentration of burned rock. It is a typical feature in the park, with 70 locations in our database. While there are 35 locations in each county, almost all the hearths are located in the lowlands. Associated stone tools include flakes, scrapers, and knives. Projectile points are not common, nor are ceramics. There are only 19 locations where these artifacts jointly occur with hearths.

Another feature type is the burned rock scatter. Depending on the amount and distribution of burned rock, this feature may be a dispersed hearth, a deflated ring, or a sheet midden. It may also be a feature in its own right with an unsuspected structure and function. There are 12 scatters in the database, but to these should be added another 49 locations that are characterized by an "indeterminate" type of burned rock midden.

The burned rock mound is a rather rare, but unique type of burned rock feature, with only eight locations in the database. These locations are all in wooded areas at high elevations. Their proximity to oak trees suggests a similarity to one of the functions postulated for the much larger and more numerous burned rock mounds of central Texas, that is, acorn processing.

Artifact concentrations and artifact scatters lack the presence or association of any type of feature, burned rock or otherwise. These locations still have a function; they just lack a discernable structure.

Unburned stone alignments, stone walls, stone circles, and stone rooms do occur, but they are rare and poorly defined. Isobel Gilmore remembers seeing a room or small room block on the west side, now covered by sand and silt. The TAS recorded a stone alignment, also on the west side that looked like the foot of a wall; this may be the same feature. Ceramics at about this location includes Casas Grandes types, which are associated with above-ground structures farther west. Pithouse features have been identified in the Salt Flat vicinity, although not in the park.

Distribution of features

The distribution of the features we've mentioned falls into three groups by elevation—low, medium, and high. In previous work, we looked first at lifeszones or ecozones or paleoenvironmental reconstructions. Here, we are letting the burned rocks take the lead. This lead still doesn't change very much because the first group of sites, the largest group, clusters from 3,500 to 5,000 feet. This is the elevation range of the former and current grasslands. The most common features here are burned rock hearths (41 locations). Indeed, hearths in other locations are quite rare. Sites without any visible burned rock or burned earth, i.e., artifact scatters, are the next most common (37 locations), followed by burned rock concentrations of indeterminate structure. At the bottom of the list are the ring middens, which we found in only 19 locations.

There is a basic toolkit associated with hearth sites: chipped stone flakes, and cutting and scraping tools. Other tools may occur as well, but whatever the hearths on the west side are being used for, these three things are essential to the process. Hearths are strongly associated with arroyos, so proximity to water is also indicated. Hearth sites rarely have good datable artifacts, but those that do are usually assigned to the Late Archaic or Late Formative, with a few Early Archaic and Early Formative sites possible.

The typical geographical situation for lower elevation ring middens is at the toe of an alluvial fan on the west side. They are medium-sized sites, and they are mostly representative of the Early Formative period. The west side has been heavily collected, whereas the rest of the park is in near- pristine condition. The west side has also experienced significant erosion and colluvial action. But from what we can see, if you were an Early Formative period person, you cooked your agave on an alluvial fan on the west side. Most of your forebears and your “futurebears” used the uplands instead.

Now let’s go up a bit to the intermediate elevations, from about 5,200 to 6,700 feet, where we have 51 sites. The location and pattern of use becomes more predictable and more spatially restricted. When you look at a map of the distribution of sites, you see that they often coincide with a road or trail. While this makes it look like we did our survey from the ambulance, what it really shows is that today’s trails were yesterday’s trails. There are a limited number of ways to gain access to the interior country, and these access routes have been used throughout time.

The most popular site is the ring midden, followed by indeterminate burned rock clusters; there are only 11 sites that have nothing but lithic and/or ceramic debris. The sites are most often located on terraces. If there was no terrace, any other kind of flat place was the next choice. Most sites in this group are not dated, with the major exception of sites in upper Dog Canyon, which is predominantly a Formative use area. There are a small number of sites which appear to have Paleo-Indian and Archaic components as well.

Hearths are strongly associated with arroyos, so proximity to water is also indicated.

Elevation group 3, the high country, has 71 recorded locations. This area was always popular. Dated components include four Paleo-Indian, 33 Archaic, and 23 Formative. That the gathering and processing of agave was important here is attested to by the prolific number of ring middens. They even outstrip the number of lithic scatters! The favored place to process agave was in a ridge saddle. This was close to the resource; it was sheltered and it was flat. To a lesser extent, benches and terraces were also used. The high country ring middens have greater time depth and a different toolkit than their lower elevation cousins. Sites will have both Archaic- style points and later points and ceramics. The toolkit has scraping tools as a regular feature, and cores and grinding slabs are more common than at lower elevations.

Remember the predominance of hearths in the lowlands? Here, only one hearth has been recorded. We suspect that a few are shallowly buried, but clearly, the hearth feature is not common. Twelve indeterminate rock concentrations and all of the midden mounds, those solid mounds of burned rock possibly associated with acorn processing, occur at this elevation.

We found 16 “hot spots” in the high country—places where three or more prehistoric components were identified at one site. Fourteen of these are on travel routes through the mountains. They are on or beside old trails or new trails, and on ridges that run from the bottom to the top of the mountains. Most are associated with portions of McKittrick Canyon; there are even pairs, with one site at the bottom of the canyon and another at the top.

Some concluding thoughts

The archaeological resources of Guadalupe Mountains National Park tell this story:

1. Hunting and gathering activities were undertaken by small groups of people, perhaps even family units. The data leading to this conclusion consist of the small size of the features, the small areas of artifact scatter, and the nature and quantity of the associated tools.
2. These small groups of people returned periodically to the same or similar locations, presumably to carry on the same activities. Supporting data consist of the reuse of ring middens, the multiplicity of features, and multiple periods of activity at the same location (multicomponent sites).
3. Occupation was of a temporary nature. The data consist of the lack of structures and the lack of domestic refuse at most sites.
4. Does small family groups, returning periodically, and staying only a short time sound familiar? Doesn't this define the typical visitor to a national park? May we suggest a marketing line for the park: "10,000 Years of Visitation."

Archaeological resources in Guadalupe Mountains National Park can tell us something about where these visitors came from and where they may have been going:

1. Archaeological investigation in the larger region of southeastern New Mexico provides data about Rocky Arroyo being an important route between the Pecos River and the mountains. It is not hard to imagine travelers gaining access to the present national park and high country from Rocky Arroyo.
2. Another travel route may be indicated by site clusters in the south and southwest portions of the park. This would be a north-south route between the west side of the Delaware Mountains and the east side of the Salt Basin.
3. Travel through the park is identifiable by sites (usually characterized by ring midden features) located: (a) in saddles at the head of ridges that start low and top out, (b) by lines of activity areas along high country ridges, and (c) by sites at the intersections of modern trails.

The archaeological resources of Guadalupe Mountains National Park can and do play a significant role in regional research:

1. For example, evidence of Paleo-Indian activity in the high country provides a dimension that has not otherwise been recognized in southeastern New Mexico.
2. The use of ring middens during Archaic periods is something that was only postulated before archaeological investigations at Brantley Reservoir in Eddy County, New Mexico provided dates. Archaic sites in the park can now be restudied with this new data.
3. In other parts of the Southwest, including southeastern New Mexico, a major distinction between the Early and the Late Formative is made on the basis of architecture: pit houses developed earlier than pueblos. In the park, the absence of architecture allows a more intense scrutiny of subsistence and other aspects of behavior.
4. The large number of features, which are in excellent states of preservation, permits lines of inquiry which crosscut time periods and extend across the region. An example is our personal research into the function of ring middens. We have collected and analyzed data from west of the Salt Basin, over the mountains, across the Pecos Valley, and beyond. The only gap in this extensive data transect is Carlsbad Caverns National Park.

The archaeological resources of Guadalupe Mountains National Park are still there:
For more than 25 years, the National Park Service has protected these cultural resources through avoidance and good management when developing facilities and trails. It's nice to know that we can continue to conduct our research, and we look forward to presenting another paper at the 50th anniversary symposium.

Chapter 21

The Apache Cultural Landscape in Guadalupe Mountains National Park

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Introduction
Cultural ecology is the study of a community's interrelationships with its natural, social, and cultural environments. The result of a cultural ecological study of a community is a model, or a representation of those relationships. The representation may be characterized as a cultural landscape. Cultural ecology and the representation of cultural landscapes have been key interests of anthropology since its beginnings.

Park interpreters have recently popularized the concept of cultural landscape as a unifying theme for interpretation of the cultural and natural tapestry of specific park resources. Often the interpreter's understanding of the complexities of an adequate representation of a cultural landscape is limited. Most of the presentations of cultural landscapes in parks, so far, have been focused on cultural landscape as something "out there" and the "inside" view of the landscape through the cognitive frame, or "the eyes" of the cultural participant has been neglected. I hope that the following discussion will help to expand the dialogue between anthropologists and interpreters on their shared task of adequate representation of cultural landscapes.

In 1912, the famous American linguist and anthropologist, Edward Sapir, wrote:

> It is the vocabulary of a language that most clearly reflects the physical and the social environment of its speakers. The complete vocabulary of a language may indeed be looked upon as a complex inventory of all the ideas, interests, and occupations that take up the attention of the community, and were such a complete thesaurus of a given tribe at our disposal, we might to a large extent infer the character of the physical environment and the characteristics of the culture of the people making use of it.

Edward Sapir (1929) cogently directed us to the fact that, if we hope to adequately represent a cultural landscape, we are responsible for getting "inside" language and cognition:

> Language is a guide to 'social reality' though language is not ordinarily thought of as of essential interest to students of social science, it powerfully conditions all our thinking about social problems and processes. Human beings do not live in the objective world alone, nor alone in the world of social activity as ordinarily understood, but are very much at the mercy of a particular language which has become the medium of expression for their society. It is quite an illusion to imagine that one adjusts to reality essentially without the use of language and that language is merely an incidental means of solving specific problems of communication or reflection. The fact of the matter is that the 'real world' is to a large extent unconsciously built up on the language habits of a group. No two languages are ever

> sufficiently similar to be considered as representing the same social reality. The worlds in which different societies live are distinct worlds, not merely the same world with different labels attached…. We see and hear and otherwise experience very largely as we do because the language habits of our community predispose certain choices of interpretation.

With this brief preface, let's take a look at the strategy of cultural ecology and the goal of representing an Apache cultural landscape in Guadalupe Mountains National Park. It involves: (1) library and archival research on the natural resources of the Guadalupe Mountains area and the archaeological, ethnographic, and historic records of Apache adaptation to those resources; (2) the reconstruction and mapping of potential plant and animal resources of the Guadalupe Mountains area; (3) actual ethnographic field work with living Apaches who still remember or are still practicing utilization of traditional resources; and (4) the testing of predictions of where prehistoric and protohistoric resource utilization camps and sacred sites should be. The result should be an adequate representation of the Apache cultural landscape of the Guadalupe Mountains area that will help us to understand and interpret the natural and cultural tapestry of Guadalupe Mountains National Park, as seen through Native American eyes.

To provide an adequate representation, we obviously have to go beyond what is "out there" and into the minds of the participants. We must deal with analyses that are linguistic, cognitive, religious, mythological, folkloristic, etc. In other words, we must get into the mental life of the people, we cannot be satisfied with just an external description of economics.

In brief, cultural ecology deals with the following questions: (1) What does nature provide for human thought and action to work with? (2) What do human beings actually do with these resources (how do they select them, categorize them, and use them)? (3) What do human beings think about what they do with these resources? And, ultimately and explanatorily, (4) Why do human beings do what they do with these resources?

Cultural ecology is a very rewarding approach for understanding the human condition. If specific cultural ecological representations of specific cultural groups are done well, they provide one of the most powerful, explanatory, and predictive forms of ethnography.

Because of the limitations of time and space, the following will be a brief summary of the progress of the Mescalero Apache–Guadalupe Mountains National Park cultural ecology project, which has as its objective the development of an interesting and understandable interpretive program and exhibits describing Mescalero Apache adaptation to the environments of Guadalupe Mountains National Park.

The target landscape

The traditional Mescalero Apache nuclear area, as defined by historical and ethnographic records, is the area traditionally utilized by the Mescaleros as indicated by Mescalero place names and intimate knowledge of the land and its resources (Figure 1). The peaks of the Guadalupe, Sacramento, and Sierra Blanca mountain complex represent the "sacred center" of Mescalero Apache territory. Guadalupe Peak is a sacred place of origin, creation, and visionary experience in Mescalero tradition. It is a place where White Painted Woman, the primary Apache deity, taught the ancestors of the Mescaleros the traditions and the ceremonies that make them Mescaleros. This is a place of beginning of Mescalero tradition. From this reference point, the Mescaleros consider their territory to be roughly a circle of approximately 150 miles in radius from their center in the sacred mountains. Beyond this "nuclear area," which was generally uncontested as "theirs," they traveled and had more limited knowledge of the country extending another 50 miles

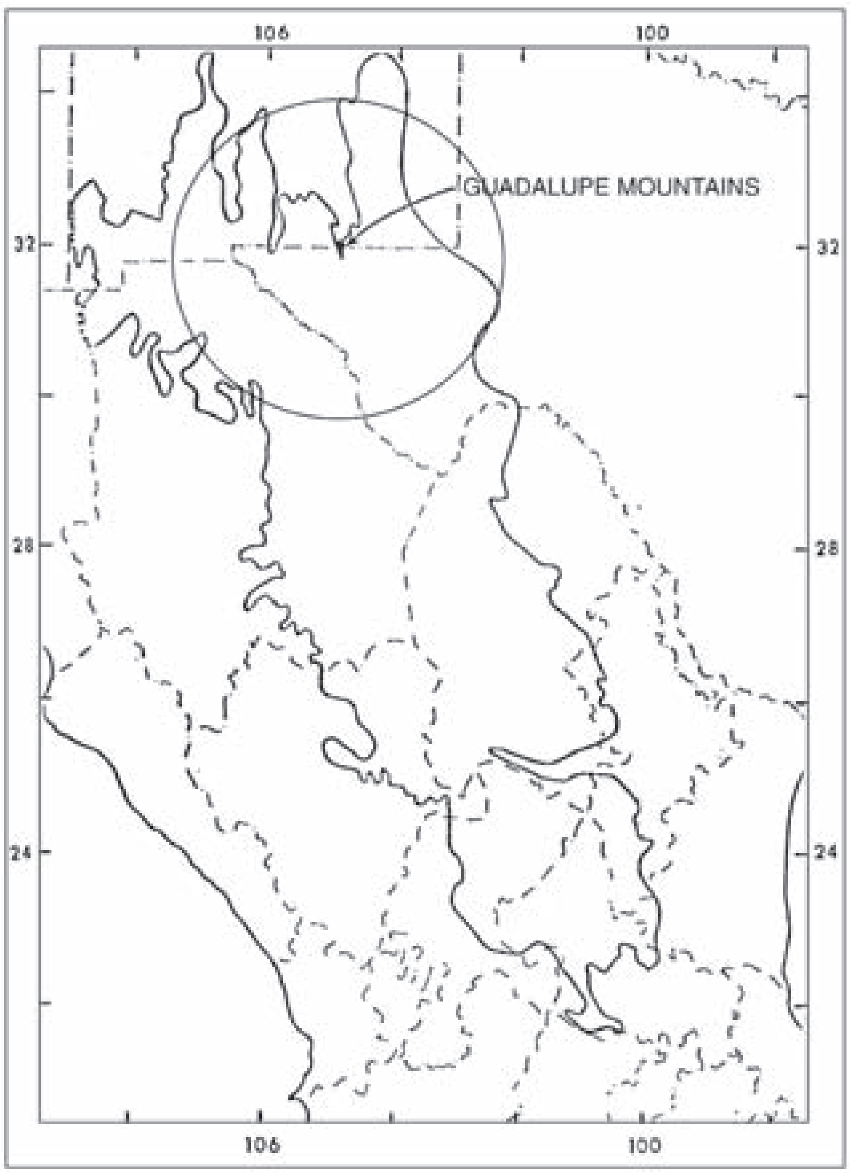
Figure 1. The traditional Mescalero Apache nuclear area, about 150 miles in radius, is utilized by the Mescaleros as indicated by Mescalero place names and intimate knowledge of the land and its resources. The extended area, also used by neighbors, was about 250 miles in radius.

or so to the headwaters of the Pecos River on the north; into the plains of Texas on the east; far into Sonora, Chihuahua, and Coahuila on the south; and into what is generally considered Chiricahua Apache territory on the west. It was recognized that this extended area was mutually utilized with their other neighbors. The general pattern until the recent effects of the pressures of the Spanish-Mexican and Anglo-American frontiers was peaceful joint utilization of the margins of their territory with their neighbors, rather than conflict on their borders.

This circular view of Mescalero Apache territory will be used throughout this paper. It really replicates the model used if one were looking at the landscape "through Apache eyes" (Figure 2). The Mescaleros have often been characterized as "desert people." However, they prefer to call themselves "mountain people." They are caught in the tangle of problems that scientists continue to be caught in when trying to generalize about such a complex area as the Basin and Range province of arid western America.

It must be understood at the outset that the Basin and Range physiographic province is very complex and within it the mountains are obviously the dominant feature. Also, the generalization of a biotic zone, such as the Chihuahuan Desert region, tends to obscure its internal complexity largely due to the climatic variations related to the altitude variations of the mountains. The Mescalero seasonally utilized the resources in the desert basins and plains grasslands, but the preference was to be in the higher altitudes in wooded uplands and in the mountains. This is where their traditions are, where their gods are, where their ceremonies are,

Figure 2. The circular view of Mescalero Apache territory replicates the model used if one were looking at the landscape "through Apache eyes." Here the nuclear area is superimposed on the boundaries of the Chihuahuan Desert (defined by Johnson 1979).



and where their hearts are. In their yearly circuits they generally moved from mountain range to mountain range, as if they were hopping from island to island. The desert basins were generally viewed as something to get across between the next mountain home, not as places that anyone would want to spend much time in, or live in.

Marshall C. Johnston (1979) has called the Guadalupe Mountains a "chink in the mosaic of the Chihuahuan Desert." It is important to note that although over 50% of the Mescalero Apache nuclear area may be included in the Chihuahuan Desert region, the region itself is studded with mountains that have essentially all of the biotic diversity of the Southern Rocky Mountains and the mountains of the Colorado Plateau. More importantly the sacred center of the nuclear area is in the Guadalupe-Sacramento-Sierra Blanca mountain complex, which is a "finger" of the Southern Rocky Mountains pointing southward into the Chihuahuan Desert. It is very important to notice that the Mescaleros were situated to get the full benefit of the "edge effect." They were situated in a transitional zone including portions of the mountain, wooded upland, plains grassland, and desert basin biotic communities. Much of their territory was classically "ecotonal" and contained a mixed biota overlapping from the contiguous communities and some biota characteristic of or unique to the ecotone. The tendency toward increase in varieties and densities of organisms in these ecotonal communities can only be interpreted as a subsistence advantage for the aboriginal Apaches. It is in such an "edge area" where the greatest diversity and density of both plant and animal resources occur. Such an edge area is also a "genetic bank" with a high potential for hybridization and new speciation. Such a complex area does not yield to quick and easy classification into biotic areas and offers both puzzlement and excitement to ecologists. According to Northington and Burgess (1979):

The critical message here is an awareness of the uniquely complex vegetational mosaics of this region produced by sudden and extreme topographic and edaphic interfaces in an essentially arid climate. These various floristic elements occur at a crossroads of major biotic assemblages: Rocky Mountain Forest; Chihuahuan Desert Scrub; Great Plains Grassland; and some elements of the Sierra Madrean Woodland (Southwestern Mountains). This geographic position is in a zone of climatic interface which results in temporarily unstable habitats containing unique plant associations. Such complexity is what makes this area so striking and interesting to both the scientist and the general public. Because most of the area in question is part of the Guadalupe Mountains National Park, preservation of these features is more assured as is the opportunity of exposing the public to nature at its heterogeneous best.

So, do not pity the poor desert Apaches! They were the fortunate stewards of a complex area providing an unusual diversity and abundance of subsistence resources. They were undoubtedly much better off than foragers restricted only to mountain, desert, or grasslands. But, please do pity the ecologist or cultural ecologist, who is faced with a baseline landscape that is largely ecotonal and does not yield to mapping in broad strokes.

Also, the environment is so dynamic and so much a mosaic of "temporarily unstable habitats containing unique plant associations" that a meaningful cultural ecology must go beyond the gross macroecological adaptation to generalized large biotic areas and must really become microecological, focusing on utilization of unique plant associations, which the Apache women knew intimately. As we shall see, Apaches were not only macroecologists, but the women in particular were also microecologists, to the point of knowing each individual stand of subsistence plants, and even knowing the location and the phenology of individual plants "personally." In other words, they were knowledgeable and skilled stewards of their "garden." Keep in mind that, to them, this knowledge was not purely "academic." It meant survival of the group.

The Mescalero Apache view of their environment and the utilization of its resources

The Mescalero Apaches are very perceptive and insightful ecologists. They carry their ecological orientation to the level of religious devotion.

According to Mescalero tradition, the Nde people (their name for themselves in their own language) are the children of Mother Earth, personified by the deity White Painted Woman. She is the primary deity, the creator, and the one great mentality for putting the world in order for the people to come. She continues to be the deity that cares for and nurtures her children.

The Guadalupe Mountains are an abode of White Painted Woman, and, symbolically, the Nde see Guadalupe Peak as representing her as she lay down to rest after the Creation. This is the center of their universe. This is where they were created (they have no myth of migration from anywhere else).

White Painted Woman gave birth to a helpmate, after being impregnated by the sky spirit of thunder, lightning, rain, and water. The offspring, a major Nde "culture hero" is Child of the Water.

The world as first created was inhabited with some troublesome primordial monsters. As soon as Child of the Water was strong enough, White Painted Woman instructed him in how to control these monsters and make the world safe and livable. First, Child of the Water was sent to get power from his father, Lightning. White Painted Woman sent him to the Sacred Mountain of the East, where black lightning struck him; then to the Sacred Mountain of the South, where blue lightning struck him; then to the Sacred Mountain of the West, where yellow lightning struck him; and finally, to the Sacred Mountain of the North, where white lightning struck him.

With all of his lightning father's powers from his vision quests to the mountains of the four sacred directions, Child of the Water then went out to control the monsters. He conquered them all symbolically, by his wits and diplomacy, not by force of arms. These monsters in the process became protectors or tutelary spirits for Child of the Water and the people to come. He went off to the east, the black world, the plains grasslands, and conquered Buffalo. He went to the south, the blue world, the desert basins, and conquered that terrible monster that kills with its eyes, Antelope. He went to the west, the yellow world, the wooded uplands, and conquered the monstrous giant guardian of that domain, Grizzly Bear. Then, he went to the north, the white world, the mountains, and conquered Eagle, the Lord of the Highest. The sacred landscape of the Mescalero Apaches as put in place by the work of White Painted Woman and Child of the Water, the archetypic mediator, is sometimes equated with Coyote in the traditions, and equated with Jesus Christ by missionized Apaches (Figure 3).

This sacred view of the landscape provides a model for human action, a core paradigm for Apache belief and values. And, notice that it provides an ecological model, as sophisticated as the macroecological model that our modern scientists have given us.

The result is a view of Earth divided into four quarters, which match the four seasons, or divisions of the solar calendar, the solstices and the equinoxes. Four is a sacred number, five if you count center. Their sacred land is bounded by the Sacred Mountains of the Four Directions. Each sacred mountain and quarter of the land was assigned a sacred color and the subdued monster of each quarter became the patron or "boss" of that domain.

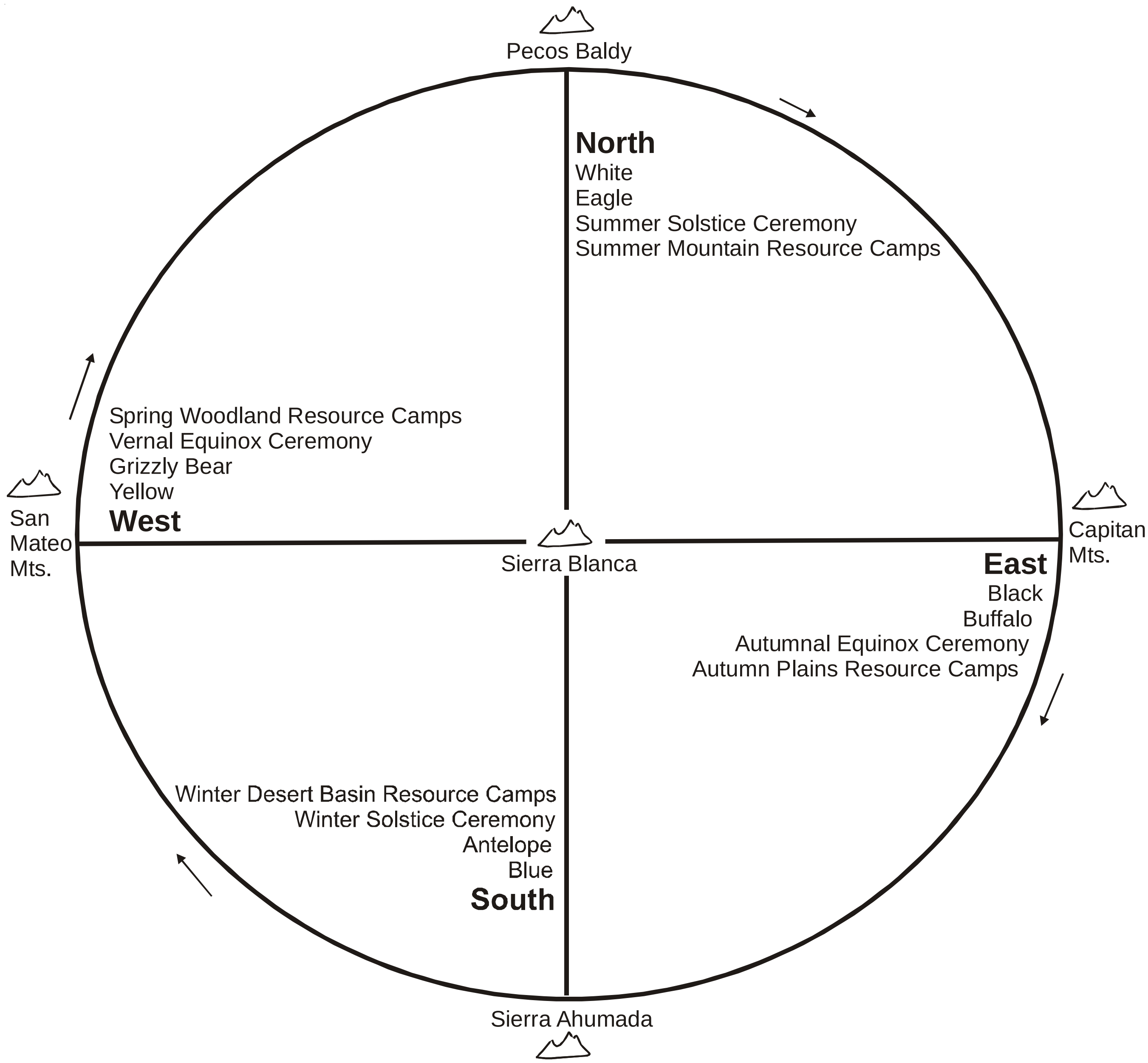


Figure 3. Sacred land of the Mescalero Apaches (Mescaleria). The sacred sunwise circle is the harmony of the universe. Four is the sacred number; five, if you count the center.

The sacred landscape model also demands action and stewardship. It mandates a general pattern of movement of the people over their landscape according to the sacred plan. Movement into each quarter of the year and the land (time and space) was ritualized with a ceremony. Movement into the plains grasslands and into the eastern reaches of the Sacred Land was appropriate just after the autumnal equinox and was signalized by propitiation of Buffalo. This opened Buffalo hunting season and piñon-pine nut gathering. Movement into the desert basins and into the southern reaches of the Sacred Land was appropriate just after the winter solstice and was signalized by propitiation of Antelope. Movement into the wooded uplands and into the western reaches of the Sacred Land was appropriate just after the vernal equinox, and was signalized by propitiation of Grizzly Bear, with a spring bear ceremony. Movement into the mountains and into the northern reaches of the Sacred Land was appropriate just after the summer solstice and was signalized by a ceremony dedicated to Sun and his surrogate Eagle. This ceremony sanctioned hunting in the mountain meadows, and a special focus on bighorn sheep and elk.

So, the sacred landscape model provides the impetus for the pattern of transhumance of the Apaches. They ideally moved in a generally clockwise circle from autumn camps in the plains grasslands, southward and downward to winter camps in the desert basins, northward and upward to spring camps in the wooded uplands, and on northward and upward to summer mountain camps. Then the cycle repeated, as regularly as a sacred liturgy. It was sacred and it was practical. This model provided their general pattern for the utilization of their resources in the general macrobiotic zones of their territory. Besides this general pattern, however, survival depended upon more detailed microecological knowledge that pragmatically modified or introduced complex variations on the general adaptive pattern.

Microecological example

A pragmatic modification was necessary for utilization of the mescal agave (*Agave neomexicana*). The mescal is, of course, the plant that the Spanish settlers of the area referred to when they named the Nde people the Apaches Mescaleros or "mescal eating Apaches." This was one of the staple and sacred plant foods of the Apaches of the Guadalupe Mountain area. There were actually four sacred plant foods, the mescal, the datil or banana yucca, the mesquite, and the piñon-pine nuts. Ideally, all four of these sacred foods are still eaten on important ceremonial occasions.

The mescal agave was harvested just as it was ready to send up its flowing stalk, which marked its maturation and subsequent death of the individual plant immediately after flowering. The plant propagates itself primarily asexually by sending out rhizomes that produce clusters of clones. These clusters of clones often form extensive stands of ten to 20 or more plants on well-drained rocky slopes. The Apache women recognize the clonal nature of these clusters and refer to them as the "mother and her children." The pattern is reminiscent of our familiar garden variety succulent "hen and chicks."

In any of these clusters the individual plants mature sequentially depending primarily upon their age. The Apache women pass on the traditional knowledge of where these stands are and the predictions about how productive each stand will be in the coming year, based upon intimate knowledge of each agave "family." When an individual plant is ready to mature the central bud begins to swell as it accumulates very nutritious nectar to be dedicated to the growth of a flowering stalk, which may grow to a height of 20 feet. The trick is to know exactly when the right time is to harvest the individual plant, just before it sends up the stalk.

The Apache women carefully inspect each plant and only harvest those that are ready. In their inspections, they are helped by the "ant people" who rushed to the maturing plants as they begin to exude their sweet nectar. The immature plants are considered "male" and "bitter" and are not harvested. If they were baked with the mature or "female" plants they would make the whole batch bitter and inedible.

So, in a very real sense, the Apache women tend their gardens of agave and come to know each plant "personally." Also, since the plants reproduce primarily by cloning and they are only harvested when they are mature and at the stage of fruiting and dying, the species is conserved. The resource was not destroyed but carefully nurtured.

Gentry (1982) has expressed concern that the Apaches probably "made large depletions in the agave population" and he even praised the Comanches for keeping the Mescaleros from harvesting the extensive stands of agaves along the eastern bajada of the Sierra Guadalupe by constant warfare. Such a statement demonstrates a gross lack of understanding of the careful stewardship of this sacred resource by the Apaches. They had the wisdom not to "kill the goose" that provided this resource.

Harvesting of the plant also required a pragmatic microecological adjustment to the general pattern of movement. The mescal agave has made a very interesting adjustment to the Guadalupe Mountains ecotonal community. It is found from the southwestern bajada in the Chihuahuan Desert zone from below 5,000 feet (where I have seen it growing beside the lecheguilla agave, a dominant of the zone) to the mountain forest zone above 8,000 feet (where I have seen it growing beside Douglas-fir, a dominant of that zone). The resource begins flowering on the southwestern bajada in early May and flowering continues upslope through August in the mountain forest zone. So, this important resource was available and was utilized by the Apaches in the Guadalupe Mountains from May through August; they moved upslope and used the resource appropriately through these months.

Summary statement

I have outlined the general strategy of the Mescalero Apache–Guadalupe Mountains cultural ecology project and some of the major features of representing a Mescalero Apache cultural landscape in Guadalupe Mountains National Park.

I have briefly outlined the problems of adequately pursuing the objectives of the project on both the macroecological and microecological levels. The details and complexity of an adequate representation of the Mescalero Apache cultural landscape will take many years.

Please accept this presentation as a brief progress report that essentially sets the questions and projects the strategy. The blanks will be filled in the next few years, resulting in a detailed report that will be useful both to the National Park Service and to the Mescalero Apache Nation.

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Chapter 22

Historical and Archaeological Investigations of Apache War Sites, Guadalupe Mountains National Park

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Historical background of the Cushing Campaign
Few who visit the Guadalupe Mountains today realize that this majestic landscape was the setting for cultural conflicts during the 19th century. Prior to European contact, several bands of Mescalero Apaches camped in these mountains. Following the Mexican-American War the Mescaleros used the Guadalupe Mountains as both a sanctuary from punitive U.S. Army expeditions and as a place to prey on travelers that used the nearby Butterfield Overland Trail.

In the span of six weeks—November 18 to December 30, 1869—the Guadalupes were the setting for three cavalry-Mescalero confrontations.[1] These actions typified most Indian War confrontations on the western frontier, which usually involved small-scale cavalry units that attacked and destroyed the winter camps of the Indians. Usually in these attacks most of the Indians would escape but in the process lose all their possessions. Unlike Civil War battlefields, which have been preserved and marked, few Indian War fight locations in the West have been found, let alone memorialized. Through historical analysis, archaeological reconnaissance, and a little luck, at least two such sites in the Guadalupes have recently been located.

The three confrontations that took place in the Guadalupes during November and December 1869 are commonly referred to as the Cushing fights, named after First Lieutenant Howard Bass Cushing, the leader of the small cavalry unit that dared to enter the Apaches' winter stronghold.

Cushing's punitive expedition originated from Fort Stanton, a military post located in the Sierra Blanca Range near present-day Ruidoso, New Mexico. Built to curb Mescalero raids, the post had been abandoned at the outbreak of the Civil War. In 1862 it was re-garrisoned as the base of operations during Colonel

Figure 1. First Lieutenant Howard B. Cushing. Photo taken circa 1870.

Christopher "Kit" Carson's campaign to subdue the Mescaleros.[2] After having been defeated in several skirmishes the Mescaleros were placed on the bleak, God-forsaken Bosque Redondo Reservation in eastern New Mexico. Consolidated with and tormented by the Navajos, the Apaches bolted from the reservation in November 1865 and returned to the Sierra Blanca, Sacramento, and Guadalupe mountains.[3]

Free again, the Mescaleros renewed their raiding on settlements in New Mexico and west Texas. In September 1867 warriors struck Fort Union's livestock herd near Mora. Captain Francis Wilson, Company D, Third U.S. Cavalry, tracked the Apaches south into Dog Canyon of the Sacramento Mountains, then east to the Guadalupes. The troopers finally caught the Apaches in the Sierra Diablo Range north of Van Horn, Texas. Wilson surprised some 40 warriors, killing six of them and putting the rest to flight. In the ensuing 15-mile chase the cavalry unit found the main Mescalero camp, destroyed it, and killed another 25 to 30 Apaches. Wilson reported one soldier killed and five wounded.[4] But despite Wilson's success, Mescalero raids continued. In March they struck the settlement of Tularosa, New Mexico, killing and capturing several of its inhabitants, and taking 2,200 head of sheep and cattle. Military patrols pursued the raiders as far as the Guadalupe Mountains before aborting their mission.[5]

In July 1868, the Mescaleros scattered a cattle herd at Independence Spring near the Guadalupes.[6] In May 1869, they attacked a wagon train on San Augustin Pass, near Mesilla, killing two soldiers.[7] To counter growing Apache activities, Captain Frank Stanwood led a Third Cavalry troop from Fort Stanton. The month-long expedition covered nearly 500 miles, all the way to Hueco Tanks and Isleta Pueblo.[8] Stanwood made some observations that proved beneficial for future military strategy. He estimated that the Mescaleros could not muster more than 250 warriors, perhaps a few more when occasionally augmented by Lipan Apaches and Comanches. He believed that the Mescaleros operated out of the Guadalupe Mountains and the Sierra Diablos.[9]

Meanwhile, Mescalero Agent Lieutenant Argalus G. Hennisee wrote to his superiors on August 31, 1869, reporting that the Mescaleros desired peace and wanted the establishment of a reservation south of Fort Stanton.[10] Hennisee's words mirrored the remarks of former agent Lorenzo Labadi, who commented in his letter of June 30, 1869 that the delay in establishing a reservation might result in the total ruin perhaps even "total extermination" of the tribe.[11] While government officials pondered their next move, the Mescaleros did not.

Under the cloak of darkness on November 13, 1869 a band of Mescaleros led by José de la Paz (also known as "Peaceful Joe") raided the Robert Casey ranch on the Rio Hondo below Fort Stanton. The warriors were so stealthful that they were able to steal all 300 head of cattle, which were corralled only 30 yards from the ranch house. No one in the Casey family, not even the two watch dogs, realized what had transpired until the next morning.[12] Casey rode to Fort Stanton and informed the commanding officer, Lieutenant Colonel August V. Kautz, as to the theft.

Kautz immediately ordered the 32 men of Company F, Third Cavalry into the field. The column was officered by First Lieutenant Howard B. Cushing and Second Lieutenant Frank Yeaton.[13] Cushing was born in Wisconsin in 1822, but at the outbreak of the Civil War was living in Illinois. He enlisted as a private in Company B, First Illinois Light Artillery. Howard was one of four Cushing brothers, three of whom were decorated for bravery during the Civil War. After the death of his brother Alonzo at Gettysburg, Howard applied for a second lieutenant vacancy in the same unit as his brother, the Fourth U.S. Artillery. Howard Cushing received a commission and served in the Fourth for the remainder of the war. Following the conclusion of the Civil War, Cushing's military career plummeted for his part in attempting to free his commanding officer from jail. After serving a one year's suspension for his indiscretions, Cushing applied for and was granted a transfer to Company F, Third Cavalry in September 1867. Three months later he received a promotion to First Lieutenant. After brief stints at Fort Union and Fort Bascom, New Mexico and in Indian Territory, Cushing's company was transferred to Fort Stanton. He participated in several scouting missions throughout the spring and summer of 1869. But now, mid-November 1869, he was to have his chance at independent command.[14]

Lieutenant John G. Bourke, who later served under Cushing in Arizona, described him as slight of frame, sinewy, and standing about 5-feet-7-inches tall. Piercing blue-gray eyes topped by a shock of light-brown hair highlighted a nervous temperament. Bourke wrote that, "His bravery was beyond question, his judgement, as I had good reason afterwards to learn, was not always to be trusted. He would hazard everything on the turn of the card."[15] Cushing's junior officer, Second Lieutenant Frank Yeaton, was new to the regiment.[16]

Cushing's troop, which included several civilian guides, accompanied Casey to his ranch where they camped for the evening.[17] On the 15th, the troop followed the Rio Hondo, discovering the arrow-shot remains of several head of cattle. On the 18th they surprised a Mescalero camp on the northern slopes of the Guadalupe Mountains, in Last Chance Canyon. This site has been located by Forest Service archaeologists, yielding numerous artifacts associated with the November 18th conflict. The troopers recovered most of Casey's livestock and captured 30 head of horses and mules belonging to the Indians. Cushing's casualties amounted to two wounded. Indian losses were about the same; however, they were now destitute, having lost virtually all their food and belongings just as winter weather was beginning in the Guadalupes. On November 23rd, Cushing returned to Fort Stanton, having completed a successful campaign that covered 370 miles in rugged terrain.[18]

Kautz permitted his energetic lieutenant to conduct another expedition against the Mescaleros. Because of the smallness of Cushing's command—only 35 enlisted men comprised Company F—Kautz augmented this force with 28 citizen volunteers.[19] On December 19, Cushing departed Fort Stanton with a pack train laden with 20-days worth of rations and extra ammunition. The troop retraced their November route during a winter snowstorm and subzero temperatures. On Christmas Eve Cushing's command re-entered Last Chance Canyon and marched southeastward, beyond the Apache camp that they had destroyed in November. A maze of diverging trails eventually became one heavily used trail, which ultimately led Cushing over the Guadalupes. From Christmas Day through the early morning of December 26th, the troop passed by several recently abandoned Apache camps.

From a point high in the Guadalupes, Cushing followed the tracks of one pony. Ten miles later, the solitary tracks grew to 20. By 11 a.m. the troop entered a wide canyon. At 12:30 p.m., sensing that an Apache camp lay nearby, some of the troopers dismounted, formed a skirmish line, and slowly advanced. An hour later Indian ponies were spotted grazing on the slopes, which caused Cushing to place additional troopers on the skirmish line just ahead of the mounted men. An Apache camp, formerly concealed by the undulating ground, suddenly came into view.[20] The camp consisted of 40 to 50 skin and brush-covered structures that sheltered some 200 persons, including a fighting force of about 80 warriors.

The warriors attempted to blunt the advancing troopers, filling the air with arrows and bullets. Some of the troopers' horses were wounded, and Lieutenant Yeaton went down with arrow wounds to his wrist and breast. He was the only person in the punitive force that was hit during the fight. Warrior firepower came too little, too late; within minutes the troopers controlled their camp. The Mescaleros scattered in several directions, making pursuit both difficult and dangerous; however, destruction of the lodges and their contents ensured Cushing's victory. For the next several hours the troopers burned large supplies of tanned and untanned buffalo, deer, antelope, and beef hides; some 20 thousand pounds of mescal; and 15 thousand pounds of jerked and packed beef. Everything else of value—clothing, weapons, and cooking utensils—went up in flames or were smashed to pieces. As to Indian losses, Cushing's report is vague, stating that "a good many Indians were killed". He also noted that "no particular effort was made to take any prisoners".[21]

After dark, the troopers and volunteers rode southwest for a mile and camped for the night. On the morning of December 27th, Cushing retraced his route, riding past the burned-out Apache camp and continued along his old trail. For the next three days his troop continued its trek through the Guadalupes, heading in a northwesterly direction as if returning to Fort Stanton. But this was a ruse; the young lieutenant was not done with the Apaches yet. On the early morning of December 30th, Cushing cut loose from his slow-moving packtrain. He picked 40 well-armed men, rationed them for four days, then proceeded south to continue to seek out and destroy Mescalero strongholds. The packtrain and remaining men, including the wounded Yeaton, were ordered to travel down the Rio Azul (now named the Black River) to the Pecos River, then march up the latter stream to near its confluence with the Rio Peñasco, and to wait there for Cushing's return.[22]

Twenty-five miles after splitting from his packtrain, Cushing's forces began to see numerous pony tracks. Shortly after 2 p.m., the soldiers watered their horse at Ojo Sutalosa, which may be the present junction of Nickel and Lamar creeks. The mouth of a major canyon lay five miles beyond. When they were about a mile from the canyon's entrance they spotted a thin plume of smoke, which indicated that the target had been discovered. Due to broken terrain it took the troopers and volunteers considerable time to negotiate the last mile. Almost too late, the Apaches spotted the approaching attackers. Some of the warriors fought a delaying action while the

Figure 2. Entrance into McKittrick Canyon, looking west. Near this location, Cushing and his troops saw a "thin plume of smoke," about one-half mile inside the mouth of the canyon, on December 30, 1869.

rest of their band scattered in several directions away from the advancing skirmish line of their enemy. Except for some of their horses, the Apaches had abandoned everything.[23] This Apache camp was smaller than the one destroyed four days earlier, numbering only 25 to 30 lodges. Nonetheless, it contained an unusually large number of inhabitants for its size, which suggested to Cushing that it consisted of refugees from the previously destroyed camps.[24]

Cushing posted men around the perimeter of the camp in order to hold back the warriors that massed above the troopers on the rocky slopes. The remaining troopers and civilian volunteers busied themselves with destroying the contents of the camp. With approaching darkness Cushing had his men round up the captured livestock then retraced their route to Ojo Sutalosa, reaching it in the early hours of December 31st.[25]

The attack column rejoined its packtrain near the Rio Peñasco, the reunited command then headed back to Fort Stanton. Cushing was proud of his accomplishments. In just 19 days he and his men had traversed more than 530 miles, negotiating some of the most rugged terrain in the Southwest under severe winter conditions, fought and won two fights, and proved to the Mescaleros that they were not safe even in their most remote haunts. Lieutenant Colonel Kautz, who initially had held a low opinion of Cushing, now admitted that the energetic lieutenant was an unusually skillful Indian fighter: he produced concrete results where others had failed. Kautz endorsed Cushing's report of the campaign, and added a recommendation that both Cushing and Yeaton receive brevet promotions.[26]

For the Mescalero Apaches, the Cushing campaign of November-December 1869 represented the most recent clashes in what was to become a series of military maneuvers designed to force the Apaches into submitting to reservation confinement. Just two weeks after Cushing's foray into the Guadalupes, another column of troopers—this time six companies of Ninth Cavalry "Buffalo Soldiers" out of Fort Davis, Texas—struck another Mescalero encampment in the Guadalupes near the headwaters of Delaware Creek. Captain Francis S. Dodge, the commanding officer, reported killing or wounding 50 Apaches, capturing livestock, and torching all their winter supplies.[27]

The destruction of the Apache camps in the Guadalupe Mountains forced the Mescalero leader Cadete and his followers to seek shelter with their sometime allies, the Comanches on the Llano Estacado. Meanwhile, Apache Chief José de la Paz, worn down physically and emotionally by the unrelenting military strikes, brought a few of his followers to Fort Stanton in February 1870. In turn, José de la Paz was sent as a peace envoy to Cadete to induce the Mescalero leader to surrender. La Paz returned in April with about 30 refugees and word from Cadete that the remaining Mescaleros would surrender, which they eventually did in the summer of 1871. On May 29, 1873, the U.S. government established the Mescalero reservation.[28]

The Cushing fights were not mammoth struggles that shaped the course of destiny. Nonetheless, combined with other military and non-military events of the period and region, they brought to a close the freedom of the Mescaleros while also permitting non-Indian settlement of the Guadalupe Mountains. The punitive tactics employed by Cushing contributed to the growing ethical dilemma that emerged during the latter half of the 19th century, specifically regarding military strikes that resulted in the deaths of women and children, as well as warriors. The Apache camps that Cushing destroyed on November 18, December 26, and December 30, 1869, should not be forgotten or lost; rather they should be found, recorded, and protected so that those who fought for their mountain homeland will also be remembered.

Archaeological investigations of the Cushing Campaign

Shortly after its creation in 1972, Guadalupe Mountains National Park commemorated the Cushing fight of December 30, 1869, by placing an interpretive sign at Manzanita Spring. Manzanita Spring is a permanent pool of water that is an oasis within an otherwise forbidding high desert landscape, and there is archaeological evidence indicating that the spring was a focal point for humans for thousands of years. Undoubtedly, various Apache bands also utilized it when they roamed through the Guadalupe Mountains during the 19th century. The historian who conducted research for the park regarding the Cushing campaign assumed that during the late fall of 1869 the Apaches must have camped in the immediate vicinity of Manzanita Spring.

There is only one problem with this assumption: the December 30th fight was reported by Lieutenant Cushing as being just inside the mouth of a narrow, steep-sided canyon. Yet Manzanita Spring is not within a narrow canyon; rather, it is at the base of the south-facing slopes of the Guadalupe Mountains. There is, in fact, only one canyon in the general vicinity that possesses similarities with Cushing's rather sketchy descriptions of the fight, McKittrick Canyon, which is located some five miles east of Manzanita Spring, and extends for several miles into the otherwise virtually impassible front range of the Guadalupes. To this day the narrow confines within the upper reaches of the canyon hold the basic needs of the 19th century Apache: there are several permanently flowing springs here; an extensive forest for providing food, fuel, and construction materials; and game animals including deer and elk are present year round. For the Apaches, the canyon's numerous side drainages also provided escape routes if a military force should ever have succeeded in finding them in their mountain stronghold. Cushing reported that his command was about a mile south of the canyon entrance when they first saw a thin plume of smoke rising from a point just beyond the entrance. Some 30 years ago two Spencer cartridge cases were found a few hundred feet east of the entrance of McKittrick Canyon, near the present-day visitor contact station. Both cartridge cases, which are in the park col-

Figure 3. Location of the Apache camp that was attacked by Cushing's troop on December 30, 1869. Artifacts associated with this attack were found just above the limestone slickrock, left of center. Photo looking south-southwest.

lection, are significant to this study because the Spencer carbine was a regulation firearm used by cavalry troopers from about 1863 up until the early 1870s. Thus, one would expect to find Spencer cartridge cases at the location of the December 30, 1869, fight. Both cartridges have headstamps that date their manufacture prior to 1869.

We also learned that Mark Rosacker, a southeastern New Mexico historian who has been researching Cushing's 1869 campaign for the last 10 years, had reached the same conclusion some years ago: that McKittrick Canyon was probably the actual location for the December 30th fight. Mark also graciously shared his research regarding Cushing's 1869 campaign.

With this information we presented our theory to Superintendent Larry Henderson, who gave his enthusiastic support for an archaeological survey within the upper reaches of McKittrick Canyon. Our area of investigation was a segment of canyon measuring approximately one mile-long and one-third-mile wide.

Our survey crew members were all volunteers; several of them are skilled metal detector operators who have assisted us during our investigations of other sites of battles in the Southwest. In addition, the park provided us with a global positioning unit for determining provenience information for any discovered artifacts. The crew members, spaced approximately 10 feet apart, walked a series of parallel transects. On the first day we worked along the south-facing escarpment of the second terrace: we were looking for evidence of a skirmish line, that is, where a line of troopers may have initially positioned themselves when they fired into the Apache camp. A rough linear scattering of Spencer cartridge cases would indicate where the troopers formed their initial skirmish line. Unfortunately, we did not expose such an artifact patterning along the second terrace, but we did find physical evidence where a metal arrow point had been manufactured, consisting of a clustering of discarded metal snips that were cut or chiseled from a piece of barrel band. This evidence, albeit meager, suggested to us that an Apache camp had been in the general vicinity.

We then surveyed the first terrace on the south side of the canyon; it was here some 30 years ago that the two Spencer cartridge cases had been found. The first terrace, we believed, appeared to be a good location for the placement of an Apache camp—the ground is level and free of large rocks and boulders, with water and wood close by. We believed the camp location would be indicated by widespread scatterings of fired bullets and cartridge cases—evidence of the final phase of the troopers' attack—intermixed with personal belongings of the Apaches.

Our work here did, in fact, produce a few artifacts that are appropriate to the time period: an unfired Spencer cartridge round, a Spencer cartridge case that had been intentionally split opened and flattened, an iron button of the type used on uniform pants of this era, a cinch ring for a saddle or horse pack, and two Henry cartridge cases. Henry cartridges were intended for use in the Henry rifle but could also be used in the Model 1867 Winchester rifle. Neither of these two firearm models was issued to cavalry troopers, who would have all been armed with Spencer carbines. It is, therefore, more likely that the weapon that fired the Henry cartridges was the personal possession of one of the civilian volunteers that had accompanied Cushing's force; it is also possible that one or more of the Apaches were armed with Henry or Winchester rifles.

Although encouraging, these few artifacts found within a 5-acre area did not conclusively prove that we had found the Apache camp. We then expanded our survey westward, towards the canyon where it becomes quite constricted and the terrace narrows to only a few feet wide on the south side of the canyon wash. It was within this constricted area, just upslope from the slickrock, that we began to find more artifacts: a fired Spencer bullet, two Spencer cartridge cases, two brass cinch rings of a type used on 19th century military equipage, a crushed gunpowder flask, a fired percussion cap, a uniform pants button, and a fragment of a cast iron kettle.

Opposite this artifact concentration and on the northern side of the wash we found a .44 caliber pistol bullet that had been fired, a piece of lead that had been pounded into a sheet, and another pants button. The two Spencer cartridge cases have headstamps indicating that they were manufactured prior to 1870.
We believe that the gunpowder flask and percussion cap reflect at least one type of weapon that the Apaches possessed, that is, a muzzle loader. The gunpowder flask was found directly under a large rock, the kettle fragment found nearby. This reflects the general destruction of the Apaches' belongings by the troopers. The buttons could have been lost by the troopers, by their civilian volunteers, or even by the Apaches.

Why didn't we find more artifacts? It is quite possible that most of the terrace edge in this location of the canyon has eroded away since 1869, thereby removing the location where the troopers piled up and burned the Apaches' belongings. Lieutenant Cushing noted that since he had lost the element of surprise, most of the Apaches had already fled their encampment and made their escape up the steep flanks of the canyon. This might explain why so few cartridge cases and bullets were found—the troopers, when they reached the canyon bottom, had few targets at which to shoot. Finally, the fight did not result in any known casualties, which is another reason for the scarcity of spent ammunition.

A few months after the successful completion of this survey, we attempted to find evidence of the Apache escape route that led out of the canyon bottom. Lieutenant Cushing stated in his report that the Apaches fled up the steep, boulder-strewn slopes overlooking their camp, that several of the Apaches' ponies had slipped and rolled down the slopes, and that the Apaches used boulders for cover when they fired their weapons at the troopers. Using this very general description, the most likely location of their escape route is the minor drainage and boulder-strewn, east-facing slope on the south side of the canyon entrance.

Unfortunately, our survey of the slope did not result in our finding any artifacts appropriate for this action, such as percussion caps, dropped rifle or musket balls, and spent Spencer bullets fired by the troopers. We then continued our survey some distance farther up the canyon and did locate one fired bullet, but its damaged condition prevented a determination as to type and caliber. Although negative information was abundant, this does not necessarily disprove our theory as to the location of the escape route: dense brush obscures much of the slope surface, and the slope itself becomes too steep at higher elevations to safely inspect it for artifacts.

In response to a previous request by the park superintendent, the following day we shifted operations to a location southeast of Lower Pine Spring and east of the park headquarters. It has long been known by local ranchers and park personnel that during the 1870s and 1880s various troops of Fort Davis' Ninth Cavalry—the famous "Buffalo Soldiers"—had established a base camp at this location. Park managers wanted us to determine the approximate areal extent and internal complexity of this camp. The survey involved metal detector sweeps of three, 15-feet-wide sample transects, the immediate area around a rifle pit, and around each of 21 rock piles. The rock piles, each one representing a formal camp hearth, are in rough alignment and are spaced between six and 10 feet apart.

Forty-eight artifacts were recovered from the sample sweep, and include uniform buttons, eight penny box nails—which were the nail size used to construct ration and ammunition boxes—10 penny framing nails, both whole and fragmented horseshoe nails, horse tack, and personal possessions such as a fragment of a silver locket, a padlock key, a fish hook, fragments of a baking powder can, and bottle fragments. None of the artifacts were collected. Artifacts found below surface were reburied within their original locations. Most of the artifacts occur within a 120-by-60-foot area that is bisected lengthwise by the linear array of rock piles/hearths.

Of some note were the discoveries of four Spencer cartridge cases, a .44 caliber round ball fired from a lever action/percussion cap-type pistol, two .58 caliber musket balls, and one .52 caliber ball that had been fired. As previously noted, the Spencer carbine was the regulation cavalry firearm when Cushing led his troop through the Guadalupes, some eight years before the Ninth Cavalry operated in these mountains. The Spencer had been an obsolete cavalry weapon for several years when the Ninth Cavalry troopers occupied Lower Pine Springs during the 1870s and 1880s; therefore, the presence of Spencer cartridge cases raises the intriguing possibility that Pine Spring was the location of Cushing's December 26, 1869, fight.

If the site dates to the winter of 1869–1870, then it would also explain the presence of the pistol, musket, and rifle balls. By the late 1870s a trooper would have had revolvers that used metallic cartridges, probably of .45 caliber. A military pistol that used percussion caps, for example the .44 caliber, lever-action Army Colts and Remingtons of the Civil War era, had been obsolete as a military sidearm for years. Thus, the .44 caliber pistol ball could have been fired in 1869–1870 by an Apache armed with an obsolete militarily percussion cap pistol; the same applies for the two .58 caliber musket balls and the one .52 caliber rifle ball, which would have been fired from a muzzle loader. Muzzle-loaded firearms of these calibers had been obsolete U.S. military weapons since the mid-1850s when the Army adopted the .69 caliber (and later, the .58 caliber Miníe conical bullet). This suggests that the musket and rifle balls had been fired by Apaches. On this admittedly scanty evidence we have reason to suspect that Pine Spring is also the site of an Apache Wars fight: perhaps the Cushing fight of December 26, 1869; or possibly this is the location of a fight known to have taken place somewhere along the southern front range of the Guadalupes in 1867.

The late 1870s–early 1880s encampment had been occupied off-and-on by several hundred troopers; therefore, the number of recovered artifacts seemed rather sparse. We suspected that the troopers had policed their living area of most of its trash then deposited the trash some distance away from the camp. Accordingly, we surveyed along the edge of an arroyo located to the south and west of the camp. In one location alongside the arroyo we did find quantities of subsurface artifacts: food and baking powder cans, bottle fragments, a Spencer cartridge case, a .45/70 Springfield cartridge case, and a uniform button. The Spencer cartridge case may have ended up in the dump as a result of policing the encampment by Tenth Cavalry troopers. The .45/70 cartridge case was used in the Springfield Model 1873 carbine, thereby an artifact reflecting the latter years of camp occupation.

We believe that more work is warranted around Lower Pine Spring. Intensive metal detector sweeps, covering a much broader area might produce evidence of skirmish lines and of the Apaches' possessions wrecked by Cushing's men when they destroyed the camp. The excavation of a number of test units within the dump would also provide a fascinating insight into what the Buffalo Soldiers took with them during their campaigns through the Guadalupe Mountains.

Note: At present (2003), NEIL C. MANGUM is the superintendent at Chiricahua National Monument in Arizona.

Endnotes

1. Adjutant General's Office, *Chronological List of Actions, etc. With Indians from January, 1837 to January, 1891*, Introduction by Dale E. Floyd (Fort Collins, Colorado: Old Army Press, 1979), 43–44; Headquarters Military Division of the Missouri, *Record of Engagements with Hostile Indians within the Military Division of the Missouri from 1868 to 1882, Lieutenant-General P. H. Sheridan, Commanding* (Fort Collins, Colorado: Old Army Press, 1972), 25.

2. Robert W. Frazer, *Forts of the West* (Norman: University of Oklahoma Press, 1977), 103; Robert M. Utley, *Frontiersmen in Blue: The United States Army and the Indian, 1848–1865* (Lincoln: University of Nebraska Press, 1981), 235–237.

3. Utley, *Frontiersmen in Blue*, 245–247.

4. Leo Oliva, *Fort Union and the Frontier Army in the Southwest* (Santa Fe: U.S. Department of the Interior, National Park Service, 1993), 353–355; also found in excerpts from Fort Union National Monument, Box 184, 39–40, Fort Union National Monument historical files.

5. *Record of Engagements*, 7.

6. Alpine Avalanche, April 3, 1913.

7. *Record of Engagements*, 19.

8. Kenneth A. Randall, *Only the Echoes: The Life of Howard Bass Cushing* (Las Cruces: Yucca Press, 1995), 49; *Record of Engagements*, 23.

9. Albert H. Schroeder, *A Study of the Apache Indians, Part III, the Mescalero Apaches* (New York: Garland Publishing Company, 1974), 72.
10. House Executive Documents, 40th Congress, 1st session, no. 1, part 3, 689.

11. Ibid., 687.

12. James D. Shinkle, *Robert Casey and the Ranch on the Rio Hondo* (Roswell, New Mexico: Hall-Poorbaugh Press, 1970), 76; Andrew Wallace, "Duty in the District of New Mexico: A Military Memoir," *New Mexico Historical Review* 50 (July 1975), 244. There is a discrepancy in the number of cattle stolen. Casey' son places the number at 300 while Lt. Col. Kautz noted in his diary that Casey had 115 head of cattle lifted.

13. Wallace, "A Military Memoir," 244; Dan L. Thrapp, *Encyclopedia of Frontier Biography*, 3 volumes. (Glendale, California: The Arthur H. Clark Co., 1988), 362; John P. Wilson, "Lt. H. B. Cushing: Indian Fighter Extraordinary," *El Palacio* 76 (Spring 1969), 40–46.

14. Biographical sketches of Cushing can be found in the following: Theron W. Haight, *Three Wisconsin Cushings: A Sketch of the Lives of Howard B., Alonzo H. and William B. Cushing, Children of a Pioneer Family of Waukesha Co.* (Madison, Wisconsin: Democrat Printing Company, 1910); Donald N. Bentz, "Sword of Revenge," *Golden West* 8 (January 1972); Randall, *Only the Echoes*; Thrapp, *Encyclopedia of Frontier Biography*, 361–362; and Wilson, "Lt. H.B. Cushing: Indian Fighter Extraordinary," 40–46.

15. Lansing B. Bloom ed., "Bourke on the Southwest II," *New Mexico Historical Review* 9 (January 1934), 46–47. Bourke's remarks were well founded. The dashing but reckless Cushing was killed May 5, 1871, in the Whetstone Mountains of southeastern Arizona by Apaches under Juh. See Dan L. Thrapp, *The Conquest of Apacheria* (Norman: University of Oklahoma Press, 1967), chapter 6, 63–78.

16. Bentz, "Sword of Revenge," 40.

17. Shinkle, *Robert Casey*, 77.

18. Wilson, "Lt. H. B. Cushing," 4041; *Record of Engagements*, 25; Wallace, "A Military Memoir," 244.
19. Wallace, "A Military Memoir," 244–245; Calvin Horn, *New Mexico's Troubled Years: The Story of the Early Territorial Governors* (Albuquerque: Horn & Wallace, 1963), 143.

20. Information of the Cushing fights of December 26 and 30 is taken from Lt. Cushing's official report dated "Fort Stanton, N.M., January 8, 1870," found in Wilson, "Lt. H. B. Cushing," 41–44. Cushing's report is also found in Letters Received, District of New Mexico, RG 98, National Archives; see also W. C. Jameson, *The Guadalupe Mountains: Island in the Desert* (El Paso: Texas Western Press, 1996), 25–38.
21. Ibid., 41–42; The unlucky Yeaton survived his return trip to Fort Stanton. Badly wounded, he spent time in the post hospital. In November 1871, Yeaton retired from the U.S. Army with the rank of Captain. Less than a year later, August 17, 1872, he died of "consumption" as a result of the gunshot wound received in the Guadalupe Mountain fight of December 26, 1869.
22. Ibid., 42–43.
23. Ibid., 43.
24. Ibid., 43; Wilson, "A Military Memoir," 245.
25. Ibid., 43.
26. Wilson, "A Military Memoir," 246.
27. Letters Sent, volume 2, Fort Davis, Captain John W. French, 25th Infantry to Acting Assistant Inspector General, Dept. of Texas San Antonio, Fort Davis, January 28, 1871. Photocopy in Fort Davis National Historic Site files marked "Utley Scrapbook."

28. C. L. Sonnichsen, *The Mescalero Apaches* (Norman: University of Oklahoma Press, 1973), 150, 151, 157.

Chapter 23

Celebrating the Historic Architecture of Guadalupe Mountains National Park

BARBARA ZOOK was an historical architect with the National Park Service Southwest Regional Office and is now a private architectural consultant in Santa Fe, New Mexico. She completed and was involved in the stabilization report for the Grisham-Hunter Line Cabin, the window repair project design for Williams Ranch, re-roofing of Ship-on-the-Desert, preliminary condition assessment of Frijole Ranch structures, preliminary condition assessment of the Bowl Cabin, and the stabilization design for the Pinery ruins in Guadalupe Mountains National Park.

It is an honor and a privilege to be here, particularly since I understand that the roof on the Wallace Pratt Lodge is leaking. I am also honored to share this session with Dwight [Pitcaithley]. When I first started with the National Park Service in 1988, my project was to survey the ruins of Fort Union and determine the type and rate of deterioration; Dwight's historic structures report served as a baseline of information for me.

We heard from Dr. Pray and others yesterday that Guadalupe Mountains National Park was established in order to offer the public an understanding of the geological values together with scenic and other natural values. In my talk today I want to highlight the concept of cultural landscapes, because as Dwight just mentioned, we start to look at our cultural resources as being integrated with the landscape. For Guadalupe, Wallace Stegner expressed it very well: "In the West it is impossible to be unconscious of or indifferent to space. Out in the boondocks it engulfs us. And it does contribute to an understanding only if because of the vast emptiness people have lived with dignity, of rareness and must do much of what they do without help, and because of self-reliance and its social imperative, being all part of the code."

In the sessions this morning and yesterday we have been introduced to the powerful individuals who have passed through the park and who have researched the park, mined the park, farmed it, and ranched it. My presentation is going to focus on how these wonderful remaining architectural features celebrate these individuals. Quite often, of the 34 features, we have lost some. Dwight mentioned the 1972 work by Texas Tech. About 13 structures no longer exist. As historical architects, historians, landscape architects, and people on the maintenance crews and the preservations crews, what we are trying to do is extend the life of these structures that exist here in the park. Yesterday Dr. Pray said Guadalupe Mountains wouldn't exist without the rock. Well, a lot of these structures would also not exist without the rock. We are fortunate that they are not adobe; they do tend to last longer. We that are trying to extend their lives have a somewhat easier job than if we were just dealing with adobe structures.

"In the West it is impossible to be unconscious of or indifferent to space. Out in the boondocks it engulfs us."
—Wallace Stegner

There have been many reports prepared in the last 10 years for the park. In 1994 Peggy Froeschaur completed a cultural landscape report of Frijole Ranch, and there are many more cultural landscape reports that need to be done here at the park: Williams Ranch, Grisham-Hunter Line Cabin, Wallace Pratt Lodge, Pratt's Ship-on-the-Desert. The National Park Service has been working very hard with limited resources to maintain all these sites. First, I am going to talk a little bit about the themes of these architectural symbols as background. Then I am going to talk a little bit about what the National Park Service is doing to preserve each of these sites and what we can do in the fu-

Often they would put their vegetables in the back of their carts, cover them with wet cloths, and travel all night long to markets in the nearest destinations.

ture. Of course, the eight major themes are ranching, commercial use, mining, military conquest, recreation, research, exploration, and farming. As you have heard over the last couple of days, ranching is probably the most prominent theme; many people acquired small ranches within the area of the park because of the 1862 Homestead Act. People like the Smiths, the Glovers, and the Williams acquired property in the ranch, and as we well know, Judge J. C. Hunter then consolidated the ranch into over 72,000 acres—one large operation along with his brothers who also drilled oil wells. The remnants of the ranching period not only include the wonderful sites like Frijole Ranch or Williams Ranch, but also the water systems and the landscape features that made ranching possible in the area. In fact, mohair wool production was viable until 1963, and we are so fortunate to have so many remnants of the ranching period and many more to be surveyed.

Another theme is commercial use. I think one of our best remnants was the Glover property, which once consisted of as many as nine structures. The Glovers moved in structures; they adapted other building materials to construct buildings that they used for their operation, which included the café, gas station, a dance hall that was also a dining hall, a store, and corrals. Unfortunately, the Glover buildings had to be demolished because they had become so deteriorated that they were no longer able to be maintained by the park. Fortunately, we have extensive documentation of the site. Farming was also prevalent in that the Glovers had a truck farm, and across the valley the Taylors raised vegetables and had an orchard. All these families would have to go to Van Horn to sell their products, so you can understand how rigorous this must have been. Often they would put their vegetables in the back of their carts, cover them with wet cloths, and travel all night long to markets in the nearest destinations. In Frijole there are extensive water systems, an orchard and fields and farming areas that the Smiths farmed along with their root cellar and spring house, using very innovative techniques in this hot, dry climate to make their lives in such a remote and isolated area.

We also have recreation, and we heard this morning about Wallace Pratt and his use of the canyon. J. C. Hunter also stocked his ranch with American elk and wild turkey and encouraged hunting. We have continued research. Then we have the military conquests that were described by Charlie Haecker yesterday. Then there's exploration. We heard this morning about the many people passing through the mountains along Butterfield Trail, the Pinery Station, and the California Gold Rush.

An older structure in the park that is representative of the exploration period is the Pinery. I think what is important to point out to you is that the Pinery ruins are constructed of stone in mud mortar. The mud mortar washes out, water penetrates, the water freezes, and then thaws and cracks the mortar, so there is an ongoing cycle of maintenance required. Eventually, what happens are the top stones fall off, and the veneer stones fall off. Once the detachment of the veneer stones occurs, the wall begins to lean. Since Guadalupe Mountains has been a national park, a struggle against these natural forces to maintain this site has been ensued by the park maintenance staff and the regional preservation crews. For instance, at the Pinery at one point the wall was leaning and it was pushed back into place. Various amendments have been studied to extend the life of the mortar, like using a product that is an acrylic-based product by the name of Roplex. We find it does extend the life. The best thing is ongoing routine maintenance, repointing the joints, and unfortunately as you well know, staff resources are limited and money is limited, so we are constantly faced with how to maintain the site.

Frijole Ranch includes the first two rooms built by the Rader brothers and then later added onto by the Smiths. There is also the spring house which has the wonderful flow of water through it that cooled vegetables and fruits that were placed there. In fact, the National

Park Service is still watering the lawn using the irrigation ditches that existed. Now with the wonderful new information provided by Peggy Froeschaur's landscape report, we can potentially interpret the original orchards and garden areas. Ranch structures also included the root cellar and the school house. What happens with wood, as you well know, is moisture rots the base. The National Park Service has repaired the base of the school house walls, installing a new sill plate that was pressure treated. The windows had to be repaired, the building's roof was replaced, and there's an ongoing cycle of applying stain to the exterior. New facilities are often needed. The National Park Service added a barn in a place where a barn previously existed. Adjacent to the fields and the garden that Peggy identified in her cultural landscape report are corrals and stone walls. Many of these are really hard for park visitors to see. Often, we are dealing with public use of the area. A new handicapped access ramp, which was installed about five years ago, now enables all visitors to access the ranch.

At Williams Ranch, Dolph Williams lived there until the early 1940s. It is distinguished because it is more of a high-style design representative of local vernacular architecture, and it is one of the few structures remaining that is made out of milled lumber. Here we have had to repair the roof with wood shingles; we have had to repair the windows and cover them for further protection because it is such an isolated site; we have had to rebuild the stone foundation. We need to do a historic structures report to identify associated landscape features like this tank and water source for the ranch. We have lost some buildings. Here is an out building that no longer exists.

In McKittrick Canyon, the Grisham-Hunter Line Cabin has been repaired in the last year or so. A tree grew too close to a corner wall; the tree was removed, and stone had to be relaid. The roof had to be repaired and has been replaced. Evident here is stone laid in mud mortar and deterioration of windows and door elements. An associated structure is a generator building and garage. It is interesting because we were so fortunate to have the 1972 baseline documentation in studying the rate of deterioration on this site; we had very good photographic documentation and measurements taken by Texas Tech students. It is interesting because the roof of this building is pretty much gone now. It helps us to know what our expectations can be, as far as the life of these buildings.

At the Wallace Pratt Lodge; the entire building is constructed out of stone except for the roof structure. As you heard this morning, the roof was carefully removed, all the stones numbered and replaced in their original locations. Unfortunately, it is leaking, and I think we have to investigate new materials to help prevent further deterioration. We are probably going to use a rubberized membrane. There are associated buildings to the Wallace Pratt Lodge as well as picnic areas. We haven't begun to interpret many of these as part of the park's interpretive program yet. Again, a cultural landscape report is needed to identify these important features and how to retain them.

The cabin at the Bowl is in a very isolated location. You hike up the mountain to visit it. It is a tribute to the people who worked as ranchers for Hunter and hand- adzed the wood and laid the wood. In this case where water is our main agent of deterioration, the sill logs are rotted and extensive work is required to repair it. The ranch hands made built-in interior furnishings.

We're constantly struggling with the roof at the Ship-on-the-Desert, which is flat decking, trying to maintain that design and keep moisture out. Fortunately back in 1988 when it was re-roofed, we looked at a lot of the documentation available in the park for the installation of a roof that failed, and tried to determine why joints and flashing were failing. We tried to design something that would last longer. Again, at Ship-on-the-Desert there are so many wonderful associated landscape features that we haven't even begun to identify, locate, and map. We are again replacing the roof.

Williams Ranch is distinguished because it is more of a high-style design representative of local vernacular architecture, and it is one of the few structures remaining that is made out of milled lumber.

The National Park Service has been constantly, every year, tackling preservation methods and materials. We want to prevent any further buildings from falling or having to be demolished. It is important that we continue to look at not only the natural resources that make Guadalupe Mountains such a wonderful place, but the architectural and archaeological features that are tributes to the people who passed through and lived in the Guadalupe Mountains. The stock tanks, the wells, the stone walls, and dams are all features here.

Where are we headed for Guadalupe Mountains National Park? As I mentioned, there has been much work over the past years: a historic structures report and a cultural landscape report each completed on Frijole Ranch. We unfortunately have lacked the resources to complete historic structures reports on the Ship-on-the-Desert, Wallace Pratt Lodge, Grisham-Hunter Line Cabin as well as cultural landscape reports for these sites. Ethnographies are needed of the people who have been so wonderfully associated with the park. Time is passing and some of these individuals are no longer here, so it is imperative for us to conduct these oral histories, to identify interior furnishings (Ship-on-the-Desert has many original interior furnishings of the Pratts), and treatment of these furnishings. Identifying circulation patterns and how to maintain the roads have been so important with the Butterfield Trail. In fact, by identifying the location of the Butterfield Trail, the highway was moved and part of it was preserved because of knowing where it originally was. Many of these structures need to be mapped using GIS. We need to record, document, and photograph these features that we can't maintain. Perhaps we need to look at the cultural landscape as part of our interpretation of this site so that we can honor those individuals who have observed, studied, and enjoyed the park as we do today.

Ecology

Chapter 24

Wildland Fire Management in the Guadalupe Mountains

TIM STUBBS has been with the National Park Service since 1969, in positions with fire management as a primary duty. He is currently the fire management officer at Carlsbad Caverns National Park and serves Guadalupe Mountains National Park as a prescribed fire planner. He has helped implement prescribed fire programs in several national parks and has assisted with interagency efforts to do the same.

"These four bodies are fire, air, water, earth."–Aristotle, *Meteorologica*

This paper presents some of the available literature that supports the wise use of wildland fire and prescribed fire in the Guadalupe Mountains and in the adjacent upper Chihuhuan Desert biome. It is also a collection of personal observations and communications regarding wildland fire in the Guadalupes. It is hoped that the reader will come to understand why the fire management program at Carlsbad Caverns and Guadalupe Mountains national parks supports frequent, low intensity wildland fire in the parks' wilderness areas. Managers of both parks believe that all scientific research and other available evidence supports this management approach and mimics what nature would be doing were we not present.

Frequent fire?

For centuries prior to settlement, large unrestrained wildland fires burned every few years in the Guadalupe Mountains. Lightning ignitions are frequent, statistically more frequent than in most of the rest of North America (Komarek 1967, Schroeder et al. 1977). Tree ring analysis completed by the University of Arizona (Swetnam et al. 1994, Baisan et al. 1995) throughout the region and locally in the Bowl area of Guadalupe Mountains National Park suggests the median frequency of fire between 1700 and 1900 in southwestern "sky island" mountains to be less than 10 years. Fire scar analysis also showed these wildland fires to be low-intensity surface fires that rarely damaged the overstory trees under which they burned. These studies and historic records in the Southwest (Bahre 1985) suggest that these fires were often very large, in the thousands of acres, and burned for weeks at a time in certain dry years, especially in the lower grasslands (Pyne 1982a).

Ponderosa and piñon pines in the west end of Carlsbad Caverns National Park and throughout the Lincoln National Forest portion of the Guadalupe Mountains show numerous fire scars (Ahlstrand 1981; author's personal observations). Texas madrone and even Torrey yuccas similarly display numerous fire scars throughout the lower elevations. Ahlstrand generalized that, between 1697 and 1922, the maximum interval between major fires in the higher Guadalupes appeared to be 30 years.

For centuries prior to settlement, large unrestrained wildfires burned every few years in the Guadalupe Mountains.

Studies done by Texas Tech University (Wright 1974, Bunting and Wright 1977) have suggested a similar high frequency, low intensity fire regime throughout the upper Chihuahuan biome of west Texas and southeast New Mexico. More recently other Texas Tech researchers have shown the beneficial effects of fire in the diversity of desert scrub communities adjacent to the Guadalupes (Monasmith et al. 1996).

Large fires?

It is well documented that the last very large natural, unsuppressed fire in the Guadalupes occurred no later than 1922 (Ahlstrand 1980). After this time a combination of heavy grazing and a full fire suppression policy limited ignitions to [fires that were] generally very small in size. In the Carlsbad Caverns area goats and sheep heavily grazed all available forage beginning in the 1920s and continuing until about 1942. Guadalupe Mountains National Park was subjected to varying amounts of grazing through this period and was know to have three times the calculated carrying capacity of cattle in the few years prior to its protection as a national park (personal communication with Kenneth McCollaum, U.S.D.A. Forest Service fire management officer 1968–1992 and lifetime rancher and resident of Queen, New Mexico).

The next very large fire after 1922 did not occur until 1974. The Cottonwood Fire in the Upper Slaughter Canyon area was over 15,000 acres despite formidable U.S. Forest Service and National Park Service efforts to suppress it. The X-Bar fire in 1976 was 12,000 acres in upper Dark Canyon. It was widely agreed that the regime of periodic large fires in the Guadalupes had returned due to the cessation of grazing on National Park Service lands and the reduction of heavy grazing on U.S.D.A. Forest Service lands.

These fires became as large as they did depsite our best efforts to suppress them using all of the modern suppression tools available and despite spending in excess of one million dollars for each effort.

Between 1974 and the present there have been numerous lightning-ignited fires in the vicinity of both national parks that reached several thousand acres despite a continued full suppression policy. Many of these are listed and described in the fire management plans for the two parks (Stubbs 1995, Sullivan 1997), and fire report files in both parks. There similarly occurred many large wildfires and management ignited prescribed fires on the adjacent Lincoln National Forest during this period even as light grazing continued.

In 1990 we witnessed two such large fires. The Big Fire covered over 33, 000 acres of timber, desert shrub, and semidesert grassland in about a week, and the Frijole Fire covered about 6,000 acres of timber in just four days, much of that as a crown fire. Both of these fires became as large as they did despite our best efforts to suppress them using all of the modern suppression tools available and despite spending in excess of $1 million for each effort. Some of us remember watching the lightning-ignited Frijole Fire in the heart of Guadalupe Mountains National Park and thinking that it very easily could burn all the way to White's City some 30 miles away. We have since similarly seen several lightning ignited large fires in 1993 and 1994 that easily could have become many thousands of acres had we not suppressed them with a very heavy hand and at great expense.

The current El Niño–Southern Oscillation (ENSO) phase is leading into a similar La Niña situation that occurred during those years of high fuel loadings and dry, windy conditions. Looking at recent history, we can expect to see similarly large, intense fires again soon in the Guadalupes. This notion of very large fires in the Southwest during the La Niña phase has been supported by ongoing ENSO fire-occurrence research being conducted at several universities, namely the University of Arizona.

Can fire be beneficial?

With all the evidence of frequent large fires, one wonders how they must affect the ecosystem as a whole and the individual species within that ecosystem. So what do we know about the effects of fire on the parks?

The effects of fire on the ponderosa pine forests as found in the high country of Guadalupe Mountains National Park are very well documented and understood (Ahlstrand 1980, Wright 1977, Swetnam et al. 1994). High frequency and low intensity fire generally increases vegetation diversity and prevents fuel accumulation and subsequent overstory consumption. Frequent fires maintain healthier forests. Infrequent fires lead to less healthy forests beset with overstocking, surface fuel accumulations, disease, insects, and dwarf mistletoe. Lack of fire sets the stage for inevitable holocaust.

Similarly, in the lower country of Carlsbad Caverns, Kittams (1973) noted that the aggressively colonizing agave-type species, such as lechuguilla and sotol, were generally killed by frequent fire and were replaced by sprouting shrubs and grass/forb species. Bunting and Wright (1977) found that after two years fire had reduced total shrub cover by 43% and total grass cover by 72% while increasing forb and shrub sprouts by 650%.

Ahlstrand (1982) showed that biodiversity in the desert shrub–semi-desert grassland communities was greatly increased by burning. He went on to say:

> The practices of suppressing fire and excluding livestock grazing, both in effect for more than 30 years on much of the study area, have permitted grasses, as well as woody and rosette shrubs, to accumulate in quantities sufficient to support fires over extensive areas. With periodic burning of perhaps every 10 to 15 years in this community, grasses can be expected to increase as scrub cover is reduced. In the absence of additional fires, coverage by shrubs can be expected to slowly increase again at the expense of grasses and forbs.

Ahlstrand completed a lengthy literature review in 1981 showing the beneficial effects of fire on 88 selected species of plants (Ahlstrand 1981).

The National Park Service continued Ahlstrand's studies with photo points (Walters 1988). In the early 1990s photo points and line intercept transects (Stubbs 1993, Mulligan 1996) have consistently shown a postburn increase of biodiversity and grass-forb density coupled with a marked decrease in agave-type cover and density. These studies continue.

The New Mexico Game and Fish Department, the Bureau of Land Management, and the U.S.D.A. Forest Service adjacent to the park have cooperated in several large (up to 26,000 acres) prescribed burns for the purpose of enhancing the deer herd and improving rangeland. Their subsequent monitoring of these areas consistently shows increased numbers and vigor of deer and better rangeland as a result. We often see large deer herds concentrated in the post-burn "greenup" of both prescribed burns and wildfires. We also occasionally see that heavy deer browse causes damage to resprouting shrubs in isolated small burns, which draw large numbers of deer to the relatively small amount of browse forage made available by small fires.

The Fire Effects Information System (FEIS), an Internet-accessible, free-access database maintained by the U.S.D.A. Forest Service (Fischer et al. 1996), describes fire's effects on many of the plant and animal species found in the Guadalupes. The contributors of local species information were largely from researchers of the various universities of the west Texas and southern New Mexico area. Fire's effects on individual species are described as positive both for the individual species and for the ecosystem or niche in which it lives.

In the early 1990s photo points and line transects have consistently shown a postburn increase of biodiversity and grass-forb density coupled with a marked decrease in agave-type cover and density.

The Texas madrone, for instance, is known to occur in riparian and seep areas of the Guadalupes. These areas tend to become brushy and quite flammable if not subjected periodically to fire. Texas madrone is killed by high intensity fire and does not resprout (FEIS data). Most large trees show abundant fire scars (personal observation) which is evidence that they have survived past low intensity fires. The question is: could they survive a high intensity wildfire if highly flammable brush was allowed to grow unimpeded underneath them as has occurred in much of McKittrick Canyon?

The National Park Service has also begun extensive study on fire's effects on a threatened species, *Coryphantha leei*, found at Carlsbad Caverns National Park. This species was subjected to a low-intensity prescribed fire in 1993. Preliminary conclusions (Mulligan and Route 1996) are that *Coryphantha leei* is quite tolerant of low intensity fire, probably due to its normal habitat of flat, exposed, rocky shelves generally devoid of most other fuels. The 1993 burn showed mortality of about 10% not accounting for what could have been natural mortality. My personal observations of the effects of high-intensity wildfire on this and other similar cactus species has approached 90% kill in some areas of the Big Fire of 1990! Could it be that by waiting for high-intensity wildfire and not allowing low-intensity prescribed or natural fire we are waiting for disaster to strike this rare species?

Similarly, Thomas (1997) has shown that fire can have various effects on succulent species in semi-desert grassland ranging from beneficial in low-intensity fires to extremely detrimental in high-intensity fires.

An allowable take of individual specimens of rare species is necessary to protect the species and ecosystem as a whole.

There are many other examples of management's need to compromise between the use of prescribed fire and the protection of individual species (LaRosa 1995). The key is that these compromises have been shown repeatedly in the management of wilderness ecosystems to best protect overall ecosystem health and integrity. An allowable take of individual specimens of rare species is necessary to protect the species and ecosystem as a whole.

So where are we going?

Both national parks, the Lincoln National Forest, and the Bureau of Land Management are engaged in continued discussions to develop an interagency fire management plan based not on jurisdictional concerns but on ecosystem management concerns. The draft of this plan defines the Guadalupe Mountains as a fire dependent ecosystem to be managed under a consistent fire management policy which strongly favors the ambitious reintegration of wildland fire, an approach suggested at this time by the best available science.

Wildland fire will only be fully suppressed if it becomes a threat to human safety or property. The "appropriate management response" will be applied to each ignition to ensure that resource management goals are being realized and that fire can continue to be an integral part of the management of the ecosystem.

Prescribed fire and manual fuel reduction will also be undertaken adjacent to developments, property, and sensitive resources to protect them from unwanted fire. Both national parks have identified large tracts of land for reintroduction of low-intensity wildland fire during the next few years through the use of management ignited prescribed fire.

Monitoring of the effects of fire on the flora, fauna, soils, air, and viewshed will continue. Funding has been requested for an exhaustive literature review on fire effects in the upper Chihuahuan Desert biome. University involvement in both literature review and data analysis will continue to be encouraged and subsidized to ensure that the suspected benefits of wildland fire continue to be realized.

The reintegration of wildland fire into the Guadalupe Mountains ecosystem will continue well into the 21st century. We will strive to restore the ecosystem, the processes, and the common and rare species, including that lately rare species: wildland fire.

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Chapter 25

Tree-ring Analysis of Ancient Douglas-fir at Guadalupe Mountains National Park

DAVID W. STAHLE, Ph.D., has been a professor for the Department of Geography and director of the Tree-Ring Laboratory, University of Arkansas, Fayetteville, for the past 20 years. He is currently working on the development of long tree-ring chronologies sensitive to the El Niño–Southern Oscillation influence, including the ancient Douglas-fir stands on Guadalupe Peak, Texas.

Douglas-fir (*Pseudotsuga menziesii*) is the most important commercial timber species in the world (Van Pelt 2001). The natural range of the species extends across western North America from British Columbia to Oaxaca. The species is subdivided into two populations, the coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*), which reaches immense size in the Pacific Northwest, and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) found on more arid sites in the inland Rockies (Lanner 1999), including the small outlying populations found in the Guadalupe and Chisos mountains of west Texas. The two types of Douglas-fir differ in terms of growth rate and size. Maximum growth rates and dimensions are achieved by coast Douglas-fir in the temperate rainforest of the Pacific coast, where the species has been reliably measured to over 300 feet in height and is second only to coast redwood as the tallest conifer in the world (Van Pelt 2001, Lanner 1999). In stark contrast, Rocky Mountain Douglas-fir on arid sites in the continental interior are often dwarfed because of moisture stress but attain remarkable ages and record an accurate and detailed history of precipitation in their annual growth rings. Some of the oldest and climate sensitive Douglas-fir have been found on petrified lava flows at El Malpais National Monument, New Mexico, where one tree over 1,274 years old was found (Grissino-Mayer et al. 1997). A tree-ring chronology over 2,129 years long was developed from Douglas-fir trees and relic wood littering the rocky fire-protected terrain at El Malpais (Grissino-Mayer 1996); this is one of the most important tree-ring chronologies ever developed in North America.

Ancient Douglas-fir is also found in the Bowl and on other restricted microenvironments in Guadalupe Mountains National Park. Researchers from the University of Arkansas Tree-Ring Laboratory have investigated Douglas-fir on the slopes below Guadalupe Peak, and we have made 456-year-long, tree-ring chronologies of earlywood width (EW), latewood width (LW), and total ring width (TRW) from core samples extracted from mature and old-growth trees. The most exceptional Douglas-firs we have located in the park thus far are found on the edge of the dry, wind-swept escarpment just west of Guadalupe Peak at about 8,200 feet in elevation (Figure 1). But we have only examined a small fraction of the potential Douglas-fir habitat in the park and believe that many additional areas of old growth do indeed exist, some with trees likely in excess of 600 years old (e.g., on the rocky north-facing escarpments east of Guadalupe Peak and above Devil's Hall trail). Exceptionally old piñon pine (*Pinus edulis*) are also abundant in the park, and we have recently obtained core samples from chinkapin oak (*Quercus muehlenbergii*) that are over 300 years old along Devil's Hall trail.

The earlywood-width (EW) chronology (Figure 2) is based on measurements of 33 cores from 17 trees. These individual EW time series are very strongly correlated with each other, and the average correlation between these individual se-

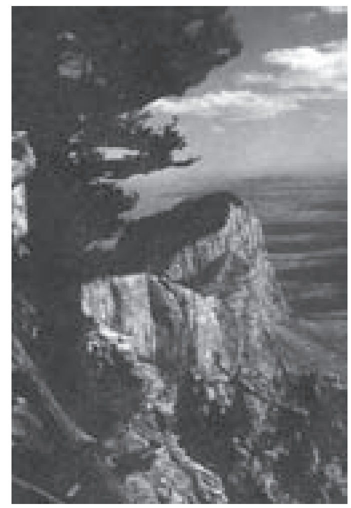

Figure 1. An ancient Douglas-fir on the escarpment west of Guadalupe Peak, overlooking El Capitan (view SSE). These trees record an intricate history of climate in their annual growth rings.

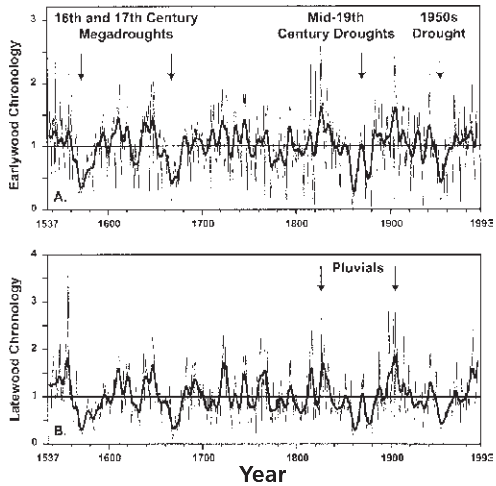

Figure 2. The earlywood (top) and latewood (bottom) width chronologies developed from drought-stressed Douglas-fir at Guadalupe Peak, Texas. These chronologies reflect winter-spring and spring-summer moisture conditions, respectively, and reveal several major decadal droughts and prolonged pluvials over the past 450 years.

ries and the master chronology (based on the remaining series) is r = 0.82 (calculated with the program COFECHA) (Holmes 1983). The latewood-width (LW) chronology (Figure 2) is based on 33 cores from 16 trees, and the average correlation between these individual series and the master LW chronology is somewhat lower at r = 0.65. But there is still a very high degree of cross correlation among the component specimens included in the LW chronology.

The EW and LW chronologies developed from Douglas-fir at Guadalupe Mountains National Park are not identical. The correlation between the two chronologies in Figure 2 is r = 0.63 ($P < 0.001$) for the full period from 1537 to 1993, so only approximately 40% if the interannual variability is shared between these two seasonal chronologies developed from the same Douglas-fir trees at Guadalupe Peak.

Correlation analyses with regional climate data indicate that the two chronologies are sensitive to different seasonal precipitation totals, with the EW chronology responding most strongly to winter-spring precipitation, and the LW chronology responding most strongly to late-spring and early-summer precipitation. This differing climate response of EW and LW is very important because two different large-scale climate phenomena have been implicated in the interannual variability of cool and warm season precipitation over the American Southwest. The El Niño–Southern Oscillation (ENSO), the great air-sea interaction over the equatorial Pacific Ocean, modulates the interannual variability of winter precipitation totals and tree growth over the Southwest, including the Guadalupe Mountains (e.g., Ropelewski and Halpert 1987, Stahle et al. 1998). Summer precipitation over the Guadalupes and the greater Southwest is modulated by the North American Monsoon System (NAMS), which tends to develop over western Mexico in June and build into the Southwest by July and August. The EW chronology from Guadalupe Peak has already been used for the tree-ring reconstruction of ENSO indices (Stahle et al. 1998), and the LW chronology has been used in an analysis of warm season precipitation over Mexico and the extreme southwestern United States (Therrell et al. 2002).

The EW and LW chronologies for Guadalupe Peak have highlighted several decade-long moisture extremes. The severe and sustained drought of the 1950s is clearly recorded in both the EW and LW chronologies (Figure 2). The 1950s drought had serious impacts on the ecosystem dynamics of both grasslands and woodlands across the greater Southwest, as has been vividly documented at the Sevilleta Long-Term Ecological Research area, New Mexico (Swetnam and Betancourt 1998). However, the 1950s drought at Guadalupe Peak was exceeded in severity and duration by the prolonged megadroughts of the 19th, 17th, and 16th centuries (Stahle et al. 2000) (Figure 2). The spatial distribution of these extended droughts, and the notable wet periods of the early-19th and early-20th centuries (Figure 2), has been recently mapped by Fye and others (2003) using the continentwide tree-ring reconstructions of Cook and others (1999). The impact of these tree-ring reconstructed droughts and pluvials on ecosystem dynamics in the 19th century have been described by West (1992) and Woodhouse and others (2002). These analyses highlight the larger ecological significance of the climate history embedded in the tree-ring chronologies now available for Guadalupe Mountains National Park, which can provide important insight into past and present trends in regional flora and fauna.

Acknowledgements
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Note: This paper is an updated (2003) version of the presentation given at the Guadalupe Mountains Symposium in 1998.

Geology

Chapter 26

Geologic Significance of Guadalupe Mountains National Park

LLOYD C. PRAY, Ph.D., is a professor of geology at the University of Wisconsin in Madison. Beginning in the 1950s, he led geology field trips in Carlsbad Caverns National Park. He began detailed research on Permian strata of the Guadalupe Mountains in the 1960s in association with other Marathon Oil geologists. Since joining the faculty of the University of Wisconsin in 1968, the major emphasis in his research, and that of his many graduate students, has been in the Southwest. He has supervised some 21 graduate students' theses in the Guadalupe Mountains working on interpretations of the Capitan reef and the older exposed Permian strata of the western escarpment. Specific topics include the origin of pisolites of the Capitan back reef, the Capitan reef and its contemporaneous fore reef and basin strata, submarine debris flows, erosion surfaces, and other strata relationships in the pre-Capitan units of Guadalupe Mountains National Park.

I wonder if any of you have been as lucky as I have been to have 21 darn good students want to come down and work their tails off out there in those hills called the Guadalupe Mountains. They have gone on to their own business of leading field trips and such—I am very proud of them—and it is one of the fun things of being in the university. You have coolies to do some of these things, but you have to know what you are doing with them and you have to have some overall projects. In that regard, I have been exceedingly fortunate to have concentrated, since about 1970, a lot of my graduate students doing doctoral and masters theses out here in the park and doing some regional work as well. It is a privilege to come down here, be part of this conference, and see what I consider a fine display of cooperation on the part of the National Park Service to put this kind of thing on. I learned some things this morning I didn't ever expect to learn and I am going to be here for the rest of the conference. I hope it will be really fun for me to get these perspectives, which are beyond my little niche of geology. But that is where I come from, and yes, to say that Guadalupe Mountains National Park is a geologic park—sure, that's my theme song. I know there are lovely things out there on the slopes. There are mosses, lizards, animals, and trees and all kinds of things that need work and research. But you know, they all are growing on rock, and they are there because of that magnificent pile of rocks, which is a national heritage, and which I am very concerned remains a national heritage. Of course, now it is in the hands of the National Park Service, which I am very pleased with.

"I want this place to be a place where geologists can come and poke and look around and learn from what's here."
—Wallace Pratt

The original 5,000 acres or so was given by Wallace Pratt, who was a real hero and first-class geologist. He said, "This area of McKittrick Canyon at the entrance is not only the prettiest place in Texas,"—you know, geologists can see pretty things, too—but he also said, "I want this place to be a place where geologists can come and poke and look around and learn from what's here"—a magnificent display of the Capitan reef that is now world famous. When that transferred back in 1972 to the "stewardship," in Jan's terms of the present park, it made a lot of us feel really good because out in some of this country you occasionally can't get into areas that you want to because of the trouble ranchers have had with some bad people. Now it is all in the park, and as I see it, with the stewardship that I am satisfied will go into it, those rocks are in good hands.

Now, there is one other introductory comment I want to make. How many of you are geologists? A little more than I'd hoped for. If there had only been a few I'd be able to get away with technological murder, and of course, professors do that all the time. But still, I am glad there are some friends of mine out there. Maybe they will be tolerant of what I want to put together for you. I wrote an abstract, and I want to call your attention to the facts in the abstract, because that is really what I want to say to you. I think what we put in there is important. It is important in terms of the National Park Service and the stewardship that is necessary with this magnificent pile of rocks that is out there in Guadalupe Mountains National Park. I have a feeling that if I were to ask you, "What is the most famous feature out there in the park?" the non-geologists would say, "Oh, it's the Capitan reef." Some of the geologists would say, "Oh, it's the Capitan reef." Well, I am going to tell you today that when the transfer was made from the McKittrick Canyon area to the entire area of the Hunter Ranch, there was a great taking-on of material older than the Capitan, which is of extreme importance, and where perhaps two-thirds of my students have worked. It has been fun working in an area where there is hardly anyone. Of course, there is nothing quite like being on a mountain range yourself, anyway. You have no one to control you and the clouds are always beautiful down here, and you can almost always find some interesting things you don't understand.

The Capitan is only the frosting on the cake.

In National Park Service circles, I hear the word "inventory" quite often. An inventory is important, but in geology, I have the feeling that some people think, "Well, it's been mapped." Or somebody wrote a whole book on it, and there are whole books written on the Guadalupe Mountains. It is not just what is where; it's how in the heck it got there. Those mysteries are the things that are exciting to scientists and should be to students—and are. When you can try to discern the reasons for it being there, then you are getting at meaningful research. That's what I would like to have the park focus on: the needs for continuing research under supervision. Sampling, yes—there's a lot of rock out there—but sampling so it doesn't hurt the side of the canyon and that people can actually bring the marvelous new techniques we have now in geology to bear on how that rock got there and what it is. That is the essence of the geological sciences. In the last two decades, we have been through great revolutions in geology with ocean floor spreading and all that stuff. There have been revolutions out here, too. One of the revolutions in geology is called sequence stratigraphy, where people try to make very detailed correlations of a rock that's here with a rock that's here; they are all time equivalent. It has gone into worldwide practice in search for petroleum, not just land areas but down under the sea; they are now capable of doing that and also in production technique. So this science, which evolved in part for carbonate rocks—and I'm a carbonate rocker, not a sandstoner—out here in the west face in the last two decades. It has been important in that way.

Well, enough generalizations. Let's get into some slides. I guess you know you're in Texas, and that the park is just the little tail-of-the-dog of the U-shaped Guadalupe Mountains. It is the high part, and it is a hunk of country in which rocks are beautifully exposed in canyons, most of them without water, but which involve research. Of course, the Capitan reef—the "caps" are right in here, and here is the Capitan reef escarpment. The Capitan gets a lot of the attention; in fact, the newspaper of the two parks is called *The Capitan Reef*. Well, I'm here to tell you in a somewhat facetious sense that the Capitan is only the frosting on the cake. It's wonderful frosting; it tastes good, and it's got all kinds of geological problems. But there is a heck of a lot of cake under it in the older rocks that are exposed out here, which are terribly important, and only in the last decade or so have been getting the attention they deserve.

This is the area; you know all about that. I only want to point out that going north there are exposures of rocks that are time equivalent of the rocks that are down here. This sequence stratigraphy involves rocks way up here and down here—I will say a little bit more about that later on. So, what do we say about it? Well, it is a big area in geology, and in this area we are dealing with a thousand feet of something. I have to tell you a story. One time we were coming off Nipple Hill with one of my partners, and we saw way down in a little gully; just before we got to the gully, there were a man and a woman. They were lying reclined as though they were having a good time down there on the side of the canyon, and we thought, well, out of decency we shouldn't come down there right on our line of traverse, we ought to go around them. Well, as we got a little bit nearer we thought, well, let's just make noises and go up there and see what's going on, and we did. The closer we got, the guy had a fishing pole, and what was he doing with a fishing pole? You know what they were doing? They were catching lizards. But do you know why? They had a thermometer and were taking the anal temperatures of lizards. That's valid research, too, but the contrast between worrying about 2,000 feet of cliffs and worrying about what temperature a lizard had, is impressive. So we all have our specialties, and they're fun.

Well, this is presumed to show something of a summary of the geologic significance of Guadalupe Mountains National Park. And it is the best North American exposure of the rocks of Permian age, 250 million years ago. The variety of types of rocks and the large scale of features enchants us to see what changes into what. It is simply phenomenal. The value of these features is global, because a lot of the studies done here by students are going out around the world to try to tie it in with petroleum exploration or just scientific understanding. On a regional scale, it's important for tourism, of course. And the more you can plug the Capitan reef as the frosting on the cake, the better. Because it is a very exciting thing, and I don't put it down. For study in the region, regional water resources tie into the Permian basin oil fields that are off here to the east a little further. There are a lot of other things that I could say of significance of the variety of features, but to me when you get to know it, you realize you don't understand it all. It is a very complex system of rocks, and that is fun for geologists, and that is part of what keeps us going on these hot days and traverses and the rest. Because we still don't understand it nearly as well as we should.

How many of you have been walking on the west face of the Guadalupe Mountains? How many of you saw water over there? There are a couple of springs, and believe me, they're on maps, but the bulk of it is treeless, it is hot, and it is beautiful because of the geology. I guess the other thing I can make as a general comment—others have made the comment—this park is a magnet for geologists, literally from all over the world. It should continue. This is a [picture of a] textbook published some years ago, but the fact is the Guadalupe Mountain Permian gets into textbooks and into research studies on carbonate rocks in all kinds of languages and all around the world. The frosting on the cake is the big white upper cliff that goes about five miles up there on the magnificent top of the escarpment. Here is the cake; it's down here. It looks less dramatic but it is pretty darn exciting. There are three live people. This is the trip one year ago with a class from Wisconsin, but they were an international group. Toni Simo [professor at the Department of Geology and Geophysics, University of Wisconsin-Madison] is right in the middle and would like to be here today. I guess we conned somebody into taking a picture of the whole group. We have been doing this now for the last 30 years, and I suppose various people have brought thousands of geologists to come and see this thing. Because until you see it, you don't appreciate it.

The fact is the Guadalupe Mountain Permian gets into textbooks and into research studies on carbonate rocks in all kinds of languages and all around the world.

It's important in my bias of this being a geologic park to realize what the enabling legislation was, and I recently had a chance to read it: "To preserve in public ownership in the area of the state of Texas possessing outstanding geological values". I could go on and say, "together with scenic and other natural values of great significance". The first and foremost, this should be kept as a national heritage for geologists. There will be a bunch of them coming on. A little bit of geology, for the non-geologists: you have heard about the Permian oceans that came into the area of the Guadalupe Mountains. There were three or four arms of the ocean that came in from somewhere, and Carol Hill has some idea that they didn't come here, but that is continued research. The Delaware Basin—the size of the Lake Michigan—ends and cuts obliquely right across the Capitan escarpment in a northwest trend, and the Capitan rims that entire area. But the only place we see it in decent outcrop, not chewed up or varied, is in the Guadalupe Mountains, so again, it is regionally significant. Then the basins are areas of one to two thousand feet deeper water during the time that shallow water sediments were going down on what we call platforms or shelves. Out here in the central basin shelf area—those are all the yellow areas—here's all kinds of oil fields, which are very juicy oil fields. Yates is right down there at the very tip of it. They are producing from rocks, not the Capitan. They are producing from rocks that are exposed up here in the Algerita escarpment.

Here's the frosting on the cake. Here are rocks, and you see ledges here which don't go here. Well, how come? Because that, too, was the edge of a shelf to a basin, and the changes in rocks as you go along in those layers are the fascinating things that are now being worked in detail. Just one thing: the frosting on the cake, the Capitan reef and the Goat Seep under-rim, make an upper lens on this sloping block of ground that we made the Guadalupe Mountains out of, both in Mexico and Texas, and water coming in, of course, goes down through the rocks that it can go through under gravity in the permeable layers, and of course we've got caves, Lechuguilla and Carlsbad Caverns, and we've got some springs down here in the Carlsbad region and the Carlsbad aquifer, which has something to do with good water out here. They go on out down to the central basin platform, and they provided some of the water drive for the oil fields that are out there. There is some value in knowing something about these rocks.

What they didn't notice for 75 years was that the sloping layers of rock were sloping from what had been a shelf area into a basin.

Here is our Capitan. Now, the interesting thing about it in terms of knowing what's there, and from 1855 until 1929 they knew there were rocks there, and El Capitan was very impressive and that's where the name Capitan comes from, but what they didn't notice for 75 years was that the sloping layers of rock were sloping from what had been a shelf area into a basin. If you go on top of Guadalupe Peak—here's looking down on El Capitan—while those layers look flat from out in the west, you can see here that they are actually not flat at all, they are sloping into, again, the basin and again, different rocks entirely here that would be up on the top of the peak. That was 75 years of not knowing why it was hard to correlate layers out there in the subsurface. It wasn't until they got into the oil fields that they began to realize, "We've got to understand this," and in 1929 three geologists came out and said, "There's a reef there." That's what makes these sloping layers. Seventy-five years. They say that geologists can't see things that are obvious, and that's true, and I hope mammalogists are the same way. Once it is pointed out, it's obvious. That was a case in point of just not recognizing what was there.

This slide is a little bit of Geology 101. What I want to use in this is that there are different ways you can go down a ski slope, for example, which might involve a reef like that from the shallow area in the basin, or you might just go down a gently declining thing like this. But the thing we know is that all the way along there are changes in rock, like from the Capitan reef out here at the edge, if that were the Capitan, into facies 5, 4, 3, 2, 1. These different type rocks are called facies. That's true whether you are on that profile or this, and that's true whether you're in shallow water or down in the deep. These changes are vital in understanding the localization of porosity. Porosity has something to do with big oil, because you've got to have the holes in the rock and making seals and all the rest. Here are two variations of the many I could show you, but just to make things complicated, we know as geologists that during Permian time the sea level changed just as it changed during our glacial ages. You put all the ice on the land and sea level goes down 300 feet; you melt it and it goes back up. Well, there were changes there. And every time you change sea level, you change the currents that are on these areas, you change the rock type, and so it is not a simple system. It could happen many times during the deposition of the Capitan.

I put these in this order, because in essence, this is the pile of rocks we have in the Guadalupes. We've got a ski slope reef, floor slope kind of thing up the frosting on the cake, and then in the older rocks we have this kind of gentle ramp, as it is referred to. The changes in the facies that we see take place in just 5 or 10 miles of the total width of this, but these might go 50 to 100 miles. You have to do regional studies. Studies that would be here in the Guadalupes are important to what is going on way up there in the Algeritas. Here's a cross section of the Capitan as such, in terms of scale, the basin is about half a kilometer deep, the red is where we were building reef at the time, and then here was stuff that sloughed off and formed on the slope, the foreslope, as we call it. Behind it all these changes in facies and wavy line evaporates. Within these bands there are again progressive changes, and progressive changes could involve porosity, but they don't have to have oil significance, it's just why the heck did it turn out the way it did?

Let's move on from the Capitan then. Here's a cross section of the west side of the entire area. This would be 1,500 meters or something like that, and here is the frosting on the cake, the Goat Seep and the Capitan reefs in diagrammatic form, but down below it there are rocks that are productive, age-equivalent rocks and can be seen in the surface of the Algerita escarpment and some 20 or 30 miles farther to the north. This is the study of the west side and should not be neglected by geologists or by preservationists. Again, the rocks we are showing you here change by the time they get up in here, and go all the way up. And as you go out from this lecture or the next lecture, on the board out there, there is a one yard high, three yard wide cross section that shows detailed work being done and summarizes all of the work on the escarpment and coming down into here—primarily by Charlie Kerans and Bill Fitchen, who was a Wisconsin student at one stage but a UT student much more recently, and he now works for Exxon. Let's take a look at those black rocks at the mouth of Shumard Canyon. People say, "Oh, they're black rocks, they're all black rocks," but you find out there are different kinds of black rocks. Why are they different, and how do they differ, and what's going on as we go through this thousand feet of stuff here into the next? Well, let's take a look at some of the people who are working it. This happens to be Peter Vale, who is the major guru of sequence stratigraphy in the world. He worked for Exxon his professional life, and he gets out in the field too. This is one of his students, named Rick Sarge, who is also one of my students. These two are primarily involved in talking about these facies out here, together with Charlie Harris and Bill and a number of other people. The real live people are trying to figure these things out. They are pretty smart people.

What we have out here is not only those changes in rock layers, but we have them on a scale that is comparable. It is not just a little laboratory model.

Here is a cross section of that. Now we have gorgeous color out there, but here is a diagram from the Algerita escarpment. South of that red line is the park. What you see is, gosh, the park geology is down in what I call the soap. It's the deep water area. It is very different in facies from this, and it is a very complicated history, but it has been fun seeing people work this out, including some students of mine. One of the things that has been done, sequence stratigraphy has evolved from taking of subsurface records by geophysical means, which send shock waves down and they are reflected back, and you can pick up records of the position, the depth, of different layers. Here is the typical cross section that might be gotten; in fact, it is the Delaware Basin line. All these squiggles mean something if you are trained in it. In the middle of this is the interpretation of what these squiggles mean, and it is highly significant. What it means is that now all over the world from the China seas to the Australian

One of the reasons for having a continuing flow of new eyes and new people working on new techniques in a thing like the Guadalupes is that the story is going to change and it is going to get better.

northwest shelf, Newfoundland, Gulf of Mexico deep water, they can go in deep water, they can get these signals and they can get the seismic waves. What we have out here is not only those changes in rock layers, but we have them on a scale that is comparable. It is not just a little laboratory model; we've got a thousand feet of rock out here that are showing these facies changes. So it is a marvelous training ground, as Rick Sarge recognized way back when, when he was working with that side.

Let's go on from there. So there's the value. In this next little part, I want to introduce you to three people who I consider the major, dominant super- geologists working the Guadalupes of the 20th century. First is a man named Phil King, who worked with the U.S. Geological Survey all his life. He worked in west Texas and southern New Mexico for a lot of it. He was a superb mapper and superb field man. He died a few years ago, but his basic work here can't be beat. Yet despite the fact that this guy had won all the prizes of the Geological Society of America and the rest—you didn't have to salute Phil King, but you felt like it because you wondered, "Could we have just a little bit of his smarts?"—he made some mistakes. You know, good people make mistakes. One of the reasons for having a continuing flow of new eyes and new people working new techniques in a thing like the Guadalupes is that the story is going to change and it is going to get better. If we just inventory what we had, then it's dead, but we want to bring it to life. Let's look at Shumard Canyon, which is on the west face. Here's a cliff 110 feet high consisting of sandstone, which would make and does make, kind of nice reservoirs out there in the bottom of the Delaware Basin. If you look at the rock in detail and look right in that particular place at the base of it, there are spalls which show these features. Now, what are they? They are ripple marks. They are made by moving currents. You see them probably on the Pecos, when it runs. In any event, in Phil King's day, ripple marks were only known from shallow water. So his interpretations were subject to the concepts of the day. We now know through work that has been done all over the world, including our own Balma, who is a guru in this particular field, that there are deep water channels which formed that body of sand; there are ripple marks all in it, and there are currents that go down into the basins all around, and this is a major part of the exploration play of petroleum geology at the present time. So, King blew it. I would never really say he blew it. He was a terrific, terrific guy and geologist.

There is another gentleman. This is a picture I took a few years ago of Norman Newell, who is a Columbia professor at the American Museum, a paleontologist and paleoecologist. He was an expert when he came into the Guadalupes with some bright students of Pacific reefs. He said this is a reef? He interpreted the Capitan reef on the basis of the modern. Now geologists say the modern is where we learn; the key to the past is in the modern. He came in and he brought a whole book, a wonderful book, and he did a lot of good work, but the fact is that he brought the Pacific models of reef into the Capitan, and you know, that's not the Capitan. When we worked the Permian reef out here, we had to say the Permian reef is like the Permian reef, and it is not like stuff we've gotten recently, or at least we're not smart enough to recognize it all right now. You learn in different ways. This is one of the reasons it's fun looking in detail, in depth. This was Normal Newell. He blew it on a few things too. Another thing he did was particularly fun for me: out there on the west face in the middle of that black rock there is a lens that looks like just a scoop, a lens sticking out of the hillside. It was a different kind of rock. He found some fossils in it, and he said these are reef fossils, and he said these are little reefs. And he found some more out there. Like this knob right there. But you know, when we got to looking at it back in the early 1960s, we discovered it was a channel. The same kind of channel that the sandstone would have gone in, but in this case it was channelized debris with some blocks that could be the size of a house. Well, that turned out to be important, because now off the central basin platform, there are some [oil] fields producing from this age rock which consist of great big chunks, a mile or so across, of debris flows which moved off the shelf and into the basin. You never know where things are going to end when you get into this game. I have great respect for Normal Newell.

Here are another two people that I want to focus on, Death Valley Scotty here; this is a picture of Robert Gunn, who worked for Shell and was a very imaginative geologist. Again, high on my totem pole, right below Phil King, I think. He came in and wrote a book in 1962 which was published in 1972. It had remarkable insights into all the carbonate rock variations out here. Some of the things that he got into, he too didn't quite get right. There are these things, these little round balls that look like golf balls that are concentric, they are pearls, if you like, but he considered that they were formed in one way. We now have kind of upset that apple cart, even though it was paraded around the world where people believed it, he wanted them formed in a different way than we think now. It is just a little detail and it is not going to make an oil field, but it's a fun thing to get involved with and try and interpret. All these three guys didn't stop from sticking their necks out and interpreting things, and of course, they didn't have all that people have now.

The latest part—and this is what tickles me. The Capitan is called a sponge reef, full of sponges. For years they were little clusters and they would stand upright, and everybody, including sponge experts who made their living on sponges, believed they were upper end sponges. A young woman from Cambridge named Rachel Wood—I wish I had a picture of her, she is a lovely-looking young lady—came in on a field trip and said, "You know what? Those sponges aren't growing upright, they're growing downward." Only one person I know had ever recorded that the sponges, instead of growing up, were growing down. That's not all the sponges. Look at this. See the tip? That's where it attached and it grew this way, it came down, and this one and this one, and this one, and this one, and... I had seen these for years and so had every other geologist I know of until Rachel Wood came in. Now that's fun—when somebody can upset an apple cart that way with just her own knowledge and her own powers of observation. That is part of the fun of this whole game.

Then there is this guy [referring to himself], and you know he stuck his neck out a few times, and he almost hopes he'll die pretty quick before somebody just proves he was completely full of it in what he thought was out there. Geology is an evolutionary science. We can't afford to neglect the evolution of the future geologists and the future concepts because they're important. Out here in the park we've got one of the best possible sites with a whole variety of facies, to say they can go out and study this for another century. My bet is in another century someone's going to make the same qualifying comments I made just now about myself. They've got more of the picture, but you know we're still learning.

It's fun in this area. This is a view from the ridge trail and to be absolutely out in those things, usually alone, I get kind of thrilled. This is the reef trail of McKittrick Canyon, of course, and many of you have climbed that. You know, when the sun begins to go down is when it gets exciting here in the Guadalupes. When the heat is off usually, and the shadows are tremendous. The west face, now that's the face for late in the day. The cliffs get pink and here is the frosting up there, above where I hike down into here, and you get a moon up there, and it is just kind of like, "My God, I'm lucky I'm here." Well, I come from up north. Almost invariably in my pictures of the sunsets on the west face, I'm not down at the base yet. Almost invariably there is too much interest up the hill, so the last part of the traverse to the pickup truck or whatever is made in the last rays of that or, some nights, starlight. It just says, and many people have the same feeling, once they're out there they want to stay there

Now that's fun—when somebody can upset the apple cart that way with just her own knowledge and her own powers of observation.

and see what's going on. I encourage all of you to use the west side trails and to stay over late into a sunset. It's great.

The last one I've got, my last slide, what do you see here if you look hard? You really see El Capitan, but you may recognize a rather obscure rainbow. You know, that's kind of symbolic. There is a pot of gold at the end of the rainbow here in the Guadalupes, but it may be rather obscure. It is there for the taking and there for the study. I want to just report this one thing. Last April at this time we were down here with another field trip group—you gotta hear this—Hale-Bopp was in the sky. One night we were driving up the road to McKittrick. It was about nine in the evening and there was a full moon. The east face of El Capitan was brilliantly lit in the moon and off there on the right above where you see the rainbow coming down was Hale-Bopp comet. Pictures didn't work out but I will never forget it. It was quite a place up there. So, I will leave you with that.

Now, I have to tell you that there are two exhibits out there by big oil people and by the Bureau of Economic Geology. I put no signs on them. I want you to see the detail that has been done on this west face, Algerita escarpment and also some photographs made by Pat Laman, who's with Exxon, and who was also a Wisconsin student at one stage of the game. Take a look at them, as you will see how much work has been done, and don't believe there isn't room for more. To you park people, I wish you well in stewarding these marvelous resources. Thank you.

Chapter 27

Geology of the Guadalupe Mountains: An Overview of New Ideas

CAROL HILL, Ph.D., has studied the geologic resources of the Guadalupe Mountains for 30 years. She is a consulting geologist and the author of ***Cave Minerals of the World***, ***The Geology of Carlsbad Caverns***, **and** ***The Geology of the Delaware Basin***.

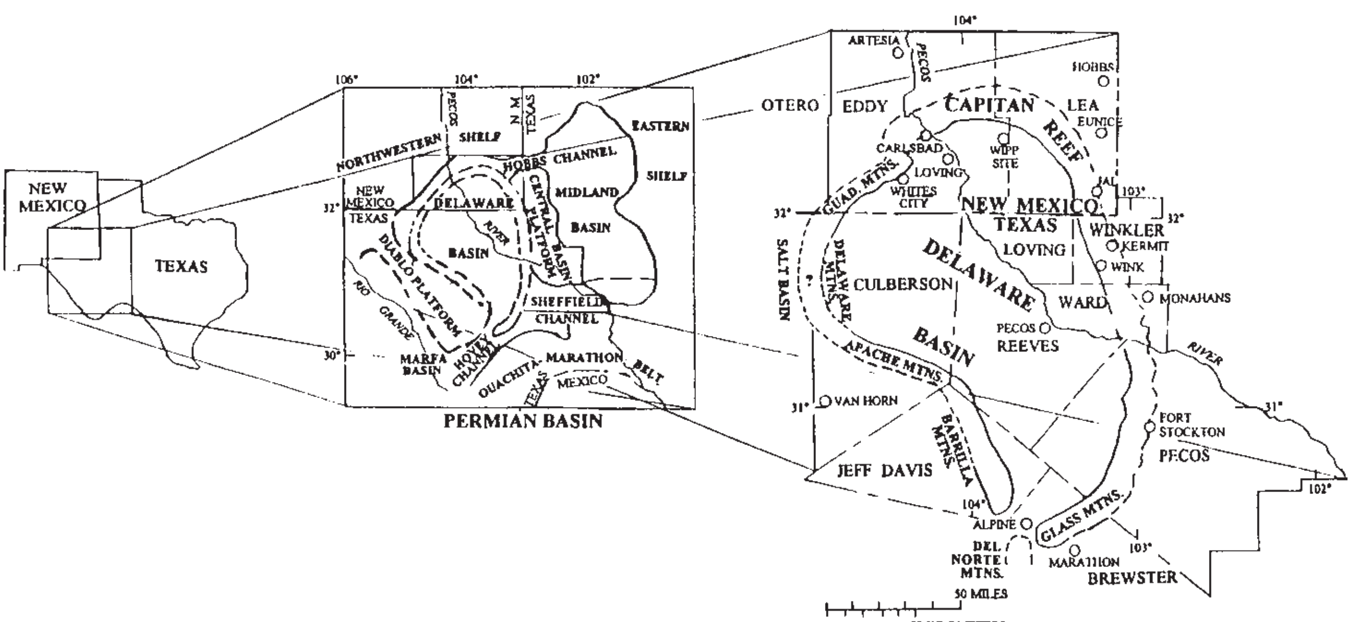
Introduction

This paper is a summary of new, and sometimes controversial, ideas on different aspects of the geology of the Guadalupe Mountains, from the Late Permian (Guadalupian) up to the present. Many of these issues were discussed in the "special topic" section of Hill (1996), but other issues are even more recent. Together, these ideas portray a somewhat different picture of the geologic history of the Guadalupe Mountains from that held only a decade or so ago.

Late Permian (Guadalupian)

Where was the inlet channel to the Delaware Basin in Permian time? In nearly every paper written on the Delaware Basin since the 1940s, the classic paleogeographic location map for the Permian of west Texas shows the Hovey Channel as being the inlet for sea water (Figure 1). But was it? Interpretations of new evidence suggests that the channel may have been on the west side of the basin rather than on the south side—in the area now known as the Salt Basin, between the Guadalupe and Apache mountains.

Figure 1. Location map, Permian Basin, southeastern New Mexico and west Texas. The Capitan reef is exposed in the Guadalupe, Apache, and Glass mountains, but it is located in the subsurface around the rest of the basin. The location of the Capitan reef in the vicinity of the Salt Basin is unknown. The Hovey Channel, supposed inlet to the Delaware Basin in Permian time, is also shown. From Hill 1996.



Four main lines of evidence support this interpretation. First, the location of the Capitan and Goat Seep formations in the area of the Salt Basin is unknown (the area marked "?" on Figure 1). The Capitan and Goat Seep reefs are known to turn from a southwestward direction at Guadalupe Peak to a southward direction through the Patterson Hills and Beacon Hill, but then these units become untraceable in the subsurface. The Capitan and Goat Seep are not encountered again (by well penetration) until exposed in the Apache Mountains near Seven Heart Gap. One possible reason why these rocks may be missing between the Guadalupe and Apache mountains is that they never formed there in the Permian because that was the location of the inlet channel to the Delaware Basin.

The second and third lines of evidence come from the Glass Mountains located near Alpine, Texas (Figure 1), where the Capitan reef is again exposed and where the inlet channel to the basin was supposed to have existed near the old railroad town of Hovey. The Hovey Channel was originally placed in the Glass Mountain area primarily because: (1) Leonardian and Guadalupian rocks in this vicinity were believed to be of deep-water, basin origin and (2) because the Tessey Limestone (equivalent in age to the Castile Formation in the rest of the basin) was believed to be a limestone facies that graded into anhydrite and then halite from south to north across the basin. Neither of these two interpretations has proven to be correct (Hill 1998).

The upper Cathedral Mountain, Road Canyon, and Word formations in the Glass Mountains—once considered to be deep-water facies—have been shown by Wardlaw and others (1990) to be shallow-marine, fan-delta to lagoonal deposits, as indicated by fossil leaves such as gigantoperoids. In addition, the Tessey Limestone turns out not to be a Late Permian marine limestone, but a bioepigenetic limestone of mid-Tertiary age formed by the replacement of anhydrite (Hill et al. 1996). In other words, the original depositional rock in the Hovey Channel area was gypsum-anhydrite, not limestone, and thus there was no facies change away from the assumed Hovey Channel inlet.

The fourth line of evidence strongly supports the other three. Heywood (1991), in his isostatic residual gravity anomaly map of New Mexico, clearly showed a circular "bull's-eye" negative anomaly in southeastern New Mexico which delineates the Permian Delaware Basin. On this map, the "entrance" to the basin appears to be on the southwestern, Salt Basin side of the Delaware Basin, rather than on the southern Hovey Channel side (Hill 1998).

Late Permian (Ochoan)

When did the Guadalupe Mountains first become emergent? The Castile Formation has been considered to be the classic textbook example of a deep-water evaporite deposit that formed within a barred and isolated basin. By "deep water" it is meant a brine-filled basin approximately 400–600 meters deep. This deep-water model has remained popular since it was first introduced in the 1940s, but recently it has been challenged by a new generation of workers such as Kendall and Harwood (1989), who presented evidence in favor of a shallow-water origin for the Castile. Hill (1996) listed eight reasons in support of a shallow-water model, and compared the Delaware Basin in Castile (Late Permian–Ochoan) time with the desiccated Mediterranean Sea basin in late Miocene time.

A shallow-water basin is also supported by a probable Ochoan-age karst episode in the Guadalupe Mountains. Hill (1987) described an early, Late Permian, "Stage 1 fissure karst" episode of cave development in the Guadalupe Mountains. Melim (1991) also identified an exposure episode in the Guadalupe Mountains that was Late Permian (Ochoan?) in age, during which time an initial stage of meteoric leaching occurred with the development of a large-scale, solution-enlarged fracture system. This solution-enlarged cave system in the Capitan Limestone implies at least a partial exposure of the reef in Late Permian (most probably Ochoan) time, and the descent of meteoric groundwater.

Mesozoic
At the close of Permian time the Delaware Basin was tilted eastward and uplifted slightly above sea level, and a marine environment was replaced by a deltaic, lacustrine (lake), and fluvial (stream) environment in the Triassic. During the Triassic and Jurassic, the area was low-lying with erosion and dissolution taking place both in the basin and the reef. During this time water slowly diffused through the Capitan reef forming Stage 2 spongework caves. Some of these caves became partially filled with montmorillonite clay, K-Ar dated by Hill (1987) at 188±7 million years (Jurassic). In the Early Cretaceous the Guadalupe Mountains area remained near sea level, with low-gradient streams and then a marine sea transgressing over the area.

What is the age of the Guadalupe Mountain summit gravels? Widespread siliceous lag gravels can be seen on the summit plain of the Guadalupe Mountains, immediately shelfward of the reef escarpment and overlying Tansill beds. The origin and age of these gravels has been a subject of debate for many years, but it now appears likely that they date from the Early Cretaceous (Hill 1996). In Early Cretaceous (Comanchean) time the Guadalupe Mountain area was traversed by low-gradient streams, which left behind their load of siliceous gravels. Then, later in the Comanchean, a marine sea transgressed over the area for a relatively brief period of time. According to S. Lucas (personal communication 1995), the Guadalupe Mountain summit gravels most nearly resemble Early Cretaceous Trinity clastics, which represent a fluvial regime just before the time of marine transgression.

Late Cretaceous–early Tertiary
How much uplift of the Guadalupe Mountain area was Laramide? The long interval of quiescence in the Mesozoic was terminated during the Late Cretaceous–early Tertiary by the Laramide orogeny, an event which elevated the entire Colorado Plateau and Rocky Mountains from New Mexico to Wyoming. A problem that has rarely been discussed by researchers working in the Guadalupe Mountains is: how much of the uplift of the Guadalupe Mountains occurred during the Laramide versus how much occurred later during the Basin and Range? Since very little work has been done on this problem in the Guadalupe Mountains, work from Colorado has been applied to this topic (Hill 1996).

Gregory and Chase (1992) showed that the entire uplift of the central Rocky Mountains in Colorado most probably happened during the Laramide, with very little of the elevation being due to Miocene-Pliocene Basin and Range uplift. This means that for the Colorado Rocky Mountains, and possibly also for the Guadalupe Mountains (part of the Southern Rocky Mountains), that the elevation of the land surface above sea level may have reached its full height (1.2 kilometers or more) in the Laramide (early Tertiary). Then, in the Miocene, Basin and Range extension and faulting uplifted the Guadalupe Mountain block between 1,000 and 2,000 meters (on its west face) relative to the downfaulted Salt Basin.

Oligocene
In the early Tertiary there was a transition from Laramide compression to Basin and Range regional extension. This transition phase was marked by an episode of volcanism in the Trans-Pecos region and to a lesser extent in the Delaware Basin (Horak 1985). Igneous dikes, with K-Ar ages of 32–35 million years, crosscut the basin just south of the Guadalupe Mountains, extending northeastward almost to Lovington, New Mexico (Hill 1996).

In the late Oligocene–early Miocene, beginning about 30 million years ago, faulting began to uplift the Guadalupe Mountain block relative to the downfaulted Salt Basin. This brought about a change in the hydrothermal regime: from one of melting and igneous intrusions to one of convective heat flow and an increased geothermal gradient. Hydrogen sulfide, produced in the reaction of hydrocarbons with anhydrite of the Castile Formation in the basin, moved into structural traps (anticlines) in the Capitan reef (Figure 2), and there, in the reduced zone, formed Mississippi Valley-type (MVT) sulfide deposits (e.g., Queen of the Guadalupes mine) (Hill 1993). The Oligocene was also a time when other MVT deposits formed in New Mexico (North and McLemore 1988).

Miocene

While the block faulting of the Guadalupe Mountains began at about 30 million years ago, the main uplift stage did not begin until about 15 million years ago. The Miocene was a time of especially high heat flow (~50°C/km) (Barker and Pawlewicz 1987), and this heat was responsible for the further maturation and migration of hydrocarbons in the basin and the convective circulation of hot fluids in the Capitan reef. As hot water rose and was cooled, the solubility of $CaCO_3$ gradually increased so that small (Stage 3 thermal) caves were dissolved in the deep-solutional zone. Higher in the depositional zone, the loss of CO_2 decreased the solubility of calcite so that the walls of these small caves progressively became lined with calcite spar (having fluid inclusion temperatures of 30–80°C and oxygen isotope values of $d^{18}O$ = -11 to -14‰) (Hill 1996). This same calcite thermal spar also filled Basin and Range fault zones, from the Guadalupe Mountains south to the Delaware, Apache, and Glass mountains (Hill 1996).

Are the large caves in the Guadalupe Mountains of sulfuric acid origin? As the Guadalupe Mountains uplifted in the Miocene, the water table–zone of oxidation progressively dropped in response to the lowering of regional base level. When hydrogen sulfide rose from the hydrocarbon basin and intersected this oxygenated zone, it formed sulfuric acid which dissolved the large cave passages in the Guadalupe Mountains (e.g., Carlsbad Cavern and Lechuguilla Cave). These large passages cut across all three of the former karst episodes (Stage 1 fissure karst, Stage 2 spongework karst, and Stage 3 thermal karst).

It is now the concensus of most karst geologists that the large caves in the Guadalupe Mountains were formed primarily by sulfuric acid and not by carbonic acid. A number of different lines of evidence attest to this sulfuric acid/hydrocarbon origin for the Stage 4 caves (Hill 1987, 1990, 1996):

1. Massive gypsum blocks (up to 10 meters high) and native sulfur deposits (up to thousands of kilograms) in these caves formed as byproducts of a sulfuric-acid mode of dissolution. Epigenic, carbonic-acid caves do not contain these types of deposits.
2. The low pH, sulfuric acid indicator minerals: endellite, alunite, and natroalunite occur in these caves.
3. High uranium, radon, and the minerals tyuyamunite and metatyuyamunite in these caves are all indicative of a H_2S system where uranium (and vanadium) precipitated along a redox boundary interface (Hill 1995).
4. Other sulfuric acid caves are known worldwide, and these are also associated with hydrocarbons. Some of these caves are actively forming today by a sulfuric acid mechanism (e.g., La Cueva de Villa Luz in Tobasco, Mexico, is a sulfuric acid cave related to hydrocarbons in the Gulf of Campeche) (Pisarowicz 1994). A milky-white river, with dissolved gypsum and sulfur, flows from the cave, and sulfur crystals are growing in areas where drip water has a measured pH of 1. Sulfur isotope values for the sulfur and gypsum in La Cueva de Villa Luz ($d^{34}S$ = -26 to -22‰) are in the same range as for the sulfur and gypsum in Guadalupe Mountain caves.
5. The isotopically light composition of the massive gypsum, sulfur, and alunite/natroalunite deposits in Stage 4 caves is the most convincing evidence for a sulfuric acid origin related to hydrocarbons. Only biologically aided reactions such as occur with hydrocarbons could have produced the large isotopic fractionations found in these deposits. Gypsum and native sulfur deposits in Guadalupe Mountain caves are sig-

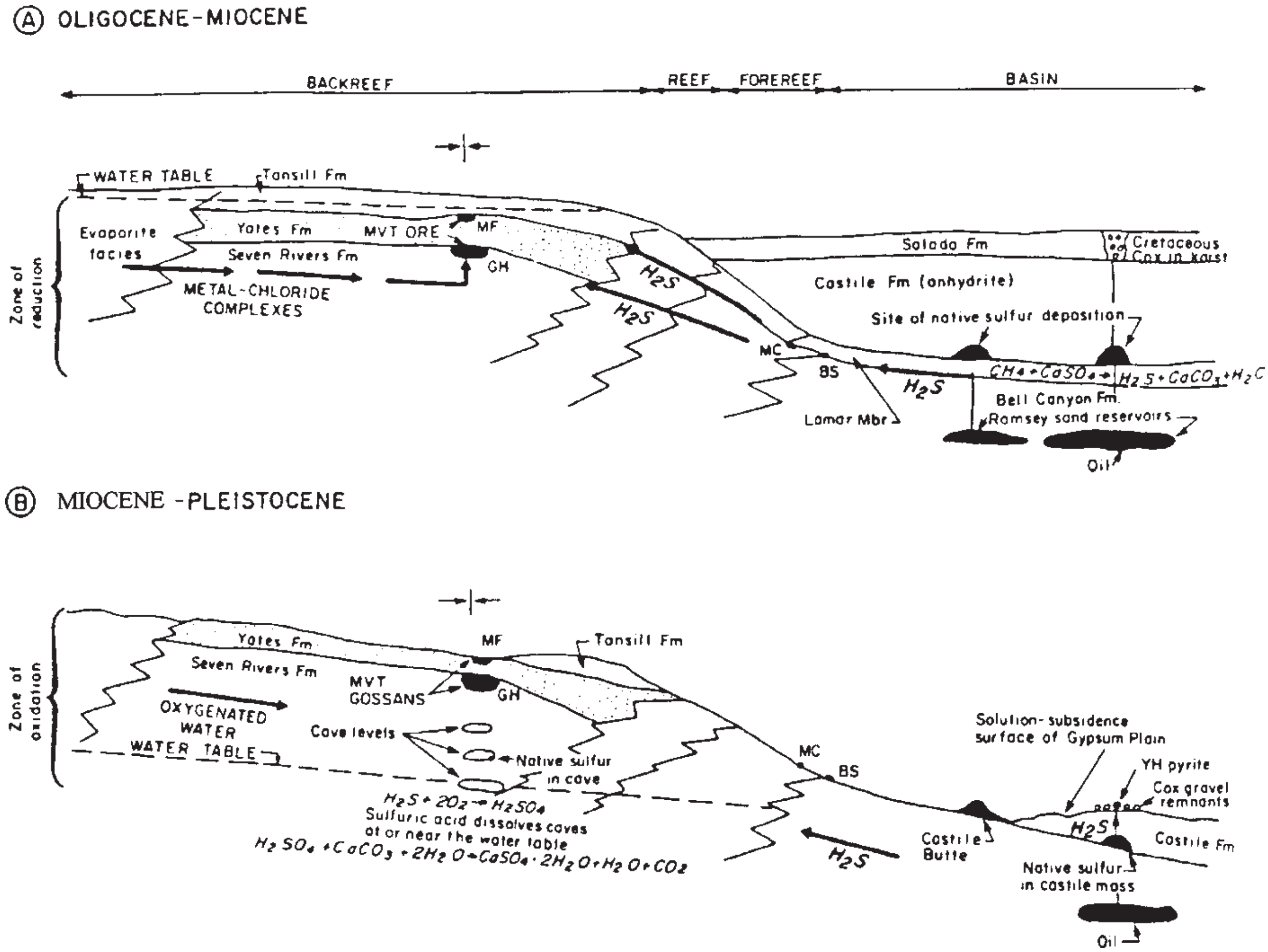


Figure 2. The idealized model for the origin of caves and for Mississippi Valley-type (MVT) sulfides in the Guadalupe Mountains proposes a genetic connection between hydrocarbons and native sulfur in the basin, and MVT deposits and sulfuric acid caves in the carbonate-reef margin. (A) In the late Oligocene–early Miocene during the Tertiary tilting of the Delaware Basin, H_2S was generated in the basin by reactions involving hydrocarbons and Castile anhydrite solutions. The H_2S oxidized to native sulfur in the basin and also migrated from basin to reef to accumulate there in structural (anticlinal) and stratigraphic (base of Yates) traps. Metals moved downdip as chloride complexes from back reef–evaporite facies; where these metals met with ascending H_2S below the water table in the zone of reduction, they formed MVT deposits. (B) Later in the Miocene and also in the Pliocene to Pleistocene, continued uplift and tilting of the Guadalupe Mountain block and Delaware Basin area caused increased H_2S generation and migration of gas from basin to reef. Cave dissolution occurred in the same structural and stratigraphic position as earlier MVT deposits, and cave passages formed where H_2S oxidized to sulfuric acid at or near the water table in the zone of oxidation. Cave levels correspond to a descending base level caused by the regional lowering of the Pecos River. From Hill 1996.

nificantly enriched in ^{32}S; depletions as great as -25.6‰ for gypsum and -25.8‰ for sulfur have been measured (Hill 1990). The same isotopically light signatures also characterize alunite and natroalunite in these caves $d^{34}S$ = -28.9 for alunite and -28.6 for natroalunite (Polyak and Güven 1996).

Hydrogen sulfide, generated from hydrocarbon reactions in the basin, migrated into the surrounding Capitan reef and accumulated in structural and stratigraphic traps (Figure 2). Where it met with oxygenated meteoric groundwater descending to the water table along dipping back-reef beds or joints in the overlying land surface, it formed sulfuric acid.

(Equation 1)

$$H_2S + 2O_2 = HSO_4^- + H^+$$

(Equation 2)

$$HSO_4^- + H^+ + CaCO_3 + 2H_2O = Ca^{2+} + SO_4^{2-} + 3H_2O + CO_2$$

The sulfuric acid produced (Equation 1) dissolved the Capitan reef limestone to produce the cave void, gypsum, and CO_2 (Equation 2). Sulfuric acid was neutralized by the limestone away from gas injection points and, therefore, horizontal cave passages in the Guadalupe Mountains end abruptly (Figure 3). The sulfuric acid reaction did not occur below the zone of oxygenation of the groundwater and hence vertical passages thin and end

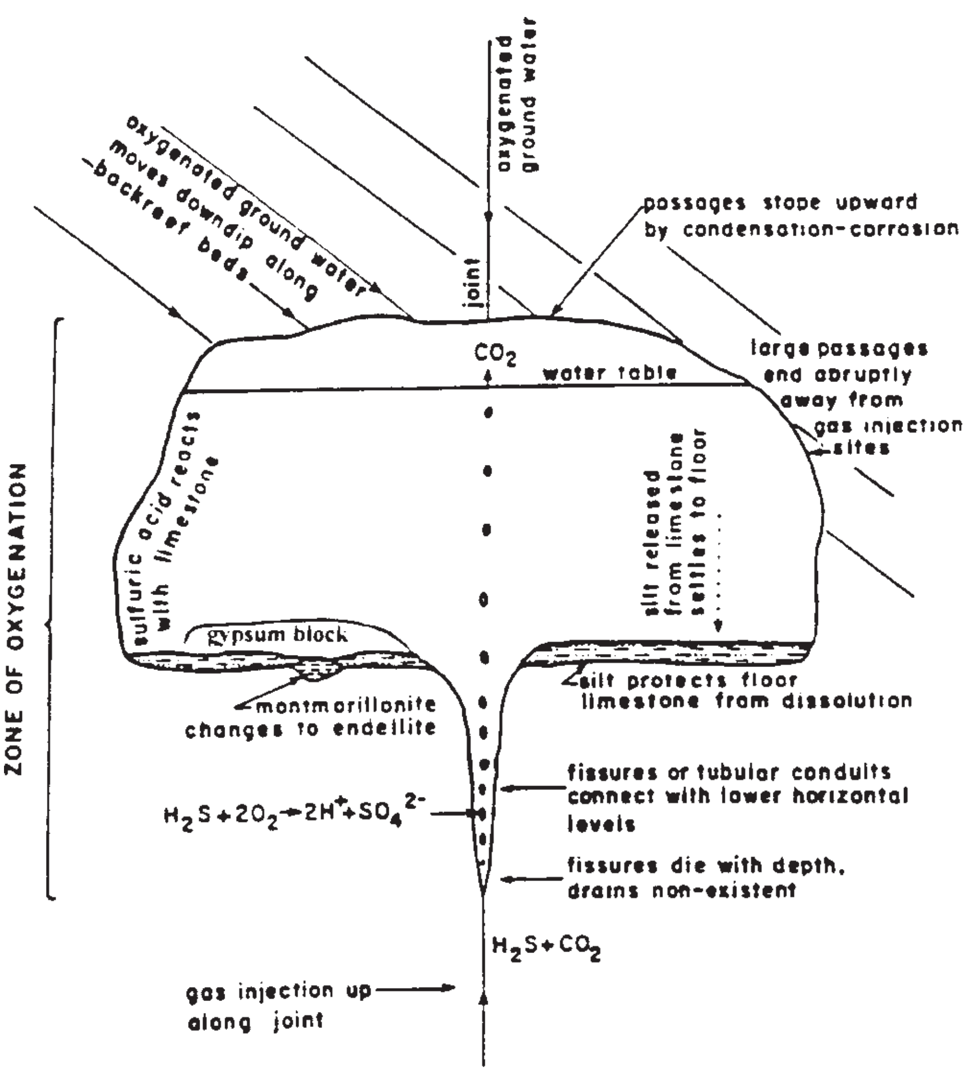


Figure 3. Model of hydrogen sulfide reaction with dissolved oxygen near the water table to form the large, Stage 4, sulfuric acid cave passages. Hydrogen sulfide from the basin ascends into the reef along injection points and reacts with oxygen in the zone of oxygenation to form sulfuric acid. The acid is neutralized by limestone away from the injection points and therefore horizontal rooms end abruptly. The sulfuric acid reaction does not occur below the zone of oxygenation and hence vertical passages thin and end with depth below large, horizontal rooms. With successive lowering of base level, new horizontal levels become connected with older horizontal levels by spring shafts and joint chimneys. The sulfuric acid dissolving the limestone forms the cave void, and insoluble residue in the limestone settles to the floor as silt. Later, dissolved sulfate created in the sulfuric acid–limestone reaction precipitates over the silt as gypsum. From Hill 1987, 1996.

with depth below large, horizontal rooms. With successive lowering of base level, new horizontal levels became connected with older horizontal levels by spring shafts and joint chimneys. Silt residue from the limestone settled to the floor; gypsum in solution (Equation 2) precipitated over the silt in slack places to form massive gypsum blocks, or directly replaced the limestone bedrock; and the CO_2 produced (Equation 2) caused further dissolution beneath the water table or condensation-corrosion of cave passages in the air zone. According to this model vertical tubes, fissures, and pits in Guadalupe caves are interpreted as having formed along injection points for hydrogen sulfide gas (bathyphreatic dissolution), and horizontal levels are interpreted as forming at the water table where dissolved oxygen was the most concentrated (water-table dissolution). H_2S degassing created the native sulfur deposits and also (ultimately) the precipitation of the secondary, later-stage uranium-vanadium minerals: tyuyamunite and metatyuyamunite. A low pH, sulfuric acid environment also caused clay minerals to reconstitute to endellite, alunite, and natroalunite.

What is the age of the large cave passages in the Guadalupe Mountains? It now appears that Stage 4 sulfuric acid caves may be older than the Pliocene-Pleistocene age ascribed by Hill (1987). Maximum uplift and tilting of the Guadalupe block is now believed to have occurred in the Miocene (15–5 million years ago). This means that hydrogen sulfide could have been migrating throughout the middle to late Tertiary with the potential for cave formation (Hill 1996). This suspicion has been confirmed by Polyak and others (1997) who $^{40}Ar/^{39}Ar$ dated alunite from four Guadalupe caves. These dates establish that the large cave passages formed from about 14 million years ago in the southwestern part of the reef (Virgin Cave) to about 4 million years in the northeastern part of the reef (Carlsbad Cavern and Lechuguilla Cave). These absolute dates are very important because they correlate with the time of major uplift of the Guadalupe Mountains and the migration of hydrogen sulfide from the basin into the Capitan reef.

Pliocene-Pleistocene

As the Delaware Basin and Guadalupe Mountains continued to uplift and tilt towards the northeast in the Pliocene-Pleistocene, evaporites were progressively eroded from west to east across the basin, and caves developed from southwest to northeast in the Capitan reef. The last lowering of the water table out of Carlsbad Cavern and Lechuguilla Cave may have taken place at about 600,000 years ago when the Capitan aquifer was breached by the Ancestral Pecos River at Carlsbad (Bachman 1980). This is about the time that speleothem growth began in Lower Cave and when clouds were forming at the Lake of the Clouds, Carlsbad Cavern, and Lake of the White Roses in Lechuguilla Cave (Hill 1996). Climate in the Holocene has become increasingly arid so that most speleothems in the caves of the Guadalupe Mountains are no longer active.

Conclusions

The geologic history of the Guadalupe Mountains is now known with some certainty. Over the last decade an explosion of new ideas has emerged as new analytical techniques have been developed. For the first time, the sequence of geologic events from the Late Permian to the present can be estimated for the Guadalupe Mountains.

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Note: Because the boundaries of the Middle Permian and Guadalupian have been defined and adopted (see Glenister et al. and Lambert et al. in this volume), the editors treat them as formal units. Therefore, the initial letters of the names and modifying words of both the period/system (e.g., Middle Permian) and epoch/series (e.g., Upper Guadalupian) have been capitalized in this context. Other geologic units in this paper follow the guidelines provided in Hansen, W. R., editor. 1991. Suggestions to authors of the reports of the United States Geological Survey. 7th edition. U.S. Geological Survey, Washington, D.C.

Chapter 28

History of the Sulfuric Acid Theory of Speleogenesis in the Guadalupe Mountains

DAVID H. JAGNOW has been a consulting geologist in Los Alamos, New Mexico, for the past 15 years. He began exploring and studying the caves of the Guadalupe Mountains in 1971. He completed his M.S. thesis in geology at the University of New Mexico. His thesis proposed the theory that the Guadalupe caves were dissolved by sulfuric acid.

The caves of the Guadalupe Mountains in New Mexico and Texas, are among only a few caves in the world that are known to have been dissolved by sulfuric acid, rather than a carbonic acid. Research in the early 1970s led to this controversial discovery and helped explain the uniqueness of the Guadalupe caves. The theory, as currently understood, is that hydrogen sulfide (either brine or gas or both) leaked upward along fractures from underlying sour oil and gas deposits. Upon reaching the oxygenated meteoric groundwater in the Capitan aquifer, sulfuric acid formed, dissolving large voids in the Capitan reef complex at or immediately below the water table. With the uplifting of the Guadalupe block over the past 12 to 20 million years, caves formed at subsequently lower elevations as the water table continued to lower. Deposits of gypsum, sulfur, chert, and other minerals in the Guadalupe caves have helped unravel the story of these caves. After 25 years of research, the caves of the Guadalupe Mountains are still revealing the secrets of their origin.

Early history

In a 1971 (lost) report to Carlsbad Caverns National Park, Steven J. Egemeier first suggested very briefly that the large rooms of Carlsbad Cavern may be the result of solution by sulfuric acid. Egemeier's thesis, published in 1973 at Stanford University, again mentioned the possibility that the caves in the Guadalupe Mountains are of sulfuric acid origin. This was based on his replacement solution, sulfuric acid theory for the Kane Caves, Wyoming.

Based on field work during 1972 and 1973, and completely independent of Egemeier, David Jagnow completed his M.S. thesis in 1977 at the University of New Mexico, proposing a sulfuric acid origin for the Guadalupe caves. Jagnow attributed the source of the sulfuric acid to oxidation of pyrite in the Yates Formation during uplift of the Guadalupe block.

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Early clues

Morphology. Egemeier had not visited many Guadalupe caves but based his hypothesis largely on the morphology of the caves: the large rooms, deep blind pits, and joint-controlled passages that abruptly terminate, which characterize Carlsbad Cavern and many other Guadalupe caves. This morphology is unusual, even for most phreatic caves. (Phreatic caves form by dissolution below the water table.)

Limonite. Jagnow first observed the thousands of limonite pseudomorphs-after-pyrite along the Guadalupe Ridge road while doing field work on October 30, 1972. These 3-to-8-centimeter-diameter cubes of limonite within the Yates Formation had originally been pyrite. With the uplift of the Guadalupe fault block, which started 12–20 million years ago (and continues today), the pyrite was exposed to oxygen-rich fresh water and slowly altered to limonite, releasing sulfuric acid during this process. Jagnow first theorized that the pyrite was the primary source for the sulfuric acid solution reaction. While the current theory indicates that hydrogen sulfide was the source for the sulfuric acid, the pyrite

Slowly, it became accepted that the sour gas and oil deposits beneath the Capitan reef complex provided the primary source for the sulfuric acid reaction that dissolved the Guadalupe caves.

may have played a role in the abundance of caves found directly below the Yates Formation in the more soluble Seven Rivers Formation.

David F. Morehouse (1968) discussed cavern development via the sulfuric acid reaction as applied to the caves in the Galena Limestone around Dubuque, Iowa. Jagnow assisted Morehouse in the collection of water chemistry data in 1965 and was familiar with this relatively new theory of cavern development.

Gypsum. The massive deposits of gypsum (up to 10 meters thick) in the Big Room of Carlsbad Cavern had always puzzled geologists. In 1972, Jagnow recognized that the gypsum was the end product of the sulfuric acid reaction. During 1972 Jagnow documented remnants of massive gypsum at many locations within Carlsbad Cavern, New Cave [also known as Slaughter Canyon Cave], Cottonwood Cave, Black Cave, Hell Below Cave, Pink Panther Cave, and the McKittrick Hill caves.

In December 1972, Jagnow discovered finely laminated (varved) gypsum exposed in the gypsum tunnel, near the "jumping off point" in the Big Room of Carlsbad Cavern. Later, finely laminated gypsum was also discovered along the Texas trail in the Big Room. Most of the gypsum in Guadalupe caves has been recrystallized, destroying the original texture. But the few exposures of the original texture indicated that the beds of massive gypsum precipitated out of solution during the final stages of solution at any one base level. (Base level solution in the Guadalupe caves is solution at or immediately below the essentially horizontal water table.) As the Big Room in Carlsbad Cavern began to drain of water and fill with air, evaporation increased, causing the gypsum-saturated water to precipitate gypsum onto the floor of the water-filled room. Thus, massive beds of gypsum floored the rooms of all Guadalupe caves as each base level slowly drained, and solution continued at lower levels. In most caves, the gypsum has been dissolved by dripping vadose water (meteoric water that drips or flows above the water table); only remnants of these massive beds remain today.

Donald G. Davis (1973) and Michael Queen (1973) described sulfur and gypsum deposits in Cottonwood Cave and concluded that the gypsum was derived at least in part by replacement of the carbonate bedrock. The exact replacement mechanism was uncertain.

Sulfur. Bright yellow, native sulfur has been found in several Guadalupe caves. To date, perhaps 50 metric tons of sulfur have been discovered at various locations within Lechuguilla Cave. But in 1972 and 1973, the sulfur studied in Cottonwood Cave, at the crest of the Guadalupe Ridge anticline, provided the strongest argument for hydrogen sulfide leaking as gas or brines from the underlying sour hydrocarbons. Slowly, it became accepted that the sour gas and oil deposits beneath the Capitan reef complex provided the primary source for the sulfuric acid reaction that dissolved the Guadalupe caves. In 1973, Davis published the first detailed description of the sulfur deposits in Cottonwood Cave.

Later history

In 1977, Art and Peg Palmer and Michael Queen discussed gypsum-replacement mechanisms at the International Congress of Speleology. In 1978, Jagnow, Carol Hill, and others published in National Speleological Society Bulletin Symposium on Ogle Cave. Jagnow's discussion of the geology and speleogenesis again attributed the sulfuric acid origin to the overlying pyrite in the Yates Formation. This paper stimulated Davis to comment on other possible sources for the sulfuric acid, and began a renewed focus on hydrogen sulfide from the underlying hydrocarbons within the Delaware Basin. Davis proposed an ascending-water theory.

Sulfur isotope analysis. Hill (1979) did the first sulfur isotope determinations on gypsum blocks in the Big Room of Carlsbad Cavern. The presence of isotopically light sulfur proved that the gypsum was not derived from the Castile gypsum in the Permian basin.

Endellite. Hill (1979) also suggested that endellite, a sulfuric acid indicator mineral, was additional supporting evidence for sulfuric acid-related speleogenesis.

Gypsum and sulfur. In 1980, Davis wrote a review of the sulfuric-acid theory of speleogenesis, and was the first to propose a hydrocarbon source for the hydrogen sulfide–sulfuric acid origin for gypsum and sulfur present in Guadalupe caves. In 1981, Hill first published her isotope results in the Proceedings of the International Congress of Speleology at Bowling Green, Kentucky. In 1982, Doug Kirkland published (in New Mexico Geology) more sulfur stable isotope values on the gypsum blocks in the Big Room of Carlsbad Cavern. In 1985, Egemeier died after a long illness. Dr. Egemeier was a pioneer in the subject of hydrogen sulfide speleogenesis. Shortly before his death, he wrote the paper "A Theory for the Origin of Carlsbad Caverns" that was posthumously published in the National Speleological Society Bulletin in 1987. He concluded that Carlsbad Cavern was formed by ascending hydrogen sulfide waters that outgassed hydrogen sulfide into the cave air. He proposed that the limestone was replaced by gypsum.

Corrosion. In 1985, Van Everdinger and others published, "Role of Corrosion by H_2SO_4 Fallout in Cave Development in a Travertine Deposit: Evidence from Sulfur and Oxygen Isotopes."

Chert. In 1987, Hill published *Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas*. Hill relates the chert deposits, beneath the massive gypsum in the Big Room of Carlsbad Cavern, to sulfuric acid speleogenesis. Hill also is the first to discuss in detail the sulfuric acid origin of the Guadalupe caves in relation to the underlying hydrocarbon deposits and Mississippi Valley-type (MVT) sulfide ore deposits.

Recent clues

Since the early 1980s, the theory of sulfuric acid solution for the Guadalupe caves has been largely accepted by those researching the caves. Additional studies of endellite, silica deposits, isotopically light gypsum and sulfur, the presence of alunite, natroalunite, tyuyamunite, and other unique minerals all point to basinal degassing of hydrogen sulfide as the most likely source of the sulfuric acid solution.

In 1990, Hill published in the American Association of Petroleum Geologists Bulletin a summary of "Sulfuric Acid Speleogenesis of Carlsbad Cavern and its Relationship to Hydrocarbons, Delaware Basin, New Mexico and Texas." She proposed that during uplift of the Guadalupe Mountains, oil and gas moved up dip within the Delaware Basin. The gas reacted with the Castile anhydrite to form H, S, CO, and "castile" limestone. She proposed that the hydrogen sulfide rose into the Capital reef along joints, fore-reef carbonate beds, or the Bell Canyon siliciclastic beds.

In 1991, Art Palmer published a classic paper on the origin of caves and offered important information on the morphology of hypogene caves (formed by warm ascending waters). Caves of the Guadalupe Mountains were used as an example of sulfuric acid–type hypogene caves.

Alunite and natroalunite. In 1992, Art and Peg Palmer reported alunite in Lechuguilla Cave; soon after Victor Polyak identified alunite and natroalunite in Carlsbad Cavern. The sulfur isotope analysis of these two minerals by Polyak and Guven indicate that they are isotopically light, are comparable to the gypsum from cave to cave, and further support the theory of sulfuric acid-related speleogenesis. Since 1992, Polyak has identified alunite and natroalunite in Carlsbad Cavern, Cottonwood Cave, Endless Cave, Lechuguilia Cave, and Virgin Cave.

Gypsum. In 1994, Marcus Buck and others provided a detailed characterization of H_2S gypsum in caves. Their work, while not yet published in full, produced a genetic classification of these gypsum deposits. Further work in this area will show whether a cave passage formed above or below the water table.

Since the early 1980s, the theory of sulfuric acid solution for the Guadalupe caves has been largely accepted by those researching the caves.

Canaa: yellow cave precipitates. Since 1994, Polyak and Cyndi Mosch have teamed up to identify many yellow cave deposits that had previously been mistaken for sulfur. Metatyuyamunite was first identified in Spider Cave. Tyuyamunite has been identified in Carlsbad Cavern and Lechuguilla Cave. The uranium minerals metatyuyamunite and tyuyamunite were precipitated after the origin of the caves, however, the redox boundaries when the caves were forming are probably the reason why uranium and vanadium became concentrated enough to allow precipitation of these minerals.

Sulfur redox reactions. In 1995, Hill published "Sulfur Redox Reactions: Hydrocarbons, Native Sulfur, Mississippi Valley-type Deposits, and Sulfuric Acid Karst in the Delaware Basin, New Mexico and Texas." This was the first detailed review of data surrounding the entire Delaware Basin relative to sulfuric acid speleogenesis.

Also in 1995, R. H. Worden and others published "Gas Souring by Thermochemical Sulfate Reduction at 140°C." They attribute the high concentrations of hydrogen sulfide encountered in deep carbonate gas reservoirs to the in situ heating and thermochemical sulfate reduction of anhydrite. This paper helps clarify the origin of hydrogen sulfide–rich gas deposits.

In 1996 Hill, Jagnow, and Mosch found gypsum in a Glass Mountain Cave with an isotope value the same as the Guadalupe caves. This was an extremely important find since it showed that the entire Delaware Basin is degassing hydrogen sulfide. Hill subsequently (1996) published *Geology of the Delaware Basin: Guadalupe, Apache, and Glass Mountains, West Texas and New Mexico*. Hill presents the story of hydrogen sulfide basinal degassing with convincing evidence from all the mountain ranges surrounding the Delaware Basin. Her publication provides an excellent summary of all the relationships previously discussed.

Research is now shifting emphasis to the unique microbes living off the sulfur compounds found in these caves.

Sulfur deposits have been recognized in at least two active caves of sulfuric acid origin: Egemeier found sulfur in the Lower Kane Cave which is developed in the Madison Limestone in the Big Horn Basin of Wyoming; Pisarowicz and others found and described sulfur in Cueva de Villa Luz in Cretaceous limestone in the southern part of the state of Tabasco in Mexico. While these occurrences do not directly relate to the Guadalupe caves, they do demonstrate that the mechanism is valid and operative today at these locations.

Latest developments

Victor Polyak and others (1997) published, "Age of formation of Carlsbad Cavern, Lechuguilla Cave and other caves of the Guadalupe Mountains based on $^{40}Ar/^{39}Ar$-dating of Alunite." Because the alunite deposits are byproducts of H_2S-H_2SO_4 speleogenesis, these ages date the formation of the caves. Using the fine-grained alunite crystals that formed at the time of speleogenesis, Polyak and others have reported radioisotope ages of formation for Cottonwood Cave (12.3 million years), Virgin Cave (11.3 million years), Endless Cave (6 million years), and the New Mexico Room of Carlsbad Cavern (4 million years). Ages are strongly correlated with elevation of the alunite cave deposit, confirming a relationship described by Jagnow (1992). It appears that the Guadalupe block began its eastward tilting at least 12 million years ago. The oldest Guadalupe caves formed high in the block, toward the western end, and younger caves formed eastward as the water table subsequently dropped, accompanying the continued structural uplift of the Guadalupe Mountains.

Summary

The past 25 years of research have established the sulfuric acid theory of speleogenesis for the caves of the Guadalupe Mountains. Debate continues over the migration routes of the gases or brines derived from the underlying formations. Research is now shifting emphasis to the unique microbes living off the sulfur compounds found in these caves. Twenty-five years from now, the caves of the Guadalupe Mountains will still be revealing the secrets of their origin.

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Chapter 29

Recording of Earth Movements in Karst: Results of a Short Trip in Southwestern U.S.A.

ROBERTA SERFACE is a speleologist in Carlsbad, New Mexico. She has been doing cave-related research since 1991. She has worked for the National Park Service and U.S.D.A. Forest Service, as well as private consultants. She is currently employed by Celtech in Carlsbad. Her experiences with speleological investigations include the Grand Canyon, southern Texas, the Navajo Nation, and New Mexico. Her plans for a summer expedition into Lechugilla Cave are currently in process to collect microbial samples for studies and research into cures for cancer.
Other author: ERIC GILLI is a geologist in Nice, France.

Description of the method

A great number of countries are affected by earthquakes (or "seisms") that cause thousands of lost lives and countless damages. Even if some experiences have been positive (e.g., VAN system, Chinese methods), a large majority of examples prove that no technique permits us to predict the occurrence of a seism. The only possibility is to search in old records to see if great seisms have already affected a country (historical seismicity). In Earth sciences it is thought that if a seism has occurred in the past, one is likely to occur again in the future at a particular location. Therefore it is very important to locate the places where many old seisms have occurred and to know the intensity of the damages. Such studies help specialists define the probability of a future seism in an area and to draw risk maps. It is common in Europe to study old writings and it is sometimes possible to discover very old earthquakes in antiquity descriptions, but in most cases it is very difficult to get usable information that is older than 500 years. In cases when written history does not exist or has been destroyed (French Revolution) those studies are impossible. Some seismologists work on old ruins when they exist or lake deposits and Quaternary alluvium to find information which may be helpful.

The study of caves is an interesting new approach to see whether great seisms have affected an area and to find whether fractures are active. As a matter of fact, caves are very good recorders for natural phenomena. In the same way the underground environment has preserved prehistoric human traces (e.g., paintings, bones, and tools) for thousands of years, they also have preserved many traces of Earth movements. As caves may be a few million years old, it is possible to discover whether many great seisms have occurred over very long periods of time.

We search two kinds of information:

1. Old seisms: which can cause collapse of soda straws, stalactites, stalagmites, or parts of the roof.
2. Active faults: seisms are caused by fault movements (tectonic). In some cases the movements are visible (e.g., El Asnam, San Andreas), but in most cases the movements are smaller and their effects are hidden by soil or vegetation. Inside caves, which are always excavated along natural fractures, even a millimeter-scale movement is observable as it causes breaks on speleothems. Larger movements may displace whole gallery sections.

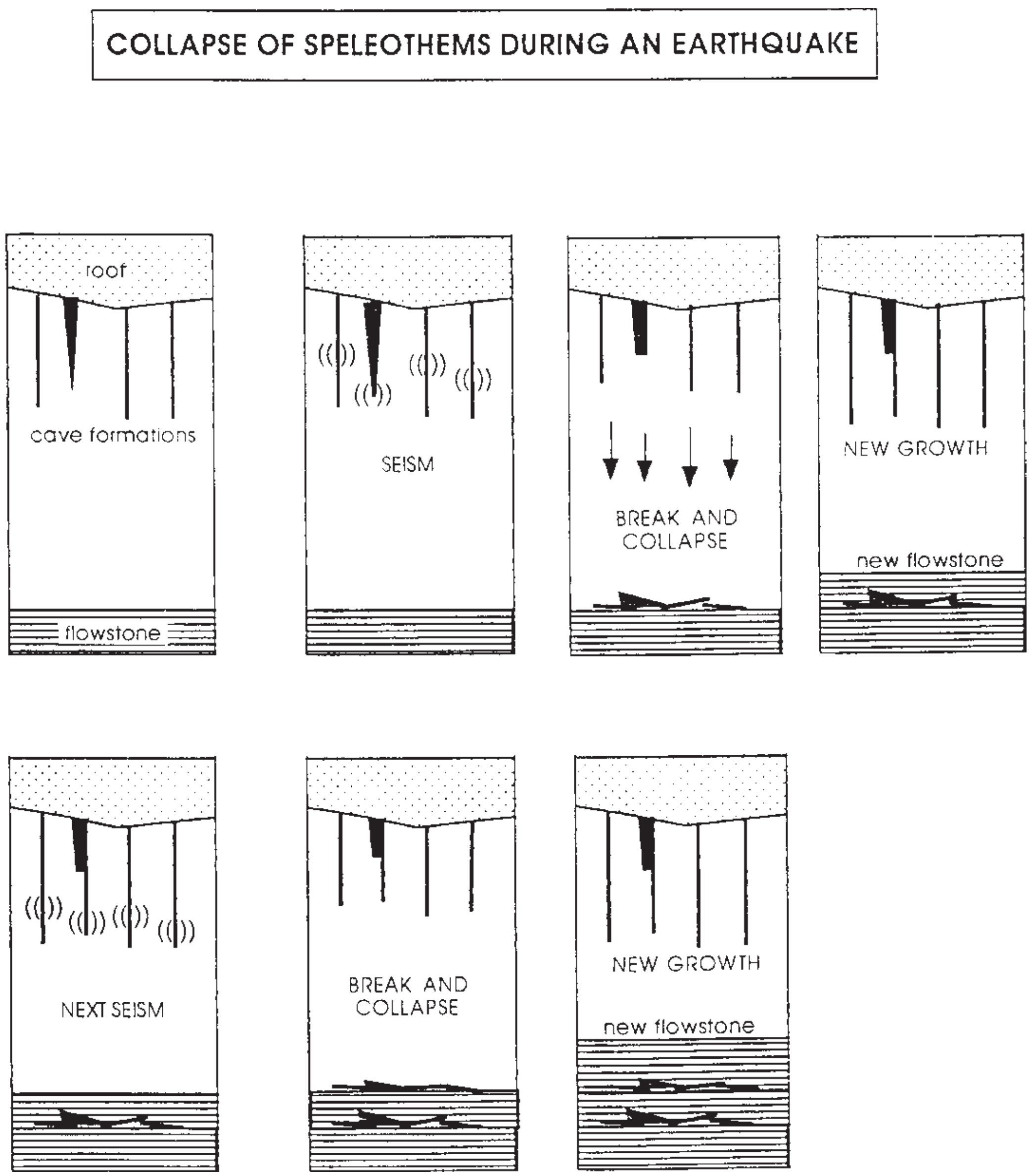
As it is possible to give an age to the speleothems, the study of the breaks is very interesting for seismic investigations. Carbon 14, uranium/thorium 180, photo luminescence, or paleomagnetism methods may be used with good results.

Since 1981 we have made observations in southern France, which is an active zone (several important seisms known since A.D. 1328). We are continuing this re - search to find known seisms recorded in caves and search for unknown ones. These studies will provide a new tool for many countries with historical seismicity. Karstic zones cover more than 10% of the emerged land in the world.

Significant previous results
1980: Method definition in southern France. Study of Cassaire Cave (Var) and Peneta Cave (Alpes Maritimes).

1986: Evidence of neotechtonics in Deux Gourdes' Cave (Vesubie Valley, Alpes Maritimes, France).

Figure 1. Collapses of speleothems during an earthquake.



1995: Turkey (Tilkiler Cave, Manavgat) where broken stalactites prove that a seism occurred in Manavgat several centuries ago. Located here is one of the largest hydroelectric dams and this dam site is considered as a non-seismic zone!

1995: Study of a slope movement for a 30,000-year period in Chemin du Castellaras Cave where formations are affected by the movement (Le Tignet, Alpes Maritimes, France).

1995: Field trip to Costa Rica to verify if the data in French caves could be attributed to tectonic events and to make a comparison between different seismotectonic areas. We have been able to see differences between the caves that are located in seismic zones (Cueva Corredores, Ciudad Neilly) and the caves in quiet places (Venado) and to realize the seismic zonation of Costa Rica.

1995: Evidence of fault movements in caves near Durance Fault (France). Dating of speleothems attributed to the 1887 seism.

1996: Study of the caves around Saint Paul de Fenouillet (Pyrenees Orientales, France) after 1996 earthquake (magnitude 5.3). Evidence of underground damage.

1996: Study of a dating method using growth laminae in 30 stalagmites (Alpes Maritimes, France).

1996: Drill sample taken in Monaco Cave flowstone producing a description of seismic history of Monaco for more than 38,000 years.

1997: Southwestern United States evidence of paleoearthquakes in Carlsbad Caverns and McKittrick Hill caves (Guadalupe Mountains, New Mexico). Present report.

1997: Study of underground damage in Barrenc du Paradet Cave (Pyrenees Orientales, France). Evidence of an east–west shock direction and a very large old seism.

Results in U.S.A (May 1997): itinerary
California

1. Mercer Caverns (May 7)
2. Mitchell Caverns (May 9)

Arizona

3. Boulder hills with petroglyphs near Tucson (May 11)
4. Sutherland Peak Cave (May 13)
5. Tectonic cracks near (northern) Flagstaff (May 15)
6. Lava River Cave near Flagstaff (May 15)

New Mexico

7. Endless Cave near Carlsbad (May 19)
8. Carlsbad Caverns (May 21)
9. Sand Cave and McKittrick Cave (May 22)
10. Hidden Cave in the Guadalupe Mountains (May 23)

Caves in California

Mercer Caverns. We spent a few days with Bruce Rogers (U.S. Geological Survey, San Francisco) looking for caves near the San Andres Fault. In fact, very few caves are known in this part of California. We only visited Mercer Caverns in the Sierra Nevada, located in the Mother Lode area near the small town of Murphys in Calaveras County. It is a small cave in a banded marble lens (Permian?) of the Calaveras Group and is the result of rocks collapsing between vertical tectonic joints. It is well decorated and has a wall of aragonite crystals at the bottom. There are several places where the columns and flowstones have been fractured, but these features seem to have been caused by subsidence.

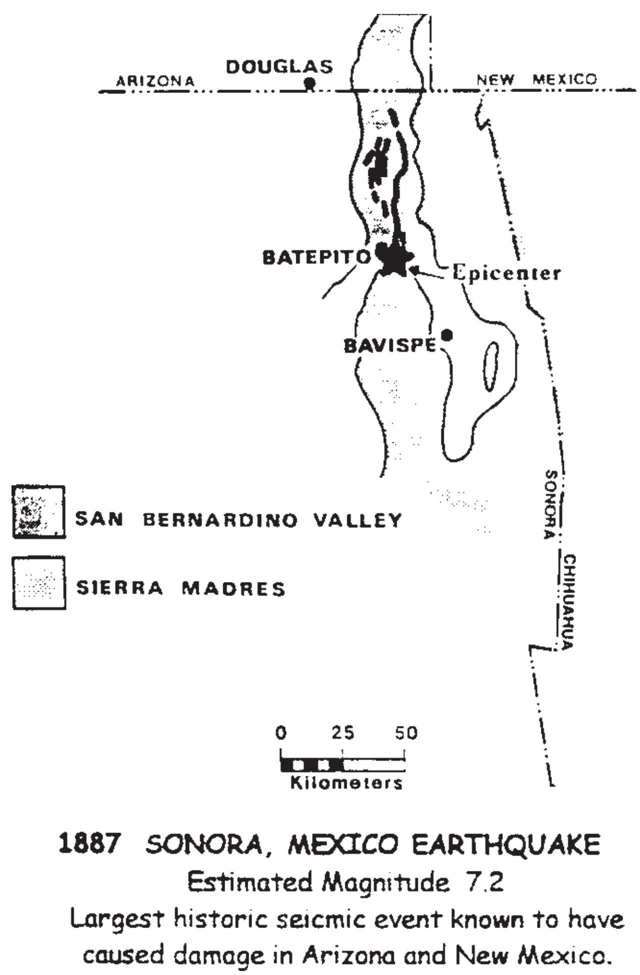
Mitchell Caverns. It is a small cave in Providence Mountains State Park in the Mojave Desert, very close to the border of Nevada and Arizona. The cave is a subvertical series of limestone beds covered with rhyolite. There are two main rooms, one of which is well decorated. It is possible to observe many breaks in the rock wall and in the flowstone, but as the cave is very close to the outside, most of the features may have been caused by decompression. The passage between the two rooms contains many broken stalactites and some are vertically cleaved. Such an unusual shape may have been caused by seismic vibrations.

Caves in southern Arizona

Seismic history. An important earthquake in the San Bernadino Valley of northern Sonora, Mexico, had caused damages in 1887 near the border of Arizona and New Mexico. A fault displacement was visible eight kilometers south to Douglas on a 50-kilometers-long main fault. The supposed magnitude was 7.2. In Sierra Vista the damage intensity (actual standardized scale didn't exist at the time) was VII to VIII. Damage included: (1) VIII in Box Canyon with rocks and trees collapsing on Ramsey Peak, (2) VII in Miller Canyon with some rock collapse, (3) VII at Fort Huachuca which opened fissures in buildings, (4) VII in Cave Canyon with large rocks collapsing, and (5) VII in Ash Canyon also with large rocks collapsing.

S.P. Cave. On Sutherland Peak in the Huachuca Mountains near Sierra Vista is a very small, well-decorated cave known as S.P. Cave. It has many stalactites, soda straws, disks, and helectites. A limestone lens in a volcanic environment acts as a natural drain for surrounding fractured rhyolite and the area has been intensively karstified. The contact between rhyolite is a faulted one with many cracks. Several fractures that affect speleothems may be observed in the entrance. This could be attributed to fault movement. In the deep parts of the cave, fractures are also visible; however, most were caused by subsidence. Large flowstone columns have been deposited on clay substratum. The clay, washed away by water, caused the collapse of these speleothems. Meanwhile in several places it is possible to see soda straws and small stalactites in the clay. Some of them are stuck vertically in the soil. The

Figure 2. The earthquake that occurred in 1887 near Sonora, Mexico, had an estimated magnitude of 7.2. This is the largest historic seismic event known to have caused damage in Arizona and New Mexico.



collapse was probably caused by the 1887 earthquake. It would be interesting to drill a segment from the soil to see if older levels of collapsed formations exist.

Hidden Cave. Located in the Santa Rita Mountains, this very small cave (where a main fault is observable) does not contain any evidence of movement or speleothem collapse.

Non-karstic signs. Close to Tucson there are several small diorite hills with large boulders covered with Native American rock art called petroglyphs. It is possible to observe collapse and displacement. Some boulders are broken and displaced without patina and a good number of petroglyphs are damaged. The movements have been attributed to the 1887 Sonoran earthquake (J. Holmlund, personal communication).

Caves in northern Arizona (Flagstaff)
Geologic environment. The area around Flagstaff is volcanic with many different basalt flows since Miocene time. The main volcano, San Fransisco Peak, is Quaternary in age. The last volcanic event has a K-Ar age of 0.60 ± 0.08 million years (R. Holm, Northern Arizona University, personal communication). Two types of cave features exist in this area: (1) lava tubes that form in lava flows when lava at the surface cools and hardens while hot lava in the interior continues to flow and eventually evacuates, leaving a void and (2) earthcracks caused by distension.

Lava River Cave. Eighteen miles northwest of Flagstaff in the Coconino National Forest is Lava River Cave, the longest lava tube in Arizona. Such caves contain no true formations, and we did not see any unusual features. This cave is around 650,000 to 700,000 years old.

Earthcracks. In the Coconino National Forest near Wupatki National Monument, some distension features affect the limestone making it possible to climb down very deep into one-meter-wide open fractures. These are in fact small grabens and it is possible that this distension phase is still going on as parts of these cracks are collapsing at the present time. Most of these cracks contain earth and small rock fill, while others drain large, urban areas and contain things such as garden hoses and barbeque grills. The same phenomena exist near Meteor Crater in Diablo Canyon located 40 miles east of Flagstaff.

Caves in southern New Mexico
Geology of the Guadalupe Mountains, Carlsbad area. The main element of the geologic environment is the Guadalupe block whose highest point is Guadalupe Peak (8,749 ft). The block that contains limestone formations (Capitan Limestone) dips towards the northeast where it disappears beneath the plains of Carlsbad. It is bordered on the west by an escarpment over salt lakes and on the south by another escarpment (the reef escarpment) over the Delaware gypsum basin.

Capitan Limestone was a Permian reef, bordered by a large evaporitic basin. It was probably covered with Mesozoic rocks. In the Miocene Epoch this place began to arch. In early Pliocene time a main fault line broke the block and the eastern part began to rise up until the present time. This movement has been extending several miles for the past six million years.

There is little evidence of faulting in the reef escarpment area that was caused by a difference of solubility between the gypsum of the Delaware Basin and the Capitan Limestone. The western part rose up forming a graben that filled in with clay and salt deposits.

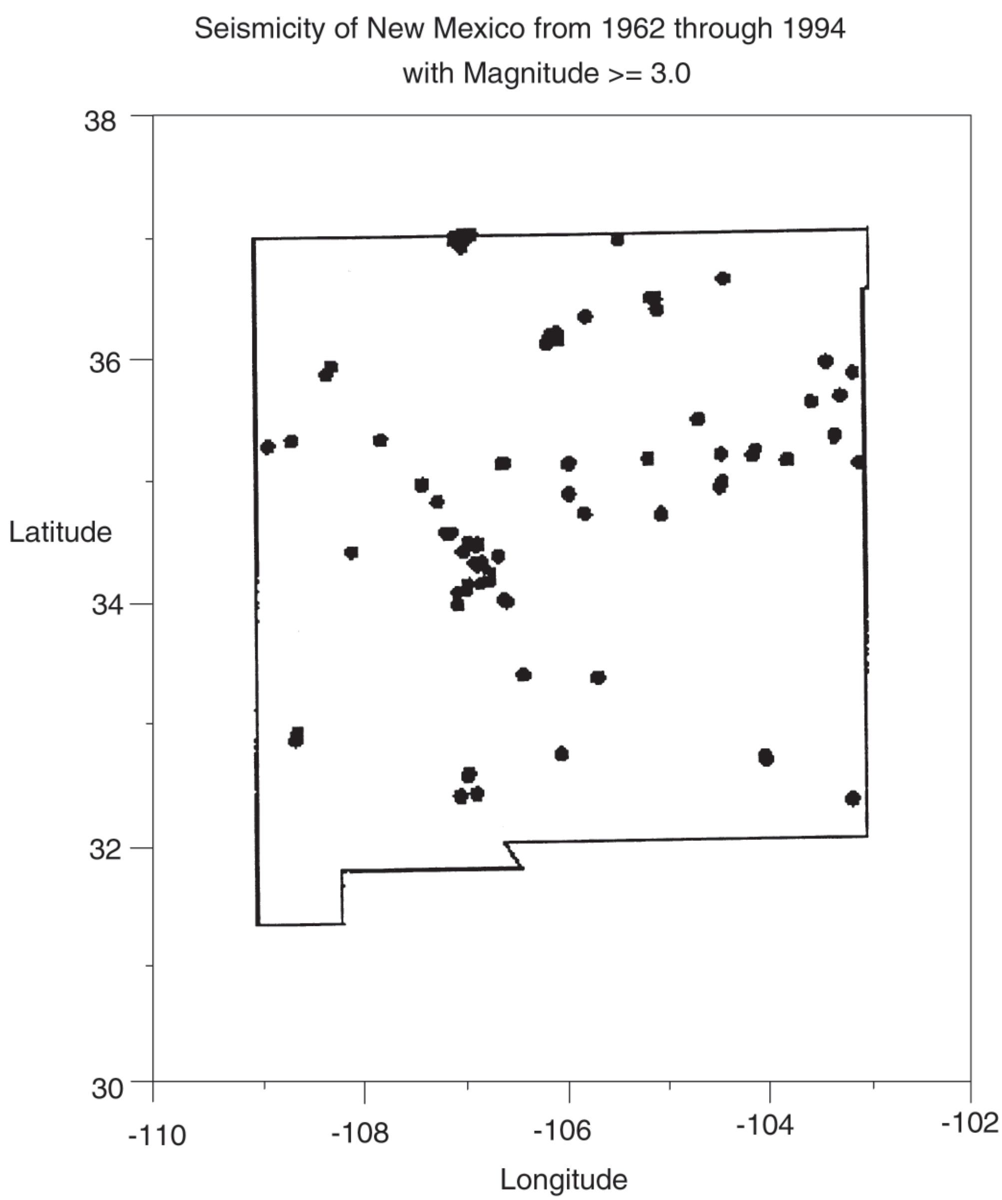
The area around Carlsbad contains many limestone caves. Most of the caves are mazes with different levels, and Lechuguilla Cave is now considered the deepest cave in the United States with more than 80 miles mapped so far. It is probable that the Guadalupe Mountain caves began to form during the late Miocene or early Pliocene when the Capitan reef began to arch and rise up. The Mesozoic cover eroded away allowing the action of water on the limestone to form the large voids. Most contain gypsum that may come from the Delaware Basin, but may also result from the action of a sulfuric acid solution on limestone in a thermal process.

The functioning of water flow and cave formation inside the Capitan Limestone is very difficult to understand as several phenomena are involved: (1) uplift speed, (2) sea level position, (3) connections between the Delaware Basin aquifer and the karstic aquifer, and (4) the presence of sulfuric acid. The water now flows towards springs in the Pecos River near Carlsbad.

The different levels of the caves show different steps in the rise of the Guadalupe block, and there is evidence that uplift of the block is continuing to - day. Recent active faults are visible and seismographs have recorded many small earthquakes.

Endless Cave. This cave is a maze with three different levels. It seems to be a hy - drothermal cave as it is located at the top of a hill which was probably covered, at one time, by an impervious layer. There are many signs of speleothem collapse.

Figure 3. Seismicity of New Mexico from 1962 through 1994 with Magnitude = 3.0.



In some places it is possible to see ancient broken soda straws that are now soldered with calcite onto the flowstone, as well as more recent breakage loose on the soil which is a result of human contact. In several places it is also possible to observe the collapse of the limestone beds between the upper level and the entrance level. The collapse has crashed down onto flowstone causing damage to these formations.

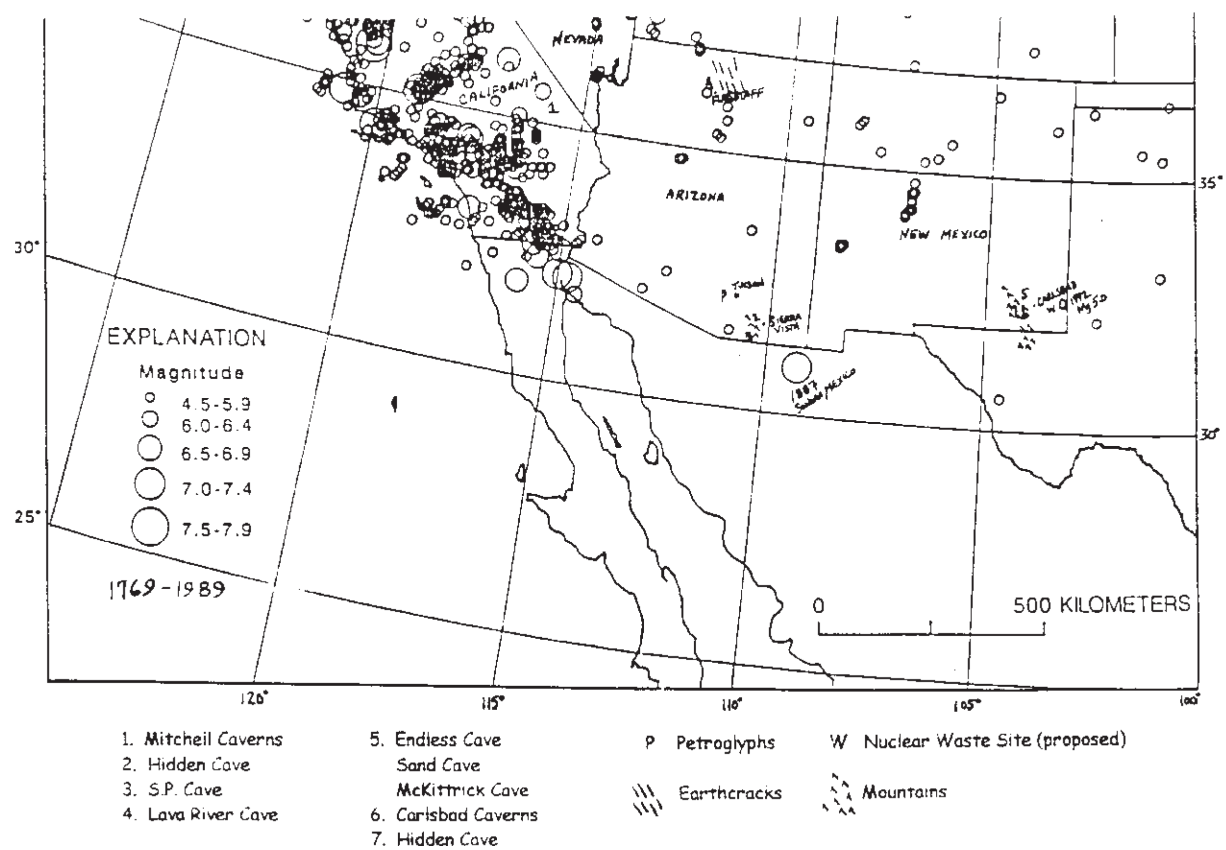
Sand Cave. This is a maze, like Endless Cave, and is also located at the top of a hill. Unfortunately in the early part of the 20th century, the cave was totally destroyed for the selling of speleothems, but the two different ages of broken formations are visible. A signature with a date of 1917 is located on flowstone in which an older collapse of soda straws is included and indicates that calcite formation is very slow and the age of collapse is older than human contact. It is possible to see many collapses in niches or difficult places to reach which excludes a human cause.

McKittrick Cave. It is also a maze cave located at the top of a hill in which we have observed two ages of speleothem collapse: a recent one free on the soil, and an older one soldered with calcite.

Carlsbad Cavern. Inside the whole cave we observed, on the soil, broken soda straws. Many large collapses are visible in many places inside this cave. One of the most important is Iceberg Rock, but this movement seems to have been a slow slip as the formations that were on the rock before the collapse are not broken. It could be possible to know the age of this collapse by dating the broken formations under Iceberg Rock.

The Big Room area shows two ages of rock collapse. The rocks of the oldest collapse have smooth edges; the more recent ones have many angles. Between Crystal Spring Dome and Rock of Ages, a little basin is full of ancient broken stalactites. In Lower Cave many broken soda straws are now covered with cal -

Figure 4. Recorded and estimated earthquake magnitudes from 1769 to 1989.



cite, forming cave pearls. In the Colonel Boles Formation a large crack in the soil was caused by subsidence.

Hidden Cave. This small shaft is located on top of the Guadalupe Mountains. The entrance is a vertical pit that goes into two separate galleries. It is aligned on a fault line but we did not observe any fault movement. In both parts many collapses are visible, and like the previous examples, two different ages may be observed. For the oldest collapse, several pieces are located behind unbroken formations proving that the breaks did not have a human cause. The soda straws of Hidden Cave are short ones and stalactites have broken extremities with new calcite growth. It is most certain that this cave has been affected by an important earthquake.

This succinct study of caves in the Carlsbad area indicates the existence of ancient seismic activity in the whole area between the Guadalupe Mountains and the City of Carlsbad. The western fault that caused the uplift of the Guadalupe block was probably responsible for some earthquakes in the past. Unfortunately, some of the caves have been partially destroyed by human activity. It would be very interesting to check preserved caves, like Lechuguilla Cave, to see if broken soda straws of the two different ages are visible.

General conclusion

In comparison to Europe where caving is free, we have been very discouraged to see the difficulties in obtaining permits for cave research. It would be interesting, for our research, to be able to visit preserved caves like Lechuguilla or Kartchner Caverns. But we have also been very disheartened to see how some caves have been destroyed by human actions and, of course, one thing explains the other.

Concerning our method, caves in Arizona and New Mexico are very dry and dusty. Calcite growth speed is much slower here than it is in Europe; however, it is possible to make good observations. The collapses are probably older than what we are used to evaluating.

Concerning the results, the California area does not contain enough caves for our purpose, which was the study of the San Andres Fault activity on cave development. In Arizona some evidence in S.P. Cave may be attributed to the 1887 Sonoran earthquake. It would be worthwhile to check for the same evidence in other caves nearby. In New Mexico this short trip revealed how caves in the Carlsbad area were affected by past seismotectonic activity. An accurate study could give much information on the seismic history of the Guadalupe Mountains. We have discovered that a project of nuclear waste disposal is in progress near Carlsbad. The knowledge of the recurrence and intensity of ancient seisms could be beneficial.

As the known seismic history of the United States is very recent, cave studies could be a very good geologic tool for seismic prevention. Such work could be done in places where active faults have been detected, to see if these faults have caused ancient earthquakes.

Acknowledgements

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In addition, Serface would like to thank Eric Gilli for sharing his knowledge of caving and seismic geology. She states, "He has opened a whole new world of cave research for me." Also, very special thanks goes to Serface's caving partner, Oz Backman, whose faithful support continues to keep her interest in research alive.

Note: Formatting of geologic units in this paper follows the guidelines provided in Hansen, W. R., editor. 1991. Suggestions to authors of the reports of the United States Geological Survey. 7th edition. U.S. Geological Survey, Washington, D.C.

Chapter 30

Guadalupian Series: International Standard for Middle Permian Time

BRIAN F. GLENISTER, Ph.D., is an A.K. MILLER Professor of Geology Emeritus with the University of Iowa. He is an active member of the International Commission on Stratigraphy and the past chair of the Subcommission on Permian Stratigraphy.
BRUCE R. WARDLAW, Ph.D., is the chief paleontologist for the U.S. Geological Survey in Reston, Virginia. He is currently the chair of the Subcommission on Permian Stratigraphy, which has formally proposed the Guadalupian Series represented in the park as an international standard.
LANCE L. LAMBERT, Ph.D., is currently an instructor of geology at Southwest Texas State University. His dissertation research resolved long-standing problems associated with the basal Guadalupian boundary, which ultimately helped lead to the formal proposal of the Guadalupian Series as the world standard reference for Middle Permian time. His other projects within Guadalupe Mountains National Park are related in theme, primarily the upper and interior boundaries of the Guadalupian Series. He annually uses the park resource for teaching the southwest Texas field geolgy course.

Looking around, I feel as if I am preaching to the choir, but it is a pleasure to talk with many old friends. The joint authors here, of course, are Bruce Wardlaw and Lance Lambert, and I might say in starting that we have a poster station and encourage you to observe this, and of course on Saturday we are running the field trip to Stratotype Canyon. There are many reasons that the three of us are glad to be here, but at the head of the list probably is the opportunity to celebrate a couple of anniversaries. The first one you know about: the 25th anniversary of the founding of the park. The second, perhaps, you are not so familiar with; it is coming up very soon, and that is the first anniversary of the international ratification of the Guadalupe Mountains section as the standard for part of a very exciting interval of geological time; that is, the Permian and the succeeding Permian-Triassic boundary. The Permian, of course, is an interval of geologic time that ranges from about 200 million years back to 250 million, in round terms. It is named for the city of Perm in the northern Urals of Russia, and it is a very old term. It was proposed in 1841 by Sir Roderick Murchison. He was invited to Russia by the czar to observe the geological successions in Russia and compare them with those that were being named, particularly in Great Britain. Many of the systems were proposed in the early 1800s. I just mentioned the first of these, which was the Carboniferous, which was proposed in 1811. The reason for the early proposal of the Carboniferous, I think, is obvious to you, because of its economic value. The Carboniferous, of course, is carbon-bearing and yields the coal measures of western Europe that allowed the Industrial Revolution, and our own Carboniferous age resource. Murchison went to Russia at the invitation of the czar and about all he was able to say was that yes, I can recognize these other systems that we have named in Britain, but you seem to have something different here at the top of the stack. It looks to be more advanced—he was looking at a few fossils—that seemed to be more advanced than those of the Carboniferous of Britain. And so he named the Permian System. As with the preceding systems, that had been named, the objective was to develop an international language so that people of Asia or Australia could recognize the same age of rocks and utilize the same terminology. In other words, the original objective was to develop an international language for geologic time. However, as many of us experience almost daily, correlation from one area to another, correlation in facies from Lloyd Pray's back reef to the slope facies, for example, is always difficult. So there was a temptation for people in different geographic areas to propose their own time scales, and the result of this was the development of what I like to call a "Tower of Babel." People were utilizing local terms, and as a result of this were really unable to communicate the correlation of geologic events.

In the last 50 years, however, a very active group, the International Commission on Stratigraphy, has been developing or choosing an international language for geologic time. I am going to restrict my comments to the Permian here and simply state that at the moment, the international commission after something like 50 years is about to achieve this international nomenclature for Permian time. The Lower Permian has its objective reference section in the southern Urals. I will show you photographs of this area and others shortly. It serves very well for this interval of geologic time. However, near the end of the Lower Permian, Earth was confronted with the collision of Europe and Asia and the in-filling of the intermediate Urals Mountain basin. The result of this is that these excellent sections, these Lower Permian sections, lower in the succession, very fossiliferous, very adept for correlation to other parts of the world, were replaced by evaporites. So the Urals, the original type section of the Permian, is no longer suitable as an international reference for the rest of the period. We need to look someplace else for an international reference for the Middle Permian, and a year ago we were delighted to have the consensus of the International Commission on Stratigraphy. This was not a quick decision, and it was not an easy decision. It was a very painful decision for the Russians, in particular, to have the reference section for the rest of the Permian transferred to other areas. There were three candidates: one was middle Asia in the high mountain country there, the second was in south China, and the third in the southwestern United States. Now without going into detail, I would like to say that the first two have serious problems. First of all, the state of knowledge—they have not been studied for as long or as intensively as the Guadalupe Mountain area, and secondly, there tend to be noncomformities there, i.e., gaps in the record more than in other areas. Also, there are other problems, particularly the matter of access. In middle Asia, some of the type sections are at 4,000 meters elevation, and most of us get nosebleeds, of course, even below that. Also, in south China, for example, there is a problem of accessibility. So almost a year ago a formal vote, or a series of formal votes by the Subcommission on Permian Stratigraphy, of which Bruce Wardlaw is now the chair and I am a past-chair, voted formally in favor of the Guadalupian as the international standard for Middle Permian time. I won't go into details, but it was ratified successively by other international groups, and the final vote a year ago stabilizes the Guadalupian name as the international standard reference for Middle Permian time.

You might well ask what is the reason for selection of the Guadalupian as the international standard? There are a number of reasons for this. First of all, the state of knowledge—and this goes back almost a century to intensive study by G. H. Girty and descriptions of fossils, and so on—and an Iowa City boy by the name of P. B. King made major contributions on the physical stratigraphy. Other people like Miller and Furnish contributed important information on the biostratigraphy, particularly the ammonoids of the area. I am still amused and occasionally rib my colleague, Bill Furnish, about the title of the Miller and Furnish 1940 monograph. It is a classic, titled *Permian Ammonoids of the Guadalupe Mountain Region and Adjacent Areas*. Of course, the adjacent areas are Mexico and China and Australia and so on! I should mention the oil companies, Exxon, Amoco, and many of the others who have made intensive investigations on the stratigraphy and sequence relationships in the Guadalupes. In terms of stratigraphy and lithology, the Guadalupe Mountains are probably better known than any other sequence of those sedimentary rocks.

A second factor is that the Guadalupian has abundant fossils. These have been studied for almost a century. I think Girty's monograph of 1902 consisted of—perhaps we'll miss a page or two—but I think it was 561 pages and 30 or 40 plates of the fossils. Others have followed, as I mentioned, Miller and Furnish on the ammonoids. The fusulines have been studied in very intense detail by Garner Wilde and others, and more recently the conodonts have received very intensive investigation. Bruce Wardlaw and Lance Lambert, for example, are collecting specimens centimeter by centimeter near the base of the Middle Permian to document in great detail the evolution of that group. Stratigraphically as well as biostratigraphically, the Guadalupian appears very attractive.

A third consideration here would be accessibility, and I can't emphasize this matter too much. This is a very, very sensitive area that we explored three or four years ago, and the request was that the park guarantee access forever to qualified scientists interested in studying the Guadalupian type section. Again, access is essential. Fortunately, the park managers agreed to this, and staff has been very, very cooperative. It is a difficult situation for the park staff, as well as some of the international researchers who tend to think that they can come in here and blast the canyons. The compromise that we have reached is a very fine one. Now, qualified scientists do have free access to the resources here.

Another matter that is important is priority. Here, I think we have the situation "by the throat" because Girty in 1902 actually proposed the Guadalupian as a time interval, corresponding to the Mississippian and the Pennsylvanian. It had the status of a series as far back as 1902. The components, or the subdivisions, of the Guadalupian again have outstanding priority. The terms Wordian and Capitanian—these are the Middle Guadalupian and the Upper Guadalupian—were proposed in 1904. I think they were used in a time sense for the first time by me and Furnish in 1961. The Roadian, named for the Road Canyon, which is the basal stage of the Guadalupian, is sort of a newcomer. It was not proposed until 1973, and this may pose a problem for us. So although we have the series agreed upon by the International Commission on Stratigraphy and the international community, we still have to document very carefully the three subdivisions: the Roadian, the Wordian, and the Capitanian.

I could go on for a long time, but there are other advantages here. A very significant one is the low thermal history of the area. The studies indicate that the temperatures have never been more than 80°C. The importance of this is that we are able to conduct paleomagnetic studies on these rocks. The paleomagnetic signatures are still there, and very importantly, we are able to trace a magnetic marker—this is the Illawarra reversal—named for Australia. We can recognize it here and we can recognize it in the northern Urals. Paleomagnetics are a very important feature. Also, absolute dating is possible because of the low temperatures here; in recent years we have had quite a few dates and there is potential for further dating. Finally, because of the low temperatures, we have the potential here for recognition of geochemical anomalies. I won't go into the details of these.

One problem to which I referred is the present day Tower of Babel. It simply indicates that in the southern Urals they like local terms. In Armenia, Iran, and the Pamirs they have other choices as in south China and Japan. The worst is Australia. They even proposed a new period there because they could not differentiate the Carboniferous from the Permian. This is the situation we are trying to avoid by development of an international standard for geologic time.

Let me show you just a couple of slides, first of all the sections in the lower Urals, then on to the Guadalupian, and then to China for the upper part of the succession. These are the standards that have been accepted. This is at Aidaralash in the southern Urals. This is the base of the Permian, and again, this has been formally ratified. It is a long, painful process, which involves both personal and national interactions, but most importantly these generate a great deal of good science. American groups together with our Russian colleagues and many, many other groups have collaborated to select and define the base of the Permian. Here is the general location. It is important to note that this is the basin between Asia and Europe. This is the European-Russian platform here. This is the depression in which the type Permian or type Early Permian developed, and it was the collision of Asia and Europe in the Middle Permian that made that an undesirable and unacceptable reference for geological time. We have evaporites there in the Middle Permian just the same as we have evaporites here in North America in the Upper Permian. This is the kind of detail that we require for such a definition. These are meters: this is zero, -30, +60, and an idea of how these boundaries are defined. In this case, there is a plethora of fossils. There are fusulinacean foraminifera; there are ammonoids, and also there are conodonts. The collective judgement of the group has been that conodonts are the best reference for definition of the base of the Permian, and the coincident top of the Carboniferous.

I will go into a little detail here. Conodonts were eventually approved for definition. This is an evolutionary morphocline—a succession of evolving forms. There is no natural break in this succession, and that is a desirable feature, because it confirms or demonstrates that there is no time break in this particular succession of rocks in the boundary succession. There is no physical evidence, but as you are all aware, sometimes there is a nonconformity where no physical evidence exists. The definition is on the conodonts, and the fusuline workers fear that their preferred boundary is 6.3 meters above, but what the hell! For practical purposes, the fusuline boundary is coincident with the conodont boundary. The ammonoid workers are a little more difficult to get along with, but their preferred boundary is 26.8 meters above the conodont boundary. For practical purposes then, this is an excellent boundary definition that can be recognized throughout the world by reference to other groups of organisms, or geochemical anomalies, or geomagnetic anomalies, or absolute dates and so on.

This is the morphocline. The succession of conodonts—small phosphatic organisms—and the first appearance of a particular species here has been selected for definition of the boundary. Russian colleagues, here is the boundary. There is a nice pavilion there at the present time. However, with the collision of Asia and Europe, shoaling upward and evaporites, we need to go somewhere else for a reference for the higher Permian. As I indicated earlier, the favored place is Guadalupe Mountains National Park. You are all aware of the general relationships here. I will just point out that the complex facies relationship that Lloyd Pray has dealt with already, the back reef, the reef, the slope and the basin, and the fact that the interfingering here allows you to correlate on physical grounds any of these facies. We can look for data, whether it is paleomagnetic data or biological data, we can look for these data in any of these facies and we can relate them to other facies. The selection of the position for the base of the Guadalupian is in the western mountain face here, at the feature that we plan to term Stratotype Canyon. This will be the international reference for the Middle Permian interval of geologic time.

The other subdivisions of the Permian—remember there will be three: the Roadian, the Wordian, and the Capitanian—will be on the eastern boundary of the park on Nipple Hill. There is a fantastic exposure there which has bentonites where we can get an absolute date. It has magnificent evolutionary continua, particularly the transitions in the conodonts, which we can trace around the world. These will be excellent references, international references, for this interval of geologic time. To come back to the point, as was made already, it is possible, of course, to trace the back reef facies into the reef itself and into the slope facies, and we can accumulate the data from each of these facies and integrate it into a single body of data because of the interfingering relationship of these facies.

The back reef is very interesting. From a biological point of view it is a bit of a disappointment; there aren't many fossils there. Again, we have geomagnetic reversals and so on, so this is a valuable part of the section. It is also a very interesting one. I think Lloyd Pray and I must have been looking at the same face here. He didn't tell you why—this is a centimeter rule here—the graded beds are reversed. But maybe I will be here some time and we can talk about that. From the reef into the slope into the basin, and one of the very attractive features of these is the increase in the diversity in the abundance of fossils such as these fusulinaceans. Again, there is some provincialism; they are not exactly the same species as elsewhere, but it is possible to correlate on forams as well as conodonts and other groups of organisms.

In the slope facies near the top of the Guadalupian, it is not very exciting in terms of paleontology, at least from a camera view, but fortunately these uppermost beds of the Lamar Limestone and post Lamar do retain important groups of fossils, particularly the conodonts. These enable us to make precise correlations to China, in particular, and the base for the international standard for the Upper Permian.

Above that, of course, are the evaporites. This was the problem in the Urals, the shoaling upwards. It is the problem here, so that we have to go elsewhere for the Upper Permian standard. Stratotype Canyon displays the arbitrarily chosen point in the conodont evolutionary continuum that forms the base of the Guadalupian. We will talk about these. Here is the ancestral form; here is the descendent form—and Lance or Bruce can discuss this at length; there is a display outside. Of course, we must mention the ammonoids. I have emphasized the conodonts—I love them—but my favorites are the ammonoids. They are some of the most useful. Again, this was a critical time for the evolution for the ammonoids. The oldest of the ceratites, one group of ammonoids, was in the Roadian at the base of the Guadalupian. These are actually characteristic of the Mesozoic, the dominant Mesozoic forms. They originated back in the basal Guadalupian. You can see the diversification. I apologize for even putting this one in, but that is the distribution of ammonoid groups in the Carboniferous and Permian. I would make the point that the extinction of the Paleozoic ammonoids was not a catastrophic event; it was a sequential event that actually began in the Guadalupian. Again, [this picture shows] the nasty evaporites that make that sequence unsatisfactory.

We have to go elsewhere, and of course the fewer the standard references, the easier and more useful these references are. We finish up with three, and remember that this involves the top of the Carboniferous, defined by the base of the Permian; the Middle Permian, the base of the Middle Permian defines the top of the Lower Permian. This is the Permian-Triassic boundary that we are looking at here. This is in south China halfway between Shanghai and Nanjing. There is the boundary with three characters up there collecting the boundary beds. Here is the actual boundary itself; it is that point there. I collected that slab and it is on display, you might want to look at this. Again, this is becoming monotonous. It is an evolutionary cline of conodonts and the first appearance of a specific conodont in the middle of this bed [number] 27 represents the base of the Triassic, and therefore, by definition, the top of the Permian. I would also like you to note that there are other lithologies here: this white shale, the black shale, and other black shales here. There are all kinds of useful exciting characteristics of this boundary succession: paleomagnetic, geochronologic, and also isotope anomalies, carbon anomalies and so on.

This is the boundary in the wall we are looking at. This bed is 16 centimeters in thickness, and this interval is the one on display out there. Again, the first appearance of the designated conodont at this level in the middle of this bed is the international reference for the base of the Triassic.

We are very grateful and thankful that the Tower of Babel has collapsed, or at least it is in rubble, and we are in the process then of developing this international language! The delightful thing is that the Guadalupian will play a very important role in these definitions.

Notes: Because the boundaries of the Middle Permian and Guadalupian have been defined and adopted (see Glenister et al. and Lambert et al. in this volume), the editors treat them as formal units. Therefore, the initial letters of the names and modifying words of both the period/system (e.g., Middle Permian) and epoch/series (e.g., Upper Guadalupian) have been capitalized in this context.

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Chapter 31

Defining the Base of the Guadalupian Series—The World Standard Middle Permian—In Its Type Area, Guadalupe Mountains National Park

LANCE L. LAMBERT, Ph.D., is an instructor of geology at Southwest Texas State University. His dissertation research resolved long-standing problems associated with the basal Guadalupian boundary, which ultimately helped lead to the formal proposal of the Guadalupian Series as the world standard reference for Middle Permian time. His other projects within Guadalupe Mountains National Park are related in theme, primarily the upper and interior boundaries of the Guadalupian Series. He annually uses the park resource for teaching the southwest Texas field geology course.

BRUCE R. WARDLAW, Ph.D., is the chief paleontologist for the U.S. Geological Survey in Reston, Virginia. He is currently the chair of the Subcommission on Permian Stratigraphy, which has formally proposed the Guadalupian series represented in the park as an international standard.

BRIAN F. GLENISTER, Ph.D., is an A. K. Miller Professor of Geology Emeritus with the University of Iowa, Iowa City. He is an active member of the International Commission on Stratigraphy and the past chair of the Subcommission on Permian Stratigraphy.

Introduction

The geologic time scale provides the major ordering framework for understanding Earth history. It may thus come as a surprise to some that the nomenclature of the time scale is still evolving. This is in part because different names have been applied to rocks of the same age in different countries. Because geology is a global science, a single international language for the units of the geologic time scale is desirable to ease communication and to encourage stratigraphic precision. The International Union of Geological Sciences (IUGS) serves to coordinate international committees of recognized specialists from varied countries to formally ratify component units of the proposed world standard. They have erected a set of criteria and established procedures for selecting reference standards (Cowie et al. 1986, Remane et al. 1996; refer also to Glenister et al. 1992, Lambert et al. 1995, and Remane 1996 regarding the Guadalupian). Meeting those criteria and following the established international procedures, the Guadalupian Series has been selected as the world standard reference for the Middle Permian Series (Spinosa 1996, Jin et al. 1997).

The basal boundary of the Guadalupian, a clear definition of which is essential for precise international correlations, is designated by the evolutionary first occurrence of the conodont, *Jinogondolella nankingensis*. The ancestor, *Mesogondolella idahoensis*, evolved into *J. nankingensis* through a short-lived mosaic paedomorphocline. A paedomorphocline is a temporal series of populations through which juvenile characteristics of an ancestral species become progressively expressed in increasingly adult stages of the descendant species. Because of the complex evolutionary interplay between individual characters, a precise point within the transition can be selected to clearly define the first occurrence of *J. nankingensis sensu stricto*—and thus the basal Guadalupian Series boundary as proposed by Glenister and others (1992). This point is selected at the first specimens retaining serrations beyond juvenile growth stages. In preliminary sam-

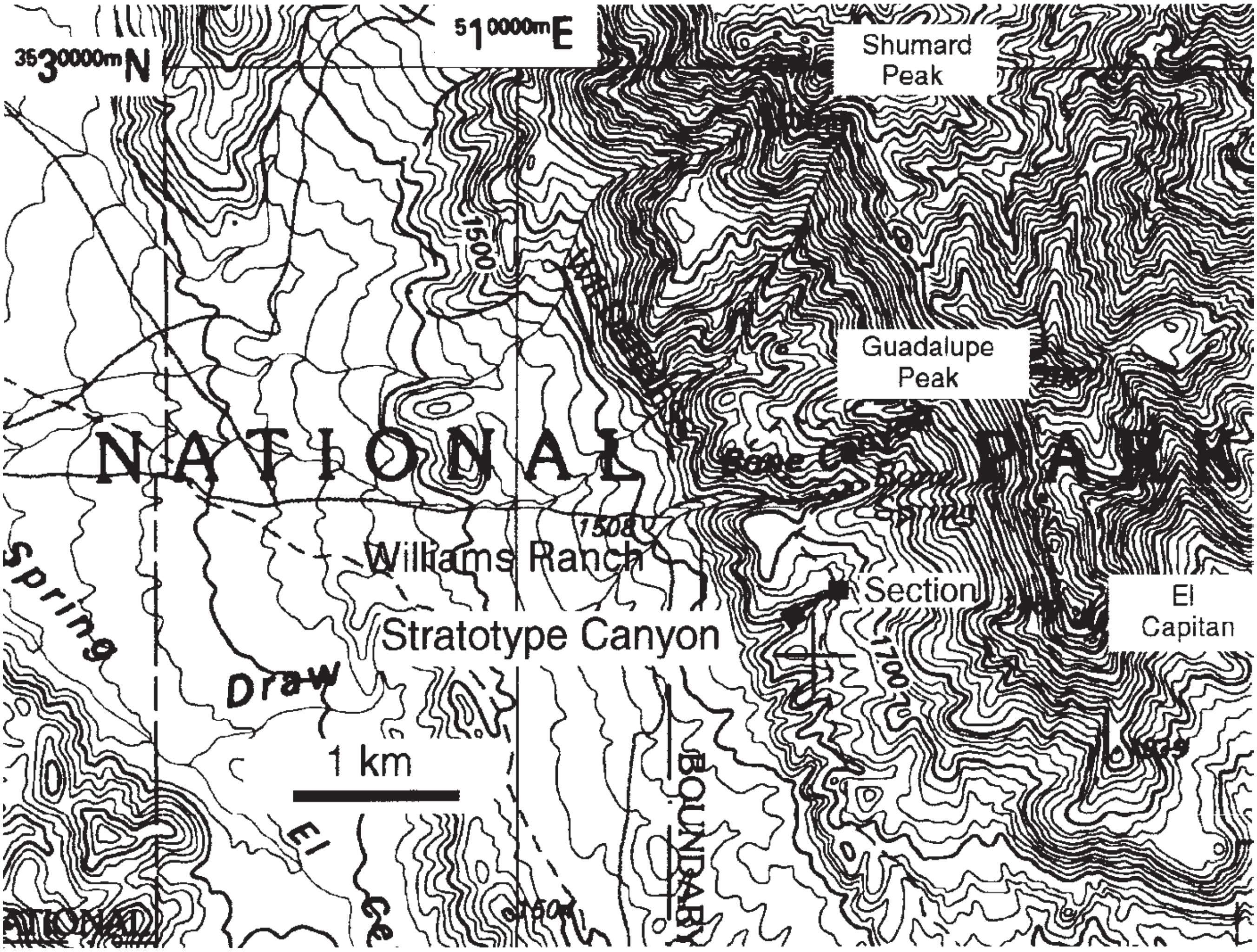

Figure 1. Location of Stratotype Canyon in Guadalupe Mountains National Park.

pling of Stratotype Canyon (set aside by the National Park Service for preservation and study of the boundary stratotype that marks the base of the Guadalupian) (Figure 1), such specimens occur in sample W92-8, at 140 feet (42.7 m) above the base of the Cutoff Formation (Table 1). The sampled horizon lies within monotonous pelagic calcilutites, 11.25 inches (28.6 cm) below a prominent shale band in the middle part of the El Centro Member (Figure 2.).

The Paedomorphocline

Qualitatively the evolution of *J. nankingensis* involved numerous taxonomically important characters, including: the acquisition of anterior serrations, alteration of cusp size and placement, isolation of carina denticles (from an initially fused state), and the narrowing and protrusion of the lower attachment surface (Lambert and Wardlaw 1992).

The most conspicuous change in character was the acquisition of serrations along the anterior platform margins. When first developed, serrations were indistinct and restricted to juvenile specimens. In successive populations, the juvenile serrations became more distinct, but subadult and adult forms masked those serrations beneath subsequent histological laminae. The smoothed serrations were masked initially at the element margin, leaving faint relict serrations adjacent to adcarinal furrows on subadult forms. In slightly younger populations, adult specimens display the faint serrations, whereas those on preceding growth stages became better defined. This pattern of incrementally increasing serration was carried progressively later through ontogeny in successive populations until the pronounced serrations characteristic of *J. nankingensis* at all growth stages were attained. Such serrations are distinctly visible in lateral view as notches along the anterior platform margins. Notches are not discernible from this perspective on earlier transitional forms.

Concomitant in lateral view, the cusp became less pronounced in both relative height and width, while migrating subtly to a more posterolateral position. The fused anterior carina denticles of adult *Mesogondolella idahoensis* became increasingly discrete through the transition, a character state common to both *J. nankingensis* and juvenile *M. idahoensis*.

Similarly in lower view, the broad, flat, and commonly recessed basal attachment surface of adult *M. idahoensis* became narrower through the transition, simultaneously developing a consistently protruding keel. This trend in adult morphologies represents a reverse pattern of the ontogenetic development patterns for individuals of typical *M. idahoensis*.

Emphasizing practical biostratigraphic utility, morphotypes from this clinal transition are assigned to taxonomic categories on the following criteria: (1) Initiation of the transition (earliest transitional morphotype) is recognized among populations in which serrations first appear and are restricted to juvenile growth stages. These specimens remain assigned to *M. idahoensis* with regard to formal taxonomy. (2) *J. nankingensis s.s.* first occurs in specimens that display prominent serrations in subadult growth stages. Prominent is here defined as the distinct expression of serrations, which in lateral view form conspicuous notches along the anterior platform margin. (3) The extinction of *M. idahoensis* is denoted by populations that no longer include unserrated juvenile specimens. (4) The last occurrence of the transitional morphotype is denoted by populations that no longer include adult specimens without prominent serrations. These criteria explicitly lead to some range overlap of morphotypes from complete sections, as would be expected for evolutionary transitions. More importantly, these criteria unambiguously characterize the chronostratigraphic boundary interval.

Quantitative analysis of characters through the transition was briefly discussed by Lambert (1994) and illustrated graphically by Lambert and Wardlaw (1996). Because the transition is expressed along a paedomorphocline, characters were examined both independently from size, and as function of size and stratigraphic level.

Size (as a proxy for relative maturity) was standardized by reference to a character that exhibits growth in a linear relationship to the remainder of the element. Selection of a standardized reference character is complicated for Permian gondolellids because of inconsistent allometric fields resulting from variable bowing and arching of individual elements. However, a reliable approximation can be achieved by using carina length as a measure of allometric size. To minimize error introduced by warping of the allometric field from bowing, carina length was measured from denticle apex to denticle apex, extending from the anteriormost denticle to the tip of the cusp. These distances were integrated then standardized to a value of 100 for each element. All landmark distances were scaled to this standard parameter, producing results measured as a percentage of carina length, independent of size (Lambert 1994).

The above method also provides a precise definition of juvenile, subadult, and adult forms; and allows for rigorous comparisons between juvenile and adult growth stages with similar character states. Actual carina length was recorded for subdivision of the three taxon groups into ontogenetically-based components for separate analysis as a function of size.

The complete results of this complex morphometric analysis will be presented in Lambert and Wardlaw (in prepara-

Sample		Meters	Feet	Unit
37	MHB-690-13	61.7	202.5	Williams Ranch Member, Cutoff Formation
36	MHB-690-12	50.9	167.0	Williams Ranch Member, Cutoff Formation
35	W92-12	50.5	165.5	Williams Ranch Member, Cutoff Formation
34	MHB-690-11	50.2	164.5	Williams Ranch Member, Cutoff Formation
33	MHB-690-10	45.9	150.5	Williams Ranch Member, Cutoff Formation
32	MHB-690-9	45.7	150.0	Williams Ranch Member, Cutoff Formation
31	W92-11	45.6	149.6	Williams Ranch Member, Cutoff Formation
30	MHB-690-8	45.6	149.6	Williams Ranch Member, Cutoff Formation
29	W92-10	45.1	147.8	Williams Ranch Member, Cutoff Formation
28	W92-9	43.8	143.7	Williams Ranch Member, Cutoff Formation
27	MHB-690-7	43.0	141.0	Williams Ranch Member, Cutoff Formation
26	W92-8	42.7	140.0	**Proposed Basal Guadalupian Boundary**
25	W92-7	41.8	137.2	El Centro Member, Cutoff Formation
24	W91-23	40.0	131.2	El Centro Member, Cutoff Formation
23	W91-22	38.1	125.0	El Centro Member, Cutoff Formation
22	W92-6	36.9	120.9	El Centro Member, Cutoff Formation
21	W91-21	36.3	119.0	El Centro Member, Cutoff Formation
20	W92-5	35.9	117.9	El Centro Member, Cutoff Formation
19	MHB-690-6	35.2	115.5	El Centro Member, Cutoff Formation
18	W91-20	35.1	115.0	El Centro Member, Cutoff Formation
17	W91-19	34.9	114.6	El Centro Member, Cutoff Formation
16	W91-18	34.5	113.1	El Centro Member, Cutoff Formation
15	W91-17	34.0	111.5	El Centro Member, Cutoff Formation
14	W91-16	33.5	110.0	El Centro Member, Cutoff Formation
13	W91-15	32.9	108.0	El Centro Member, Cutoff Formation
12	W91-14	32.0	105.0	El Centro Member, Cutoff Formation
11	W91-13	31.4	103.0	El Centro Member, Cutoff Formation
10	MHB-690-5	31.4	103.0	El Centro Member, Cutoff Formation
9	MHB-690-4	30.9	101.5	Shumard Member, Cutoff Formation
8	W91-12	30.2	99.0	Shumard Member, Cutoff Formation
7	W91-11	29.6	97.0	Shumard Member, Cutoff Formation
6	W91-10	28.0	92.0	Shumard Member, Cutoff Formation
5	W91-9	26.2	86.0	Shumard Member, Cutoff Formation
4	W91-8	24.4	80.0	Shumard Member, Cutoff Formation
3	MHB-690-3	1.5	5.0	Shumard Member, Cutoff Formation
2	MHB-690-2	0.6	2.0	Shumard Member, Cutoff Formation
1	MHB-690-1	-0.3	-1.0	Top of Bone Spring Limestone

Table 1. Conodont samples from the Guadalupian stratotype. The table is a list of coarser initial sampling.

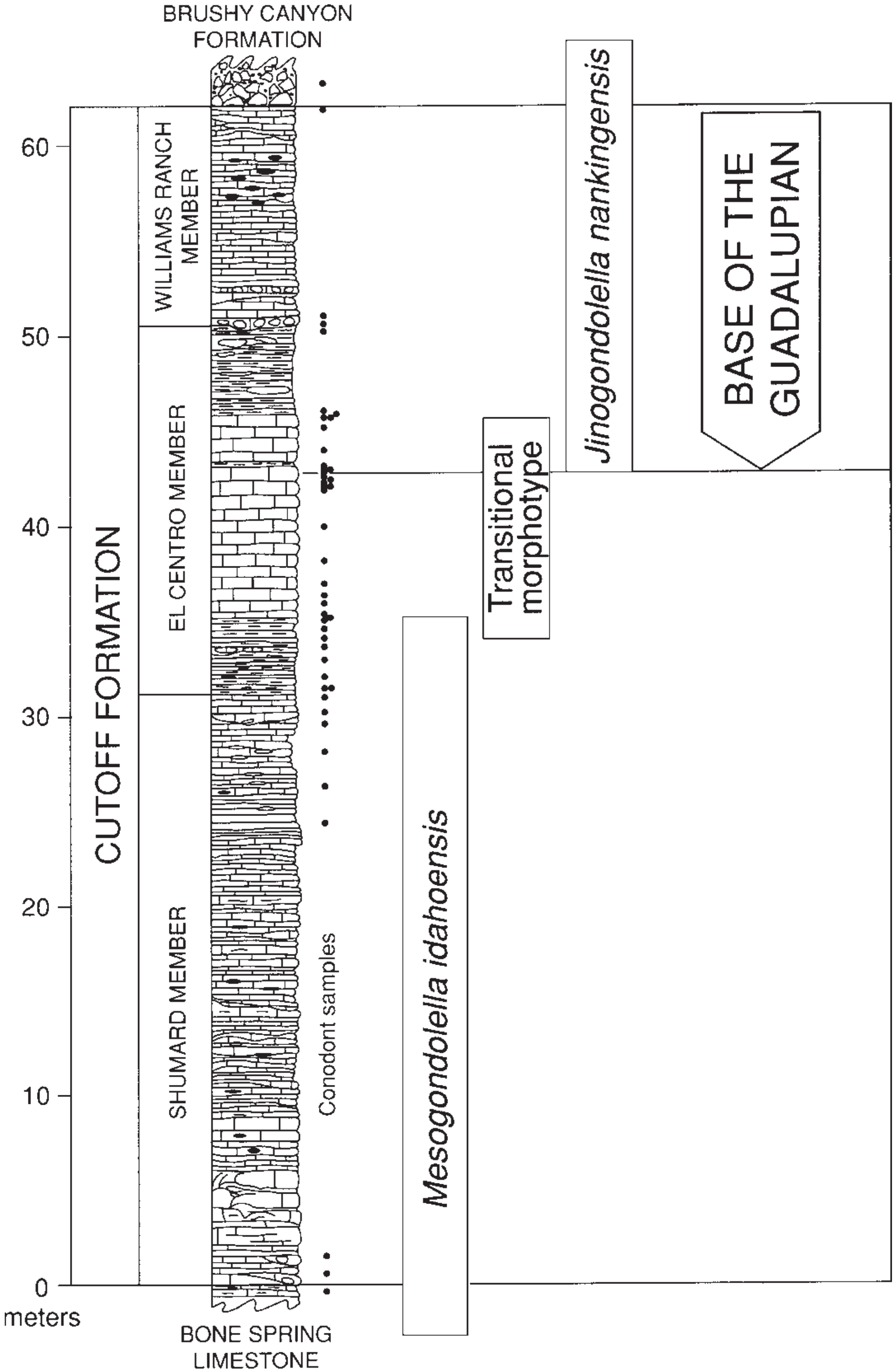

Figure 2. Columnar section of the Cutoff Formation in Stratotype Canyon with position of biostratigraphic samples and ranges of pertinent conodont species. The first occurrence of *J. nankingensis sensu stricto* defines the base of the Guadalupian Series. Note: as illustrated by the dots on the figure, which are immediately below the proposed boundary, the El Centro Member has been sampled more finely (bed by bed) for ongoing detailed morphometric analysis than the initial sampling listed in Table 1.

tion). The initial results confirm that the transitional form observed qualitatively can be characterized quantitatively (Lambert 1994). These preliminary results can be summarized as follows:

1. A direct linear relationship demonstrates an increasing degree of serration through the transition. Overall, small specimens in mid-transition fall nearer the mean for *J. nankingensis*, whereas large specimens from the same sample fall nearer the mean for *M. idahoensis*.
2. Both cusp height and width (elongation) show a decrease through the transition. Once scaled for size (relative maturity), the mean of the transitional form lies approximately half way between those of *M. idahoensis* and *J. nankingensis* for both measures.
3. Platform width is consistent for all three taxon groups when standardized for size.
4. The transitional form and *J. nankingensis* have identical measures that indicate less bowing (lateral displacement) than occurs in *M. idahoensis*.
5. *M. idahoensis* is significantly less arched (vertical displacement) than either the transitional form or *J. nankingensis*, again the latter two sharing an essentially identical mean arch ratio.
6. There is a decreasing relative width of the lower attachment surface through the evolutionary morphocline.
7. The keel forms a more significant component of the lower attachment surface in *M. idahoensis* than it does in either the transitional form or *J. nankingensis*, but it protrudes more in the latter.
8. Comparison of length measurements for the discrete portion of the penultimate anterior carina denticle to the fused portion of the same denticle show that the discrete portion of the transitional form is essentially the same as that of *J. nankingensis*, and both are larger than that mean length for *M. idahoensis*. Conversely, the mean fused portion of that denticle in the transitional form is approximately the same as that for *M. idahoensis*, both of which are significantly larger than for *J. nankingensis*. The overall evolutionary pattern for this character is from predominantly fused (*M. idahoensis*) to relatively discrete (*J. nankingensis*).

Stratigraphy

The Cutoff Formation is comprised predominantly of lime mudstone and shale from pelagic suspension deposits (Harris 1987, 1992). Coarser grained lithologies, usually confined to channeliform beds, are localized in shelf-margin paleosettings and interpreted as various flow deposits. Discontinuities in shelf and shelf-margin strata die out basinward. Thus, a section located within the proximal basin paleosetting would be complete and include some fossil constituents transported in from shallower paleoenvironments.

The National Park Service, steward of Guadalupe Mountains National Park, has agreed to extend collecting permits to the international scientific community following the same guidelines used to evaluate applications submitted by U.S. citizens (Glenister 1993). Stratotype Canyon has been set aside as a geological preserve where international sampling activities will be both monitored and allowed to take place. Stratotype Canyon boasts nearly complete exposure of strata ranging from the Bone Spring Formation (Artinskian Stage) through the Capitan Formation (Capitanian Stage). The paleosetting of the Cutoff Formation in Stratotype Canyon is a proximal basin milieu.

At Stratotype Canyon the Cutoff Formation consists primarily of lime mudstone (calcilutite) and shale, with localized skeletal debris beds, scattered chert, and one thick chert marker bed. The Cutoff is subdivided into three members (Harris in press). The lower member, the Shumard, is predominantly composed of lime mudstone, with several coarser-grained shallow channeliform beds at the base. The middle El Centro Member is composed of a characteristic shale-limestone-shale triplet. That middle limestone is a medium-bedded, argillaceous lime mudstone, with a prominent shale band in its upper part in Stratotype Canyon (Figure 2). The upper member, the Williams Ranch, is lithologically similar to the Shumard Member: composed mostly of lime mudstone with several coarser-grained channeliform beds. All of these units reflect the interplay of basin and toe-of-slope deposition. Contemporaneous skeletal debris washed in from shelf paleosettings range from individual fossil particles to the larger channeliform beds, which are intercalated into the complete pelagic calcilutites.

All samples from Stratotype Canyon have yielded conodonts in varying degrees of abundance. The Permian Subcommission of the IUGS must vote, and then the International Commission on Stratigraphy must ratify exactly which sample will formally denote the basal Guadalupian (Middle Permian) boundary. The material analyzed as of now indicates that current sampling is tight enough in the critical intervals to present first and last occurrences that should not change significantly with the subcommission's vote or with additional sampling (Figure 2).

The first occurrence of the transitional morphotype, as defined above, is sample W91-16 (110 ft, 33.5 m; see Table 1) near the base of the El Centro Member of the Cutoff Formation. The last occurrence of *M. idahoensis* is sample W91-19 (114.6 ft, 34.9 m), from the very top of the lower shale in the El Centro triplet. The first occurrence of *J. nankingensis* is sample W92-8 (140 ft, 42.7 m) high in the medial part of the El Centro middle limestone. The last occurrence of the transitional morphotype is sample MHB-690-9 (150 ft, 45.7 m) from the uppermost El Centro middle limestone. Although last occurrences in this section appear to coincide with relatively minor lithofacies changes within the El Centro Member, the biostratigraphic record is robust: all evolutionary initiations (first occurrences) are recorded within monotonous lithologic successions distinctly inside the lower shale and middle limestone lithofacies of the El Centro Member of the Cutoff Formation.

Conclusion

The base of the Guadalupian Series, world standard reference for the Middle Permian, occurs in the El Centro Member of the Cutoff Formation within the evolutionary paedomorphocline from *Mesogondolella idahoensis* to *Jinogondolella nankingensis*. That basal boundary is defined on the initial evolutionary appearance of *J. nankingensis sensu stricto* in Stratotype Canyon (Guadalupe Mountains National Park, west Texas), which occurs at 140 feet (42.7 m) above the base of the Cutoff Formation, in the middle of the El Centro Member.

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Chapter 32

Permian Extinctions: A Fusilinacean's Way of Life and Death

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Introduction

In recent years much effort has been concentrated upon reaching closer consensus in definition of the major periods of Earth history. Whenever such work is undertaken it is natural to assume that occasional startling results will be achieved. One is reminded of the great controversy that developed over what finally constituted the breakthrough for definition of the Cretaceous-Tertiary (K/T) boundary. Today, hindsight shows us that a thin iridium layer marks, for many, a "golden spike" position for this boundary, and all would seem to be well among the world's Cretaceous-Tertiary pundits. This iridium layer is thought to represent fallout from one or more giant meteorite impacts on Earth.

But even here, all might not be so well according to a recent report of studies from Israel's Negev Desert, reviewed in *Geotimes* by Bartlett and Wexler (1998) and Collins (1998). The K/T boundary impact has previously been blamed for the near total extinction of Mesozoic oceanic plankton; however, these recent studies suggest that Late Cretaceous marine environments in the Negev underwent many periods of stress during a four-million-year period leading up to the K/T boundary time.

Similar controversy has raged about the great dinosaur extinctions that took place at K/T boundary time. How did it all happen? And now there are good reasons to suspect that, indeed, an extremely large extra-terrestrial impact site in the general area of the southern Gulf of Mexico, just off Yucatan, played a major role in providing the global spread of the iridium clay layer and the subsequent demise of the dinosaurs. These relatively new data have electrified the field of paleontology and excited the fertile minds of young and old alike. "Make no bones about it," dinosaur bones are big business today.

Again, in a manner similar to the arguments dealing with the extinction of so many oceanic plankton species, there are those workers in the field of dinosaur studies who would suggest that a single event might have done nothing more than deplete many, but not all, of the large dinosaur species. G. S. Paul (1988) pointed out that giant meteorites were crashing into Earth throughout the Mesozoic. Indeed, he plotted six "possible ones," and suggested that "the best documented of these, the Late Triassic impact, did little or nothing to the world dinosaur population."

To the many less initiated, so awed by the sheer size of some individual dinosaurs, the catastrophe must have been the greatest event in Earth's history. But to those who spend their lives studying Permian life, the real truth presents an entirely different story. "End-Permian" time was by far the greatest extinction period in the entire history of Earth.

Even for the End-Permian, some would suggest a singular cause and effect. There are reasons, however, to suggest that a single catastrophe was probably not the cause of the great Permian extinctions. Most likely there were a series of events, occurring over a 5-to-10-million-year period, culminating in a final knockout blow. Not all of the suggested causes for the extinctions can be considered herein; however, volcanism and the late history of the fusulinacean foraminifers offer insights that ought to be considered seriously to help explain the demise of much of Permian life.

Extinctions and some possible causes

Numerous paleocontinental reconstructions of Earth have been offered for Late Permian time. For the present purposes, however, the one shown here (Figure 1) by Lin and others (1985) and recently utilized by Erwin (1992) is preferred because of its simplicity and its assumptions of an early opening of the Atlantic Ocean. This reconstruction is helpful in understanding how a Tethys-connected superocean, Panthalassa, and the early-rifted Atlantic Ocean provided ample conditions for comingling of some Tethyan and North American faunas. On the other hand, the comingling was not complete because of other, restrictive factors.

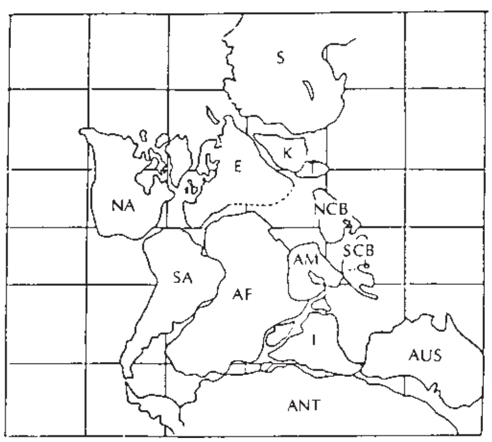


Figure 1. Paleocontinental reconstruction for Late Permian time. AF = Africa, AM = Asia Minor, ANT = Antarctica, AUS = Australia, E = Europe, I = India, K = Kazakhstan, NA = North America, NCB = North China Block, S = Siberia, SCB = South China Block, T = Tarim. From Lin et al. 1985. Reprinted by permission from *Nature* 313:444–449. Copyright 1985 Macmillan Magazines Ltd.

Nevertheless, enough is now known to provide workers with a chronostratigraphic road map for correlation of the entire Permian (Figure 2). Inasmuch as the present paper considers only the Middle (Guadalupian Series) and Late (Lopingian Series) Permian, the full history of fusulinacean life will not be considered nor will other groups of Permian life, except briefly to emphasize some important observations about life and extinction rates in general.

SYSTEM/SERIES		STAGES
TRIASSIC		GRIESBACHIAN
PERMIAN	LOPINGIAN	CHANGHSINGIAN
		WUCHIAPINGIAN
	GUADALUPIAN	CAPITANIAN
		WORDIAN
		ROADIAN
	CISURALIAN	KUNGURIAN
		ARTINSKIAN
		SAKMARIAN
		ASSELIAN
CARBONIFEROUS		GZHELIAN

Figure 2. Permian chronostratigraphic subdivisions. After Jin, Wardlaw, Glenister, and Kotlyar 1997.

Sepkoski (1982) developed a compendium of marine family life, from which Erwin (1992) plotted extinction percentages for 17 major groups during the Asselian, Sakmarian, Leonardian, Guadalupuian, and Dzulfian series of the Permian (Figure 3). For the present purposes, in order to follow the generally accepted subdivisions of the Upper Permian (Figure 2), the Dzulfian becomes the Wuchiapingian, or Lower Lopingian. The Leonardian is retained in this chart to represent the Artinskian and Kungurian, combined. These data are utilized later (Figure 5) to express composite extinction rates.

Still utilizing data from Sepkoski (1986), Erwin (1992) plotted Permian and Triassic extinctions in marine genera as percentage extinctions, and total number of generic extinctions (Figure 4). From these plots, there is no question that the greatest extinctions in the Permian actually took place during the Guadalupian, and diminished dramatically thereafter.

The data from Figure 3 is shown in a different manner in Figure 5 as composite extinction rates for each of the Permian series. Estimates for the latest Permian Changhsingian stage have been added to

Marine family	Percentage extinction A	S	L	G	D
Foraminifera	0	0	3	6	38
Porifera	0	0	18	24	10
Tabulata	0	14	15	42	100
Rugosa	0	6	38	62	100
Gastropoda	0	0	15	25	11
Bivalvia	0	3	2	12	11
Cephalopoda	17	0	20	43	47
Other Mollusca	0	17	40	33	0
Other Arthropoda	0	0	21	33	25
Ostracodes	4	8	8	35	29
Bryozoa	10	4	4	23	65
Brachiopoda	0	3	12	34	71
Crinoidea	0	16	5	93	0
Other Echinodermata	5	5	5	37	8
Conodonta	0	20	0	20	25
Other taxa	0	0	0	9	3
Marine vertebrates	0	0	0	39	0

Figure 3. Extinction percentages for 17 major groups of marine families during each series of the Permian. Families not resolved to series were not used in the analysis. A = Asselian, S = Sakmarian, L = Leonardian, G = Guadalupian, D = Dzulfian. Data from Sepkoski 1982. After Erwin 1992.

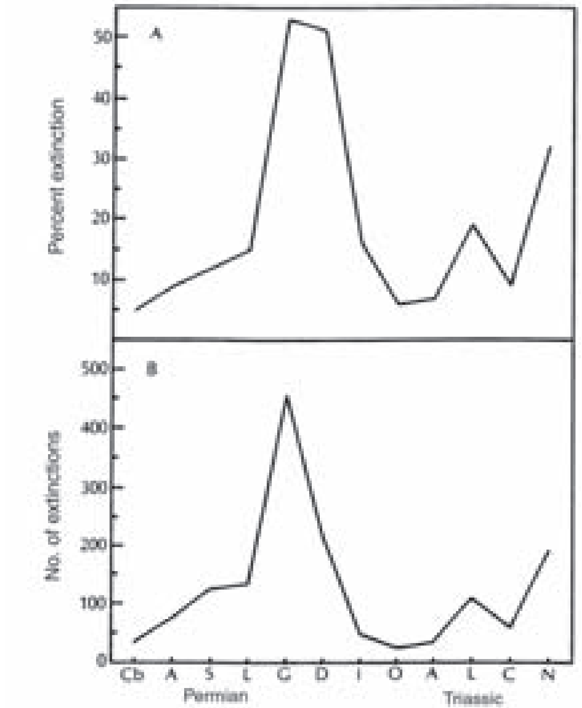


Figure 4. Permian and Triassic extinctions in marine genera. A: Percentage extinction. B: Total number of generic extinctions. Data from Sepkoski 1986. After Erwin 1992.

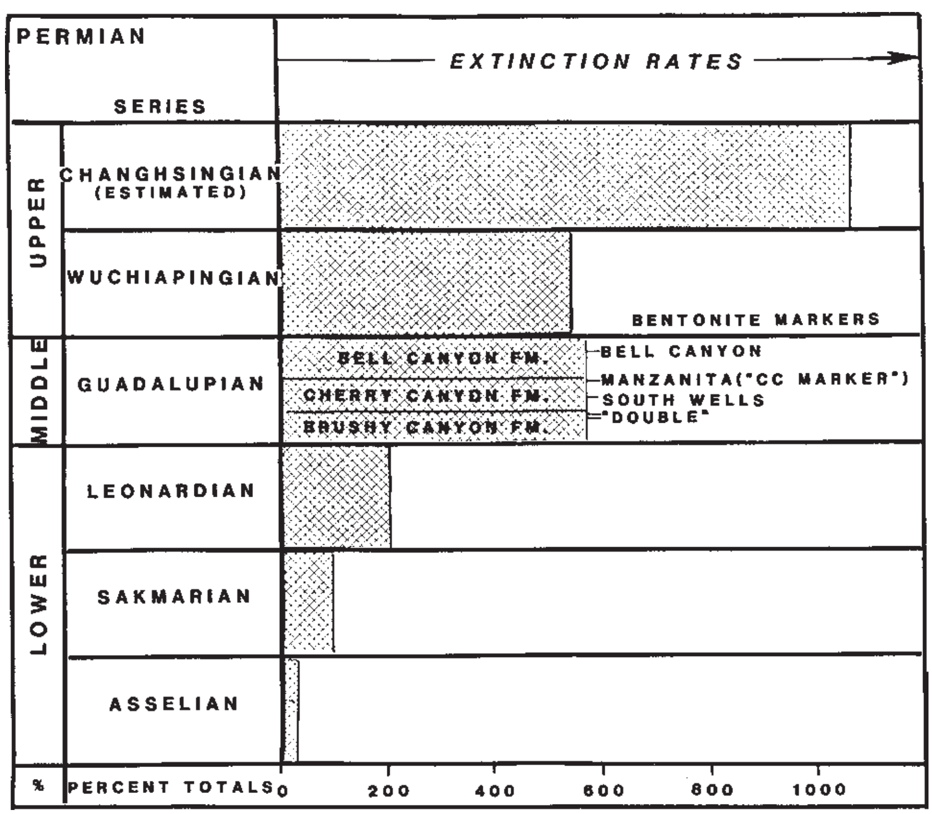


Figure 5. Composite extinction rates for each of the Permian series based on data from 17 major marine family groups. After Erwin 1992 (except for the Changsingian). Bentonite marker names after Wilde 1975.

these data. This has been done only to complete the Permian picture. While the data might not be shown as precisely as that of Sepkoski, the point is made: of those major marine family groups that were still living near End-Permian, the extinction rate was greater than the Guadalupian only because the numbers were already so greatly diminished that the composite rates are skewed proportionately.

Bentonites. Four important bentonite levels that were named originally by Wilde (1975) from Guadalupian rocks at the surface or in the subsurface accompany the composite extinction rates in Figure 5. These bentonites were referred to by initials at the time, and more recently interchangeably as follows (youngest to oldest):

1. Bell Canyon (BC bentonite), upper part of the Bell Canyon Formation
2. Cherry Canyon, or Manzanita (CC marker bentonite), near top of Cherry Canyon Formation, beneath the Manzanita Limestone
3. South Wells (SW bentonite), about the middle of the Cherry Canyon Formation
4. Double (Double bentonite), near top of Brushy Canyon Formation

Recognition that a given claystone or shale is of bentonitic origin is often difficult. Certain criteria, however, have been shown to be helpful in identifying bentonites, especially the ones found in the Guadalupian of the Permian basin:

1. "Bentonite" is defined as "rock composed essentially of a crystalline clay-like mineral formed by devitrification and chemical alteration of a glassy igneous material, usually a tuff or volcanic ash" (Ross and Shannon 1926 after Todd 1976). Newell and others (1953) referred to most of the bentonites of the Guadalupe Mountains as "metabentonites" and emphasized that they were commonly associated with apple-green cherts.
2. Apple-green color, waxy texture, often floculent, or fluffy, when brought into contact with water (King 1948, Newell et al. 1953)
3. Most Guadalupian bentonites are considered to have been altered, consisting of authigenic crystalline clay minerals such as kaolinite, illite, chlorite, and smectite. Often present is authigenic pyrite, detrital quartz, feldspar silt grains, and occasionally, glass shards are still recognizable (Garber, Grover, and Harris 1989)
4. Presence of euhedral biotite and sanidine, characteristic of volcanic rocks, and a lack of nonvolcanic minerals, such as garnet and tourmaline (Todd 1976).
5. Highly radioactive character, due to high concentrations of thorium that produces a strong incursion on gamma-ray logs. Some of the Guadalupian bentonites produce a characteristic signature on the gama-ray log, which allows for rather precise identification in the subsurface. This is particularly true for the Cherry Canyon marker, which displays a "double kick" and can be followed over wide areas of the Permian basin.

Permian-age volcanic terranes have not been identified specifically in the immediate proximity to the Delaware Basin, which at the time consisted of a deep marine basin, bordered by a shallow shelf with broad evaporite flats extending landward for many miles (Figure 6). This fact would call for the volcanoes to have been located far into the interior of Mexico, and perhaps beyond, to the virtual edge of the North American continent, where they have since been lost under younger sediments and zones of plate subduction.

The normal history of sedimentation during the Permian was deposition along shelf margins of reefs or broader carbonate ramps that were succeeded over and over again. The lateral positions of these platforms varied with rise and fall of sea level, and were interrupted from time to time by siliciclastic bypass, thus filling the basin with deeper-water carbonate muds, shales, or sandstones (Figure 7).

This pattern of sedimentation was only occasionally intruded upon by the volcanic fallout alluded to earlier. Thus, each layer of bentonite, as it were, now exists as a perfect time line by which rather close correlations are possible. Such bentonites were unable to withstand the unstable conditions along shelf margins, however, due to strong wave activity. Because of this caveat, considerable problems often exist in trying to correlate given bentonites preserved in the basin with those preserved back on the shelf.

Fortunately, fusulinacean foraminifers were living prolific lives during the same time that the volcanic fallouts were occurring, thus providing another excellent tool for constraining the great pile of sediments in terms of age (Dunbar and Skinner 1937, Wilde 1975, 1990).

Bentonite-fusulinacean correlation examples

A 34-well cross section constructed 25 years ago in the northern Delaware Basin was generalized by Wilde (1975) to

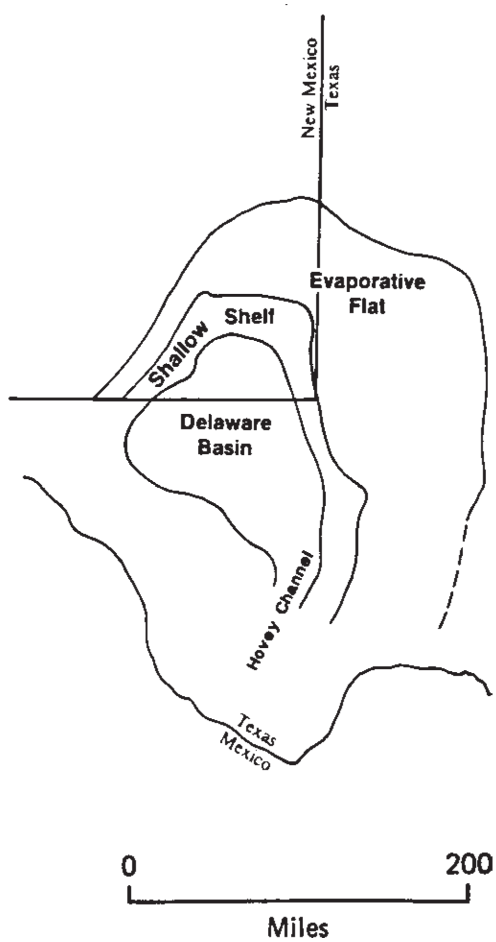


Figure 6. Late Permian (Upper Guadalupian). From Garber, Grover, and Harris 1989. After Ward et al. 1986.

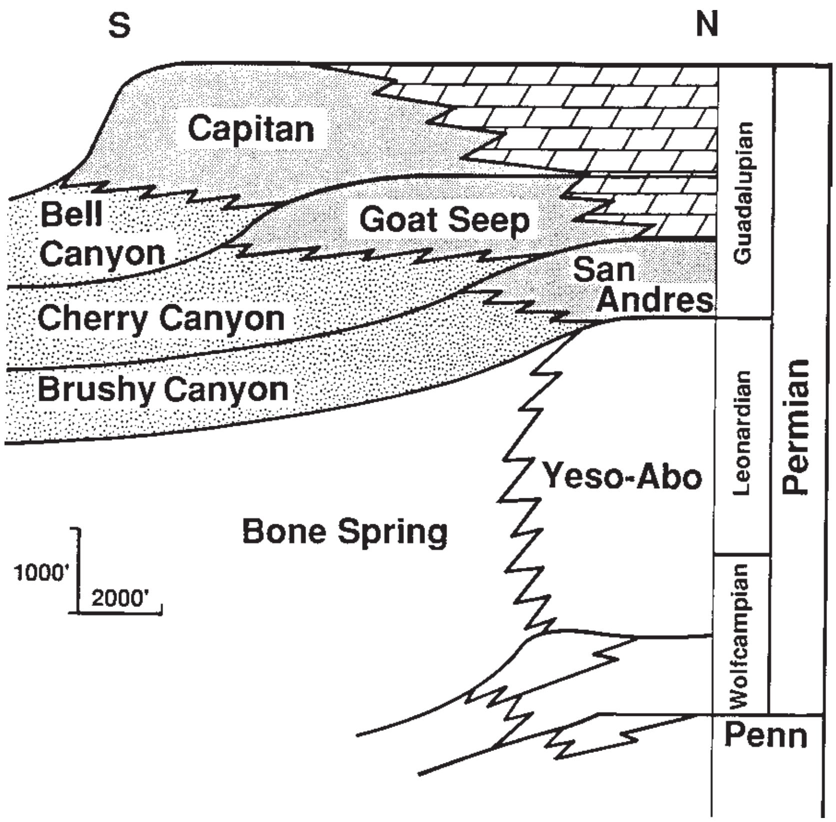


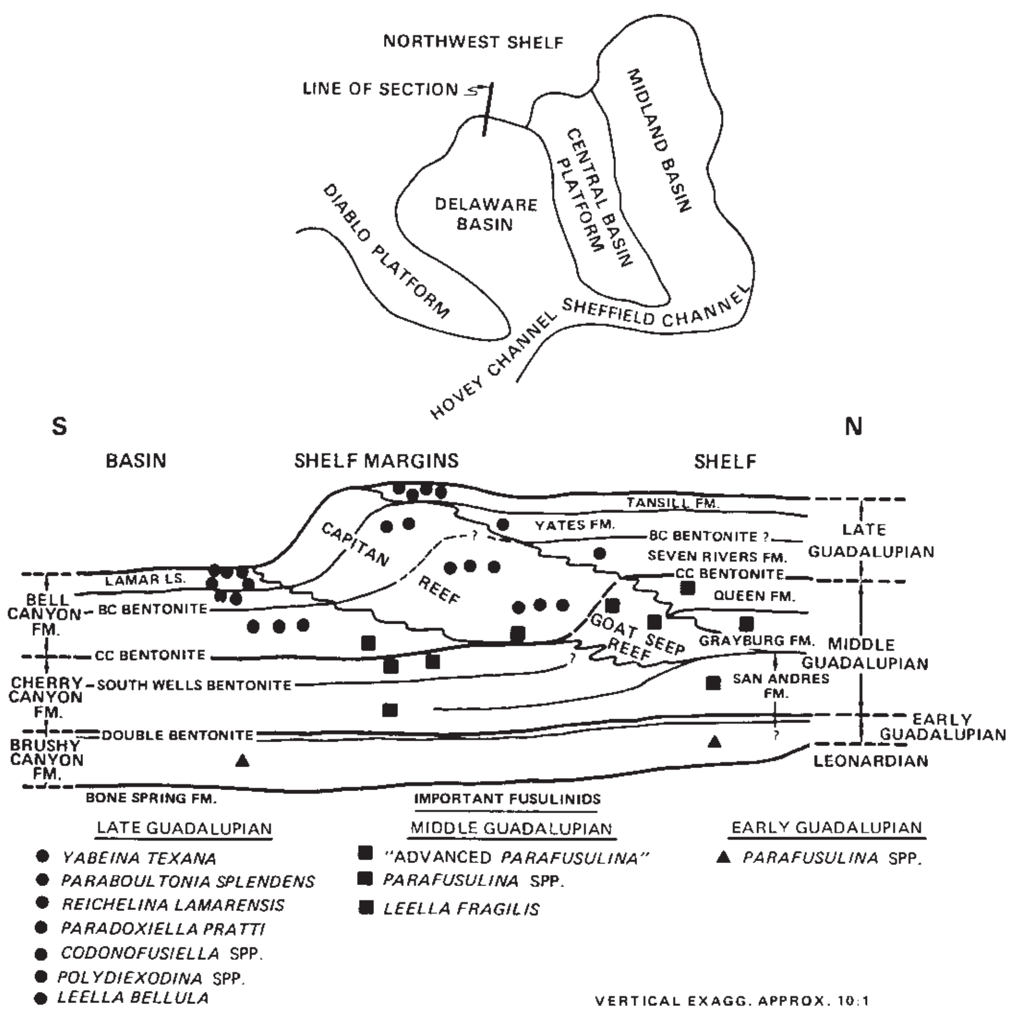
Figure 7. Summary cross section of the northwest shelf, Delaware Basin. After Garber, Grover, and Harris 1989.

demonstrate the utility of combining bentonite correlations with fusulinacean biostratigraphy. As can be seen in Figure 8, the fusulinaceans serve best in the areas (shelf margins) where the bentonites are absent or overlooked in samples; and, in turn, the bentonites serve best on the shelves and out in the basin, where the fusulinaceans are either absent or rare.

On the outcrop, numerous examples of combining bentonites with fusulinaceans for correlative purposes can be documented. One excellent example that has been documented, yet never published, is located in the southern Delaware Mountains (Figure 9). The location is in a complexly faulted area of Trew Canyon (Section 22, Block 94, PSL Survey, Culberson County, Texas) at the head of a small tributary to Scott Canyon, less than two miles north of the Trew Ranch house. The section is 500 feet (152 m) thick, and straddles the Cherry Canyon–Bell Canyon boundary (Figure 10).

In the area, the Cherry Canyon Formation is represented by 200 feet (61 m) of basinal, dark gray-colored shales, interrupted by only occasional thin, basinal limestones with fusulinaceans in the lower half. Siliciclastics are conspicuously absent. About the middle of this section is an algal mound that is prominently displayed in the slope. The mound, less than 35 feet (about 10 m) thick, is an algal boundstone, which appears to grade rather abruptly on the

Figure 8. Generalized cross section from northwest shelf showing fusulinid-bentonite control. After Wilde 1975.



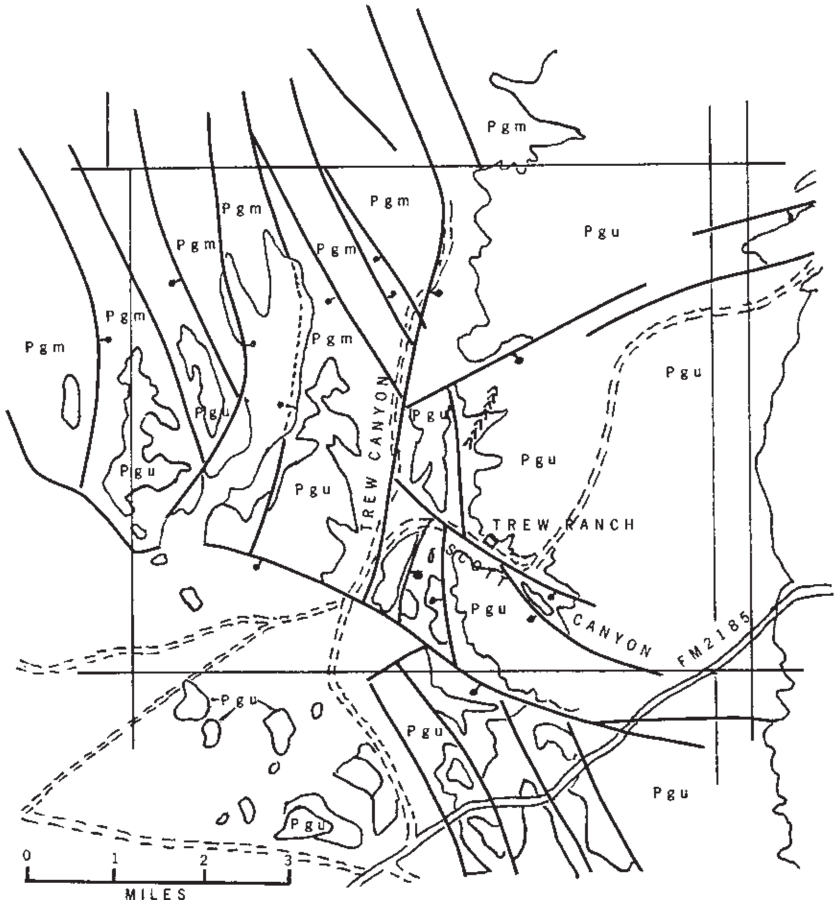


Figure 9. Geologic map of portion of south Delaware Mountains, Culberson County, Texas (Block 94). PSL survey showing location of measured section. After King 1948, 1960.

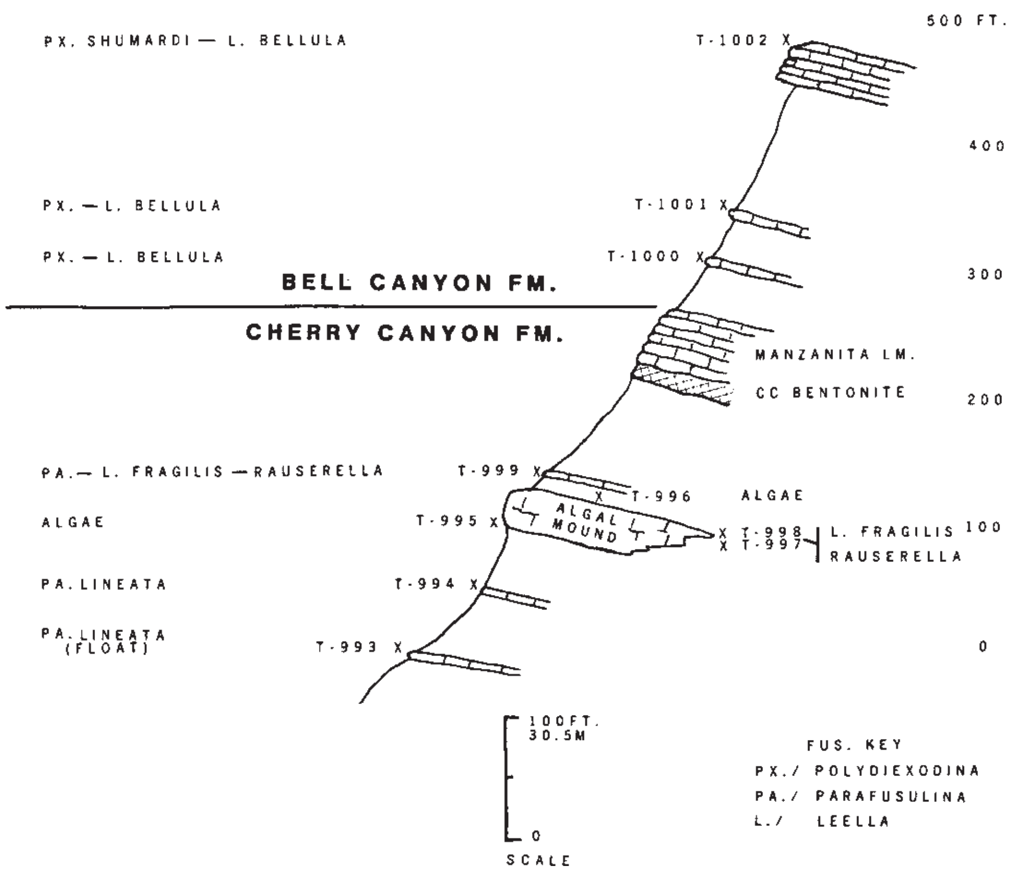


Figure 10. Stratigraphic section, south Delaware Mountains, Culberson County, Texas, showing faunal control and CC bentonite. See Figure 9 for location. From Wilde 1998.

back side into basinal sediments. At the time of discovery this feature was not believed to be any kind of slide block. Thus, if the interpretation is correct, water depths at the time of deposition could not have been great, certainly not below the euphotic zone of light penetration.

Approximately 10 feet (3 m) above the top of the algal mound is a thin limestone carrying the highest, Middle Guadalupian fusulinacean fauna discovered in the section. Here occurs *Parafusulina* sp., *Leella fragilis,* and *Rauserella* sp.

The Manzanita Limestone is easily identified 100 feet (30.5 m) above this highest fusulinacean level, holding up the slope and immediately overlying the Cherry Canyon bentonite. Here, the Manzanita Limestone is something over 40 feet (12 m) thick, and by definition, marks the top of the Cherry Canyon Formation (King 1942, 1948).

Late Guadalupian fusulinaceans were collected at three levels in the overlying Bell Canyon Formation at 40 feet (12 m), 80 feet (24 m), and 180 feet (54.9 m) above the Manzanita top. Similarly, the highest Middle Guadalupian fauna occurs 180 feet (55 m) below the lowest Late Guadalupian faunal level, which contains *Polydiexodina* and *Leella bellula*. Thus, the faunas constrain the age of the bentonite very closely.

More than 75 miles (120 km) northeast of the outcrop discussed previously, near the county line separating southeastern Loving and northwestern Ward counties, Texas, is a well that is chosen to show the top of the Cherry Canyon overlying the Cherry Canyon bentonite marker by 180 to 190 feet. Such intervals vary widely around the basin, depending on individual choice of tops for the Cherry Canyon and its possible disconformable relations to the overlying Bell Canyon Formation. Even so, one cannot miss the Cherry Canyon marker signature below this top. This well—the Exxon, Keith Camp Trustees et al., No. 1—is located 1,980' FSWL and 1,320' FSEL, Section 33, Block 1, W&NW RR Survey, Loving County, Texas. The well, displayed as a borehole compensated sonic log, illustrates the double kick referred to earlier.

Todd (1976) published an interesting study of an oolite-bar progradation in the San Andres Formation across an area of central Upton and Reagan counties, in the Midland Basin. In that study, Todd's examination of one well, in particular, exhibited an upward shallowing facies succession above an easily recognizable, green bentonite bed (Figure 11). This well—the Pure, Hanks No. 1-A, Upton County—when placed in cross section context with other wells (Figure 12) demonstrated the diachronous nature of the oolitic sequence with relation to the bentonite. The bentonite could represent the South Wells bentonite (Figure 5) (Wilde 1975) because of its position. It is not the Cherry Canyon marker.

Gulf, PDB-04 well, Eddy County, New Mexico

In 1989 in an SEPM core workshop publication, Garber, Grover, and Harris published the detailed results of a continuously cored research well in Eddy County, New Mexico, at the north end of the Delaware Basin (Figure 13). The well is the Gulf, PDB-04, 247' FSL, 1,288' FEL, Section 32, Township 20S, Range 32E. The importance of reviewing this well is that practically all of the parameters discussed previously are brought into play in this unique borehole.

The PDB-04 well was cored continuously from the Rustler-Salado section into the shelf equivalents of the Capitan (Tansill, Yates, and Seven Rivers formations) prior to entering the reef itself. Finally, the well cored out of the reef into basin sediments of the lower Bell Canyon and upper Cherry Canyon formations.

The upper portion of the core (Figure 14) encountered bentonite in the lower part of the Yates Formation (1,931–1,932 ft) which the authors believe represents the BC (Bell Canyon) bentonite originally identified by Wilde (1975) (Garner

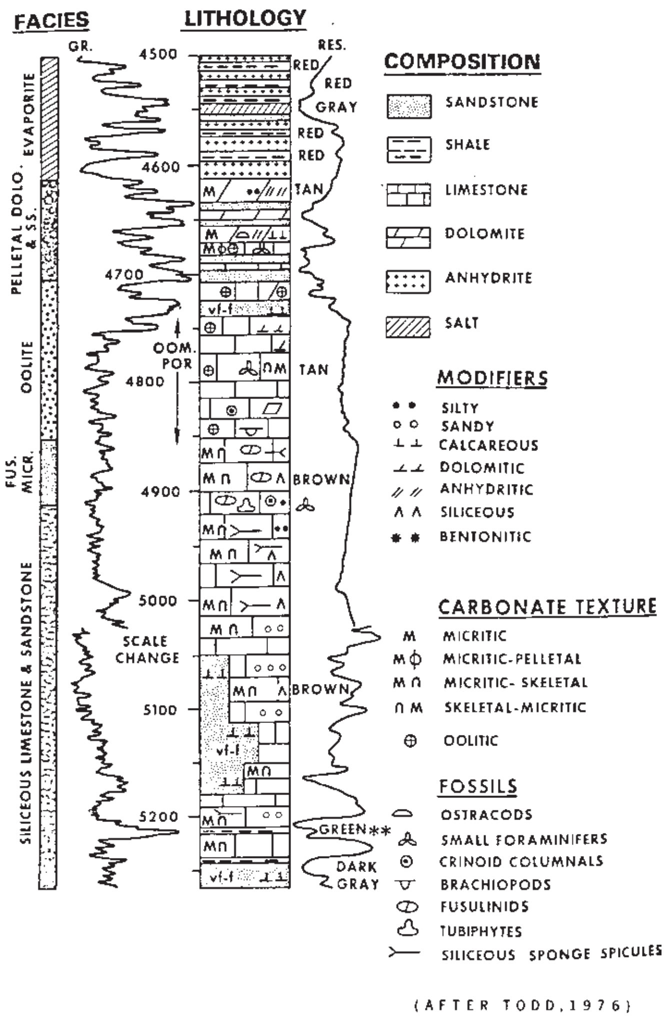


Figure 11. Facies succession, bentonite marker. Pure No. 1-A Hanks well, Upton County, Texas.

By utilizing data from the PDB-04 well and data from King (1948), Wilde (1975), Tyrrell (1962), and Garber and others (1989) constructed a profile based upon the fusulinacean-bentonite controls discussed herein, expressing the depositional history with time slices (Figure 17).

Evolution of Late Guadalupian fusulinaceans

Polydiexodininae. Coincidentally, or so it would seem, certain very strange things began happening to the fusulinaceans, shortly after (geologically speaking) volcanic ash began falling across the Permian basin. And there is some evidence that Earth's plate boundaries were in states of tension and subduction, indicative of an early beginning of the breakup of the supercontinent, Pangaea.

et al. 1998). This writer agrees with that conclusion. Garber and others (1989) also identified the CC (Cherry Canyon marker) bentonite (Figure 15) in the lower portion of the core, at 4,021 feet (4,023 ft on wireline log). The easily recognizable double kick signature is once again on the gamma ray/sonic.

Chevron engaged the author at the time of the study to identify the fusulinid faunas in the core (Figure 16). In that study, however, fusulinaceans were not studied below 3,827 feet, where *Polydiexodina,* a Capitanian genus, was still present. Thus, no Middle Guadalupian fusulinacean forms were found, but the Cherry Canyon bentonite marker at 4,023 feet constrained the basal part of the core, as noted earlier.

Large Permian fusulinacean genera with cuniculi, such as *Parafusulina,* had become giants by the close of the Middle Guadalupian (Dunbar and Skinner 1931; Dunbar, Skinner, and King 1936; Dunbar 1953). From Late to Middle Guadalupian rocks (but probably pre-Cherry Canyon marker time) in western Sonora, Mexico, for example, Dunbar (1953) has described *Parafusulina antimonioensis,* whose megalospheric shells attained lenghts of 25 to 30 millimeters or more, and widths up to 5 millimeters. Microspheric shells attained lengths up to 62 millimeters. This writer can testify

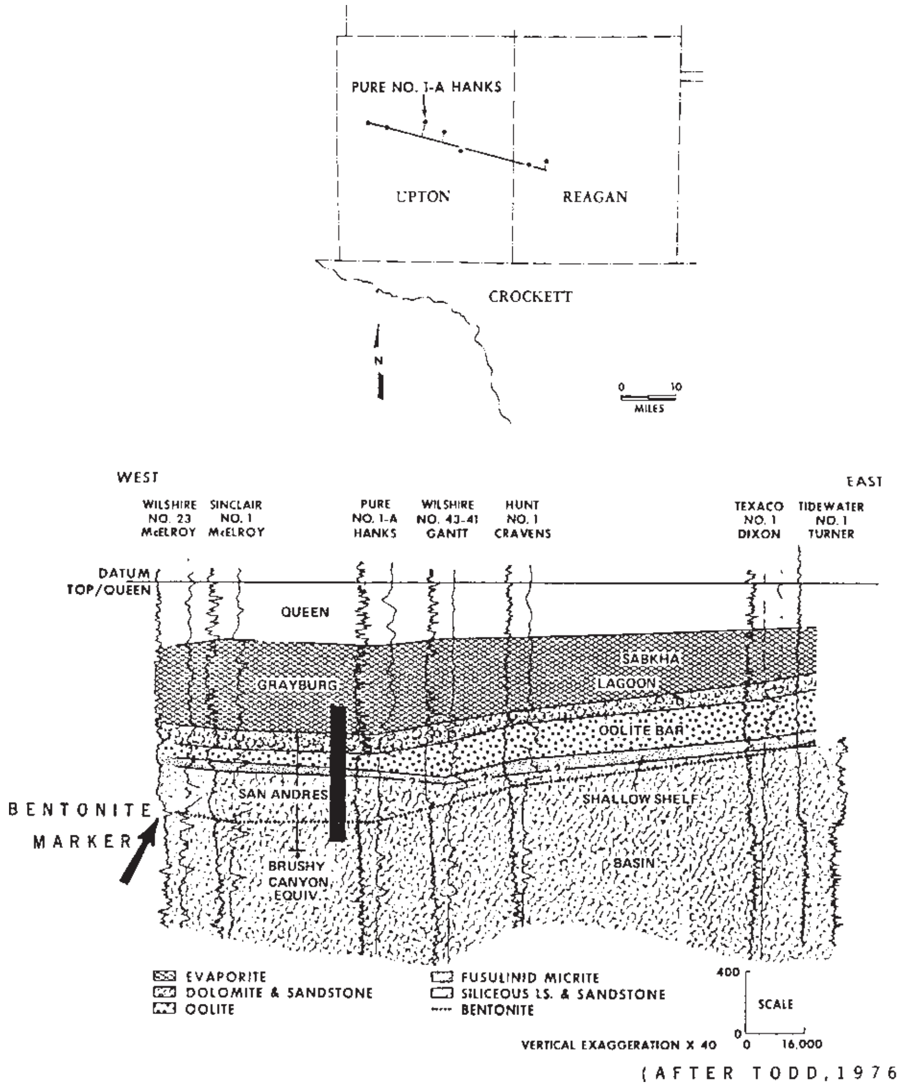


Figure 12. Oolite bar progradation, San Andres Formation, Midland Basin, showing bentonite time line.

to these gigantic sizes from having collected at the same locality. Specimens are truly of pencil size!

But even for these giants, a single, central tunnel remained characteristic, except for the rare microspheric shells, which characteristically have no central tunnel. In Early Guadalupian (Roadian) time, however, an interesting genus, *Skinnerina*, had already come on the scene without the well-defined central or median tunnel common to most fusulinid genera. *Skinnerina*, instead, displays sporadic multiple tunnels (Figure 18, Figure 19). Arguments persist as to whether such forms constitute a dead-end lineage, as thought by Skinner (1971), or whether *Skinnerina* represents the beginnings of a lineage culminating in *Polydiexodina* (Figure 18, Figure 19).

During the Middle Guadalupian, particularly in Eurasia, *Eopolydiexodina* appeared with the same lack of any well-defined median tunnel but with sporadic, multiple, secondary tunnels. The septal folds are intense and squared off with secondary material in both *Skinnerina* and *Eopolydiexodina*, which is also characteristically *Polydiexodina*-like. The writer suggests that the three genera are parts of an evolutionary continuum.

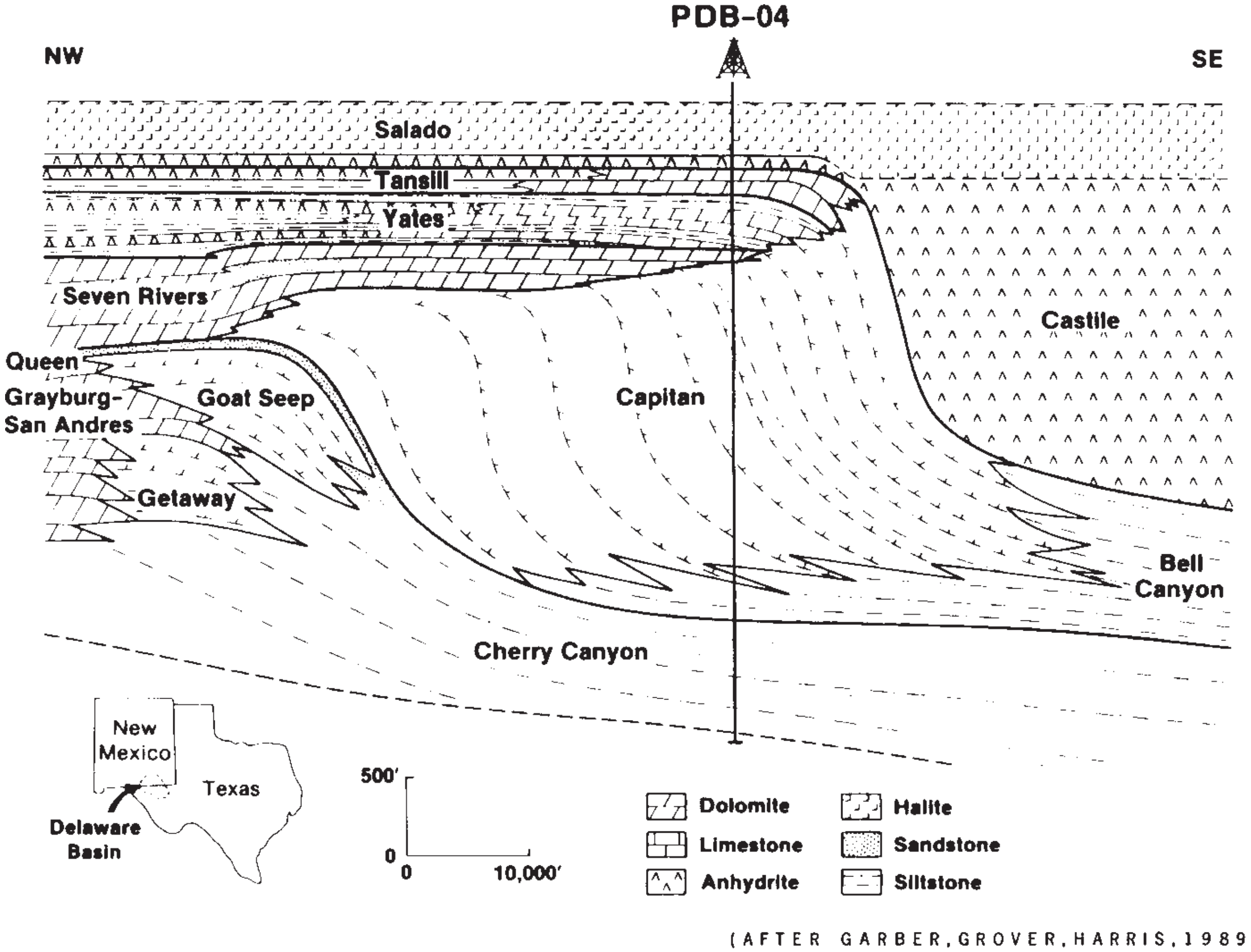


Figure 13. Cross section showing stratigraphy and lithology in area of Gulf PDB-04 well. After Garber, Grover, and Harris 1989.

Something very strange began to occur at the close of the Middle Guadalupian. Consider the fact that the giant *Parafusulina* species seemingly had no need, merely because of size, to develop multiple tunnels. Consider the fact that *Polydiexodina* apparently "needed" to attain not only well-developed multiple tunnels but also a well-developed central or median tunnel. Apparently, continued existence of these large forms depended upon the attainment of a more highly developed tunnel system. Perhaps something was happening to the sea water, accompanied by extensive volcanic ash blanketing the ocean waters. We shall return to these ideas later.

What we do know, however, is that *Polydiexodina,* with all its size and beautifully developed tunnel system, did not hang around much longer than about a million years. Apparently the Late Guadalupian seaways were becoming very stressful for these foraminifers.

The highest occurrence of *Polydiexodina* in the Guadalupe Mountains is the McCombs Limestone, and its Yates-Capitan equivalent, on the shelf and shelf margin, respectively. This correlation is to the top of Yates "B" on the shelf (Newell et al. 1953, Mruk and Bebout 1993, Garber et al. 1989).

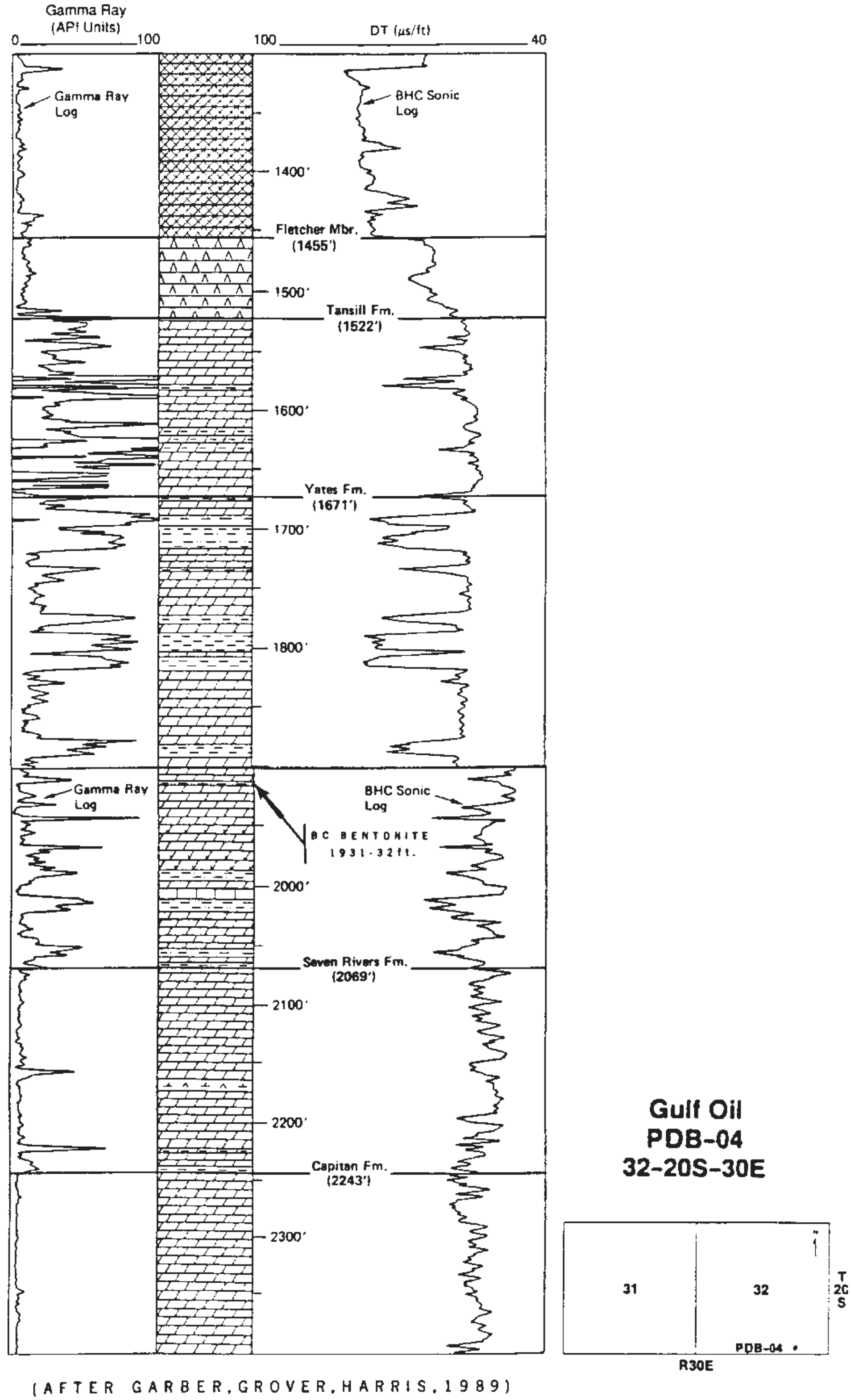


Figure 14. Sonic log, lithostratigraphy of upper portion of PDB-04 well, showing position of BC bentonite marker in shelf Yates Formation. After Garber, Grover, and Harris 1989.

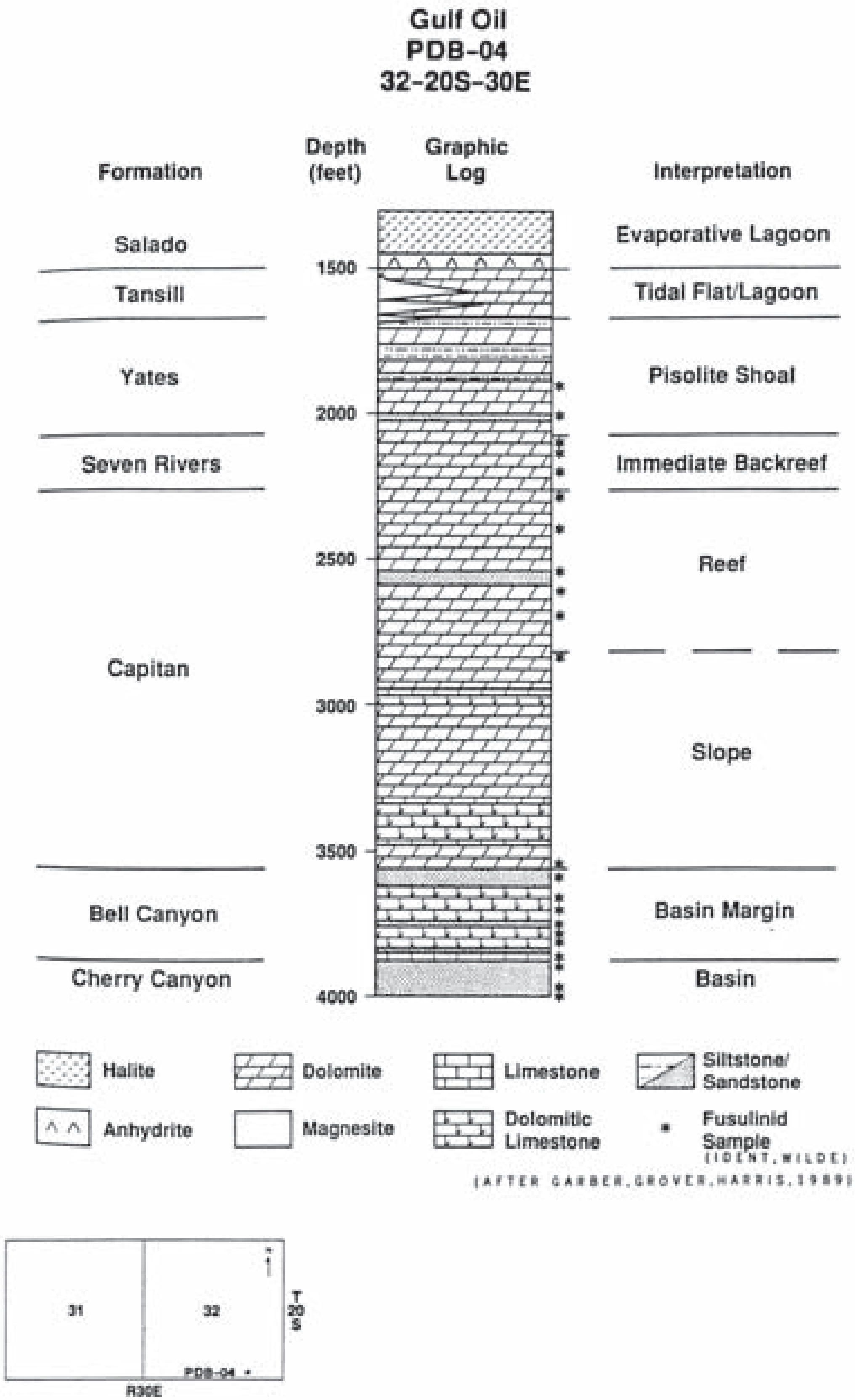


Figure 15. Sonic log, lithostratigraphy of lower portion of PDB-04 well, showing position of CC bentonite marker. After Garber, Grover, and Harris 1989.

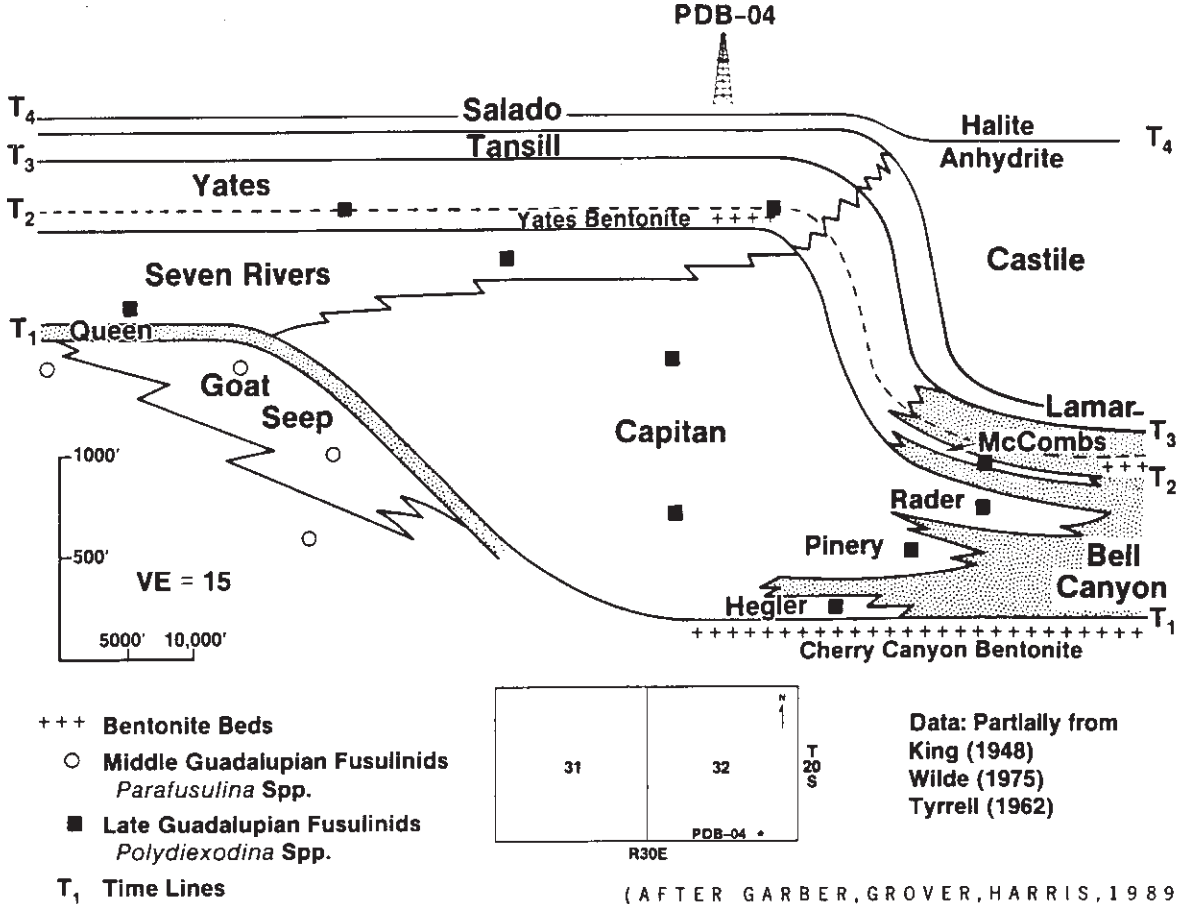


Figure 17. Summary cross section showing time lines based on lithostratigraphy, fusulinid biostratigraphy, and bentonite markers in area of PDB-04 well.

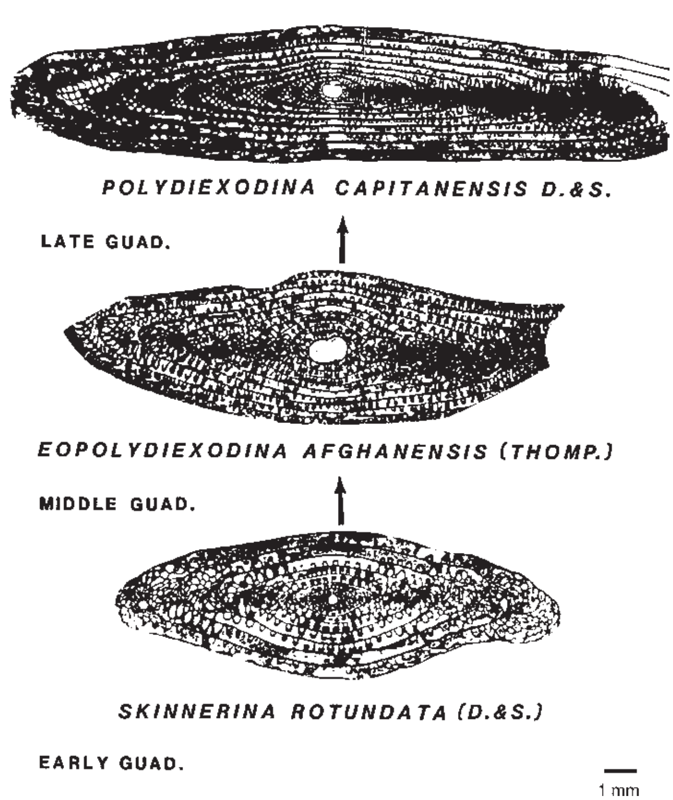


Figure 18. Evolution of the Polydiexodinids.

Yabeina. Approximately 56 feet (17 m) above the McCombs is the basal Lamar Limestone. Here occurs one of the phenomena of fusulinacean biostratigraphy for the Delaware Basin: a tiny example of the Tethyan fusulinacean genus *Yabeina* (*Y. texana*) (Skinner and Wilde 1955) made its appearance. This form represents an intrusion from the outside, so to speak, as the first known occurrence of a "typical" Tethyan fusulinacean in the entire Permian basin history. Some workers would prefer that *Y. texana* not be considered a member of that genus because of its tiny size; however, it has all of the characteristics of *Yabeina*. And whether or not it is called by that name, the fact remains that it is a representative of the subfamily Neoschwagerininae, whose members are Tethyan.

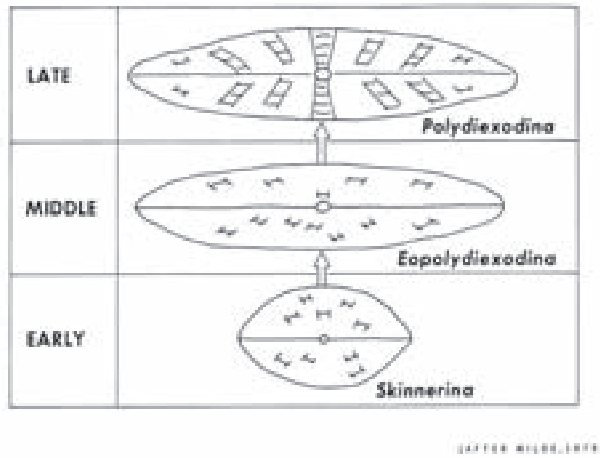


Figure 19. Evolution of the Polydiexodininae during Guadalupian time. After Wilde 1975.

Almost as quickly as *Yabeina* arrived in the Delaware Basin it was gone for good, and no later member of the Neoschwagerininae ever entered the Basin again. The picture is, as if to say, that the basin environment was not right in terms of size development for individual species, and definitely unsuited for continued development of progeny. What was happening to the sea water?

Boultoniinae. All members of the subfamily Boultoniinae are minute, yet complex fusulinaceans, with a type of preservation that is difficult to describe. When the subfamily was erected, Skinner and Wilde (1954) recognized this problem of description: "In thin section the spirotheca of even the best preserved specimens has a translucent to transparent quality which produces a glassy or resinous appearance." This quality is clearly not one of poor preservation; most members are beautifully preserved. Indeed, minute septal pores that are plugged with secondary material are seen in most of the genera, and in fine detail. This feature is also present in *Schubertella*, the probable ancestor to the group. The boultonids got their start in the Early Permian in genera such as *Boultonia* and *Minojapanella*, but a sudden outburst occurred about the time that *Yabeina* left the Delaware Basin. This outburst continued through Lamar Limestone and Reef Trail (post-Lamar beds, King 1948) deposition.

One member of the group, *Codonofusiella*, with an uncoiling habit, had already gotten its start in Early Capitanian time; however, by Lamar time some unusual changes were occurring within the lineage (Figure 20). From a codonofusiellid species, such as *C. extensa* (Figure 20, 1–3), arose an entirely new genus, *Paradoxiella* (Figure 20, 4–12), with features more akin to later Mesozoic and modern forms. The following stages spell out the transition:

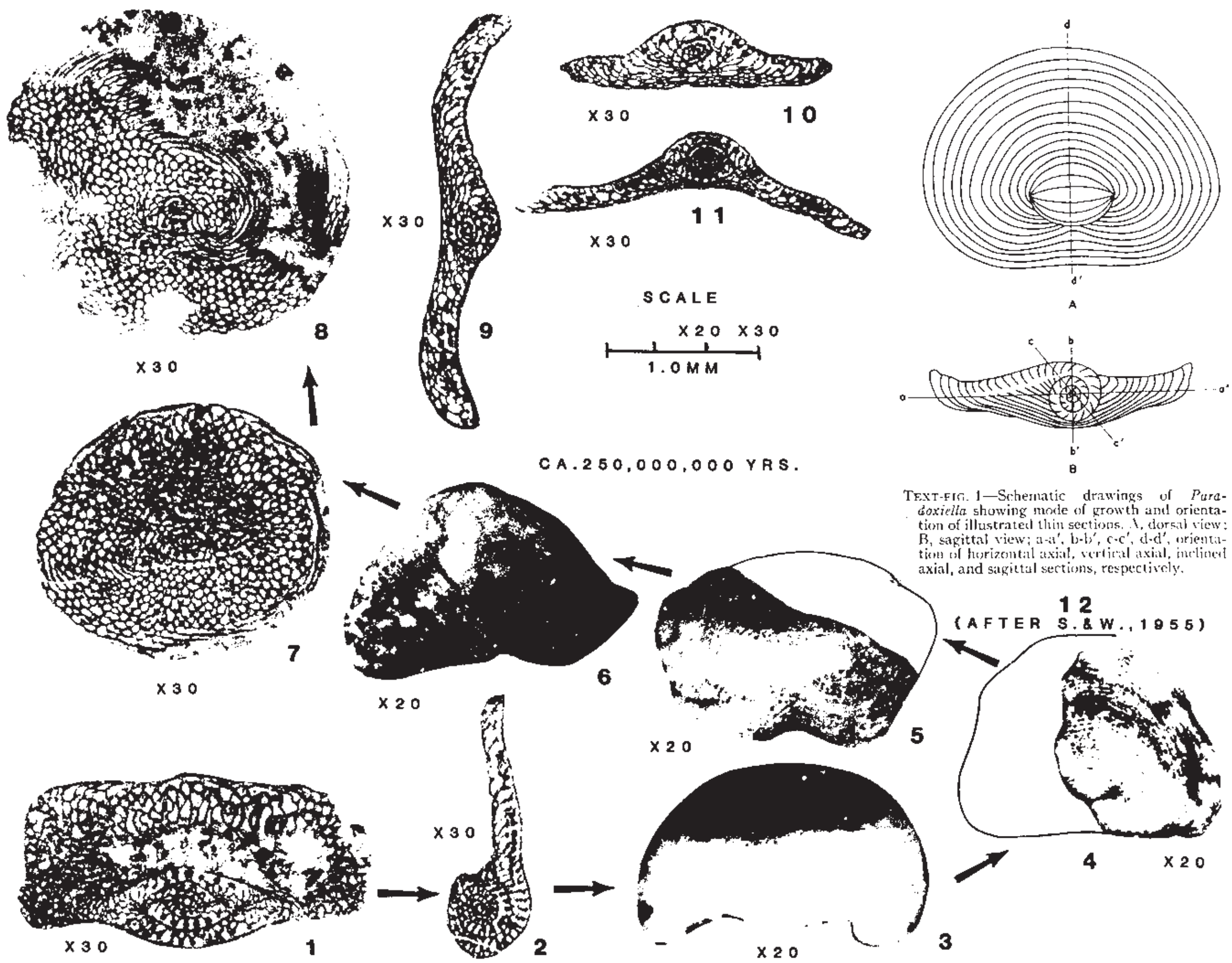
Stage 1. A *Boultonia*-like form began to uncoil in Early Capitanian time, producing *Codonofusiella*.

Stage 2. Some time between the deposition of McCombs and Lamar limestones a Codonofusiellid began to extend its uncoiled flare along the axis of coiling and tangentially. Thus, the portion of the flare in the axial area is curved back upon the axial extremities, causing a pronounced bulge of the shell at each end (Figure 20, 3). This advanced form is typified by *Codonofusiella extensa* (Skinner and Wilde 1954, 1955) whose type locality is the “middle” limestone of Brown (1996) at the mouth of McKittrick Canyon.

Stage 3. In the middle of the Lamar Limestone one sees the zone of *Paradoxiella*, a genus in which the uncoiling has been taken to the utmost extremes (Figure 20, 4–12). In *Paradoxiella*, the uncoiled flare is also extended laterally as before and recurved around the poles of the coiled body of the shell terminating against the posterior side of the shell. This mode continued until opposite ends of the recurved flare reached the shell’s center. Then the flared septa, as it were, bridged across the middle to become annular. Because of this most unusual growth pattern, new terminology was needed to describe the various orientation patterns (Figure 20, 12) (Skinner and Wilde 1955). In finality, the shells have a sort of coolie-cap appearance and commonly fell onto the lime mud floor with the posterior side protruding upward.

Once again, occurring in a single evolutionary group is what might be interpreted as stressed conditions. Whether stressful or not, *Paradoxiella* had a relatively short life, occurring only during the middle of Lamar Limestone deposition. But its occurrence was widespread; species were described from Japan (Sada and Skinner 1977, Ishii and Takahashi

Figure 20. Evolution of Codonfusiella to Paradoxiella.



1960) and China (Sheng and Sun 1975). In the latter instance, this writer believes that the species described as *Codonofusiella orthonios* by Sheng and Sun, is in reality a *Paradoxiella*. These Asian forms occur with huge *Yabeina* in the upper part of the *Yabeina* zone.

***Paraboultonia* and *Lantschichites*.** It is beyond the scope of the present paper to consider the entire story of *Paraboultonia* and *Lantschichites*. This has been discussed in detail in Wilde and Rudine (1997). Both forms have been found to occur together from the top of the Lamar Limestone through the Reef Trail Member (post-Lamar beds, King 1948) to the base of the Castile Formation. *Paraboultonia* is elongate, with strongly folded septa and exhibits cuniculi, openings at the base of opposed folds of septa, as is seen in the older large genera, *Parafusulina* and *Polydiexodina*. The final whorl of *Paraboultonia* is inflated, but the septa do not rise off the floor to uncoil as in *Codonofusiella*. However, in *Lantschichites* uncoiling does occur, and indeed, *Lantschichites* is considered to be an elongated subgenus of *Codonofusiella*.

The point to be made here, however, is that these two forms appear to represent end members of a line of boultonids that developed very quickly during the Late Guadalupian–Early Lopingian and then died out, following a pattern experienced by other fusulinacean genera ahead of them.

End-Permian

By the close of the Permian all of the fusulinaceans had died out, but numerous species of boultonids, represented by such genera as *Palaeofusulina*, not present in the Delaware Basin because of the onslaught of evaporitic conditions, continued to the end. Numerous other minute genera hung on to the end with them.

Some major changes had obviously occurred in the chemistry of the sea water. There is no good reason to argue, as this author did many years ago (1955), that the arrival of evaporites and salts signaled the ultimate demise of *Polydiexodina*, for example. Perhaps this could constitute a reasonable argument in the case of the Delaware Basin history, but such an argument fails to consider the worldwide aspect of fusulinacean evolution. *Polydiexodina* and *Paradoxiella* did live at approximately the same time elsewhere. *Yabeina* coexisted elsewhere with *Paradoxiella* in healthy abundance and size. But in the Delaware Basin *Yabeina* arrived, did not enjoy a healthy existence, and either left or died out.

Conclusions

Two lines of evidence, one well-documented, the other speculative but plausible, suggest an explanation for what happened to the fusulinaceans during the Guadalupian and at End-Permian time.

There seems little doubt that volcanism played a commanding role in the demise of the larger fusulinaceans in the Delaware Basin. Not mentioned earlier, but true, the Manzanita Limestone, which overlies the Cherry Canyon marker bentonite, is rather light-colored with a pale-green aspect, and, according to Newell and others (1953), the depth of water during Manzanita deposition was much shallower than for most of the other limestone deposits of the basin margin two miles from the basin rim. Also, and most telling, the Manzanita Limestone lacks many of the faunal groups with the exception of ammonoids and rare brachiopods and gastropods (Newell et al. 1953). The Manzanita had no shelf margin reef equivalent either. It is very compelling to suggest that the volcanism that was associated with the Manzanita deposition also played a role in the demise of large *Parafusulina* and subsequent proliferation of *Polydiexodina,* with its well-developed tunnel structures.

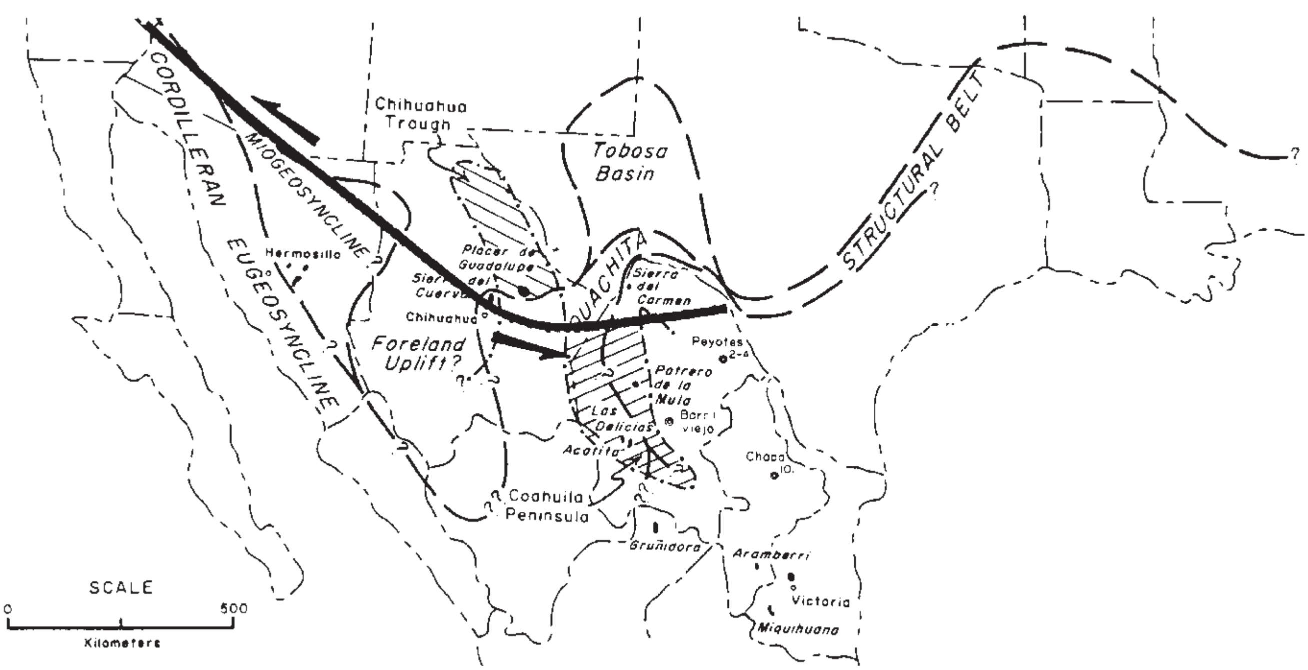
But a new element was conspiring with the volcanism to limit *Polydiexodina,* and later *Yabeina,* to a short life in the Delaware Basin. To be sure, the continuing volcanism did not help. A restrictive inflow of sea water, possibly coupled with altered sea water content, was occurring. The earlier high CaCO$_3$ production of the basin margin was now being shut down. Although CaCO$_3$ production during Lamar deposition was strong, many changes were about to occur. The prolific Capitan reef was dying and became subaerially exposed because of relative sea level fall at the close of Lamar–lower Tansill deposition. By the time a rising sea level had reestablished itself in upper Tansill–Reef Trail time, only scattered patch reefs were being developed (Noe 1996). With increasing aridity and the closing of the Hovey Channel (Figure 6, Figure 8), evaporative conditions proved to be devastating for reef development.

By the close of Lamar deposition, the minutely complex fusulinaceans had completely taken over in the Delaware Basin, matching worldwide changes. Thus, the Hovey Channel could not have sealed off the Basin completely, at least prior to Castile deposition. There was not only continued freshening, but continued evolution of the tiny fusulinaceans. Sea water over the entire Earth seemed to be undergoing major change due to ocean-floor spreading brought about by the central fissures of the Pacific (Panthalassa) and the Atlantic ridges juxtaposed to major plate boundaries.

The structural speculations of Bridges (1964) have been modified to express simply the idea that large left-lateral movements of Late Permian plate boundaries could have been involved in moving Panthalassic waters in and out of the Delaware Basin while volcanoes were spewing ash over the landscape (Figure 21). Close of the Permian was not far away, but its end was already in sight during the Guadalupian.

All kinds of causes have been offered for the End-Permian extinctions, including salinity changes, global cooling, tectonics, extra-terrestrial impact, marine regression, and others, in no particular order. Erwin (1992) argued that the most likely cause of these extinctions "was tectonically-induced climatic instability and marine regression which brought

Figure 21. Structural speculations in northern Mexico. Modified after Bridges 1964.



about trophic instability." Wilde (1975) offered similar arguments based on observed mineralogical changes in fusulinaceans as a possible result of continental plate displacements.

Finally, it is suggested that plate tectonics might offer a single cause and effect scenario for lumping most of the suggested causes of End-Permian extinctions. Plate tectonic activity and ocean-floor spreading moved continents, rerouted sea water flow, caused volcanic eruptions, and elevated mountains of carbonates, which added CO_2 to the water column with water and ice runoff. Adding large amounts of CO_2 to the world's oceans offers one of the best opportunities for anoxic conditions to develop. A number of workers have recently argued for a "superanoxic, stratified superocean" at the Permian-Triassic boundary as the defining cause for Permian extinctions (Sepkoski 1986, Erwin 1992, Knoll et al. 1996, Isozaki 1997). This "cause," however, is only an end result of all that had begun a few million years earlier in the Guadalupian.

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Note: Because the boundaries of the Middle Permian and Guadalupian have been defined and adopted (see Glenister et al. and Lambert et al. in this volume), the editors treat them as formal units. Therefore, the initial letters of the names and modifying words of the period/system (e.g., Middle Permian), epoch/series (e.g., Upper Guadalupian), and stage/age (e.g., Early Capitanian) have been capitalized in this context. Other geologic units in this paper follow the guidelines provided in Hansen, W. R., editor. 1991. Suggestions to authors of the reports of the United States Geological Survey. 7th edition. U.S. Geological Survey, Washington, D.C.

Chapter 33

Sponge Diversity Patterns in the Middle Capitan Reef of the Guadalupe Mountains, Texas, and Their Environmental Implications

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Introduction

The Guadalupe Mountains of Texas and New Mexico provide unparalleled exposures of the marvelously preserved Capitan reef system (Figure 1). Considered a classic teaching example, the reef is visited by hundreds of geologists annually. Despite its very different biological composition, the middle Capitan reef is remarkably similar in morphology and dimensions to modern reefs and to other ancient reefs. Because of fortuitous conditions of burial and erosion, part of the original depositional profile of the Capitan is intact. Its profile, in fact, is hauntingly similar to the steep front of modern reefs.

One feature common to almost all shallow-water reefs today is a significant change in faunal diversity and community composition with depth. Such

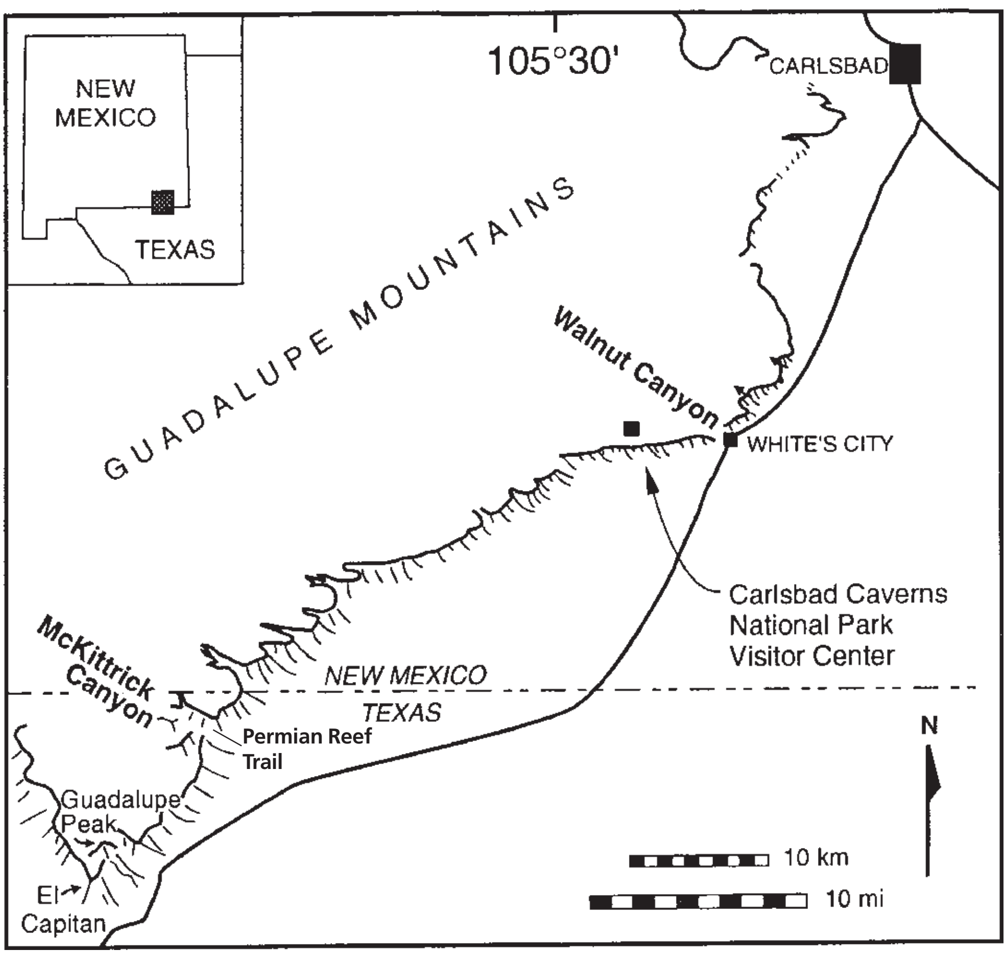


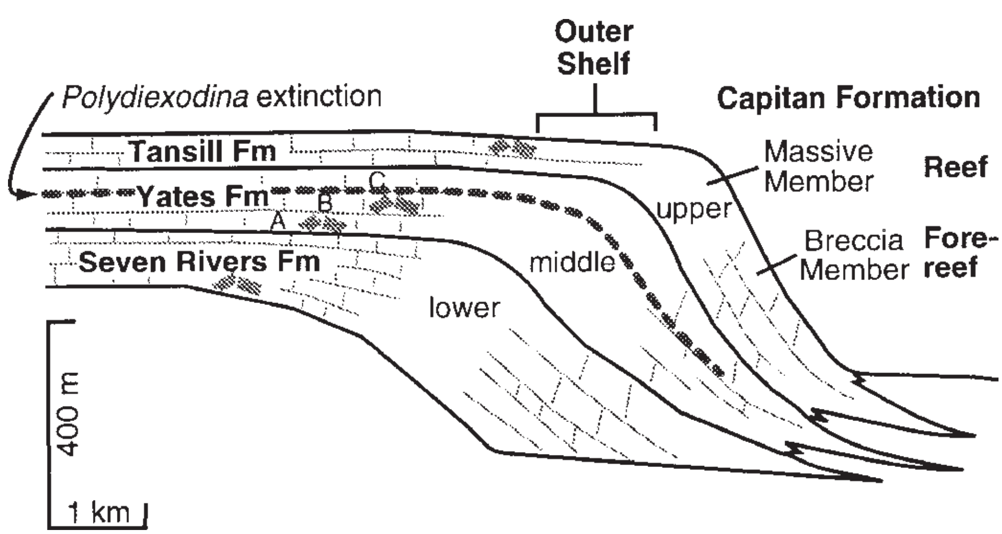
Figure 1. Map indicates the locations of the Guadalupe Mountains and the Permian reef geology trail in McKittrick Canyon from which the samples in this study were collected.

changes are well-documented for corals (e.g., James, 1983, Bianchi et al. 1997, and many others), and similar changes have been observed in many other groups as well, including sponges (Alcolado 1990, 1994; Alvarez et al. 1990; Diaz et al. 1990; Schmahl 1990; Liddell et al. 1997; Reed and Pomponi 1997). Unfortunately, it is difficult to recognize faunal changes with depth in the fossil record because burrowing, sorting by waves, and other processes alter and destroy the original community composition.

Fortunately, the Capitan reef does contain well-preserved assemblages. In contrast to modern reefs, the Capitan community, like other Permian communities, contained few organisms that could damage the reef itself (Wood et al. 1996, Fagerstrom and Wiedlich in press). Preservation of the reef in situ was also enhanced by the contemporaneous encrustation, largely by the presumed red alga Archaeolithoporella (Wiedlich and Fagerstrom 1998), and by the binding of reef organisms through the precipitation of lime mud, or micrite, by bacteria (Kirkland et al. 1998). Furthermore, and most remarkably, the excellent exposures and lack of structural deformation allow us to determine the water depth at the time of deposition along the front of the reef.

The Capitan Formation itself consists of two members: a Massive Member, which comprises the reef, and a Breccia Member, consisting of the fore-reef debris (Figure 2). The Capitan has been divided into lower, middle, and upper units by correlation to the interfingering Seven Rivers, Yates, and Tansill formations on the shelf to the northwest. Time lines have been drawn through these rock units using index fossils, most commonly fusulinids (e.g., Newell et al. 1953). These rice-shaped protozoans sometimes grew to surprisingly large sizes. The large fusulinid *Polydiexodina* is one of the most prominent and distinctive, and being commonly about two-centimeters long, it is easily seen in outcrop. Its extinction marks a prominent time line that can be carried through the Capitan Formation, and it defines the profile of the reef as it appeared during deposition of the middle Capitan. During this phase of its deposition, the reef had a nearly vertical profile (Kirkland et al. 1993). In some places the ancient reef profile runs almost parallel

Figure 2. Diagram shows the spatial relationships and stratigraphy of the outer shelf, reef, and fore-reef facies of the Permian reef complex in the Guadalupe Mountains. The Seven Rivers, Yates, and Tansill formations correlate to the lower, middle, and upper Capitan reef facies, respectively. The *Polydiexodina* extinction provides a time line illustrating the original, nearly vertical profile of the reef and shelf margin. The samples in this study were collected from the middle Capitan Formation parallel to this time line.



to the modern erosional surface (Figure 2, Figure 3). The time line defined by *Polydiexodina* is so prominent and the nearly vertical depositional profile it defines so striking that tracing it in outcrop is a common field exercise for geology students.

The goal of this study is thus to document the contemporaneous faunal changes within the reef along the *Polydiexodina* time line and to correlate these changes with the original water depth. In this way faunal patterns can be tied directly to bathymetry, allowing inferences to be made about oceanographic conditions in the Delaware Basin and the environmental controls on the organisms that lived there.

Methodology

One of the places where the ancient reef profile parallels the modern erosion surface is along parts of the Permian reef geology trail in McKittrick Canyon (Figure 1). In the parts of the trail that we studied, walking down the trail is analogous to diving deeper and deeper down the face of the reef. Because of this fortuitous configuration, we were able to plot the location of each sample with respect to the shallowest part of the reef, the outer shelf–reef transition (Figure 3), and thus deduce water depth (±10 m) at the time of deposition.

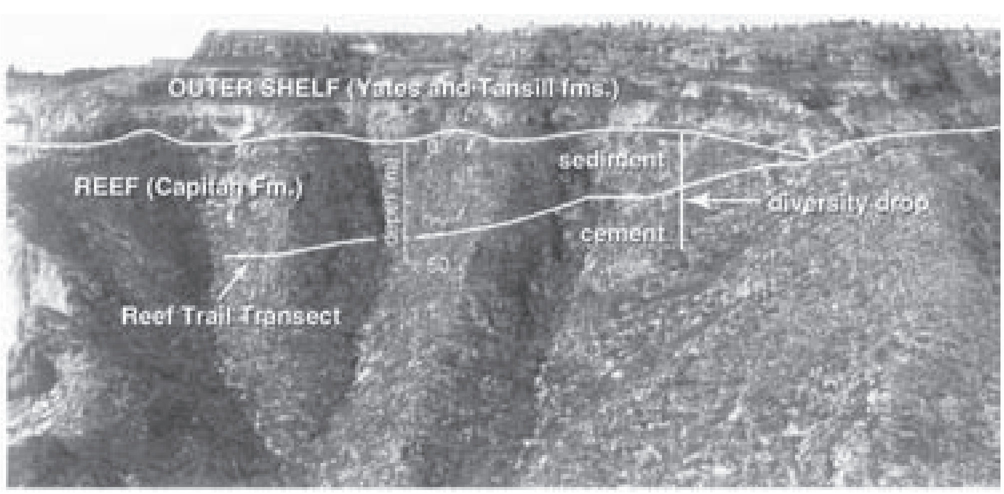
Samples used in this study were collected from the Capitan Massive at approximately five-meter intervals, beginning at the outer shelf–reef transition, and continuing downward along the trail to an elevation (and paleodepth) about 50 meters below the transition (Kirkland et al. 1993) (Figure 3). In order to determine relative elevations, the sample sites were marked on a photograph of the exposure then measured off the photograph in relation to elevation markers surveyed by the Texas Bureau of Economic Geology. The fusulinid *Polydiexodina* is common throughout this part of the reef, and the time line defined by its extinction is easy to trace.

Results

The Massive Member of the middle Capitan Formation exposed in McKittrick Canyon contains numerous sphinctozoan and inozoid sponges. These sponges have a solid, basal skeleton of calcium carbonate, which in the case of sphinctozoans, forms distinct chambers.

Between the outer shelf–reef transition and a position 15 to 20 meters below, samples exhibit a high overall diversity, with at least 13 species and 10 genera of sphinctozoans, as well as one species of inozoid, being present (Figure 4, Table

Figure 3. Photograph of the Permian reef geology trail in McKittrick Canyon. The outcrop here nearly parallels the original depositional surface as indicated by the *Polydiexodina* time line. Samples were collected along the reef trail transect from the outer shelf–reef transition down to a paleodepth of about 50 meters below. The drop in faunal diversity is about five meters below the transition from grainy sediment to cement-dominated fabric.



	Depth below reef–outer shelf transition (m)												
	0	3	12	15	17	18	24	27	35	37	40	43	46
Sphinctozoans													
Lemonea	x	x	x	x		x	x	x	x	x	x	x	x
Colospongia	x	x											
Ambithalamia		x					x	x	x				
Girtyocoelia		x		x			x						
Guadalupia				x									
Cystothalamia		x		x									
Amblysiphonella		x		x	x	x	x			x	x	x	
Parauvanella		x		x	x								
Discosiphonella			x	x									
new genus				x									
Inozoids				x					x				x
Hexactinellids?	x												
Bryozoans	x					x					x		
Acanthocladia			x	x	x		x					x	x
sheet		x											
encrusting		x					x						
stick-like			x										
Coral				x									
Algae													
Green Algae									x				
Phylloidal			x										
Dasyclad	x												
Mizzia		x											
Collenella	x												
Pseudovermiporella		x				x							
Archaeolithoporella	x	x	x	x	x	x	x	x			x	x	x
Problematica													
Shamovella (=Tubiphytes)	x	x	x	x		x	x	x					x
Lercarituba							x						
Articulate Brachiopods	x	x	x					x	x	x			x
Foramanifera			x			x			x				
Encrusting Forams	x	x		x			x						x
Unidentified Fusulinids								x	x				
Polydiexodina	x	x	x	x									
Mollusks									x				
Gastropods	x	x	x										x
Bivalves	x	x											
Arthropods	x	x											x
Echinoderms	x	x				x						x	
"Worms"						x							

Table 1. The genera present within samples taken from 0 to 50 meters elevation below the outer shelf–reef transition along the Permian reef geology trail in Guadalupe Mountains National Park, Texas. The sediments change character with increasing water depth below this transition. The unit was extensively dolomitized along a fracture between 5 and 10 meters depth, preventing any meaningful analysis of samples from that interval.

1). In addition to the indeterminate inozoid, these taxa include: *Ambithalamia*, *Amblysiphonella* (3 spp.), *Colospongia*, *Cystothalamia*, *Discosiphonella*, *Girtyocoelia*, *Guadalupia*, *Lemonea* (2 spp.), *Parauvanella*, and a new porate genus distinguished by having exaules and reticular filling tissue. Each species was usually represented by just one individual per sample. Unfortunately, replacement of the original reef rock by dolomite along fractures (Melim 1991) prevented meaningful sampling between 5 and 10 meters below the outer shelf–reef transition. The original total diversity within this zone may therefore have been even higher. However, the same rock type and species abundances were found above and below this zone, so there does not appear to have been any significant lithologic or faunal change across the dolomitized interval.

At a point 15–20 meters below the outer shelf–reef transition, sponge diversity plummets (Figures 5, Figure 6, Table 1). Samples collected at this point and at points below are dominated by just one genus of sphinctozoan sponge, *Lemonea*

Figure 4. Photograph shows the sphinctozoan *Lemonea*, one of the more common genera in the Capitan Formation. This taxon dominates faunas of the upper Capitan (Rigby et al. 1998) and those samples from the middle Capitan occurring more than 20 meters below the outer shelf–reef transition. Note that successive generations attach to and hang from older individuals. Photograph by Rachel Wood.

(Figure 4). Although *Ambithalamia*, *Amblysiphonella* (4 spp.), *Girtyocoelia*, *Parauvanella*, and one inozoid are also present, their occurrence is sporadic and their abundance is low. *Lemonea*, on the other hand, is represented by two, three, or even more individuals in almost every sample.

A similar but less pronounced drop in diversity is seen among the other fauna within the reef (Table 1). Once again, the greatest diversity of organisms is found in samples taken 0–15 meters below the outer shelf–reef transition. Green algae, mollusks, brachiopods, encrusting foraminifera, and corals are more common in samples from shallower depths (Table 1). Sponges, bryozoans, and the presumed red alga *Archaeolithoporella* are more common than other organisms at depths greater than 15 meters below the outer shelf–reef transition. The unusual organism *Shamovella* Rauser-Cernousova (formerly *Tubiphytes*, see Riding 1993) is also present at these depths but only occurs in local concentrations.

The character of the rock also varies with depth below the outer shelf–reef transition. Samples collected less than 12 meters below the reef to outer shelf transition were dominated by grains. These grains are poorly sorted, subrounded to rounded, and include fragments of dasyclad algae, bryozoans, *Shamovella*, bivalves, ostracods, and what are probably sponges (Kirkland and Moore 1996). The mud content in these grainstones to packstones varies from sample to sample and even on a microscopic scale. Very little lime mud (micrite) is present and cement and similar crystalline material comprises no more than 10% of the samples. However at depths greater than 12 meters below the outer shelf–reef transition, the rocks are characterized by cement-filled voids that make up 15–70% of each sample (Table 1).

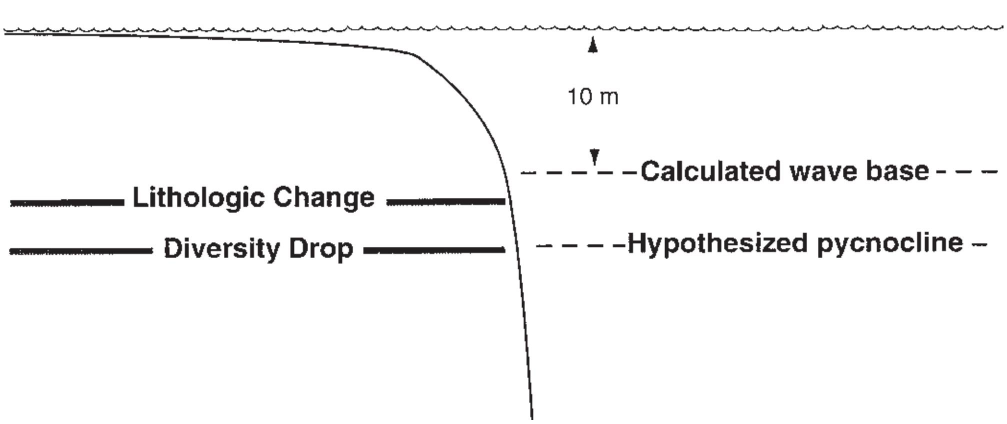


Figure 5. Diagram illustrates the positions of calculated wavebase and the interpreted pycnocline relative to the observed lithologic change and drop in biological diversity.

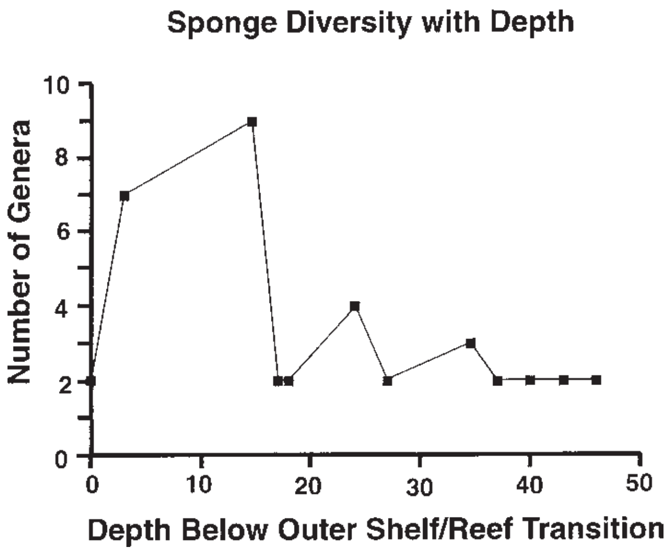


Figure 6. Plot shows changes in sphinctozoan generic diversity with depth below the outer shelf–reef transition along the Permian reef geology trail in Guadalupe Mountains National Park, Texas. Whereas the taxa in the shallower assemblages are about equally abundant, *Lemonea* dominates the assemblages below about 17 meters.

Subtle variations also occur in the composition of the frame-building community and in the nature of the binding elements. In samples taken 0–10 meters below the transition from reef to outer shelf, organisms that could fill the role of frame builders are present. These include sphinctozoan sponges, the green alga *Collenella*, and bryozoans. These organisms are commonly encrusted by one or more layers of micrite, the innermost being very thin (0.05 mm) and having distinct, ovoid holes. Successive encrustations may be as much as 10 millimeters thick.

Approximately 15 meters below the contact between the reef and outer shelf, *Collenella* is absent. Relationships between the organisms are easier to recognize. Bryozoans and sponges clearly form cavity walls and act as frame builders. Accumulations of fine-grained micrite, probably precipitated by microbes, are much thicker (1–3 cm) than they are higher in the reef.

Figure 5 illustrates the sedimentary and faunal changes with respect to the outcrop. Interestingly, the drop in biological diversity occurs about 5 meters below the change from grainy sediments to cement-rich boundstone.

Interpretation

We interpret the change in rock type and the distinct drop in diversity seen below the outer shelf–reef transition to be the results of changes in the physical environment and water mass below wave base. The reduced diversity in the deeper samples suggests some kind of environmental stress, but of what sort?

In terms of modes of life, the closest ecological analogues to the Capitan sphinctozoans in modern open marine environments would be heterotrophic demosponges. The diversity of such sponges is usually greatest at depths of 10–30 meters or more, with much greater diversity in deep waters than in shallow ones (Hartman 1977; Alcolado, 1990, 1994; Wilkinson and Evans 1989; Schmahl 1990; Liddell et al. 1997; Reed and Pomponi 1997). Based on a comprehensive, global study of sphinctozoans, the optimum water depth for Permian and Triassic sphinctozoans in reefs was 15–40 meters (Senowbari-Daryan 1990).

Some of the environmental conditions known to influence modern sponge distributions include: turbulence and turbidity (Pouliquen 1972, Sarà and Vacelet 1973, Sarà 1978, Wilkinson and Evans 1989, Alcolado 1990, Diaz et al. 1990, Liddell et al. 1997), the frequency of environmental disturbance (Alcolado 1990, Diaz et al. 1990), light levels (Pouliquen 1972, Sarà and Vacelet 1973, Wilkinson and Evans 1989), the character and availability of the growing surface (de Laubenfels 1955, Pouliquen 1972, Sarà and Vacelet 1973, Bergquist 1978, Diaz et al. 1990, Bakus and Ormsby 1994, Liddell et al. 1997), salinity (Pouliquen 1972, Sarà and Vacelet 1973, Alcolado 1990, Bakus and Ormsby 1994), oxygen levels (Sarà and Vacelet 1973), and temperature (Hartman 1958, Wells et al. 1960, Pouliquen 1972, Sarà and Vacelet 1973, Bakus and Ormsby 1994). Predation (Sarà and Vacelet 1973, Bergquist 1978, Bakus and Ormsby 1994) can also affect the distribution of some sponge taxa.

In modern reefs, turbulence and turbidity are important controls on sponge distributions (Pouliquen 1972, Sarà and Vacelet 1973, Sarà et al. 1978, Wilkinson and Evans 1989, Alcolado 1990, Diaz et al. 1990, Bakus and Ormsby 1994, Liddell et al. 1997), but produce a markedly different diversity curve than that seen in the middle Capitan. Because sponges are filter feeders, their diversity is greatest where the water is neither stagnant nor excessively turbulent (Sarà and Vacelet 1973). In stagnant waters, the current is too weak to bring food to the sponge, and oxygen levels may also be too low. In modern settings, though, sponge diversity at less than 30 meters is limited because turbulence fills the water with fine sediment and interferes with filter feeding (Alcolado 1990, 1994). In addition, the high wave-energy at these shallow depths results in high levels of environmental disturbance and stress that can reduce diversity (Alcolado 1994, Bakus and Ormsby 1994).

Our samples, however, showed diversity peaking at a water depth of less than 20 meters. Below this diversity plummets (Figure 6, Table 1), suggesting that controls on diversity in the middle Capitan were very different from those in modern reef settings, and that high levels of turbulence, turbidity, and rates of environmental disturbance were thus less important than other factors in controlling the distribution of Capitan sponges.

Changes in light levels affect distribution of modern coral and some sponge species (Pouliquen 1972, Sarà and Vacelet 1973, Wilkinson and Evans 1989) because these organisms contain photosymbionts. However, no morphological evidence exists to suggest that these Permian sphinctozoans had such symbionts. In addition, most ancient and all modern sphinctozoans inhabit caves, crevices, and the undersides of reef cavities, so the likelihood of their having had photosymbionts is very low. While light levels could have affected planktonic abundance and food supply, light and high levels of planktonic productivity in clear waters continue to 30 meters or more, rather than the inferred depth of 15–20 meters for the sudden drop in diversity in our samples. Furthermore, high levels of light may result in high levels of ultraviolet radiation (Wilkinson 1982). The deleterious effect of such radiation would result in higher diversity in deeper waters—the pattern seen in many modern reefs—but the exact opposite of what is seen in the middle Capitan reef.

The nature of the sediment can also influence sponge species distribution (Pouliquen 1972, Sarà and Vacelet 1973, Diaz et al. 1990, Bakus and Ormsby 1994, Liddell et al. 1997). However, the shift from grainy to cement-rich sediments occurs 10–15 meters below the outer shelf–reef transition and about five meters above the drop in sponge diversity. There is thus no direct correlation between the type of substrate and faunal diversity. While many modern species distributions are also affected by competition for limited substrate, the frequent lack of contact between the sphinctozoan sponges in the upper Capitan has been interpreted to suggest that little, if any, spatial competition occurred between them (Wiedlich and Fagerstrom 1998).

Predation by spongivores can influence species distribution today (Sarà and Vacelet 1973) but probably had almost no effect on the diversity patterns of Permian sphinctozoans. Those groups of fish and turtles that eat sponges today did not evolve until much later. Furthermore, the demosponges preyed upon in modern oceans have proteinaceous skeletons much softer and more nutritious than the hard, calcareous skeletons of the Permian sphinctozoans.

The most plausible explanation of the observed diversity pattern in the middle Capitan is a rapid change in water conditions with depth. The Capitan reef fringed the Delaware Basin, a nearly enclosed embayment. As such, its circulation would have been very restricted, and many authors have suggested that at least during some intervals of Permian time, this basin experienced hypersaline conditions (e.g., Harms 1974). Evidence of high salinity includes ghosts of gypsum crystals in the basinal sediments of the Lamar Formation. The inner shelf at this time was about 120 kilometers across and very shallow (Adams and Rhodes 1960), and dense, saline waters could have formed on the shallow shelf and then flowed into the basin.

Oxygen levels might also have changed with depth within the Delaware Basin. Being a nearly enclosed embayment at equatorial latitudes (Darke 1989), the waters within the basin would not have experienced seasonal overturn. Most of the strata within the basin are characterized by large amounts of organic matter, fine laminations, and a very low or no faunal diversity (L. C. Babcock 1974). These observations suggest that the deepest basinal waters were usually poorly oxygenated, stagnant, and that the water mass within the Delaware Basin was probably intermittently stratified with respect to oxygen and possibly with respect to temperature and salinity (Harm 1974, Given and Lohmann 1985, Kirkland George 1992).

Temperature, however, could also have been important in producing the sponge distributions observed in the middle Capitan. Temperature is the main factor controlling the geographic and bathymetric distributions of many sponge species today (Hartman 1958, Wells et al. 1960, Pouliquen 1972, Sarà and Vacelet 1973). Species are adapted to certain temperature ranges and are largely limited to water depths in those temperature ranges (Sarà and Vacelet 1973). Changes in temperature can also have a dramatic influence on filtration rate in some marine sponges, with a temperature increase of 6°–12°C as much as quadrupling the filtration rate (Riisgard et al. 1993). Although the sphinctozoans of the Capitan lacked spicules, temperature could have affected their ability to precipitate a calcareous basal skeleton.

The outer shelf deposits just above the part of the reef that we studied in detail contain coated grains, stromatolites, and oriented, articulated crinoids (Kerans and Harris 1993). We interpret this as evidence of current activity, rapid sedimentation, and abundant light. We suggest that these outer-shelf units were deposited above normal wave base. Modern wave base on continental shelves is typically 10 meters (Dietz 1963), and based on calculations involving the size of the basin and the prevailing winds, normal wave base within the Delaware Basin at this time would also have been about 10 meters. This is in close agreement with inferences that outer-shelf sediments were deposited in 12 to 15 meters of water (Hurley 1989, Kerans and Harris 1993). Given this, the outer shelf–reef transition would have to have been at about 15 meters depth or less.

The transition between grains surrounding a few thinly encrusted organisms and true boundstone may mark approximate wave base. The delicate organisms that formed the framework for much of the Capitan reef may only have been sturdy enough to survive in the quiet water below wave base. In our samples, grainy sediments change to boundstones 10–15 meters below the outer shelf–reef transition. Interestingly, the sudden drop in sponge diversity observed in this study occurs approximately 5 meters below this change in rock type.

The depths postulated for major changes in salinity and oxygen levels are much deeper than the observed drop in sponge diversity seen in our samples. L. C. Babcock (1974) documented a gradual drop in oxygen with depth in the Delaware Basin during deposition of the Lamar Member of the Bell Canyon Formation. Salinity might have increased gradually with depth or the change may have been abrupt (Harms 1974).

The depth to the pycnocline is difficult to establish. In modern, open-ocean reef settings, the pycnocline is 30–40 meters depth, but with the restricted circulation of the equatorial Delaware Basin, a change in water composition could have occurred just below the zone of well-mixed water, that is, normal wave base.

In the absence of good circulation, the evaporation and heating of surface water might have produced a layer of warmer, slightly more saline water below the pycnocline. Climatic models suggest that surface water temperatures within the Delaware Basin may have been as high as 40°C during the Late Permian (Moore 1990). Elevated temperature and salinity both reduce the amount of oxygen dissolved in water, so this water mass might also have had somewhat lower levels of dissolved oxygen. Some combination of slightly higher temperature, slightly higher salinity, and slightly lower oxygen could have made the water mass below wave base less suitable for the growth of sponges and many other organisms, resulting in the low diversity we observed.

Below wave base, the water would only rarely be mixed with the surface layer, and would therefore tend to be less oxygenated and stratified. If the change from grainy sediments to boundstones is also related to wave base, then one would expect the faunal change to occur at a depth slightly below the shift in rock type. This is, in fact, what is seen. The drop in faunal diversity is approximately five meters below the depth at which the grainy sediments largely disappear. The pattern of microbial layers also fits this scenario, for layers of microbial micrite were probably related to layers of gelatinous mucilage that would not have withstood wave action. Thick layers of microbial micrite are present below the change in lithology and below the drop in diversity. Although such a relationship between rock type, diversity, and wave base remains speculative, it fits the pattern of sedimentological and faunal changes observed within the middle Capitan.

The genus *Lemonea* dominates our middle Capitan, deep-water samples. The low sponge diversity of these samples suggests that this assemblage represents a community living under stressed conditions. *Lemonea* was apparently able to thrive in conditions that many other Capitan reef sphinctozoans and inozoids could not tolerate.

In this context, it is significant that *Lemonea* becomes the dominant sponge towards what would have been the shallowest part of the Capitan reef, where sponge diversity appears to decrease (Rigby et al. 1998). The last stages of the uppermost Capitan consist of only a few scattered patch reefs (Noé and Mazzullo 1992, Noé 1996, Senowbari-Daryan and Rigby 1996, Rigby et al. 1998). Although the causes of the demise of the Capitan reef are not yet known, it clearly was beginning to wane near the end.

Many of the factors believed to have caused the Permian–Triassic mass extinctions would also have stressed the Capitan reef complex. Possible causes of the mass extinctions include global warming and climatic instability (Parrish et al. 1986), changes in oceanic salinity (Fisher 1964), widespread anoxia (Wignall and Hallam 1992, 1993), increased volcanism (Yin et al. 1992, Holser and Maragritz 1987), and many others. Unfortunately, the relative timing and magnitude of each of these factors is still far from clear. Sphinctozoan sponges had increased in diversity throughout the Permian, but about 70% of Upper Permian genera had gone extinct by the beginning of the Triassic (Rigby and Senowbari-Daryan 1995). Environmental conditions were undoubtedly deteriorating within the Delaware Basin towards the end of the Guadalupian, stressing the organisms that lived there.

Thus, one can envision for the middle Capitan reef an upper, well-oxygenated, normal salinity water layer populated by a variety of different sponges and other organisms, with a deeper, slightly warmer, slightly more saline, and less oxygenated water mass dominated by *Lemonea*. We suggest that the abundance of *Lemonea* in both low diversity situations and the deeper water in the middle Capitan and in the late Capitan reef, indicate that it thrived in stressed conditions that other sponges could not

Species	LC	MC	UC
Ambithalamia n. sp.	x	x	
Amblysiphonella guadalupensis (Girty 1908a)	x		•
Amblysiphonella cf. *A. Merlai* (Parona 1933)	x		
Amblysiphonella sp. 1		x	
Amblysiphonella sp. 2		x	
Amblysiphonella sp. 3	x		
Amblysiphonella sp. 4		x	
Amblysiphonella sp. 5		x	
Amblysiphonella sp. 6		x	
Amblysiphonella sp. 7		x	
Colospongia americana (Girty 1908b)		•	
Colospongia sp. (Senowbari-Daryan and Rigby 1988)		x	•
Corymbospongia permica (Senowbari-Daryan 1990)			•
Cystothalamia nodulifera (Girty 1908a)		x	•
Cystothalamia ramosa (Senowbari-Daryan and Rigby 1988)			
Cystothalamia sp. (Girty 1908a)		•	
Discosiphonella mammilosa (King 1943)	x	x	•
Girtyocoelia beedei (Girty 1908b)		x	•
Girtyocoelia sp. (Yurewicz 1976)	•		
Guadalupia zitteliana (Girty 1908a)		x	•
Guadalupia explanata (King 1943)	x	•	•
Guadalupia? favosa (Girty 1908a)		•	
Lemonea cylindrica (Girty 1908a)		•	•
Lemonea conica (Senowbari-Daryan 1990)		x	•
Lemonea cf. *L. conica* (Senowbari-Daryan 1990)	x		
Lemonea polysiphonata (Senowbari-Daryan 1990)		x	•
Parauvanella minima (Senowbari-Daryan 1990)		x	•
Parauvanella sp.		x?	
Sollosia ostiolata (Parona 1933)			•
Sollasia? sp. (Girty 1908a)			•
Uvothalamia? sp.		x	
• = found in previous studies; x = found in our study to date			

Table 2. Sphinctozoan sponge taxa recognized from the Capitan Formation. *Amblysiphonella, Discosiphonella,* and *Girtyocoelia* were previously recognized from the middle Capitan by Kirkland et al. (1993) but were not identified to the species level. These authors also first described *Guadalupia zitteliana* from the middle Capitan. *Amblysiphonella, Cytosthalamia, Girtyocoelia,* and *Guadalupia* were previously recognized from the lower, middle and upper Capitan by Yurewicz (1976) but were not identified to the species level.

tolerate. This, in turn, may explain why it is one of the most abundant sponges in Late Permian reefs worldwide.

Conclusions

Our data demonstrate a dramatic drop in sponge diversity within the middle Capitan reef, 15–25 meters below the outer shelf–reef transition, and a fundamental change in rock type from grainy to cement-rich sediments 10–15 meters below this transition. These represent inferred water depths of no more than 25 to 35 meters and 20 to 25 meters, respectively. In contrast to modern reefs, sponge diversity was highest at water depths of less than 25 meters and lowest at depths greater than 25 meters. The sharpness of this change in sponge diversity, occurring over an interval of less than 2 meters, suggests a significant change in the character of the water mass. This change occurs about 5 meters below the shift in depositional character from grainy to cement-rich sediments, indicating that the faunal turnover may not be directly related to changes in the nature of the substrate. Because the Delaware Basin was equatorial, we suspect that a pycnocline (thermocline?) existed, effectively separating the water masses above and below. The water mass below the thermocline could have been slightly warmer, slightly saltier, and/or contained less dissolved oxygen than the surface waters. Given the environmental sensitivity of most reef organisms, any combination of these factors could have been less conducive to the growth of sponges and many other organisms. Such a subtle change in the character of the water masses across the pycnocline could explain the observed drop in sponge diversity. Unfortunately, whatever the cause of the drop in diversity, it was too subtle to leave a direct record in the rocks. As a result, we are forced to make our best guess.

The abundance of *Lemonea* in low diversity settings, both in the deeper (> 25 m) waters of the middle Capitan reef and in the presumably stressed upper Capitan reef, indicates that it could tolerate conditions that other sponges could not. This ability to survive environmental stress gave *Lemonea* an advantage as the reef system began to wane towards the close of Guadalupian time.

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Note: Because the boundaries of the Middle Permian and Guadalupian have been defined and adopted (see Glenister et al. and Lambert et al. in this volume), the editors treat them as formal units. Therefore, the initial letters of the names and modifying words of the period/system (e.g., Middle Permian), epoch/series (e.g., Upper Guadalupian), and stage/age (e.g., Early Capitanian) have been capitalized in this context. Other geologic units in this paper follow the guidelines provided in Hansen, W. R., editor. 1991. Suggestions to authors of the reports of the United States Geological Survey. 7th edition. U.S. Geological Survey, Washington, D.C.

Chapter 34

Application of the Permian Brushy Canyon Formation in Guadalupe Mountains National Park as an Outcrop Analog for Deep-marine Petroleum Reservoirs

MICHAEL H. GARDNER, Ph.D., is a research assistant professor with the Colorado School of Mines. His studies in sequence stratigraphy, sedimentology, and reservoir characterization have seen him as a frequent visitor to the west and south faces of the Guadalupe Mountains.

It's a pleasure to be here, particularly given all of the wonderful resources that the park has provided for the research that we have been doing over the last four years. I must confess to a bit of embarrassment over the clunky title of my talk, and despite the bad grammar I could have just named this talk, "Why Parks Are." Most of us, particularly those of us who are geologists, understand the geologic heritage that many of our national parks have in terms of scenic splendor and the biological and cultural overlays on that geologic framework that results in our recognition of them as special places. Certainly Guadalupe Mountains National Park fits that, and I think of all the parks we have in the National Park System, Guadalupe Mountains National Park best reflects its geologic heritage. The research that has gone on over the last century in the park is recognition that geologists have understood that we are looking at a very special landscape. In fact, it's a very rare circumstance to preserve a landscape that is 250 million years old and to be able to see it essentially in its undeformed state. That is why we see the special attributes that this park has. That is what has led to the voluminous research, particularly with respect to the carbonate reef. This paper will discuss a feature associated with the reef that is sort of its orphaned cousin. Those are the basin deposits that occur below the reef. I'll present not only the results of the research we're doing, but how we're using that information.

Geologists have long come to the Permian reef. In fact, many of our modern carbonate models owe some lineage back to an understanding of the Permian reef system and how carbonate reefs evolve. The use of that information gets lost in the literature in terms of what was the "crystallizing thought" that led to that concept. Was it an outcrop in west Texas that made me realize the stratigraphic relationship in Abu Dhabi? Or alternatively, just an understanding of the reef itself focuses the emphasis on that geographic position of Earth.

I'm in the fourth year of a research consortium at Colorado School of Mines that is funded by a variety of oil companies. What is interesting about our research is that none of it is geared toward exploration and development in the Permian basin. I shouldn't say "none of it"—that's a pretty absolute statement—but I would say the majority of people that are interested in our work are interested in its application as an analog to other outcrops and formations around the world. That provides us with an opportunity, and in fact, is an attribute of parks that is commonly not expressed or appreciated as such. Because of the unique geologic circumstance that created this undeformed 250-million-year-old landscape, we now have an opportunity to go out and look at relationships that we will never see in the subsurface. Petroleum geology is essentially a subterranean endeavor and we are only looking at analog data. There was a

It's a very rare circumstance to preserve a landscape that is 250 million years old and to be able to see it essentially in its undeformed state.

gentleman in the audience at a previous talk who asked, “What are those squiggly lines?” Well, that’s rock in the subsurface. That is how we have to translate the information we see on the surface to make predictions and to try to understand relationships where we have limited data. People come to outcrops to try to acquire visual images of how rocks are arranged and how the architecture produces different kinds of petroleum systems. In our consortium, as I mentioned, the people—I would like to think—are interested in our research. But in reality, the reason why they fund our work is because these rocks arguably represent the most continuous exposure of deep-water deposits in the world. It is because of that this that people come to this park—to look at the geology of these deep-water deposits.

Our emphasis is not so much on finding more oil in the Delaware Basin, but trying to understand why the oil that’s there is where it is.

What I would like to share with you—and this is a pilot run on some new technology—is how we’re taking the results from [our studies in] the park and making that information more accessible to geoscientists around the world who are trying to use our information. The reason why there are so many people interested in these types of deep-water deposits is [because] that is where the petroleum industry has shifted the bulk of their exploration effort today. Just an example to emphasize why we need outcrop information: the last lease sale in the Gulf of Mexico—this is offshore—drilled through 1,500 feet of water to hit earth. Just the right to do that cost $20 million. It costs another $20–$30 million to drill a hole. So these people are making $50 million decisions based on those squiggly little lines. People need to have information about how those rocks are arranged. That is probably the most important aspect of an outcrop.

What we are trying to develop here is not only to study these rocks but come up with methodologies of how to portray the data. What we are trying to develop is what I’m calling this “analog catalog.” What we are really interested in is how these 250-million-year old rocks relate to all the other deep-water rocks that we have around the world. So here you can see superimposed on the modern and ancient submarine fans of the world, the Permian Delaware Basin shown in here. This represents our study area relative to the size and morphology of all the deep marine fans. For example, this dark blue essentially outlines the Bengal and the Indus fans, and then you can see the Amazon and the Mississippi fans. These are the submarine channels that were mapped by Paul Weimer in the Mississippi fan, which our exploration targets for petroleum geologists. What you can see is that relative to the size of submarine fans, the rocks that we have that compose those geomorphic features is a relatively small volume.

What we want to do then is put that into some kind of geographic and geologic context. So here we’re looking at a map. Carlsbad would be at about this position; here’s the Guadalupe Mountains, and this is the outcrop belt of the deep-water deposits, which include the Brushy Canyon, Cherry Canyon, and Bell Canyon formations. They are dipping in this direction, reflecting structural dip into the basin. You can see over here, this green is a position of a stratigraphic cross section taken from the outcrop. Now, in addition to this sort of geomorphology, you can see these splotches of colors out in here. The rocks are dipping to the east into the basin, and these same colors are what are producing oil out here in the basin. These rocks are color coded to these oil fields. That is where the oil that is producing out of these rocks occurs in the basin. As I mentioned, our emphasis is not so much on finding more oil in the Delaware Basin, but trying to understand why the oil that’s there is where it is. The idea is that a geologist would be able to come in, look at an image of a map showing a particular area, and then be able to come in and look at any other kind of visual image of that particular data set. After all, geology is visualization. It’s a visualization science. It’s how we visualize geometric arrangements of rock. So I can look at that in a map, or I might want to come over here and look at that in a cross-section view, and I could come in that cross-section view and look at that cross section. So now, this is a cross section taken from the outcrop. What I can see here is where those oil fields are actually occurring within a volume of rock. Each one of those green boxes represents the main hydrocarbon pools of oil that are trapped within these rocks. We basically then take an essentially 3,000-feet section and hydrate it to those key areas that are controlling the distribution of hydrocarbons within the basin fill. We can then go back to the outcrop and try to understand why these different pools are here, why some of them produce more oil than others, and what controls and strategies as a geologist that I would want to use to try to exploit and maximize that particular resource base.

I might want to come back and just compare that cross section to what I saw on the map. The geologist who is working in the North Sea off the coast of Norway may have an idea and want to see if there is anywhere else in the world where that particular geometry or arrangement or attribute may be expressed. If so, what are the issues I need to be concerned with in terms of verifying or testing that particular hypothesis? This is a way in which we can then visualize the information.

We have been working the entire outcrop belt over this area but this presentation is going to be restricted to the work we have been doing in the national park. If we look at the geologic map of the west face, the different colors show the different layers of rock that basically compose the western escarpment of the Guadalupe Mountains. You can see there are some very different changes, some different color patterns that are occurring on that map that I need to understand. For example, why is there this sudden loss of yellow package at this point here? Or why is the brown package pinching out up here in A? What are those relationships and how am I to try to understand that? I can look at that stratigraphy in map view, and I can look at that information in cross-section view. Here is that same rock looked at in a cross-section slice through Earth's surface. What I can see is that some of those pinch-outs are related to these terminations of the strata against this big edge of the reef, the shelf margin of the Victorio Peak. Furthermore, I can look at that relationship and I can see that the geometry is such that there is a lot of relief on that. These orange patterns are not ubiquitous across the cross section. The yellow patterns, which represent sandstones, appear to be somewhat randomly distributed in space through that. What does all that mean? Well, now I have to come back and I have to interpret this information. This is just based on, if we all go out and we look at the west face—and I will focus on this area right in here—and if I come over to that area, that's what I see. For example, that lower sandstone that was pinching out is replaced by another sandstone that steps up higher, and there is another one offset to the right. What this is or what that cross section is, is just basically an interpretation or a way of visualizing this rock architecture. Now I have to understand this. To do that, let's go back to the geologic map. I have to think about: what does this represent in terms of the depositional patterns that occurred 250 million years ago and also the more recent things that have modified to produce this landscape? The first thing I am concerned about is these pinch-outs and what is controlling the orientation of that pinch-out. We would interpret that to represent a series of submarine canyons that basically are overlaid on that outcrop, so if we superimpose those submarine canyons onto the orientation of the outcrop belt, we now have some kind of understanding of those very strange geometric arrangements. For example, in this particular submarine canyon here's the reef trail, the old shelf margin 250 million years ago. Here are a series of submarine canyons that are incised into that reef. And you can see as we move into the basin, they expand as we move away from the canyon head. Well, this is really important, because what it tells me as a geologist is that as I go along the outcrop in [one] orientation, as [if] I was a Permian grain 250 million years [ago], I'm going basinward. I'm moving into the basin, but I'm doing that in an oblique fashion. The sediment is basically coming one way, and I'm going another way. So I need to understand how that geometric change is going to

The geologist who is working in the North Sea off the coast of Norway may have an idea and want to see if there is anywhere else in the world where that particular geometry or arrangement or attribute may be expressed.

What we were interested in, was if we charged this outcrop with hydrocarbons, how much of it are we going to recover? How is it going to flow? Where are we leaving it behind?

affect my interpretation. For example, the body of knowledge we have on sediment body geometry says that bodies will be oriented in this direction and will be shorter in length in this direction. Well, I can use that as a strategy in how I correlate rocks in the subsurface in my subterranean world. I can take this to another level, because what this tells me is I'm never going to be able to go within the same canyon from the canyon head out into the basin floor. I'm going to be able to go into the basin floor along this outcrop, but I'm going to do it in an oblique way. So as I walk along the outcrop, I am going to be going progressively further into the basin, but I'm going to be doing that in a very nonlinear way. So there is the actual outcrop, there is the Permian overlay onto it, and now we can go back to our cross section and now start to look at these geometric arrangements and try to understand them a little better, in terms of why there is this random distribution. I can go so far as to take those different submarine canyons, which show up here, and now compress them into one to give me a visual image of what it would have looked like if I was a Permian sand grain going from the canyon into the basin. I have taken the information from various locations along the western escarpment of the Guadalupe Mountains, and I have collapsed them into a single canyon slope system to try to get a visual image of what this deep-water environment looked like 250 million years ago. I can go into an area and look at a cross section of what that stratigraphy may have looked like. We can see then, an interpretation for that geometric offset in the types of sandstone piles that apparently were chaotic and random in distribution but now, incorporating a little bit of knowledge based on the geology, I can see that there is actually a pattern. There is a pattern whereby older and lower rocks are replaced by younger and higher rocks in a progressive fashion as they step out into the basin. Well, what does that mean? Again, I can come back to my actual rock data, look at my submarine canyons, get back to my geology, look at it in map view or look at it in cross-section view.

The people who are coming out here may be intrigued by these relationships, but what they're really after is how this relates to the subsurface. One of the things we have been doing at the School of Mines is starting to make outcrop seismic models. This is basically the same image that you have looked at here, but converted to how it looks to a petroleum geologist in the subsurface. If you look at this package of the cross section up in this area, we can come over and query the seismic expression of that, and see that there's this dark zone which is basically amplitude reflection packages that are recording the lithologic change between the sandstone and its encasing deposits. So now a geologist can look at this and say that this was the shelf edge of the Gulf of Mexico, and they're looking at seismic data, because that's all we have in a subsurface, this analog data, with the exception of the core hole. They can look at this geometric arrangement and try to understand how that might occur and to also compare to my own data in terms of whether I am seeing a geologically reasonable relationship. So now I want to go in and I want to study what the architecture of that particular reflection package is. So I can go in, back to my cross section, and now I can come in and look at the details of that sand, which is labeled UB3. Now I am at a different scale. I'm now at a scale where this entire body is only 30 meters thick, as opposed to the last scale, where we were looking at approximately 350 meters of rock. What we can look at here is an example of a three-dimensional architecture of a submarine channel complex. You can see the flow. This is a wrap-around cross section, such that this part of the cross section is this segment; this part of the cross section is this segment, and this part of the cross section is this segment. Flow came in one side and out the other, so it's a true three-dimensional depiction of what the architecture of that body looked like. You can see that we have broken out a variety of units in there that basically we call the building blocks. They are the sediment bodies that are stacking to form that larger architecture. Now, we have studied this at a variety of scales. At that scale we are recognizing and resolving bodies on the order of 5–10 meters. In this scale we're resolving beds that are on the order of 50 centimeters. This is an 896 layer reservoir model that we built for this particular outcrop. What we were interested in, was if we charged this outcrop with hydrocarbons, how much of it are we going to recover? How is it going to flow? Where are we leaving it behind? Those are the decisions that a petroleum geologist has to face with only analog data. This would be an example of what that looked like. You might want to say, well, gee, I don't believe you, Gardner. I want to see your interpretation of that. Okay. We can scroll on and look at the outcrop as we go back along this face. As we scroll along the top here, we are basically going to be moving through the outcrop. There's my first view of what we call the distal strike wall. I can then come over to here. This is how the architecture changes as I move across the face. You can see that there are some fairly dramatic changes. Finally, I end up with this very nice cross-section view of a channel -formed geometry pinching out from right to left across the outcrop, and I want to understand exactly what is controlling that particular relationship. I can come in and I can look at an interpretation of that outcrop. There was the photo, and here's the geologist's interpretation of that relationship; I can go back and actually look at that information in a variety of different ways in addition to the photo. There's the interpretation. Now I can come back and look at the details. Now I've gotten down to the scale of architecture.

Here are those squiggly lines someone was asking about. What we're doing is actually collecting squiggly lines on the outcrop so that they can be translated to the subsurface in addition to the architectural information that exists within this overall package of rocks. Now I mentioned that this was part of a bigger model, and that bigger model is this one. So there's the entire 896 layer model. One of my graduate students, Kyle Johnson, went to work for Shell for the summer and digitized this, built this into a reservoir model from which we did fluid flow models. The main goal was to try to understand how those different colors are affecting the movement of fluids through that rock. Our fluid just happens to be one of economic interest.

The point is that in the outcrop in this case, we have collected this tremendous flow of information. I would like to think that the body of work we have done has contributed to the knowledge of the geology in Guadalupe Mountains National Park. What really makes this useful—because after all, no one wants to do science that no one's going to use—is its application to other places. And that's the uniqueness that geologic parks provide us. They are opportunities to look at snapshots of Earth where we only have a limited number of examples where we can see these kinds of relationships. In this particular body, we interpret this—and you can see these gray mudstones—to represent a channel body that was confined by a slump scar on the slope. We think the slumping was very important in terms of forming this master container that produced this very highly connected architecture. It is important because of when we go to places like the Gulf of Mexico where we have these types of images. We now have to understand how the architecture is controlled. What you're looking at here is a diagram taken from some work that Shell did off of a very recent deep-water deposit in the Gulf of Mexico. What you're looking at is the base of that surface and the top of that surface. This information, which is not very well reproduced here, is the actual seismic that was shot over this site. This is the same kind of geophysical information I was showing you in our outcrop seismic model. What's important about this particular system is that what you see here is this mounded topography. That's what geologists would call a channel levy system. With these mounds being the levies that are confining that channelized depression. This is one of the key phrases that deep-water geologists use in terms of trying to convince their manager to drill a $30-million well. "Oh, I've found the channel levee complex." What's important about that is the present surface morphology of that particular fan. You can see even the effect of the Coriolis,

Geologic parks are opportunities to look at snapshots of Earth where we only have a limited number of examples where we can see these kinds of relationships.

the rotation of the water in your toilet in terms of the asymmetry of the levee height, due to the Coriolis force of Earth's rotation.

What's important is that, although that's the surface expression of it, here is the control. This is why the sand occurs here and not here. There's a container, and that container is a slump scar, and that slump scar is acting to confine that sandstone body, and furthermore, it's focusing sand to sites farther in the basin where I may want to go to find even better and higher volumes of reservoir quality rock. So it's going back to the outcrop: where we can start to see the importance of these types of features, such as slump scars, to help verify these kinds of images. To help validate, to help hypothesize, and to help test the concepts that were coming up from views based entirely on analog data.

I would like to emphasize that although the national parks provide a variety of opportunities for individuals in terms of their enjoyment of the natural environment, and the cultural and biological diversity that is preserved in these unique places, they also provide geologists—and in some cases such as in this park, perhaps the only place in the world where we can look at these kinds of relationships in three dimensions—an opportunity to get a better understanding and to increase our accuracy and our precision in the pursuit of hydrocarbons in other places in the world. That's a value of national parks that geologists certainly appreciate, but I think the general community also needs to appreciate in terms of what these types of areas offer as benefit to all of us.

Chapter 35

Orientation of Synsedimentary Folds in Carbonate Basin and Slope Deposits, Permian Guadalupian Mountains, West Texas

ALTON BROWN, Ph.D., is a research geologist for ARCO Exploration and Production Technology Company. He has worked for ARCO for the past 18 years. He is the author of sections about toe-of-slope carbonate sedimentation near McKittrick Canyon in Permian Reef Geology Trail Guidebook for Guadalupe Mountains National Park. He has recently studied the middle-lower Bell Canyon toe-of-slope deposition.

What we are going to try to do is look at a park that is under utilized. It's strange for me coming from the oil industry, following Mike Gardner. Here he is predominantly doing all this stuff, or to a certain extent, not only for its academic interest but also for application to petroleum geology. What I'll be presenting actually has very little application to petroleum geology. This is true sedimentology. We have talked a little bit about the paleoecological stuff, the stratigraphic value of the national park. What I would like to emphasize is this other aspect, the pure process of sedimentology, how rocks actually get deposited on a very small scale.

What we are going to do today is look at another type of gravity flow deposit in a deep-water basin. These are referred to as slides. What we are going to be looking at predominantly is the Bell Canyon Formation, but we will look at some of the older areas too. What we are going to do is look at the different types of slide deposits that are there, determine the controls on the different types of slides, and finally look specifically toward the tidal area, which is looking at these basal shear zones in these synsedimentary folds. Here we are again with a cross section, which we have seen a number of times before. This is the one I have assembled, and the reason this one is different from the others is because these are actually measured out: elevation is done and corrected for structural deformation, so these are actual real measured surfaces instead of cartoons. Here is the vertical reef face that we heard about a little bit earlier today on sponge growing. Right here is this little inflection. It's probably going to be something close to sea level, somewhere up there, but we are going to be way down here. Now, notice that I put down here that this is the zone of slides we are looking at. All this other area here, which is called a slope, is dominated by other sorts of mechanisms or serves as a bypass for various sorts of sediments as it is careening outward. What we are going to be looking at is what happens here with this change of flow. Now, as a sedimentologist speaking, whenever we see an inflection, like from topset going to slow, that's a major change in geological process. Likewise, we have this other major change here in which we are going from the slope to flat area. So this is another one of these critical interfaces, very much like the reef up here; we really need to understand why this whole pile of sediments is moving in a seaward direction.

Well, the main point we are going to talk about is up here at the Lamar, which is the upper part of the Bell Canyon group. The little red dots here indicate other parts of intervals in which we have seen these soft sediment folds. In addition to these, we also have some type of slide deposits. There are three types: Type 1, 2, and 3. Geologists always like to number things before they actually get to naming them.

What we are going to talk about are various technical terms. I am not going to describe these now; we are just going to take a look at the pictures so we can see them. They have slightly different distribution on the slope. Type 1 is higher up on the slope. These are paleoslope

We really need to understand why this whole pile of sediments is moving in a seaward direction.

angles, starting from as high as 12 degrees down to maybe three degrees. Type 2 picks up somewhere in the three-to-four-degree range, going down to about a one-degree paleoslope. Type 3 gets out here where it's very gentle, less than half a degree. I have not been able to follow it up any shallower than about one-degree paleoslope. We can talk about where the paleoslopes come from.

Type 1. Well, again, as I said, these are steeper dips. Generally, we have throws around 30 to maybe 100 meters or so. There are various types of rocks here, which we will talk about by looking at the photos. Here is an example of one. This is a cliff that occurs on the south side of McKittrick Canyon—everybody has looked at it at various times. This one is actually obliquely done; it's a little bit of a close-up. The interval I like to point out is this very prominent surface, which comes up more or less like so. Notice that beds at the top appear to onlap this. But if you look closely, you will also see that beds below it are truncated at the surface. Now, two things could have happened here. We could have had erosion followed by an onlap-type deposition. But in fact, if you look carefully, you can see that one interval here, the base of this thick bedded unit here, actually corresponds to approximately the surface right there. This is actually behaving like a normal fault. Beds have been offset along this particular surface. Let's take a closer look at the next one up in the section. This is in the cliff at the north side. I didn't climb up the cliff myself; it would be quite an undertaking. Here we see an interval which is about the middle of the Lamar equivalent. Here are turbidites, mostly thin bedded turbidites. Overlying this is a waxy stone, which is equivalent to a carbonate mud, whereas these turbidites are predominantly carbonate sand size material. Up here you can see this very characteristic pinch and swell. This is something that indicates that what's happening is that we are getting thin layers of incipient slumping and sloughing of material down a slope. Because mud slopes generally tend to fail at steeper dips; they tend not to hang around very much.

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Now, the surface in which we are really interested in this type is this surface which comes right down through here. Here is a turbidite bed with a classic sequence. This is a sequence of sedimentary structures geologists recognize, and the whole thing is being cut very nicely at this surface. You can get within an inch of this thing and see no evidence of deformation whatsoever. The reason is because these are sand-sized grains; they don't deform like mud. Also in this surface it's harder to see. Right down here you actually see the exact same thing, in which another bed has been cut and is actually onlapping this surface. So that was our Type 1: no deformation, very plain and flat. This occurs mainly in grain stones.

Type 2. This type is what we refer to as rotational slumps. Instead of having a flat surface, these will have a concave up surface. Now, these occur a little bit lower in paleoslopes, and they occur in mud-rich sediments. In addition to this, we start to see our first evidence of soft sediment deformation; we are going down the slope. Now, this is a little bit hard to see, but this is the exact same cliff on the south side of McKittrick Canyon again. The area we are looking at is where the dips are a little bit steeper. Where we are now is this more gently dipping stuff down toward the base of Lamar, right down through here. This is the underbedded siltstone and limestone through here and this is a very mud-rich interval, which is the lower part of this particular formation. Notice here, you see "funny beds" which are sort of concave upward. If you look at this particular turbidity current deposit right here—I'm sort of tracing it out correctly—you see it actually truncates things. What happened is that this particular interval was an area of rotational slumping, very much like a series of landslides or avalanches, but here it occurred on a mud surface on the bottom of an ocean under about a half a kilometer or so of water. After it happened, turbidites came along and shaved off a little bit of the topography and smoothed it out. This same sort of irregular area extends on beyond the visitor center; it is an area which is sometimes called the mound area on the little cliff in front of the visitor's area and a little bit along the road farther down. Now, if we can't look there, again, we have to go to the other side of the canyon to look in more detail. You can look at this same stratigraphic interval, through which we have measured sections, and see that near the base of these features we are starting to see soft sediment deformation. There is a little recumbent fold. A recumbent fold is a folded rock which is sort of on its side; it's recumbent, it's lying down. Just for a little nomenclature, this is called the fold axial plane, where we sort of connect the bits at the highest kinkiness, and the fold axis is actually the line which goes along the folds parallel to that little bit there that is most kinked. This again is a laminated mud-rich rock, and that's the reason it deforms like this.

Type 3. We see abundant evidence of soft sediment deformation, and these occur predominantly in mud-rich sediments. Type 3 also has a plainer translational glide. It is a very, very flat surface. But here, let's take a look at an example of one of these. Again, this is from a road cut somewhere outside the park, so we are not supposed to talk about it very much. This is the old road cut. But this is just too great to miss. Look down here. Here's the fold; everybody can see this fold, right? Now, this is recumbent again because the axial plane is nearly flat, right? There's the fold axis right there, and we will talk about more of that later. But notice that the rocks that are overlying it are flat. I didn't go quite far enough to show that. This little fold here bends up, but the bed immediately above it just keeps going on and on. Look down here. I think you can see it again. Here beds are flat lying; here they are folded. There's a fold there, and a fold there. Now, the only way geologically you can do this is if you have a surface of dislocation, which we call a décollement surface. It's a French term. And that décollement surface runs right down here and the upper one runs right like so. So we have a zone between two layers in which we have something like a fault that's almost flat, and in between all the sediment is smooshed up and screwed around. What's happening here is we are getting at a very low degree dip, less than a degree dip, very far down on the slope, in which we are getting this messed deformation through here in an otherwise flat bedded unit.

Now, let's talk a little bit about what exactly is causing the different types of deformation fabrics and types of slides. The easiest way to see this is by comparing the paleoslope vs. the sediment type. Paleoslope go from steep-to-intermediate-to very-gentle, and sediments go from muddy-to-grainy. Now, if we start off at the steep dips, where we have muddy sediments, we see this pinch and swell boudinage type fabric, remember? Because we are starting to get these little tiny sloughs coming down the hill. On the other hand, where we have grain deposits, we get these big, flat translational surfaces. Why is this? Grainy bodies tend to be a lot more stable on steep slopes, so they don't deform the same way, but every once in a while they do fail, but as a big, flat surface.

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Now, on the intermediate slopes, we also have muddy deposits, and here we tend to get rotational slumps. Why is this? This slope is so steep that instead of forming a big, long continuous area, it just wants to slough out on top of itself, and as a result we get a lot of deformation associated with this rotational behavior. Notice in this intermediate area in the grainy strata, we see no apparent slumps. The reason is because at these slope angles, the grainy deposits are perfectly happy to stay where they are. They are not moving by these grainy deposits. Now, whenever we get to the very gentle part that's out in the basin, we have again these flat surfaces, the Type 3, but again, we are getting a lot of sediment deformation and likewise as before, with the thin grainy beds out there we see no evidence of deformation. Now, let's talk a little bit about deformation types and then we will get to the orientation part, which I think is very interesting.

First, at the rotational slumps, we have various sorts of mud and remolded sediments. These are all deformed and redone. We have some disorganized soft sediment folding but also we see that

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concentration of deformation occurs mainly on the low angle part, so for example, if we are going out again to look at the steep dipping part along the drive to the visitor center, we don't see deformation there, we see it at the bottom part, where it tends to flatten out. Now, a translational glide is what we saw up on the slope. We had the grainy fabrics with almost no deformation at all. That would be very hard to identify unless we have a really excellent outcrop, as we do here in McKittrick Canyon. Where we do see these things, they are referred to as a basal shear zones. This develops in muddy fabrics. This particular fabric is predominantly dominated by recumbent folds and very commonly we have at least one, and usually two, décollement surfaces and sometimes even more than this within it.

So, now let's talk a little bit about orientation of these folds. I will finally give you the title of it, and this is what I spent most of my time on, on the poster and the other presentation. Basically, we have a very unique situation. That is the fact that we have an extremely well-constrained paleoslope. This reef was exposed a long distance. We have a slope strata through here, so we know which way is down dip during deposition, and that's toward the base and all those arrows pointing through there. Well, it turns out that this allows us to do very accurate comparisons between various paleoslope indicators, which we can see on an outcrop scale, compared to the real paleoslope we know is there. So we can double check and make sure that the things we think are playing downslope really do indeed point downslope.

Okay, the other thing I should point out here is that here I think we really do tend to have a slope apron at the time of Lamar deposition rather than the channel system, so we really do have a constant slope of this area. And, of course, relatively undefined sections we all know. Now I'm pointing out this other soft sediment recumbent fold from down the outcrop, only this one is messed up just a bit more, and you can think about this for your amusement and entertainment, but let me just show you what's happening through here. You have folds that come around like so; here's another one that comes around like so, bend up like so and comes back down like this. These are refolded recumbent folds, but they are called coaxially deformed, meaning they are folded around the same fold axis. Now, if we were to go through here and measure all these orientations, all the fold axes are still pointing the same direction. And what direction is that? Well, here we see it. This particular old bar diagrams is called a rose diagram; what this shows is the orientation of the various fold axes. Now, north is that way, of course, and south is down here. This dashed line here is basically the strike of the Tansill shelf edge as defined by the outcropping reef. Here is the orientation of the axis. It's symmetric because we don't know whether it's pointing up or down. Notice that the axis is almost perpendicular to the shelf edge.

Now many people imagine a landslide or things like this as being some big bulldozer pushing down, and as a result of this, you expect sediments to sort of pile up in front and form an axis that's more or less parallel to the strike instead of parallel to the dips. The question is: how do we get these things pointed in a down-dip direction? The answer required coming back to look at these sediment fabrics. This is something that is called progressive deformation. This is where a rock has not just a single period of folding but continues to be folded through some geologic period of time that may be short or may be long, but as a result it has a strained history. What happens in this case is one initially forms what is referred to a buckle fold, which is the bulldozer-type effect in which we get things parallel to the strike, but as we continue to deform, various parts move down the slope faster than others, because of these décollement surfaces, and as a result, the fold gets rotated into a down-dip direction, and the fold axis goes from a more vertical position to a flat position. This is called progressive deformation, and as a result of this, we rotate the axes around so that they are now pointed in a downslope direction at the same time that the axial planes go from almost vertical to flat. So, basically this is something that is different from things that have happened in the past. In the past, structural geologists have gone to these hugely deformed areas at continental margins, trying to guess which way the fold axes are telling them the paleoslope is. They don't have an independent way of telling it, so as a result there is quite a bit of literature, but most commonly we think about this bulldozing argument up through here. However, here we clearly have this paleo dip orientation. And the answer actually was already worked out some time back—I didn't realize this until after I got fairly far along here. These guys didn't know the exact slope, either, but they recognized the fact that we had progressive deformation. Basically, here we have the same argument again, and this basically proves it. Here we have a case where we can actually document this process occurring.

So to conclude, basically the study here demonstrates this particular model, a Ferrell and Eaton 1987 model. It really does work. We see progressive deformation; we can prove it here because we know the paleoslope orientation. We also can demonstrate here that the slide type is controlled by both paleoslope and sediment type. There has been a lot of discussion about what actually controls different deformation mechanisms. The other thing we can say here is that basically the slide type also controls the type of deformation we see associated with these soft sediment things; in particular, the concept of the basal décollement developing with an upper and lower décollement surface, so we can have this sort of rotation of slides into downslope directions.

Finally, of course, I would like to finish by acknowledging the National Park Service for allowing me to look at their rocks. I should say that no rocks were harmed during the purpose of this particular operation. This is one which doesn't appear on your records because no samples were collected.

Chapter 36

Lacustrine Paleoenvironments in the Trans-Pecos Closed Basin

DAVID E. WILKINS, Ph.D., is a post graduate instructor with the University of Utah, Department of Geography. He is currently researching the late Quaternary paleoenvironments of the Trans-Pecos.
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Introduction
The last glacial maximum (LGM) in the intermountain western North America was a period of cooler temperatures and increased effective moisture and runoff; these cooler, mesic (so-called pluvial) conditions were accompanied by the formation of lakes in what Currey (1994a) terms "hemiarid lake basins." He defines these lake basins as being both topographically and hydrographically closed, with tributary areas being in a water- surplus state in the basin high-lands and in a water- deficit state in the basin lowlands. Within each basin, the boundary between zones of water surplus and zones of water deficit is what Currey (1994b) calls the hydroclimate equilibrium line altitude (HELA). For lakes to form and persist in these basins, the cumulative annual water budget must be positive, such that precipitation must be greater than or equal to potential evapotranspiration.

This paper presents and examines the geomorphic and sedimentary evidence of late Pleistocene paleolakes in the Trans-Pecos closed basin and the implications of the timing and duration of these lakes during the LGM.

Paleolake studies: western North America
Reconstructions of late Quaternary climates in the intermountain region of western North America are based on the interpretation of a spatial and temporal aggregation of proxy evidence and morphometric (e.g., hydrometric, limnometric, glaciometric) data. Evidence for the presence of contemporaneous permanent or persistent (102 to 103 year duration) lakes over a wide range of latitudes and elevations (e.g., paleolakes Bonneville and Lahontan) (Benson et al. 1990) and under different basin configurations with respect to tributary characteristics or catchment geometry (Currey 1991, Enzel et al. 1992), allows for a generalization of climate conditions at a broad spatial and temporal resolution. However, this same evidence shows that late Quaternary climates in the region were not homogeneous, but demonstrated a spatial heterogeneity influenced by local responses to broad climate forcing (Mock and Bartlein 1995); this spatial heterogeneity reflects the geographic factors (e.g., latitudinal extent and topographic range) that influence the temporal and spatial variability in a palaeolake basin's response to climate change.

Hemiarid basins that are situated along a climate boundary zone or threshold, separating states of hydroclimatic equilibria, exhibit more dramatic response to changes in hydroclimatic variables than basins situated away from the climate boundary. It is the capability of these basins to change rapidly between equilibrium states, in response to changes in basin conditions that favor their utility as potential high-resolution records of abrupt climate change.

Trans-Pecos closed basin: environmental setting
The Trans-Pecos closed basin is an internally drained, hydrographically closed region bounded by the Guadalupe and Delaware mountains to the east and the

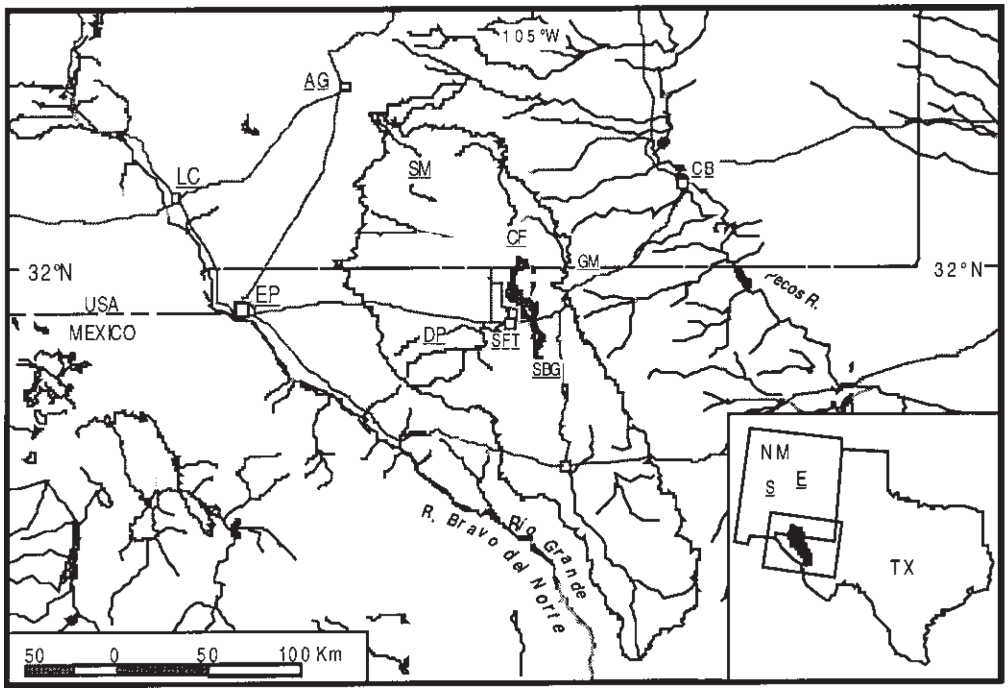

Figure 1. Trans-Pecos closed basin regional setting. Underlined abbreviations refer to toponyms: EP = El Paso, SM = Sacramento Mountains, AG = Alamogordo, LC = Las Cruces, CF = Crow Flats, GM = Guadalupe Mountains, DP = Diablo Plateau, SFT = Salt Flat, SBG = Salt Basin Graben, CB = Carlsbad, S = Lake San Agustin, E =Lake Estancia. From Wilkins 1997.

Diablo Plateau to the west in far west Texas and south central New Mexico (Figure 1). It encloses over 22,000 square kilometers in Texas and New Mexico and includes the western portion of Guadalupe Mountains National Park. Elevations range from 2,918 meters on Sacramento Peak, New Mexico, to 1,087 meters at the deepest point in Salt Basin, a northwest-southeast trending half-graben located approximately 160 kilometers east of El Paso.

Modern climates and biomes in the study area vary from arid upper Chihuahuan desertscrub at lower elevations to humid, mixed conifer forests (*Pinus-Picea-Abies* sp.) at higher elevations (Tuan et al. 1973, Van Devender et al. 1984). Temperatures at Salt Flat, Texas, located near the floor of Salt Basin (elevation 1,100 m), range from warmest-month mean of 27°C in June and July to a coolest-month mean of 6°C in January, with a mean annual temperature of 17°C (Griffiths and Bryan 1987). Mean annual temperatures at higher elevations in the Sacramento Mountains are estimated to be approximately 5°C based on local climate data applied to a mean annual environmental temperature lapse rate of 7.2°C/1,000 meters (Van Devender et al. 1984).

Average annual precipitation totals range from 280 millimeters at Salt Flat to more than 760 millimeters at Sacramento Peak in a summer maximum precipitation regime (Tuan et al. 1973). Mayer and Sharp (1998) show precipitation has a strong dependence on elevation in the basin. High magnitude storms sometimes result in shallow flooding of portions of the floor of Salt Basin; these inundations seldom persist for more than a few weeks under the high modern evaporation rates, estimated to average between 175 and 200 centimeters per year on the basin floor (Bjorklund 1957, Kohler et al. 1959).

Four major (i.e., > about 1,500 km^2) and numerous minor catchments direct runoff into what was the inundated area of Salt Basin (Figure 2). Analysis of catchment parameters by Wilkins (1997) reveals that the five largest catchments are very similar, and mean elevation is the characteristic best used to distinguish between catchments. Using this param-

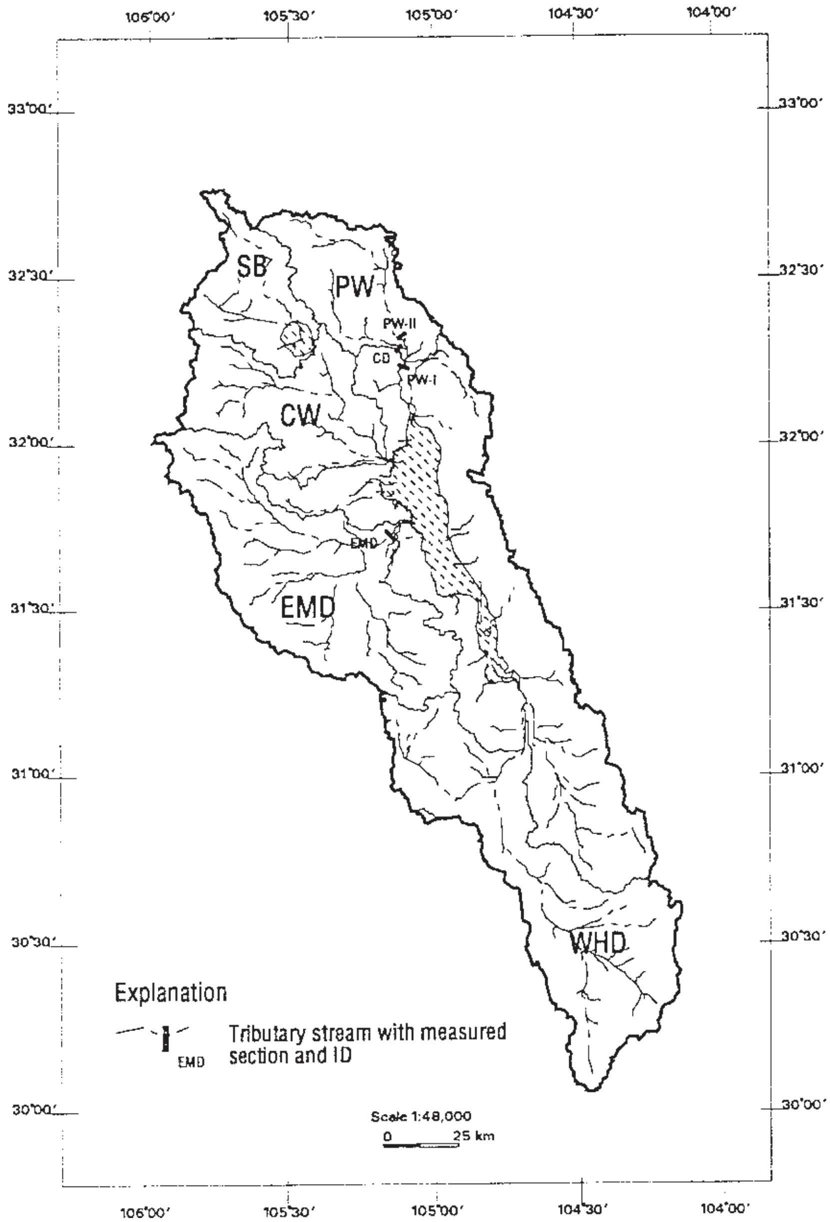

Figure 2. Catchment boundaries for the five largest catchments in the Trans-Pecos closed basin. Catchments are identified by their initials: EMD = Eight Mile Draw, CW = Cornudas Wash, SB = Sacramento River Basin, PW = Piñon Wash, WHD = Wild Horse Draw. Hachured polygons represent the maximum extent of paleolakes in the basin. Produced from USGS 1:250,000 digital elevation model data.

eter, the catchments are categorized as belonging to one of two hydroclimatic regions: a northern highland catchment region (mean elevation > 1,600 meters) or a southern lowland catchment region (mean elevation < 1,600 m) (Wilkins 1997).

The Sacramento River system terminates in a nested closed basin with a local base level elevation 200 meters above the floor of Salt Basin. There is no evidence of channel incision, indicating overflow, at the subbasin threshold, so any runoff generated by this catchment is contained within its boundaries and either lost to evapotranspiration or transferred through the groundwater system into the floor of Salt Basin (Wilkins 1997).

No perennial surface water reaches the floor of Salt Basin graben, but the graben does receive significant groundwater contributions from the Permian Bone Spring Limestone underlying the Sacramento and Guadalupe mountains

(Bjorklund 1957, Boyd and Kreitler 1986, Mayer and Sharp 1998). Sediment sequences filling the graben culminate in modern playa evaporites, indicating hydrographic closure. Groundwater levels in the Crow Flats area (Figure 1), near the northern end of the graben, are very close to or at the surface of the playas and include contributions from both valley fill alluvium and Bone Spring Limestone (Bjorklund 1957). Expressions of surface water interception are visible as depressions and sinks on the Diablo Plateau to the west and the Sacramento Uplands and the Crow Flats areas to the north. Modern groundwater discharge from the Bone Spring Limestone into the Salt Basin alluvium is probably less than 100,000 acre feet (2,800 m^3) per year, roughly equal to the modern recharge (Bjorklund 1957).

Trans-Pecos closed basin: LGM paleolake record

The Trans-Pecos closed basin contained deep lakes at various times during the LGM, much like other hemiarid basins in western North America. The basin terminus, Salt Basin, was the site of Lake King, the name given to the succession of lakes that formed during the late Pleistocene (Miller 1981). The descriptor "deep" (i.e., depth > 2 m) is used here relative to the long-term range of lake depths in this particular lake basin.

Paleochannels, shorelines, and laminated sediments are evidence of periods of increased effective moisture in the region. The laminated sediments are visible in erosional remnants of breached lake floor sediments (locally known as "islands") interspersed between the evaporite-encrusted playas that occupy the modern Salt Basin. Fragments of shorelines from Lake King are preserved around the periphery of Salt Basin positioned 8 to 14 meters above the modern basin floor (average elevation 1,100 m). Depositional shorelines have been identified for both Lake King (i.e., Salt Basin) and Lake Sacramento (Figure 2) (Wilkins and Currey 1997).

Wilkins and Currey (1997) develop a model limnograph for Lake King (Figure 3), inferring changes in lake surface elevations from changes observed in the sedimentary record. Maximum elevations of the model hydrograph lake cycles are reconstructed from the paleolake geomorphic record taking into consideration the elevation, superposition, and relative preservation of depositional shoreline segments (Currey 1994, Sack 1995).

In the Lake King model, transgressive and regressive phases of paleolakes are reconstructed from sequences of contrasting sedimentary environments ob-

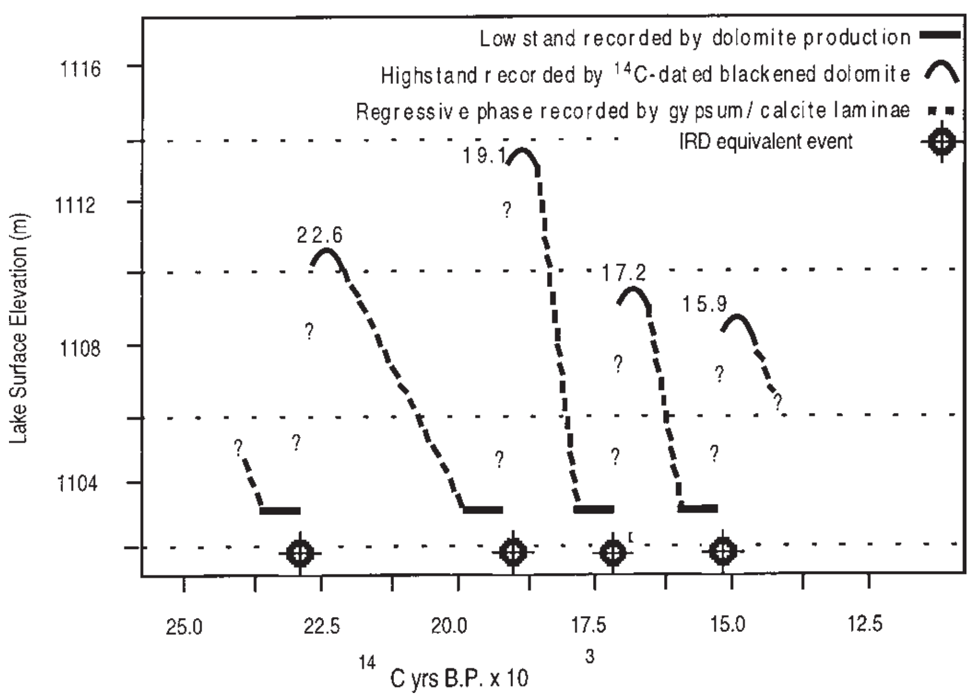

Figure 3. Lake King model hydrograph denoting shifts between states of basin hydroclimatic equilibria, with respect to time and North Atlantic IRD events (Bond and Lotti 1995, Wilkins and Currey 1997).

served in the lacustrine stratigraphy. Lacustrine lowstands, represented by "troughs" in the model limnograph, were accompanied by higher rates of evaporation and an increasing magnesium:calcium ratio in lake waters that resulted in the deposition of dolomitic sediment layers (Friedman 1966). Climate changes marking the onset of mesic LGM conditions were accompanied by increased inflows of fresh water and rapidly rising lake levels. Stratification of the limnia through rapid freshening and deepening of the water column was accompanied by formation of anoxic bottom conditions. Subsequent anaerobic bacterial decomposition of iron oxides within the dolomitic layers resulted in Fe_2S darkening of the dolomite, creating the characteristic "black mats" (Wilkins and Currey 1997). Samples of the organic material found in these sediments have been radiocarbon-dated (Figure 3) (Wilkins and Currey 1997), providing ages for four abrupt climate changes during the LGM. Locally, an apparent uncomformity between the oldest and the youngest black mat is evidenced by their close stratigraphic proximity (4 cm). This suggests Lake King underwent at least one phase of complete desiccation or subaerial exposure accompanied by erosion of lacustrine sediments.

The sharp contacts between the dolomite layers and the overlying sediments suggest that the onset of mesic conditions were abrupt. After conditions supporting lacustrine environments were reestablished, lakes are thought to have reached their maximum elevation early in their cycles, as indicated by the "peaks" in the limnograph. During these cycles, lakes were maintained in a quasi-steady state of annually fluctuating water levels and chemistry that are represented by varve-like evaporite couplets of organic-rich calcite layers alternating with gypsum-dominated sediment layers. The calcite layers are interpreted as annual cycles of seasonal increases in calcium, total alkalinity ($HCO_3^- + CO_3^{2-}$), organic matter, and pH driven by early season runoff. Late season lake evaporation resulted in depletion of total alkalinity levels (with respect to SO_4^{2-}) and precipitation and deposition dominated by gypsum (Wilkins and Currey 1997).

Examination of playa floor exposures revealed packages of more than 100 of these couplets, giving an indication of the duration of these lakes. The absence of codepositional disturbance in the couplets indicates that they were deposited and buried in deep water, low energy conditions; absence of in situ postdepositional disturbance of the couplets through displacive transformation of evaporites implies that the couplets were buried sufficiently deep as to preclude this. The number of seasonal cycles in the packages of sediments suggests that the return to moisture-deficit conditions was gradual, culminating in high rates of evaporation from shallow bodies of water that resulted in the formation of the dolomite.

Trans-Pecos hydroclimates: factors and responses

Mifflin and Wheat (1979) infer dual hydroclimates for hemiarid basins in Nevada, similar to the one reconstructed here for the Trans-Pecos basin, basing their results on mean annual temperature and precipitation trends at several climate stations. Their data indicate that stations at higher elevations (with correspondingly cooler temperatures) have significantly greater precipitation than the intermediate and lower elevation sites; the analogy is the upper elevation sites represent tributary conditions and the lower sites represent lake conditions. Isohyetographs of New Mexico and Texas support a similar relationship in the Trans-Pecos region (e.g., Tuan et al. 1973).

The patterns in the model limnograph for Lake King suggest that runoff from the catchments to the inundated area were HELA-controlled; that is, a catchment's ability to contribute to the inundated area of the basin varied with the position of the HELA. Highstands occurred only when conditions improved such that the HELA lowered sufficiently in order to include the larger, but lower elevation, catchments, resulting in increased runoff and higher magnitude stream discharge to the terminus. This model is supported in part by the absence of well-developed channels terminating at the level of the modern playa. The channel systems for Eight Mile Draw and Cornudas Wash both terminate near the elevation of the Lake King maximum highstand, suggesting a correlation between improved hydroclimatic conditions in those catchments and increases in lake surface elevation.

Climatic conditions in the Trans-Pecos closed basin during the LGM are reconstructed for this study by extending the findings of other researchers in the region. A study of periglacial features (Blagbrough 1991) in the Capitan Mountains of New Mexico (33.75°N, 105°W) places the LGM elevation limit of permafrost (MAT 0°C) at approximately 2,440 meters. Taking this as the permafrost isotherm surface altitude (PISA), and applying Péwé's (1983) temperature gradient (80 m/1° latitude) places the PISA at approximately 2,520 meters in the Sacramento Mountains (summit 2,918 m) and 2,580 meters in the Guadalupe Mountains (summit 2,667 m) 45 minutes latitudinally south of the Sacramento Mountains; using these parameters, the Guadalupe Mountains would have been the southern limit of alpine permafrost in western North America. Assuming the mean annual environmental lapse rate of 7.2°C/1,000 meters in the adjacent Otero basin to the northwest (Van Devender et al. 1984), the mean annual temperature at Salt Flat, Texas, (elevation 1,185 m) would have been lowered to approximately 10°C, roughly equivalent to modern conditions in the Sacramento highlands to the north.

Temperature, among other variables, is a major factor influencing rates of evaporation from open water surfaces (e.g., Tuan et al. 1973, Mather 1985). Other studies on climate factors affecting lake level variations (e.g., Mifflin and Wheat 1979, Benson 1981, Hostetler and Benson 1990) also recognize the importance of this relationship, using it to minimize the importance of increased precipitation as a factor in the persistence, if not formation, of lakes in the Great Basin during the LGM. Street-Perrott and others (1989) present a similar argument that even without a significant increase in precipitation, higher lake levels could have been favored by increased cloud cover and cooler temperatures in the summer season (i.e., period of greatest evaporation).

The impact that cooler LGM climates had on precipitation and runoff is uncertain. It is probable that snow cover in the basin highlands would have persisted into, and possibly through, the summer at the highest elevations, thereby extending runoff from those areas. Another result of lower temperatures would have been to reduce the importance of evaporation as a limiting factor, or hydroclimatic threshold, in generating runoff: with lower background evaporation rates, the position of the HELA surface would then have become precipitation limited. Increases in cloud cover and accompanying precipitation would have been dependent on timing, sources, and direction of flow of atmospheric moisture.

LGM teleconnections

Climate simulations of North America during the LGM show that the areal extent and height of the Laurentide Ice Sheet split the 500-mb polar jet stream into a northern, polar branch and a southern branch (Kutzbach et al. 1993). A high pressure cell and the accompanying anticyclonic flow originating from the ice sheet displaced the southerly branch of the jet by as much as 6° to 20° equatorward; modern mean winter position of the polar jet along the west coast is 42°N and summer position is 58°N (Street-Perrott et al. 1989, Hostetler and Benson 1990). This displacement brought increased winter precipitation, with estimates ranging from +5 to +35 percent (Dawson 1992), to intermountain western and southwestern North America. This increased winter precipitation, coupled with increased summer cloud cover, reducing local evaporation while increasing effective moisture (Hostetler and Benson 1990), corresponds well with the LGM high lake levels in the Great Basin (Mifflin and Wheat 1979).

The position of the LGM subpolar winter storm track, with the accompanying moisture enhancing and energy-reducing cloud cover it provided, was critical as it provided the increased moisture required to initiate lake cycles in western North American hemiarid basins.

Locations of prevailing LGM winter storm tracks (i.e., CCM January) at the longitude of the Trans-Pecos region are poorly constrained, a result of the coarse resolution of the climate models. Evidence presented in this paper, however, indicates that the tracks remained to the north of the region. Allen and Anderson (1993) invoke an equatorward shift to place the storm track over the Lake Estancia basin (35°N, 106°W) at 19,770±160 radiocarbon-years-before-present (^{14}C yr BP), and again at 13,700±105 ^{14}C yr BP, to explain the high lake levels that formed abruptly in that basin. Rapid freshening events similar in amplitude and corresponding to the Lake King highstands (within the 1-sigma error of the black mat ^{14}C dates) also have been identified by Phillips and others (1992) in the Lake San Agustin basin (34°N, 108°W).

The mechanism most likely to have driven these changes in the position of the storm track was a periodic strengthening of the Laurentide high pressure cell. Under this model synoptic pattern, the resulting increase in anticyclonic wind flow would have displaced the storm tracks equatorward from their intraglacial mean positions as far south as the New Mexico and Texas (low latitude) lake basins.

The timing of these episodes of latitudinal shifts in the storm tracks corresponds to periods of cooling in the North Atlantic marine and Greenland ice records (Bond and Lotti 1995). Mikoljewicz and others (1997) report similar conditions have been modeled for the North Pacific Ocean, suggesting that the effects of the North Atlantic–North Pacific teleconnections may extend into western North America. Most studies of these northern-hemisphere cooling events focus on the marine or Greenland ice records. Ongoing studies are searching terrestrial records for indications of these events as evidence of their global impact (Broecker 1995). Phillips and others (1994) raise the question as to a causal relationship between fluctuating Greenland ice temperatures and expansion and contraction of Searles Lake (36°N, 117°W), suggesting that six lowstands between 33,600 and 26,100 ^{14}C yr BP were synchronous with Greenland interstadial episodes. Oviatt (1997) notes a similar relationship between the onset of North Atlantic warming and five regressive oscillations in Lake Bonneville (41°N, 113°W) between 21,000 and 13,000 ^{14}C yr BP. In both cases, a teleconnection is implied between changing paleolake levels and changes in temperatures over the continental ice sheets; this suggests that the mean positions of the winter storm tracks over western North America ranged between more southern positions during cooling events to more northern positions as temperatures over the continental ice sheets rose.

The timing of the onset of lake cycles in Lake King corresponds well, but not perfectly, to those cooling events and highstands identified in paleolakes San Agustin (fig. 35 in Phillips et al. 1992) and Estancia (Allen and Anderson 1995); discrepancies between the reported timing of these events in Lake King and New Mexican hemiarid basins result from the expected lag effects produced by differences in latitude as the mean storm track shifted. That the onset of transgressive events corresponds with the latter stages of the North Atlantic cooling events, coupled with the short tenure of these lake cycles, implies that full pluvial conditions in the basin were restricted to only the most extreme equatorward shift in the storm track.

Summary and discussion

The record of lake cycles in the Trans-Pecos closed basin indicates that conditions favoring formation of deep-water lakes varied with time. The formation of Lake King seems to have been a result of the basin to generate sufficient runoff;

persistence of lake cycles benefited from, first, lower temperatures and evaporation rates and second the ability of the Sacramento Mountains (northern basin highlands) to generate runoff for the Sacramento River–Lake Sacramento and Piñon Wash systems, which operated as groundwater transfer nodes to Salt Basin.

Water transferred in this fashion is protected from the evapotranspiration that limits catchment contribution to the inundated area of the terminal basin (Langbein 1949). Analogous to a leaky toilet, the superelevated (with respect to the terminal basin floor) piezometric surface resulting from groundwater discharging into Salt Basin (the bowl) sustained in large part by the influent discharge from the Sacramento subbasin (the tank), reduced lake area variability for Lake King and, benefiting from lower evaporation rates, was able to support small, shallow lakes between highstands.

Hydrologic analysis of the five largest tributaries, including the Sacramento River and Piñon Wash systems, reveal no major differences in catchment parameters save for area and range of elevations. Absence of continuous lacustrine sedimentary records indicates that the tributaries were ineffectual in generating prolonged and sustained runoff and discharge into the inundated area. This implies that the mean lower position of the HELA was limited by precipitation to an elevation somewhere above the runoff generating hydroclimatic threshold area; as hydroclimatic conditions improved (i.e., as available moisture increased), the HELA descended until the area contributing runoff (that area above the HELA) reached that threshold.

The term "quasi-pluvial" is used here to describe hydroclimatic conditions in hemiarid basins—where background evaporation rates were low as a result of lower LGM temperatures yet long-sustained surface-water runoff contributions persisting on a time scale of 100 to 1,000 years (Currey 1994b), were absent or discharge volumes were insignificant in terms of impacting palaeolake volume. Background LGM rates of evapotranspiration were low and relatively time invariant, but availability of moisture at levels great enough to generate runoff was a function of extrinsic hydroclimatic factors other than temperature. Only when those factors were favorable did moisture availability in the basin increase to a level that resulted in rising lake events; this episodic modulation of moisture availability in hemiarid basins provides the rationale behind the description of quasi-pluvial.

During the LGM, moisture was supplied to western North American hemiarid basins by winter storm tracks that were positioned several degrees south of modern position. The variability of available moisture in those basins was a function of latitude; basins farther north benefited from a more reliable source and amount of moisture, a factor reflected in higher pluvial hydrologic index values (e.g., Mifflin and Wheat 1979). Basins such as the Trans-Pecos closed basin at the extreme southern range of the storm track lacked this constancy, and the lacustrine sedimentary record reflects this.

Much like the polar ice record in Greenland that provides a record of rapid climate shifts—acting as what Taylor et al. (1993) term a "flickering switch"—the lacustrine sedimentary record provided by these storm-track margin basins may reveal the effects of what have been largely described as high latitude climatic events. Abrupt climate changes that led to equatorward shifts in the storm tracks are recorded in the lacustrine sedimentary records along meridional alignments of quasi-pluvial paleolake basins. As data on lake cycles are refined, these wide-ranging arrays of lake basins may prove useful as long transects of paleoclimate-change records, with distance of the basin from mean storm track positions and persistence of lake cycles interpreted as measures of global climate change intensity.

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Chapter 37

Fossil Assemblages of Mollusks as Indicators of Past Communities in the Guadalupe Mountains, Culberson County, Texas

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Introduction
Environmental changes in North America from the Pleistocene to the present have affected the extent and composition of communities. Within the Guadalupe Mountains, evidence of environmental change has come from studies of mammal remains from cave deposits, pollen profiles, and plant macrofossils from packrat middens (Van Devender, Spaulding, and Phillips 1979). Perhaps the most useful or direct evidence of plant community change has come from studies of packrat middens. The middens are created by the activities of woodrats (*Neotoma* sp.) and contain plant remains from the immediate vicinity of the nest, which are cemented together by urine and preserved in arid environments by drying. Such deposits are easily dated by radiocarbon methods. Packrat midden studies may be limited by scarcity or absence of rock outcrops with dry fissures conducive to midden preservation. Such outcrops are lacking on lower mountain slopes in the Guadalupe Mountains. Reconstruction of past plant community changes on such slopes have to be inferred using models of life zone depressions or from other indirect lines of evidence. Assemblages of fossil mollusks offer one such line of evidence that can be used to interpret past changes.

Mollusk shells preserve well in sediments, especially those derived from limestone substrates. In the Franklin Mountains fossil assemblages have been recovered from buried talus or colluvium that has been exposed by arroyo cutting as well as from soil accumulations (Metcalf and Johnson 1971, Worthington and Metcalf 1998). Metcalf and Fullington (1976) listed species in a fossil assemblage occurring in Pine Spring Canyon as the type locality of *Ashmunella nana*. Shells have generally been destroyed in fluviatile sediments deposited by currents of sufficient strength to transport gravel. Herein we report on two mollusk assemblages from shallow soil accumulations on the bajada on the east side of the Guadalupe Mountains where studies of middens, pollen, and faunal remains have not been done.

Methods
Two assemblages of mollusks were collected near Frijole Ranch in Guadalupe Mountains National Park at 1,667 meters elevation. The first was collected about 100 meters southwest of the ranch house from a road cut near the parking area. From 11 to 12 kilograms of soil substrate at one-meter depth, 466 shells of 11 species were collected (Table 1, Site 1). The second assemblage was recovered from drift deposited on the hiking trail 75 meters north of the ranch house. From two business envelopes full of drift material, more than 200 shells comprising 19 species were obtained (Table 1, Site 2). The small arroyo was explored to locate the source of the shells. It was determined that the shells came from within 100 meters of the trail where the arroyo had cut 1.0–1.5 meters into soil substrate. The arroyo was found not to originate from the roughland higher elevations of the mountains some distance farther to

the west, so that drift shells clearly seem to be of very local provenance. Shells were separated and identified in the laboratory and organized into collections of the Laboratory for Environmental Biology at the University of Texas at El Paso and of Guadalupe Mountains National Park.

Discussion

The present habitat around Frijole Ranch is an open juniper woodland and grassland (Genoways et al. 1979). This is in the upper Sonoran zone, which is known to be relatively depauperate of snails (Metcalf and Smartt 1997). Only *Gastrocopta pellucida* is known for certain to live in the area today, but other species are expected including *Hawaiia minuscula*, *Glyphyalinia indentata*, *Helicodiscus singleyanus* and *Thysanophora hornii*. The fossil assemblages are rich in species, many of which seemingly cannot survive in the area today. Assemblages of mollusks contain species with different ecological amplitudes.

Information about the present distributions of the species in the Guadalupe Mountains that were also found in the fossil assemblages is included in Table 1, and is from the work of Fullington (1979). It is clear that many of the species found as fossils survive today only at considerably higher elevations. Others are more generally distributed, reaching lower elevations. Interpretations of such fossil assemblages generally focus on where one would have to go today to find the most species shared with a fossil assemblage of interest. One can then infer from the extant habitat what the past environment might have been like. Problems that hamper such interpretations include the lack of radiocarbon datable organic matter, possibility of import from other habitats, and confounding effects of suitable microhabitats. The age of the fossil assemblages treated here is not known. Sediments at Site 1 represent a shorter interval of time than those at Site 2, the latter spanning up to 1.5 meters of soil accumulation, and obviously including some Holocene material along with that from older, Pleistocene sediments. The fauna seems to have lived at a time when the environment was cooler and wetter. This strongly suggests a time in the late Pleistocene, although Site 2 also seems to include shells from Holocene sediments. Evidence that the assemblages are not of greater

Table 1. Gastropods recovered from two sites near Frijole Ranch (1,667 meters), Guadalupe Mountains National Park, with notes on their present distribution in the mountains from the work of Fullington (1979).

Species	Site 1	Site 2	Notes
Cionella lubrica	x	x	General over mountains where leaf litter occurs
Discus whitneyi		x	No living populations known
Euconulus fulvus		x	1,920 meters
Gastrocopta armifera armifera	x	x	McKittrick Canyon
Gastrocopta contracta		x	1,920 meters
Gastrocopta pellucida		x	Found near the sites
Gastrocopta pentodon	x		1,890 meters
Gastrocopta pilsbryana		x	1,981 meters
Gastrocopta procera	x	x	Upper Dog Canyon at 1,890 meters
Glyphyalinia indentata		x	General over mountains
Hawaiia minuscule	x	x	General over mountains
Helicodiscus eigenmanni		x	1,981 meters
Helicodiscus singleyanus	x	x	South McKittrick Canyon at 1,615 meters
Holospira montivaga	x	x	1,524 meters
Nesovitrea hammonis		x	1,920 meters
Punctum minutissimum		x	2,011 meters
Pupilla blandi	x	x	McKittrick Canyon drift
Succinia sp.	x		No information; elsewhere occurs at lower elevations
Vallonia gracilicosta	x	x	2,011 meters
Vallonia perspective	x	x	McKittrick Canyon at 1,615 meters
Vertigo gouldii		x	2,286 meters

age is provided by the fact that the shells are from shallow sediments and lack encrustations so that they wash clean.

A model that has been proposed for a late Pleistocene [(11,590 ± 230 years before present (BP)] community structure in the Guadalupe Mountains at 2,000 meters on a xeric west -facing slope is that of a mixed conifer community of Douglas-fir (*Pseudotsuga menziesii*), limber pine (*Pinus strobiformis*), Colorado piñon (*Pinus edulis*), and Gambel oak (*Quercus gambelii*) (Van Devender and Wiseman 1977; Van Devender, Spaulding, and Phillips 1979). At the south end of the Guadalupe Mountains packrat middens from Williams Cave at 1,500 meters elevation and dating from 12,010 ± 210 BP indicate a rich piñon-juniper community including New Mexico locust (*Robinia neomexicana*), black cherry (*Prunus serotina*), netleaf hackberry (*Celtis reticulata*), and oak (*Quercus* sp.). The mollusk assemblages (Table 1) are from the more mesic east side of the mountains and from an elevation intermediate to that for the two communities noted above.

The altitudinal distributions of land snails in several nearby mountain ranges in New Mexico have been reported (Metcalf 1984, Dillon and Metcalf 1997). In these mountains the greatest numbers of species and specimens are found today in the mid-transition to mid- to-upper Canadian zones (2,286–3,048 m) (Dillon and Metcalf 1997). In the Organ Mountains the gastropod fauna triples to quadruples at 1,920–2,040 meters elevation (Metcalf 1984). In the Sierra Blanca (Lincoln County) transect, the gastropod fauna increased from 5 to 21 species between 1,700 and 2,073 meters (Dillon and Metcalf 1997). This pattern is similar in the calcareous Sacramento Mountains with the greatest densities of gastropods occurring within the general range of 2,195–2,834 meters (Dillon and Metcalf 1997).

Table 2. Late Pleistocene plant communities (Van Devender et al. 1979).

2,000 meters—west-facing slope (about 13,000 before present)	**Subalpine forest**
	Picea sp.
	Juniperus communis
	Pseudotsuga menziesii
	Pinus strobiformis
	Pinus edulis
	Ostrya knowltonii
	Quercus gambelii
	Arctostaphylos sp.
	Robinia neomexicana
	Rubus strigosus
2,000 meters—west-facing slope (11,590 ± 230 before present)	**Mixed conifer forest**
	Pseudotsuga menziesii
	Pinus strobiformis
	Pinus edulis
	Juniperus sp.
	Ostrya knowltonii
	Quercus gambelii
	Robinia neomexicana
	Celtis reticulate
1,667 meters—east slope (Frijole Ranch)	**?????**
1,500 meters—south facing bajada (12,010 ± 210 before present)	**Piñon-juniper community**
	Pinus edulis
	Juniperus sp.
	Robinia neomexicana
	Prunus serotina
	Celtis reticulate
	Quercus sp.

We believe the diversity of the gastropod fauna reported here is consistent with the model postulated by Van Devender, Spaulding, and Phillips (1979) of a mixed conifer woodland (transition zone) existing in the Guadalupe Mountains during late Pleistocene time. We suppose that this zone was lower on the more mesic east side of the mountains in accordance with patterns reported in these mountains today (Gehlbach 1979). Diverse gastropod assemblages of this type are not found today in the open grassland and juniper community at the site or from piñon-juniper communities elsewhere in southern New Mexico or western Texas.

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Note: Formatting of geologic units in this paper follows the guidelines provided in Hansen, W. R., editor. 1991. Suggestions to authors of the reports of the United States Geological Survey. 7th edition. U.S. Geological Survey, Washington, D.C.

History

Chapter 38

The Butterfield Overland Stagecoach through Guadalupe Pass

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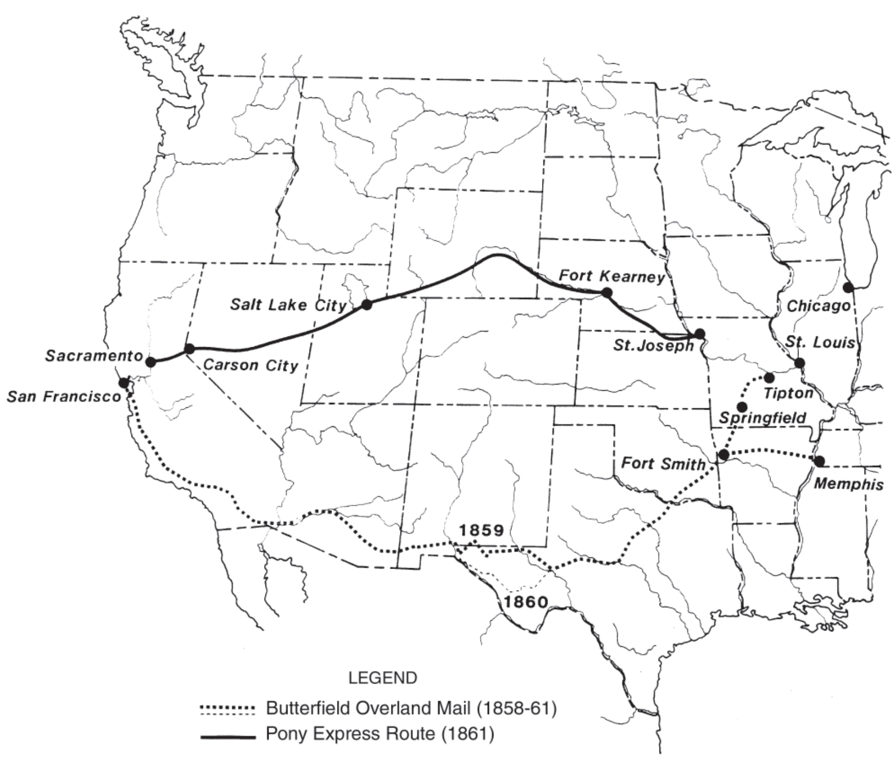
The Mexican War ended with the United States purchasing large tracts of land in what is now the southwestern part of the United States. The war also settled the right of Texas to enter the Union and, just two years after that, gold was discovered in California. So many people rushed to California just two years later and in 1850 California joined the Union. It's hard for me to realize that this happened 26 years before Colorado had enough people to join the Union. At any rate, there was a great clamor in congress and in the East and West both, especially the West, for an overland mail service, an overland mail contract, and an overland stagecoach. As usual, congress did nothing and then finally in 1857 they authorized an overland mail contract. They made the mistake of leaving the choice of the route up to the postmaster general. Well, it so happened that the postmaster general was from the South, and he insisted on a southern route.

At about that same time, an interesting character by the name of John Butterfield came on the scene. His home was in Utica, New York, and as a boy the sound of the stagecoach as it roared by in a cloud of dust thrilled him. He determined that when he grew up he wanted to be a stagecoach driver, and he did. He was so good at it that he was soon made manager of the line and he branched out

Figure 1. Butterfield overland mail and pony express route.



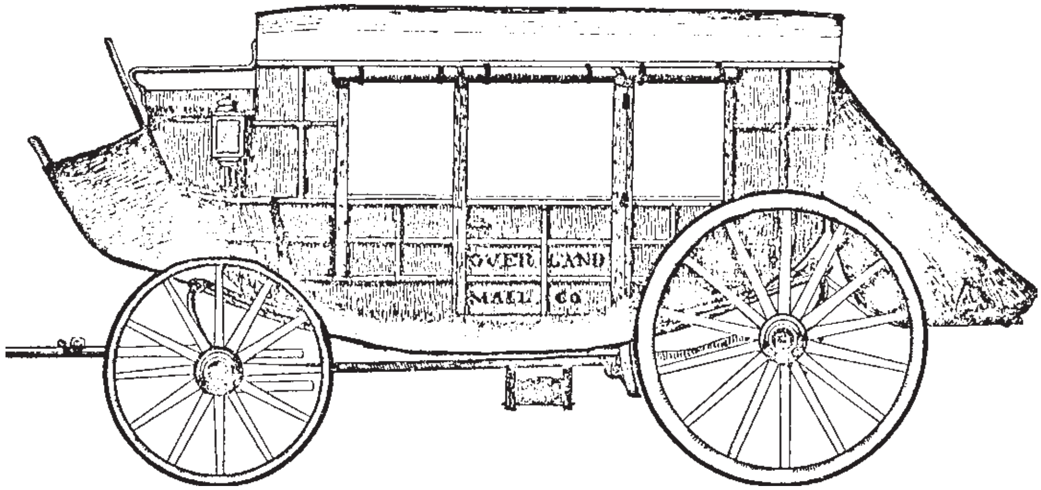


Figure 2. The Butterfield "Celerity" stage wagon was designed in the coach factory of James Goold in Albany, New York, where, in 1857, 100 of these wagons were built and placed in the overland service in 1858. They were more adaptable to the roughness of mountain and desert country than the regular high bodied coach. The seats were not upholstered but were constructed so that the backs could be lowered to make a bed, permitting the passengers to take turns sleeping at night. This type of vehicle was used exclusively between Springfield, Missouri; or Fort Smith Arkansas; and Los Angeles, California. Drawing by R. P. Conkling.

to form stagecoach lines of his own, which he later converted into railroads. By then he was wealthy. He invested heavily in real estate and in steam ships on Lake Erie. As a staunch Yankee, Butterfield submitted a bid for the northern route of the overland mail to commence from the railhead of Saint Joseph, Missouri. The route would go up into Nebraska, Wyoming, Salt Lake City, across Nevada and across the scenic Sierra Nevada into Sacramento, with the mail going on down by steamboat to San Francisco. But as a practical stagecoach man, he realized that the heavy snows of the Rocky Mountains and the Sierra Nevada would be formidable barriers to any efficient schedule for the mail, and a more practical route lay to the south. Butterfield made a very shrewd suggestion of two routes: one starting at Saint Louis and the other one starting at Memphis, and the two routes joining at Fort Smith, Arkansas, then going through Indian Territory across Texas and what was later New Mexico, Arizona, and California. He won the $600,000 a year mail contract and he organized the overland mail company with a capital stock of $2 million. He spent $1 million of that the very first year on equipment and supplies. One thing he did was purchase stagecoaches from three different makers. One particular manufacturer from Albany, New York made the Celerity Wagon. Butterfield thought that the design with the front wheels smaller than the rear wheels would be much better in the Rocky Mountain West, and it was.

Several years earlier Butterfield had joined with two other New York State express owners, Henry Wells and William Fargo, to form the American Express company. He remained the director and vice president of that firm until the day he died, and that firm is still alive and kicking today. Nobody thought Butterfield could meet the stiff mail contract of two stagecoaches per week with a maximum travel time of 25 days between Saint Louis and San Francisco. They accused him of stock throwing. Why, that was an average of 112 miles a day. Existing lines were only making 25 miles a day. He simply had heard the post horn again and could not resist this biggest challenge of his life, because he was already wealthy and really did not need that job. Those who scoffed at the project did not count on the hard-working genius of John Butterfield. He never took a day of vacation in his life. He pored over the reports of boundary commissioner Bartlett and Army Captains Marcy and Pope. The existing mail line from San Antonio to San Diego over the Jim Burch line was a very haphazard affair. One or two wagons a month plodded along and stopped each night for the passengers to cook their own meals and bed down on the ground. Well, that just was not the way John Butterfield operated. He built stagecoach stations all along the route. He put his coaches on a schedule. The meals were ready for the passengers when they arrived, and he only allowed 20 minutes for meals and less for a change of horses. He also put lanterns on his coaches so that his stagecoaches rolled both day and night. But what a task—almost 3,000 miles of mostly unimproved trail through hostile Indian country! Postmaster General Brown called this the longest stagecoach line in the world. It was actually 2,795 miles long. There were only three cities along the entire route. Franklin, which we know as El Paso, Tucson, and a small town of 6,000 people called Los Angeles. He built 139 way stations along this route. That was expanded later to 150. His son, Daniel Adams Butterfield, drew up a schedule between these stations. Old John had a photographic memory and his associates were inspired by his enthusiasm. He could tell you the schedule and the mileage between any of those stations, though he never saw most of them.

Our knowledge of the Butterfield stage comes from two chief sources. First, the *New York Herald* was the only newspaper that thought the event was important enough to send a 23-year-old cub reporter with the interesting name of Waterman Lily Ormsby along on the first stagecoach west. His interesting narrative was published in serial form as it was received. Second some 70 years later when Roscoe Conklin retired from the Army in El Paso, he and his wife drove along the entire 3,000 mile route three times, documenting both the route and the preservation of the stations, and their three-volume report is an invaluable contribution.

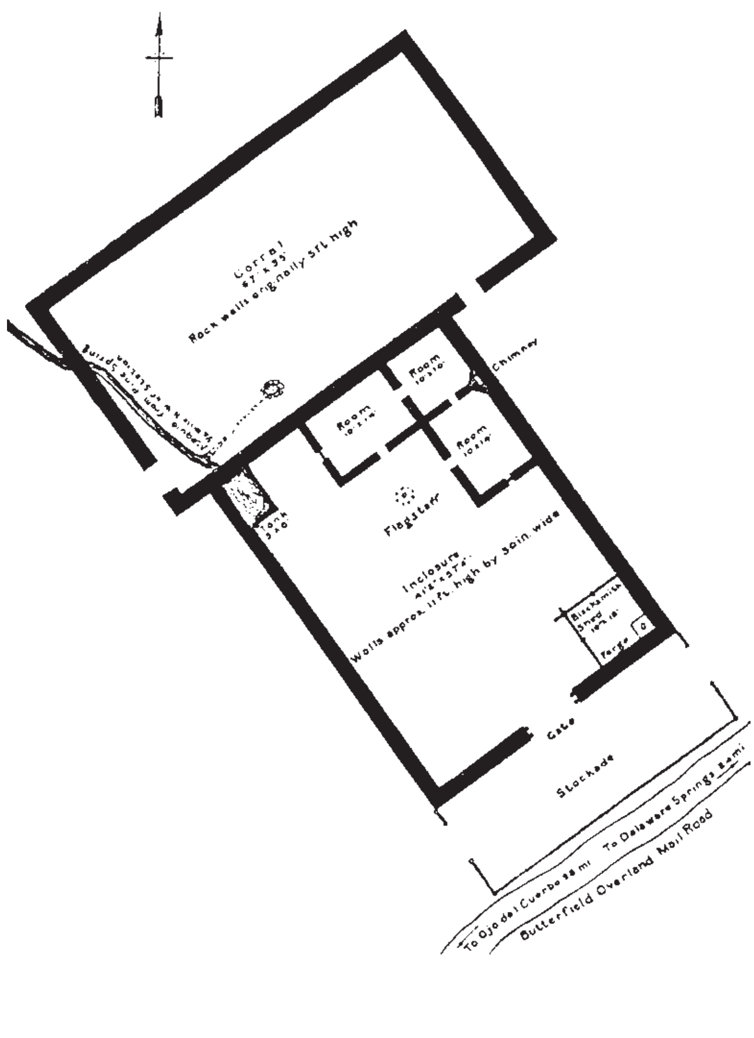
On September 14, 1858, a coach started out from San Francisco and two days later the train took the mail and five passengers from Saint Louis westward to the rail's end at Tipton, Missouri. John Butterfield and Waterman Ormsby were two of the passengers. Since the project was bound to fail, nobody saw them off. The first stagecoach driver was his son, John J. Butterfield, Jr., and he drove the stagecoach all the way to Fort Smith, Arkansas, except when the old man himself took over the reins. Parent Butterfield disembarked the first stagecoach at Fort Smith, and that's as far west as he ever got. The first stage went through Indian Territory and crossed the Red River into the northeast corner of Texas at Colbert's Forge. They went through the tiny hamlets of Gainesville and Sherman and they went on to Fort Belknap and Fort Phantom Hill. Both of these posts had been abandoned by the Army, but Butterfield went into the ruins and built stagecoach stations in both of them. From Fort Phantom Hill they went through Buffalo Gap, 11 miles north of Abilene, and they came to Fort Chadburn. This first Butterfield stagecoach trek was ignored by the eastern United States, but in every fort and town in the West that it came through, it set off riotous demonstrations. The arrival of the first westbound mail in Fort Chadburn was an occasion for celebration on the part of the drivers, and Ormsby said they appeared to have been having a jolly good time for a long time before we got there. Any excuse, you know.

Indians, having raided the corrals a few days earlier, left only wild unbroken mules. When they hitched the wagon to these wild mules, they dashed off in a mad plunge through the trees where the top of the wagon with its canvas covering was completely demolished. This threw Ormsby out of the stagecoach and he almost refused to go any further, but he did so, saying, "If I had any property, I certainly would have made out a hasty will." They then crossed the Colorado River [of Texas] and ruts can still be seen there where the Butterfield stages crossed. The adobe station there fed him a breakfast of mesquite beans and pork. I thought mesquite beans in September were hard as a rock, but that's what they apparently had.

On they went to the head of the Concho River, which was the start of a long 75-mile trek across the Ano West Tecano, which had no water whatsoever. The head of Concho Station was one of the chain of 25 stone and adobe fortified stations that were built by Butterfield between there and Mission Canyon in Arizona. These were built along the Spanish posada style with a high -walled corral and small rooms attached to the inside walls. There was only one entrance wide enough to admit a coach and team in case they were being chased by Indians. Ormsby wrote that they came to the head of the Concho at 2:30 in the morning of Saturday, and the Dutchman who was head of that camp had breakfast for them at 2:30 a.m. I do not imagine they were sleeping too much in that bouncing coach anyway. There were no cushions in those coaches, but the backs of the seats did recline so that they could take turns sleeping—maybe. The Dutchman gave them a breakfast of broiled bacon, short cakes, and coffee, which was considered quite an aristocratic meal for so early a settlement. At least an hour was lost in catching and harnessing more wild mules for the team and for the cavalcade which had to go with them, because there was no change of mules for the next 75 miles. Their wagons were well supplied with canteens of water.

Well, from the head of Concho they went across the dry desert and went through Castle Gap and arrived at the Pecos River at the famous Horsehead Crossing of the Pecos. Here, they did not cross the Pecos. They took an improved road from there up to what's

Figure 3. The Pinery Station ruins stand on the north side of Highway 62, opposite Pine Spring camp on the summit of Guadalupe Mountain Pass. The location is in Culberson County, Texas, Township 1, Block 65, Section 44, previously on the property of Walter Glover and the Grisham-Hunter Corporation, now within Guadalupe Mountains National Park.



now the New Mexico state line. It was a road built by Captain John Pope, who had the idea. He knew that the Llano Estacado would be a formidable barrier to railroads if they did not drill some water wells. So he got some money from congress and got water- well drilling rigs run by a steam engine, and the boiler had to be transported all the way from Indianhoma down on the Gulf Coast, up through San Antonio and up this way. Well, those sand dunes on the east side of the Pecos are quite a formidable barrier to transportation, so John Pope had to build a road from Horsehead Crossing up to Pope's camp. He drilled those three wells, which are really interesting to geologists; he abandoned his camp after the last of the third wells because the rusty Pecos River water had rusted his boiler out in August 1858. So Butterfield took over Pope's camp a month later. They went three miles farther on the Pecos River and crossed at a nice rock crossing there and then headed up Delaware Creek. The next station was at Delaware Springs. They had a nice meal there consisting of jerked beef, bits of bacon cooked over a fire of buffalo chips, served with raw onions and wormy crackers.

Ormsby also reported on the hydrogen-sulfide smell of the springs, and if you have been to Delaware Springs, you know it's still bubbling hydrogen sulfide to this day.

The next station was the Pinery Station in present day Guadalupe Mountains National Park. The entire station was not quite formed at that time, only the corral had been built. The crew was still living in tents, but they fed him a grand meal of venison pie and baked beans. Water came from Pine Springs by means of an acequia which is an open ditch, to the tank in the northwest corner of the Pinery Station. Ormsby was moved by the beauty of the area: "It seems as if nature saved all her ruggedness to pile it up in this colossal form of Guadalupe Peak, sometimes called Cathedral Peak, which rears its head up 4,000 feet above the level of the plain. The wild grandeur of the scene is beyond description. The road winds over some of the steepest and stoniest hills I have yet seen. It is enough to make one shudder to look at the perpendicular side of the canyon."

Ranger Roger Reisch and I have both walked out to the Butterfield line from the old road parking area, down the canyon to the present highway. We are both of the opinion that the rock work which you see there on the north wall above the present highway is probably the stone work of the Butterfield engineers to get them through Guadalupe Pass. Conklin's drawing of the station at the Pinery shows the rock walls of the corral were originally five feet high. The rock walls of the fortress area, with its only one gate entrance, were 11 feet high and 30 inches thick.

The first stagecoach went through Guadalupe Pass then again climbed to higher ground at the bottom of the pass, and it was here that the first westbound and eastbound Butterfield mail coaches passed each other at 7 p.m. on September 28, 1858. Both were several hours ahead of their schedule. The trail continued northwest across the Salt Flat graben to the Cornudas Mountains, the station at the tinaja of Hueco Tanks and on into the town we know as El Paso. Captain Henry Skillman drove the first westbound stagecoach all the way from Horsehead Crossing of the Pecos to Franklin, and when it got to Franklin, it was several hours ahead of schedule. This first stagecoach passage went on through New Mexico and one reason that the Butterfield line was successful was that the Army had just completed negotiations and peace treaties with the Apaches. Mangus Coloradas and all of the resident Indians watched the first stage go by, as did Cochise, watching them go through Apache Pass in southwestern New Mexico. They went on through Arizona and Ormsby describes their arrival in San Francisco. "Just after sunrise the city of San Francisco came in sight, and never did a traveler enjoy a more distant sight. We struck the pavement and to no little surprise of everybody, we finally drove up at the stage office with our driver giving a shrill blast of his horn. It was just 23 days, 23 hours and a half from the time that John

Butterfield had taken the bags at St. Louis." I had the satisfaction of knowing that the correspondent from The *New York Herald* had kept his promise and come through with the first mail. He was the only passenger to do so, and the only one who ever made the trip across the plains in less than 50 days.

Well, San Francisco went wild. They had a great celebration. They had Waterman Lily Ormsby give them a speech and the same thing happened in Saint Louis when the eastbound stage came in.

In recent times commemorative transportation monuments have been placed at the Pinery Station. One was placed by the Highway Department of Texas and another by American Airlines, whose airmail route recognized the original Butterfield Trail as its route flying over the Guadalupe Mountains.

So far as we know, the Butterfield station stagecoach line was eminently successful. It was only short-lived because the Civil War severed the line in March 1861. As far as we know, it never failed to meet that contract schedule. John Butterfield suffered strokes and died in 1869. His son, Daniel Adams Butterfield, became a brigadier general and served as chief of staff to the infamous General Joe Hooker, who commanded the Army at the Potomac. While with this army, he composed the bugle call that we know as Taps.

Chapter 39

Felix McKittrick in the Guadalupe Mountains of Texas and New Mexico

ROBERT HOUSE is an interpretive park ranger at Lyndon B. Johnson National Historical Park. He researched several historic aspects of the Guadalupe Mountains during his two -and- a- half years stationed at Guadalupe Mountains National Park.

I thought I'd cover a little bit on Felix McKittrick, who has been sort of a shadowy figure here, and yesterday I ran into somebody who said, "What are you going to talk about?" I answered, "About everything we know about Felix McKittrick, so someday when I'm gone they can put on my tombstone, 'he knew all there was to know about Felix McKittrick,' and somebody else can say, 'Who were either of these two guys?'"

At a symposium on the Guadalupe Mountains, it is fitting that a geologist, R. S. Tarr, State Geologist of Texas, makes one of the first records of McKittrick Canyon in an official report in the mid- 1890s. Stories about Felix McKittrick sandwich in nicely between the Butterfield stagecoach days and Mr. Pratt.

The name "McKittrick" has become attached to a number of the landforms in and about the Guadalupe Mountains of west Texas and southern New Mexico, but by the mid- 20th century, its origins had become as ephemeral as the wisps of clouds that hide among those peaks and canyons.

The search for McKittrick was launched by a distant kinsman who happened upon the sign for the canyon of that name in the late 1920s. Time did not permit this chance encounter to develop into a search, but James McKittrick of Pana, Illinois, returned in 1965 to the Carlsbad area to question some of the older residents. He would find several versions of the story, and learn that the name most often mentioned was Felix McKittrick. A National Park Service naturalist, Peter Sanchez, remembered seeing a reference to Captain Felix McKittrick in a magazine article.[1]

The inquiries reached the pages of the *Dallas Morning News* in June 1965 when the patron saint of chili aficionados, Frank X. Tolbert, devoted a column to the McKittrick mystery. Tolbert offered his readers "Kid McKittrick," an obscure gunman supposedly killed in the El Paso Salt War, and another "old-timer's" recollection of a "part-Delaware" McKittrick who worked on a ranch near present-day Carlsbad.[2]

By August of 1965, James McKittrick had a reference to Felix McKittrick from Denton, Texas, and his captaincy of a Confederate cavalry unit. His Carlsbad sources had remembered a McKittrick associated with the Chisum cattle operation.[3]

Guadalupe Mountains National Park Superintendent Donald Dayton continued the inquiries as late as 1975 when another McKittrick relative, Billy S. Thompson, wrote for information on the name of the canyon. Dayton had little to go on beyond the material generated by the 1965 letters of James McKittrick. Thompson and Dayton apparently let the matter rest after an exchange of information.[4]

After the flurry of activity on McKittrick in the period between 1965 and 1975, the references to a person by that name were limited to the dugout in the canyon[5] and speculation bolstered by J. E. McKittrick's Carlsbad inquiries. Some people remembered he was a cattleman, and others that he was an outlaw.

In 1994, a new round of interest in the facts on McKittrick began to generate discussions and tentative inquiries into available sources. One book in the park library listed McKittrick as Chisum's foreman, and placed him in charge of one of two herds brought into New Mexico in 1866. Further, Felix McKittrick was listed as a rancher on the eastern slope of the Guadalupe Mountains, and a canyon on the south end of the mountains is named for him.[6] The additional link to the John Chisum cattle empire, and the later troubles in Lincoln County, introduced an element of possibility that the heretofore shadowy Felix might be chronicled with the better-known figures of that era.

The key to Felix McKittrick did involve looking at Chisum, and in contacting his relatives in Kentucky, principally Billy Thompson. From McKittrick's roots in Mackville, Kentucky; his arrival in Denton County, Texas, and association with John Chisum; his move to New Mexico; and his final relocation to Arizona and his death there, a series of images collects into the most complete picture to date.

Born in Mackville, Kentucky on November 26, 1828, Felix was the youngest son of Robert McKittrick and a grandson of Captain John McKittrick, Revolutionary War veteran and founder of the Kentucky community. Felix had an older brother, Fielding, and upon their father's death the two youngsters were cared for by a guardian appointed by provisions of the will. The brothers shared in the estate in the equal amounts of $302.01. On February 24, 1846, Fielding apparently leaves Mackville, and no further references appear.[7]

The United States entry into the Mexican War provided McKittrick with his first chance to leave Mackville during service in Captain Mark R. Hardin's Company I, Fourth Regiment of Kentucky Volunteers from October 4, 1847, until July 25, 1848. The honorable discharge issued in Louisville, Kentucky, provides the best description of Felix McKittrick: age 19, with grey eyes, light complexion, and five-feet-nine-inches in height. His listed occupation is cabinet maker.[8]

Even before the Mexican War, Texas had issued lands to a number of impresario colonies to bring in settlers. By the mid-1840s, one of the largest—the Peter's Colony—would bring the first of over 2,000 Kentucky families to an area stretching from the present-day cities of Denton to Abilene.[9] The colonists would provide a buffer for the western push into the Indian frontier, and reinforce the Peters' claims to a vast empire.[10] Among the Kentuckians moving to the colony by the early 1850s is Felix McKittrick.

Denton County will grow from the scattered communities like Alton and French Settlement which listed among their prominent citizens Jim and John Chisum, Emory Peter, and Felix McKittrick. By 1854 McKittrick will have been elected sheriff, and be listed with Peter and the Chisums as prominent cattlemen. The money from his father's estate and land apparently provided McKittrick with the means to a secure future in Texas.[11] By 1860 McKittrick had real estate valued at $1,700 and a personal estate of $20,000.[12]

Also by 1860, Felix McKittrick had returned to Kentucky and married Almira Peter, sister of Emory. The ceremony was performed in Mackville by the Reverand John S. Coy on January 26, 1860. Emory Peter also married a Kentucky bride, Eliza McKittrick, likely a cousin of Felix. Both families would experience loss before 1860 ended, with Almira dying November 11, 1860, along with her newborn child. Eliza Peter would also be lost under similar conditions. Her body was sent home to Mackville.[13]

One of the first associations of McKittrick and Chisum was recorded in Denton in 1860 when they located the body of John B. Denton for whom the county was named. Chisum kept a promise to his father, Claiborne Chisum, to recover Denton's body, and he had it reburied near the Chisum home. By the time of the discovery, McKittrick and others are cattlemen like Chisum.[14]

The outbreak of war provided McKittrick with new avenues for leadership, but his Civil War service will also result in the beginning of a long direct association with Chisum. On February 8, 1862, Felix will assume the captaincy of Company G, 18th Texas Cavalry in Denton. Though the unit will serve with Walker's Texas Division; Granbury's Brigade, and see action in Atlanta, and with Hood in Tennessee, he will resign for health reasons. McKittrick's request for resignation on November 8, 1862 was granted four days later.[15] The medical problems are not specified, but he was able to contribute to the war effort. One year later the Chisum operations moved from Denton County to the Concho River country, and while the cattle were being relocated, Felix and six other hands worked to build cabins and pens.[16] Chisum, McKittrick, and others would bolster the war effort as contractors for the Confederate government, and be canny enough to exchange their Confederate dollars for cattle.[17]

The end of the Civil War opened new markets for Texas beef in the industrialized north, but lucrative markets already existed in New Mexico. General James H. Carleton's unfortunate reservation experiment at the Bosque Redondo created a government contract for beef to feed the Navajo survivors of the Long Walk and Mescalero Apaches forced from the Sacramento and Guadalupe Mountains.[18]

The two "Long Rail" herds under Chisum and McKittrick drove from the Concho range to the Pecos, striking Horsehead Crossing en route to the Bosque in December 1866. Later that year 10,000 head of cattle would be seen on the Pecos route to the New Mexico free grass.[19] The Chisum herds traveled freely on the first trip, but the Horsehead route would ruin more than one cattleman.

Even the trail-hardened Chisum outfit fell victim to the Apaches. Pitser Chisum took over a herd of 1,200 steers at the Pecos and quickly lost them to the raiding Mescaleros at Black River. Another herd of 1,000 head, plus 150 horses and mules disappeared into the Sacramento Mountains. No government claims were ever paid on these loses.[20]

Despite the risks, other Texans like Charles Goodnight and Oliver Loving were bringing additional herds over the trail they pioneered, and the route the "Chisum Jinglebobs" used the previous year. Anticipating the competition, Chisum men had quickly settled on available water, claiming the range along the face of the Guadalupes, up the Pecos to the Bosque Grande. Rattlesnake Springs, below the Carlsbad Caverns, McKittrick Canyon, and later McKittrick Spring, were all held by men associated with the growing Chisum empire.[21]

Attacks on the cattlemen continued into the 1870s with the Chisum outfits hit by Comanches raiding out of Texas. A roundup crew under Felix lost 80 horses in one raid, and one of the hands went down under the bullets of the raiders.[22] There were so many raids by Mescaleros and Comanches that the Chisum hands were on foot during the branding season in 1874 and 1875, and at least one herd coming up the Pecos was left with only the horses the men on guard were riding. Moving the herd only three or four miles per day, the outfit took 15 days to reach the Bosque Grande Ranch.[23]

Chisum moved his headquarters to the South Springs, near present day Roswell, in 1874, and McKittrick followed, building the first house on the Jacobs Ranch.[24] McKittrick became the overseer of the agricultural operations for Chisum, and grew wheat, buckwheat, and rye on his adjoining acreage.[25]

During the buildup of the South Springs property, another possible scheme came to light and tied McKittrick and his friend Chisum into the Lincoln County troubles. The Tunstall Store in Lincoln showed ledger entries for John H.

Tunstall's payment of taxes for a number of prominent ranchers including the old Texas partners. McKittrick and Chisum are listed together in the accounts.[26] The pair also appears with Robert Beckwith in 1874 in the Robert Casey ledger from Lincoln County.[27] Many ranchers depended on credit, but the Tunstall tax payments lead to speculation that McKittrick and Chisum planned to transfer land to Tunstall.[28] The South Springs land was not the only holding of McKittrick, and he sold a ranch on the Rio Hondo to George Taylor after his farming venture took shape.[29]

The McKittrick-Chisum connection seems solid into 1878 with Felix signing for improvements on property belonging to Chisum, Hunter, and Evans at Croton Springs in Arizona. Chisum had closed out much of his New Mexico holdings to Hunter and Evans, and resumed business, presumably after settling with the commission company.[30] In a deposition to the government regarding his claim for losses to the Comanches, Felix testified he was bossing trail herds destined for the Apache reservation in Arizona, and represented Chisum while there.[31]

As the Lincoln County troubles heated up, McKittrick went his own way, and established a ranch near Seven Rivers. In June 1880, the census enumerator found Felix, age 50, widowed, and listed as a dealer in cattle. He is listed as a native of Kentucky. Living with McKittrick is Charles Thomas, 25, also listed as a dealer in cattle. Thomas, like many of the Seven Rivers ranchers, was a Texan.[32]

Joining the Seven Rivers ranchers put McKittrick between his former friend and partner Chisum, and the group of small ranchers, mostly south Texans. At the time he was known to be friendly to Chisum's enemies.[33] McKittrick's new partner, Charley Thomas, was riding with Billy the Kid when the Kid killed would-be gunman Joe Grant in the Hargrove's Saloon in Fort Sumner.[34] The Kid and Thomas were on speaking terms, if somewhat strained, with the Chisum roundup crew on the day they all went to the saloon.[35]

Chisum's herds were targeted by outlaws all over the region, and brands were burned over his Long Rail, while the "jingle bobs" were lopped off, eliminating his signature earmark.[36] The description of the McKittrick-Thomas herd leaves no doubt about their origins. The pair operating out of their McKittrick Spring dugout soon boasted quite a number of cattle with their own signal markings. The herd had no ears, no horns, and was branded 666 on the shoulder, sides, and hip. Chisum was said to have remarked, "They call me the cattle king, but I think Mac has me bested." To which McKittrick replied, "I'm one of your best scholars."[37]

The bold inroads into Chisum's cattle would not be tolerated. Pitser Chisum reported the thievery in 1879 when he wrote Fort Stanton's Commander Henry G. Carroll about stock with unusual marks. Most of the brands registered went to names previously unknown among cattlemen, Chisum noted.[38]

Hiding places for stock were numerous in the Guadalupe and Sacramento mountains. Many ended up in McKittrick Canyon, a place identified with Felix, though the Apaches received the blame for many of the thefts.[39]

McKittrick was still in business in 1882 when John Meadows went to work for him while waiting for a job with a friend moving to the territory. While working with Felix, Meadows witnessed an event involving lawman Pat Garrett and McKittrick's sense of fairness and humor. Garrett had arrested Hugh Beckwith for murdering his son-in-law, William H. Johnson, and was taking his prisoner to Lincoln. Needing to see to another warrant, Garrett left Beckwith in the custody of Felix and Meadows. McKittrick let Beckwith sleep outside the dugout, unguarded, and the sunrise revealed no prisoner in sight. Garrett accepted McKittrick's story, and Meadows always believed that the lawman feared a mob in Lincoln would have lynched Beckwith, so he contrived an escape that left two men a way out.[40]

The lawlessness in Lincoln County would prompt Chisum to enlist his own "warriors"—hired gunmen—to patrol his ranges. Many Texans moving west from other range wars found employment with the Jingle Bob King.[41]

McKittrick may have also partnered with another veteran of the Chisum outfit, Emory Peter, his brother-in-law and fellow Kentuckian. Family traditions place them at McKittrick Canyon after both left Chisum.[42]

The days were long gone when Felix McKittrick would be the joker-in-residence at the South Spring Ranch and the trusted friend and partner of John Chisum. By 1885 he was gone to Arizona, and he wrote Walter Thayer of Carlsbad inquiring about the people they both knew on the Pecos. Felix had not heard from any of them in a long time, and by 1889 had sold his cattle to Charley Thomas. He let Thayer know that many of the Pecos battlers were using other names out in Arizona.[43] Indeed many were living north of Clifton, Arizona, in the Blue Range seeking refuge and anonymity like Felix.

Some time after his move to Arizona, Felix returned to Kentucky and visited Mackville. His family remembered the visit, and he was perceived as a real westerner in their accounts.[44]

The account of his death lists the cause as drowning and records that Captain Felix McKittrick was found February 22, 1901, in the Blue River. He had fallen over the front of the wagon and his head was in the water. His team of horses had not moved. A former acquaintance added some details, "Cap" McKittrick would come by Clifton, get too much to drink, and tell tales about the old days in New Mexico and Arizona.[45] He was buried in the Blue Cemetery.

McKittrick's estate at the time of his death consisted of a claim against the United States government for the attack by the Mescaleros on the Chisum roundup crew on the Pecos. Felix filed the claim on July 31, 1879, and it was pending when he died. He left any proceeds to two of his nieces back in Kentucky. Emory B. Peter acted as executor. Peter joined S. S. Burdett, an attorney from Washington, D.C., in bringing the case to a close in February 1903 when the award of $1,680 was paid to the estate, less $260 to Burdett. Through the years the government had sought to throw the [Indian depredation] case out because (a) Felix had not filed in a timely manner, (b) because the Indians might have been Comanches, and (c) in a final insult, because the claimant had resided outside the United States and was not a citizen, based on the fact that Felix had been in Mexico, serving as a soldier in the Mexican War.[46]

Many characters in the history of the "wild west" suffer from efforts to make them bigger than life, and their associates get painted with the same brush. Chisum's great herds and experiences in Lincoln County furnish material for endless versions of that event. McKittrick, by comparison, lives on the periphery, but is no less colorful, and by the sheer accident of living amidst geologic wonders and natural beauty will in no small way be remembered always. McKittrick Canyon in the Guadalupe Mountains and McKittrick Canyon in the Blue Range of Arizona are fit monuments.

Endnotes

1. Jeter Bryan, "Never Mind: McKittrick Canyon Search Fun, But Fruitless." *Current Argus*, Carlsbad, New Mexico, Sunday, March 14, 1965. James McKittrick talked to a rather long list of old-time residents of the Carlsbad and Seven Rivers area. His letters are in the files at Guadalupe Mountains National Park, but there is no documentation of his conversations with the local people he contacted.

2. Frank X. Tolbert, "Tolbert's Texas: On the McKittrick 'Mystery'" *Dallas Morning News*, June 1965. The clipping copy I have has no date other than this. Tolbert did make a plea for preserving the beauty of McKittrick Canyon.

3. Letter, James E. McKittrick to Peter Sanchez, August 10, 1965. Copy in Guadalupe Mountains National Park files.

4. Letter, Guadalupe Mountains National Park Superintendent Donald Dayton to Billy S. Thompson, October 14, 1975. Copy in Guadalupe Mountains National Park files.

Dayton replied in part, "No definite factual evidence has surfaced as to whether the Felix McKittrick who enlisted in the Confederate Army in Denton County, Texas, was the same man who later worked the cattle lands with John Chisum, and who spent time in the area of what is today Carlsbad and the Guadalupe Mountains."

5. Guadalupe Mountains National Park report: "Known Structures in Guadalupe Mountains National Park." The second structure listed is the McKittrick dugout in McKittrick Canyon.

6. Frank Collinson, *Life in the Saddle*.

7. Washington County, Kentucky records referred by Billy Thompson; Fred L. McKitrick, *The McKitricks and Roots of Ulster Scots* (Baltimore, Gateway Press, Inc. 1979); Letter: Beulah Thompson to Billy Thompson, October 25, 1975. The Fred McKitrick genealogy study contains gaps, but establishes the McKitricks (McKittricks) as Scots, later settled in Ulster, Ireland. Felix will always be referred to as Irish by writers who knew him. Beulah Thompson repeats the family tradition that Fielding ran away with some type "show." She gives 1885 as the date of a return trip Felix made to Mackville.

8. Bounty-Land Warrant Application 29.577.160-47, Mexican War. National Archives, Can 2187-Bundle 176.

9. T. R. Fehrenbach, *Lone Star* (New York, Macmillian, 1974), 284.

10. Ty Cashion, *A Texas Frontier: The Clear Fork Country and Fort Griffin, 1849–1887* (Norman, University of Oklahoma Press, 1996), 23

11. Ed F. Bates, *History and Reminiscences of Denton County* (Denton, McNitzky Printing Co., 1918), 137, 306.

12. Census of the United States, Denton County Texas, p. 433. In what will cause confusion later, McKittrick lists his age at 30. His occupation is stock raiser.

13. Washington County, Kentucky: marriage records p. 110; Denton County Historical Commission, IOOF Cemetery Survey, 1982, p. 71, Almira's birth date is January 18, 1834; Beulah Thompson letter, October 25, 1975. Mrs. Thompson confirms that Almira died soon after childbirth, and the child also died. She noted that Felix was no stranger to tragedy.

14. R. G. Johnson, letter of October 30, 1900; in *Denton Record-Chronicle*.

15. Confederate Archive, Chapter 1, File Number 92, page 30, received from David Williams, letter February 5, 1995. Felix's medical report shows six cards for his time in service.

16. Harwood P. Hinton, "John Simpson Chisum, 1877–84," *New Mexico Historical Review*, 31 (July 1956), 177–205.

17. C. L. Douglas, *Cattle Kings of Texas* (Fort Worth, Branch Smith, Inc.), 115.

18. Robert M. Utley, *The Indian Frontier of the American West 1846-1890* (Albuquerque, University of New Mexico Press, 1984), 84–85.

19. Clayton W. Williams, "That Topographical Ghost-Horsehead Crossing." *Old West* (Winter 1974), 50. Charles L. Pyron, traveling the El Paso-Guadalupe Mountains–San Antonio route estimated the numbers of cattle. Horsehead Crossing is accurately located in the Williams' article.

20. Douglas, *Cattle Kings*, 118; Collinson, *Life*, 142.

21. Eve Ball, *Ma'am Jones of the Pecos*, (Tucson, University of Arizona Press, 1969), 132; Lily Klasner, *My Girlhood Among Outlaws,* (Tucson, University of Arizona Press, 1972), 35, Edited by Eve Ball. The Rattlesnake Springs are identified with Hank Harrison, and the reference here is that he brought a few cattle and held the land. This may explain the actions of people like McKittrick who owned cattle in Denton County. If so, the Chisum outfit seems to be a large organization with many "partners." The Klasner book links McKittrick to the canyon for a long period of time, noting he camped there for years and "made it his headquarters." By the time the army pursues the Mescaleros into the canyon they have abandoned their camp and left the stock. McKittrick was not occupying the canyon then.

22. T. Dudley Cramer, *The Pecos Ranchers in the Lincoln County War*, (Oakland: Branding Iron Press), 56.

23. Mary Whatley Clark, *John Simpson Chisum: Jinglebob King of the Pecos*, (Austin: Eakin Press, 1984), 24; J. Frank Dobie, *The Longhorns*, (New York: Bramhill, 1982), 75.

24. *Roswell Record*, "Something More of the Past," M. A. Upson, April 15, 1892. Ash Upson is the same person who appears on the census at the Heiskell Jones Ranch and the ghostwriter of Pat Garrett's book on Billy the Kid.

25. Clarke, *John Simpson Chisum*, 113; Mary Hudson Brothers in *A Pecos Pioneer* reports the same information on the farming activities.

26. Frederick Nolan, *The Lincoln County War: A Documentary History*, (Norman: University of Oklahoma Press, 1992), 132, 142. Tunstall's entries are not dated after July 21, 1877.

27. Robert Casey, Biographical File, J. Evetts Haley Collection: J. Evetts Haley History Center, Midland Texas.

28. Nolan, *Lincoln County,* 170.

29. Sid J. Boykin interview with J. Evetts Haley, June 23, 1927, XIT Ranch, Volume 1, JEH Library, Midland, Texas.

30. Letter, Harwood P. Hinton to Alex Williams, May 15, 1978.

31. RG-123, *Records of the United States Court of Claims, Indian Depredation Records, Case Files, March 5, 1891–March 17, 1894; September 21, 1917.* Felix McKittrick, Case Number 5936.

32. U.S. Census, County of Lincoln, Territory of New Mexico. Taken by A. H. Whetson, June 1880. McKittrick and Thomas are Family 31. Their near neighbors are Family 33, the Heiskell Joneses, including boarder, Ash M. Upson.

33. Letter: A. A. Anderson to Almer Blazer, October 31, 1931. Robert Mullin Collection, Nita Stewart Haley Memorial Library, Midland, Texas.

34. Pat F. Garrett, *The Authentic Life of Billy the Kid*, (Norman: University of Oklahoma Press, 1954, 1980), 87. This is the book likely ghostwritten by Ash Upson.

35. Robert M. Utley, *Billy the Kid: A Short and Violent Life*, (Lincoln: University of Nebraska Press, 1989), 131–132.

36. Hinton, *J.S. Chisum,* 332.

37. Mary Hudson Brothers, *A Pecos Pioneer*, (Albuquerque: University of New Mexico Press, 1943), 50.

38. Hinton, *J. S. Chisum*, 330.

39. Klasner, *My Girlhood*, 35.

40. Early Experiences of John Meadows, Tularosa: J. Evetts Haley Library, Midland, Texas.

41. Clarke, *John Simpson Chisum,* 25.

42. H. P. Hinton to Alex Williams, June 19, 1978. Sharon McKittrick Brown related the family story to Tom Brown of Artesia.

43. Letter: Felix McKittrick to Walter Thayer. Original belongs to Mary Helen Brunt, Carlsbad, New Mexico.

44. Letter: Beulah Thompson to Billy Thompson, October 25, 1975.

45. Solomonville, Arizona, *Bulletin*, March 8, 1901; Letter: Anderson to Blazer.

46. RG-123, Case Number 5936.

Chapter 40

The Career and Contributions of Wallace E. Pratt

JIM W. ADAMS is an American Association of Petroleum Geologists (AAPG) certified petroleum geologist in Midland, Texas. He was instrumental in securing corporate funds for park preservation actions on the Wallace Pratt residence, Ship-on-the-Desert. He worked as a geological advisor for Exxon, U.S.A. for 43 years.

Wallace Pratt was born in 1885 and raised on a farm in northern Kansas. Being number six of 10 children, he had to earn his own way through college. He graduated from the University of Kansas with a Bachelor of Arts Degree in 1907 and a Bachelor of Science Degree in 1908. He was unable to find a job as a geologist, so he stayed in college and received a Master of Arts Degree in 1909. He then signed on as a geologist with the Division of Mines of the Philippine Islands. When he returned to Kansas in 1915, he earned another degree as Engineer of Mines. He then took a job with the Texas Company in old Mexico where he was thrown in jail and rescued with other Americans by gunboats.

He began his long successful career with the newly formed Humble Oil & Refining Company in early 1918. As their first geologist, he was named chief geologist in Houston; he later became a director and vice president. Wallace Pratt's success as an oil -finder came chiefly through his brilliant mind and his capability as an organizer. He quickly hired a staff of 10 geologists and insisted on their being closely associated with all drilling wells. He started a research laboratory where they could study cores and well samples. He cleverly integrated oilfield scouts, landmen, geologists, and geophysicists into his exploration department, so when any of these people got a lead on a new prospective area, the Humble Company could move quickly to acquire valuable leases at low cost.

His thinking frequently ran contrary to prevailing geologic prejudices of the day. So many of his ideas have become accepted by modern-day geologists they don't seem spectacular unless we notice just how early Pratt came to his conclusions.

1917: Pratt was a founder of the American Association of Petroleum Geologists (AAPG) and their fourth President.

1919: Pratt was a member of the team that went to New York to secure money for a badly needed refinery and a pipeline from the Ranger Field to the Gulf Coast. Standard Oil Company of New Jersey purchased a half-interest in Humble at that time for $17 million. Because of Texas law, however, it was agreed that "Jersey" would not interfere with Humble's board of directors.

1920. Pratt realized that the gas produced with oil was helpful to push the oil through the reservoir rock into the well bore. This started him on a lifelong quest to prevent the burning of gas flares: Pratt was probably the first person to recognize the reservoir recovery factor. He said, "I can't get away from the idea that the flow from such wells does not represent the total volume of oil in the reservoir…. I doubt if these wells flow as much as 50% of the total volume available."

1921: Pratt said, "Our first great exploration success…resulted purely from a breakthrough we made in geological knowledge." He was poring over the field maps late one Saturday night on the kitchen table of his field geologist in Mexia, Texas. The rock structure had been mapped as an anticline, but the data just didn't fit that explanation. Finally it dawned on Pratt that the mecha-

Figure 1. Wallace E. Pratt. Photo courtesy of the American Association of Petroleum Geologists.

nism trapping the oil was a fault, not an anticline! Three new oil-finding concepts entered his mind that night:

1. Faults can trap petroleum; this was a sealing fault (they were generally considered to leak).
2. The fault plane dipped at an angle to the west (the prevailing thought was that they were vertical).
3. The dip on the fault meant that acreage west of the surface expression might be productive, yet this area was not even leased!

Wallace Pratt was so excited that he telephoned the president of Humble at 2:00 am Sunday morning requesting permission to lease as much acreage as he could get. He was given $400,000 authority; 175 of 180 wells drilled on this acreage were productive. Using these new concepts, Pratt's team was very successful also in the Luling and Powell fields. He doubled Humble's production from 8 million barrels of oil in 1920 to 17 million in 1923. Humble thereby passed up Texaco as the largest producer in Texas.

It was also in 1921 that he first became interested in McKittrick Canyon. "I had been told simply that it was the most beautiful spot in Texas, so I drove 100-odd miles in an old Model T to see for myself…. So over a period of years and largely with borrowed money, I gradually achieved full ownership of McKittrick Canyon and its surrounding acreage." His first interest was strictly for the scenery, but he soon came to realize that he had purchased one of the world's most outstanding exposures of an ancient carbonate reef.

1925: Pratt was at first slow to use geophysics in oil prospecting, but by 1925 he had nine crews in the field including magnetometer, gravity and seismic. During the early 1920s, Humble participated in drilling most of the major Texas oilfields; nearly all of the larger (lease) trades were negotiated by Wallace personally. He was also elevated to Humble's board of directors that year.

1926: Pratt recommended that Humble hire its first petroleum engineer. With John Suman, he supported increased conservation measures, wider well spacing, and more reservoir research. Pratt urged the Railroad Commission of Texas to force operators to reinject panhandle gas to maintain reservoir pressure, and Humble started this practice on its own leases in many fields.

1927: Humble discovered the Sugarland (Texas) Field as the first major field discovered by seismic methods. Under Pratt's leadership, some 300 geologists and landsmen met in Iraan, Texas, to effect the first voluntary production proration agreement in the huge Yates Field.

1928: Humble voluntarily joined its first field unit by turning over a lease to Conoco in Coleman County, Texas. Unitization is accomplished for energy conservation by water flooding or other means with one company operating the entire field for the benefit of all lease owners. Upon the strong recommendation of one of his geologists, Wallace Pratt started leasing in what later proved to be the large east Texas Field.

1929: Pratt's company started a public information campaign to permit state agencies to prorate oil and gas production and permit unitization of fields to conserve energy. Humble also helped the State of New Mexico draft a model conservation law; it also proposed the formation of the Interstate Oil Compact Commission.

1930: Between the time that Dad Joiner's well in east Texas received its first show of oil and the final completion of the well, Wallace Pratt leased another 12,000 acres for $500,000. He correctly surmised that the first three scattered productive wells were part of one long productive trend and leased accordingly. It took nine years to develop these leases, but on their own, they tripled Humble's 1930 reserves and made it the largest operator in the field with 16% of the proven acreage. Of course, this prolific uncontrolled field caused the price of oil to drop below $0.10 per barrel during

America's Great Depression, and hard times came to the oil patch until World War II.

In a letter I received from Wallace Pratt, which I treasure, he wrote: "We built our first home in McKittrick Canyon in 1930 (we had to go clear to Sweetwater, Texas, to get a stonemason). Our first home was located at the mouth of North McKittrick where it joins Main McKittrick. Our first home is generally known as 'Pratt's Hunting Lodge' although we have never hunted nor permitted hunting on our property. Both of our homes are constructed of fine-grained closely laminated, silty limestones of the marine facies of the Bell Canyon. Both were included in our gift of McKittrick Canyon to the National Park Service to become the nucleus around which it accumulated all of the present Guadalupe Mts. National Park."

Also during this year, Pratt's geophysicists developed the industry's first gravity meter to replace the slower torsion balance.

1931: Pratt converted all Humble seismic crews from refraction surveys to Everett L. DeGolyer's more progressive reflection surveys. He also established a training section for professional personnel.

1933: This was a banner year for 48-year-old Wallace Pratt. He was made a vice president of Humble Oil. He learned how to fly, bought an open-cockpit airplane, and built a landing strip on the McKittrick Canyon Ranch so they could enjoy it more. During his lifetime, he also flew this plane to New York and Alaska. It was also in 1933 that Pratt accomplished what was to him a highlight of his career: he negotiated a lease of the huge King Ranch, the largest single lease ever written: over one million acres in 11 counties of south Texas. The lease terms were specified by Robert Kleburg of the King Ranch, but the integrity of Wallace Pratt was a key factor in these negotiations. Pratt had infuriated Kleburg 15 years earlier when he canceled a lease because of checkerboard provisions that he felt were not in the best interests of Humble or the King Ranch. Pratt's argument was that if 10 different companies operated wells on the ranch, who would Kleburg go to when someone ran in to his pet bull? Facing a $3 million inheritance tax and not wanting to sell part of their prize herds, Robert J. Kleburg, Jr. came around to Pratt's way of thinking. Kleburg's terms of this new lease were:

1. No lease bonus!
2. Humble would lend the ranch $3,500,000 at 5% interest
3. Annual rentals of $127,824
4. ? royalty on production
5. 20 year lease (renewed until year 2000)

Humble's president was opposed to this lease in rank wildcat territory during the height of the Great Depression. With low oil and gas prices, he wanted Pratt to get partners to spread the risk. Gulf, Shell, and Texaco all turned down the chance to participate. Wallace Pratt remained optimistic: "Unlike most of my fellow geologists, I was convinced that hydrocarbons are normal constituents of marine sedimentary rock" (Copithorne 1982). Pratt's arguments were so impressive that Humble's board of directors not only approved the King Ranch lease, but gave him authority to lease an additional two million acres between Corpus Christi and the Rio Grande. It took many years to develop the King Ranch, but Pratt's lease yielded Humble over 1,000 oil and gas wells. When these large gas reserves were discovered, there was no outlet, so Pratt personally pushed gas contracts with refineries in the Houston area and got a pipeline built to supply them. The huge King Ranch gas plant that was necessitated by these transactions also generated profit for Humble.

1933: The discovery of Tomball, Pledger, and Greta fields added a trillion cubic feet of gas to Humble's reserves. Humble also started running Schlumberger electric logs in 1933.

1934: Humble's discoveries at the Means Field (Andrews, Texas), Tom O'Conner (south Texas), and Hastings Field added 315 million barrels of oil to Humble's reserves, thus exceeding the reserves of Gulf and Texaco combined. Wallace

Pratt did an extensive study and found that oil consumption was exceeding even the good rate of discovery. Despite the glut of oil in east Texas, he predicted that the United States would someday need to import oil; therefore, he accelerated leasing 50% greater than 1933!

1935: Pratt's exploration team discovered the Anahuac Field (200 million barrels of oil) while the Katy Field yielded Humble's largest gas reserves.

1936: Amelia Field was a Humble seismic discovery while Talco yielded another 80 million barrels of oil reserve.

1937: During the Great Depression when the price of oil fell to less than $1 per barrel, many oil companies ceased leasing and reduced drilling and began laying off professional personnel. Wallace Pratt's genius lay in pursuing a course directly opposite to that of industry. He reasoned that leases were cheap and personnel were cheap, so he expanded lease acquisitions, drilling, and hiring. The official history of Humble states: "Pratt's courage—his willingness to think and act independently—merits special emphasis. At the very time when much of the American Oil Industry had greatly reduced…its search for oil, he led his company in an unprecedented campaign for building up its reserves. He persuaded his associates on the Humble Board…by the persuasiveness of his facts and arguments" (Larson and Porter 1959). "Pratt's high standing outside the company was an important factor…he worked for the advancement of petroleum geology, better production methods, and the conservation of resources… In the lease market, he had a reputation for fair trading…. He was an outstanding geologist as well as an administrator" (Larson and Porter 1959).

1937 also brought the discovery by Humble of Friendswood Field near Houston, of North Crowley in Louisiana, and Wasson Field in west Texas. In this year of Humble's largest expenditure for leases ($8 million), Wallace Pratt (June 30, 1937) was made a director and executive committee member of Standard Oil Company of New Jersey. He left Humble but not without some trepidation. He said, "My instinct has always been to distrust any enterprise that requires a new set of clothes" (Copithorne 1982).

During Pratt's tenure with Humble (from 1918 to the prorated year 1937) he and his exploration team succeeded in raising the company's reserves from 32 million barrels of oil to 1.9 billion barrels of oil, more than twice that of its nearest domestic competitor. They increased production from 11,759 barrels of oil per day to 138,660 barrels per day, with a capability of 150,000 barrels per day. By 1941 production on Pratt's leases had risen to 149,972 barrels of oil per day with remaining oil reserves proven at 2.7 billion barrels (14% of our nation's total) plus 6.6 trillion cubic feet of gas.

Wallace and Iris Pratt moved to a flat overlooking Central Park in downtown Manhattan.

1937–1945: Wallace Pratt's career with "Jersey" was also successful. He set up an office in France that discovered the Parentis Field (France's largest oilfield). He was also instrumental in establishing sound relations with the government of Venezuela that were very important to Jersey's large operations there.

The Humble Company's contribution to the war effort during these years was outstanding. Many employees served in the Armed Services, others in Oil Planning Boards in Washington. Humble's greatest contribution was in oil production, the largest in the nation; pipelines—the "Big Inch" pipeline from Texas to the East bypassed German submarines in the Gulf of Mexico; and refining—Humble developed high-octane airplane gasoline and also made valuable synthetic butyl rubber from patents obtained from I. G. Farben of Germany during the 1920s. Events in the life of Wallace Pratt during the war were:

1941: He delivered four lectures to the Department of Geology of his alma mater, the University of Kansas, which contained his most famous quotation:

"Where oil is first found, in the final analysis, is in the minds of men" (Salvador 1982).

1942: Pratt was made a vice president of Standard Oil Company of New Jersey.

1943: Wallace and Iris Pratt were marooned one week in the McKittrick Canyon cabin by a flash flood. This caused them to think about building another house on the ranch.

1944: He predicted the discovery of important oil deposits on the North Slope of Alaska. Humble secured leases there and participated in the Prudhoe Bay discovery.

1945: At the age of 60, Wallace Pratt retired from Standard Oil of New Jersey, but did not retire from geology. I have often marveled that this active man, with the entire world at his fingertips in that office in downtown Manhattan, chose to move to the solitude and quiet of McKittrick Canyon. For the next 15 years, he didn't have a telephone and lived 10 miles from the nearest neighbor and 60 miles from the nearest post office. Wallace and Iris Pratt built a larger home near the mouth of McKittrick Canyon out of the same type of limestone flagstones as the cabin. This was the famous "Ship-on-the-Desert" that was designed on the lines of an oil tanker. It is long and narrow with railings above the first story protecting extensive sun decks. A second story "bridge" is located in the center which features large picture windows with magnificent views: McKittrick Canyon to the northeast, the Delaware Basin to the south, and Capitan Peak to the west. Access to the bridge is by a unique circular stairway: one vertical pole with radiating steel plates and circular handrail like that in a submarine.

Wallace Pratt was very fond of the wooden bookshelves that he had especially built while in New York. He brought these with him when he retired to the ranch and he donated them to the National Park Service where they can be seen in the Ship-on-the-Desert today. When Exxon closed their office in Midland, Texas, I requested that they donate books to fill these bookcases. They graciously gave "The Ship" a complete set

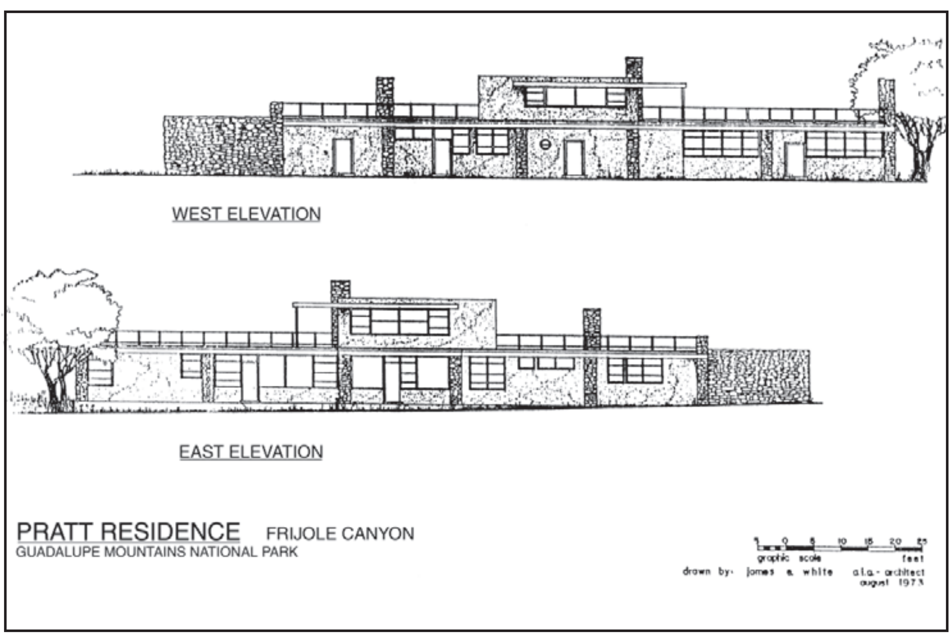


Figure 2. The second Pratt residence, Ship-on-the-Desert, in the Guadalupe Mountains. Drawing by James E. White, A.L.A. Architect, August 1973.

of bound American Association of Petroleum Geologists Bulletins (1917–1997: 80 years!) and a complete set of the Journal of Sedimentary Geology (1933?–1996).

I once made the mistake of calling this house the "Ship-of-the-Desert." Wallace Pratt quietly corrected me: "No, Jim, the Ship-OF-the-Desert is a camel." The National Park Service has now designated this building as The Wallace Pratt Ship-on-the-Desert Research Center, and it is a useful dormitory for research geologists, biologists, botanists, ecologists, environmentalists, and cave experts needing a home within park boundaries.

During his retirement years, Pratt set up a consulting office in Carlsbad to which he would commute in his airplane or in "his" of "his-and-hers" Mercedes Benz—back in a time when NO Americans bought foreign cars.

He also drilled a few oil wells on his own, many of which were successful! It was also in 1945 that Pratt was named the first recipient of the highest honor awarded by AAPG: The Sidney Powers Memorial Medal. In presenting this medal to him, another pioneer oil finder, Everett L. DeGolyer aptly summarized Pratt's contribution by saying, "He has raised the profession of petroleum geology to an eminence and a dignity which it would not otherwise attain." To all such honors, Wallace Pratt modestly replied, "I was lucky. The time just happened to be ripe for someone with my bag of tricks to come over the pike."

1946–1947: Wallace Pratt traveled extensively as one of the first AAPG distinguished lecturers. He predicted that enormous quantities of oil and gas would be found by offshore drilling on continental shelves all over the world, and that eventually we would need to use solar energy also.

1948: The Pratts lived in Washington where he served as assistant chairman of the National Security Resources Board. It was at this time that the American Institute of Mining and Metallurgical Engineers awarded him the Anthony Lucas Medal.

1950–1959: Many more honors came to Wallace Pratt. The president of Columbia University, Dwight D. Eisenhower, gave him the university's James Forman Kemp Medal. API presented him with the Gold Medal for Distinguished Achievement. Both AAPG and the Roswell Geological Society made him an honorary life member. I attended the latter presentation where the president talked at length about all of Wallace Pratt's achievements. When Wallace was finally allowed to speak, he thanked the president and quietly added: "I got so enthused listening to that marvelous introduction that I couldn't wait to get up here to hear what I had to say."

1960: When Iris Pratt's arthritis needed more treatment, they moved to Tucson, Arizona. As a young geologist, Wallace had longed to see granite, which Kansas did not have at the surface. He was overjoyed to spend his last years walking around some of the oldest granite on the continent. They first offered the McKittrick Ranch to son, Dr. Wallace Pratt, Jr., provided he would live on the ranch. He wasn't interested. This triggered the first of three acreage donations totaling about 5,632 acres to the National Park Service which he felt would be the ablest custodian of the beautiful scenery of McKittrick Canyon as the nucleus for the future Guadalupe Mountains National Park. This grant was made with concurrence of his heirs. They donated about one-third of their acreage to the park including the McKittrick cabin and the Ship-on-the-Desert and retained about two-thirds as a working cattle ranch. Then Wallace and Iris Pratt built a third house on the ranch for the enjoyment of the family. The following year, Iris persuaded Wallace very reluctantly to give up flying at the age of 76.

1969: Wallace was the keynote speaker at the dinner honoring him and others being inducted into the Permian Basin Hall of Fame in Midland, Texas. Throughout his life, he was a generous contributor to the University of Kansas and the AAPG where an office tower at the Tulsa headquarters is named after him. But one of his most lasting gifts was the one he gave to you and to me: the everlasting beauty of the Guadalupe Mountains and their canyons. Today when we come to the visitor center we hear a tape extolling the natural beauty and geological significance of this "prettiest spot in Texas." It is Wallace Pratt's voice urging us to enjoy the same things he enjoyed here: "tongues in trees, books in the running brooks, and sermons in stones."

Wallace Pratt stayed up late on Christmas Eve in 1981. He was dictating letters to his friends. He passed away as gently as he lived on Christmas Day at the age of 96. As Pratt himself said many times to others: "Vaya con Dios."

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Chapter 41

The Role of History in Managing NPS Areas

DWIGHT T. PITCAITHLY, Ph.D., is the chief historian for the National Park Service. He has worked as an historian for the National Park Service on a variety of projects for the past 10 years.

If mountains are good for the soul, then the Guadalupe Mountains are good for my soul. Having grown up here, they have been part of my existence for as long as I can remember; they were magical and mystical and very seductive for me as a boy scout. I went camping and hiking in and around them during the 1950s. I knew men who had hiked to the top of the Guadalupe Peak and I held them in awe. I could imagine that, but I never did it until about five years ago. I am sure it was a lot easier when I did than when they did. My first excursion into the Guadalupes wasn't until 1963 as a laborer at Carlsbad Caverns when Dick Stansbury, who then was chief of maintenance for the park, and I went out to McKittrick Canyon to the Wallace Pratt Lodge, the first Pratt cabin. (Just for the record I picked up trash the first season and cleaned toilets the second season.) I think we got a refrigerator out of there and took it to the dormitory at Carlsbad Caverns. That was my first entry into the heart of the Guadalupe Mountains. I was of course quite taken by that. I remember that when I was returning from Vietnam in 1966, I had shipped back and spent a month in San Diego and then got a leave of absence, or whatever you call it, furlough. I remember getting on the bus in El Paso and getting a left hand seat so I would be sure and see the Guadalupes as they loomed ahead. And it wasn't until I went through Guadalupe Pass I knew that I was home and everything was going to be okay. I have a painting of the Guadalupe Mountains in my dining room so that I get a good dose of the Guadalupes every day, and I plan on a long engagement with the Guadalupes, getting to know more of it over a long period of time. My will stipulates that after my demise and cremation, I am to be sprinkled in the Guadalupe Mountains. I can't say I'm looking forward to that, but it's there nonetheless.

Let's talk some history. One hundred years ago, William James wrote of being in the mountains of North Carolina and seeing what he perceived as pure squalor. "The forest had been destroyed," James wrote. Settlers had killed all the trees, planted their crops around the stumps, and built crude cabins and crude fences. The result was hideous, a sort of ulcer, without a single element of artificial grace to make up for the loss of nature's beauty. Ugly indeed seemed the life of the squatter. But as he became better acquainted with the region and its inhabitants, James began to view the landscape through their eyes. "When they looked on the hideous stumps," he wrote, "what they thought of was personal victory. The chips, the girdled trees, the vile split rails spoke of honest sweat, persistent toil, and final reward. The cabin was a warrant of safety for self, wife and babes. In short, the clearing which to me was an ugly picture on the retina was to them a symbol redolent with moral memories and sang a very paean of duty, struggle and success" ("On a Certain Blindness in Human Beings" in William James: Writings, 1878–1899).

Perceptions shape the way we look at things: the natural world, history, other cultures, our own culture, the federal government. Perceptions are based on our own experiences, knowledge, ethnicity, social circles, economic status, political outlook, and geographical roots. Even as we thought we understood the concept of nature, William Cronon, Richard White, and others are challenging us to think about it in new

Perceptions shape the way we look at things: the natural world, history, other cultures, our own culture, the federal government.

and different ways, even suggesting that wilderness is a cultural construct and not an environmental abstract. Bill Cronon in particular has opened our minds to the idea that the American landscape of 1492 and after had been shaped and molded by Native Americans for generations, and the concept of virgin forests was, in reality, not so real.

Historians regularly deal with the wonderfully interesting intersection of history, myth, and culture. Many of our most cherished cultural traditions are built not on solid historical documentation but on cultural traditions that help us make sense of a sometimes confusing and dissonant past: Washington praying in the snow at Valley Forge, Betsy Ross sewing the first flag. I'll not mention Washington chopping down the cherry tree.

The National Park Service harbors its own cultural traditions. For decades the Washburn expedition of 1870 through Yellowstone served as the genesis of the national park idea. It is now more completely understood as the origin of a happy partnership linking first the Northern Pacific and later other railroads with tourism and national parks. (For years the diorama of the expedition in the Department of the Interior museum carried the mythic tradition. A second label put up in recent years adds an additional layer of understanding to that event.)

What is a useful history to one generation does not work for the next, thus prompting a reconsideration or reassessment.

But we don't like to have our perceptions of truth challenged, our contemporary perceptions or our perceptions of the past. We get comfortable with the worlds we create, and yet we know instinctively that our truths are not universal, that others have perceptions that are different from ours, and that the open discussion of those differences can be intellectually and emotionally stimulating and—gasp—may even prompt us to modify our previously assumed truths. Historians in particular see their work as evolutionary. What is a useful history to one generation does not work for the next, thus prompting a reconsideration or reassessment or to use the other "R" word, revision, of the past. Indeed, history has a way of bringing us up short. Just as we think we have it all figured out: everyone in their place, events all in order, someone, usually a historian or writer of some vision comes along and stirs the pot, reorders the past, adds new players to the game, gives us a different perspective on the past, encourages us to think differently about what we thought we knew, adds a new and different voice to preconceived notions about "the olden days."

That is as it should be, the way it has been since written history began. We know this in our personal lives. We know that our perceptions of events change as we age, as we mature, as we move from place to place, as we learn more through reading and thinking about events we witnessed earlier. (Those who have experienced war certainly know that firsthand accounts of battles differ depending on whether the author was an officer or enlisted, whether the account was written immediately after or decades later.) It is, I think, those evolving perceptions about the past that imbue the profession of history with the excitement that currently characterizes its conferences, journals, and stimulating discussions over breakfast and beer. A sense of anticipation: what will Bill Cronon or Donald Worster or Patty Limerick do to us next?

Interesting then—isn't it?—that as a society we have trouble accepting different interpretations of the past. We tend to want a seamless unchanging past; one that reaffirms assumed truths; one that minimizes conflict and embraces a dominant narrative of progress, upward mobility, and success all leading to happy endings—sort of an Ozzie and Harriet version of history. The western writer Wallace Stegner thought the formation of a mythic past, personal and collective, cuts us off from not only our past but from ourselves, and thus hinders our ability to know how to adapt wisely and responsibly to our environment and to changing contemporary conditions. Our understanding of the past is not a monolith, rigid and static, but dynamic and fluid, and we search for truths knowing that ultimate truth will always elude us. Historians also understand now that our understanding of history comes not just from the written record but from various remnants from our past. Perhaps Stegner said it best (I am a Wallace Stegner fan) when he wrote, “The past becomes a thing made palpable in the monuments, buildings, historic sites, museums, attics, old trunks, relics of a hundred kinds; and in the legends of grandfathers and great-grandfathers; and in the incised marble and granite and weathered wood of graveyards; and in the murmuring of ghosts” (from Wolf Willow 1962).

It is the historian’s responsibility to listen to those murmurings and legends, visit monuments and graveyards alike, examine “relics of a hundred kinds.” Historians look for and interpret stories. Historians in the National Park Service look for stories that connect us with specific places. They link relics—those physical, tangible reminders of our collective past—to us in the present and give them purpose and meaning. Historians approach natural parks no differently than they do cultural parks; indeed, over the past decade or so, we have seen the lines blur between our artificially imposed labels of “natural” and “cultural.” Is Saratoga National Historical Park with its forests and fields and creeks a natural park or a cultural park? The blending of professional sensibilities at such places is a healthy development for the [National Park] Service, as I will note later.

Because we now recognize the impact of human occupation on all of your parks, we recognize increasingly that historical information provides the beginnings of a framework for understanding the natural processes of place. To know that indigenous people used fire on a regular basis to renew vegetation, clear land, or herd wildlife gives us insights regarding nature of the landscapes we have been charged with preserving.

It is not surprising, then, to remember that one of the first studies commissioned by the National Park Service at Guadalupe Mountains National Park was a historical overview of human occupation and use of this park. That was quickly followed by a structural and archeological survey. The latter was accomplished under contract with Texas Tech University during the 1970s where I was then a graduate student in history. (I missed out on that contract, but a year later drove Tech’s 1953 surplus Air Force ambulance, all 7,000 pounds of it—you can talk to Paul and Susana [Katz] about their driving it earlier—to the Arkansas Ozarks where I constructed the same sort of structural survey along the Buffalo River.) Baseline information from historians and archeologists enable us to chart a clearer course in all our management activities.

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The second area where historians play a major role in managing natural areas is through the preparation of administrative histories. These studies do not focus as much on the resources of the park, but on how the National Park Service as an agency has managed those resources over time. They provide an introspective look at a federal agency that historically has not been very introspective. If they are worth doing (and they are) they are worth doing right, and that means producing an unvarnished analysis of the failures as well as the successes of park management. These histories should not be laudatory, although praise when deserved is always appreciated. Instead, they should provide us a clear sense of where we have been so we can increase the chances that the decisions we make in the future will stand a better chance of being right (or at least more right). Administrative histories are done individually (involving one park) or collectively (involving multiple parks or processes). Had Hal Rothman stayed around, I would have said something about his work, but since he chose to leave before I talked, I will not mention Hal Rothman and his contribution to our understanding of us and our agency.

I would be remiss in my comments if I didn’t mention three recent administrative histories that are shaping the future of natural resource management throughout the National Park Service. Linda Flint McClellan’s *Building the National Parks: Historic Landscape Design and Construction* published by John

Preserving Nature in the National Parks has been embraced by the bureaucracy and is being used to alter the course of the agency.

Hawkins University Press provides a historical perspective on how the National Park Service conceived and constructed its own brand of cultural landscapes. Ethan Carr's *Wilderness by Design: Landscape Architecture and the National Park Service* just out by the University of Nebraska Press is a parallel work that looks closely at the design of complex built landscapes such as historic districts in several national parks. And finally, I must make mention of a book I trust all of you have read or will shortly read: *Preserving Nature in the National Parks: A History* by Richard West Sellars represents the critical analysis of National Park Service management practices at its finest. (They didn't pay me to give this plug, but I notice there are a stack of books out there that I'm sure the purveyors would just as soon not take back to their office. So if you don't have a copy, please get one.) Sellars has provided us an unblinking assessment of how this agency has done during its first 80 years of managing natural resources in the parks. It is critical and fair and it prompted the director to initiate an overhaul of the natural resource management program, an overhaul being discussed and refined this week during the National Leadership Council meeting in Washington. It was not without a little trepidation that Sellars offered his book to the National Park Service. An earlier generation of managers would not have received [it] so acceptingly. I think it is an encouraging sign of the maturation of the National Park Service that *Preserving Nature in the National Parks* has been embraced by the bureaucracy and is being used to alter the course of the agency. We should all be thankful that Richard Sellers had the experience within the agency and the training and perspective of an environmental historian to craft this marvelous book. We should also be thankful that Regional Director John Cook had the vision to support—without hesitation—what turned into an almost decade-long labor of love for both men.

Finally, I should mention the work of other historians whose vision at the global scale help us understand the natural world in historical perspective and the role of human occupation within it. Bill Cronon, Don Worster, and Richard White, among others, have prompted us to think differently, to conceptualize our work more broadly, to examine and question our purpose and goals more thoroughly. Their work constantly reminds us of the seamless interconnections between nature and history, between natural processes and human activities through time.

Managing the national parks into the 21st century will require greater attention to balancing visitor use with preservation of natural and cultural resources. How do we manage wilderness areas that reflect 18th and 19th century human occupation? How do we effectively preserve historic places that contain rare and endangered species? How do we deal with historic places threatened by natural processes?

These are not easy questions, and they do not engender easy answers. Today the National Park Service has not one mandate, but many mandates. We are the creation of congress, and while we take our lead largely from the Organic Act, we also are bound by subsequent directions from congress: the 1935 Historic Sites Act, the 1964 Wilderness Act, the 1966 National Historic Preservation Act, the 1969 National Environmental Protection Act, and many others. Our job is to balance these various charges in such a manner that respects the integrity and significance of all the resources within our care. During the 1960s the National Park Service divided our resources—your resources—into three categories: natural, historical and recreational. Today the value of hindsight has taught us that a more holistic approach to resource management not only makes more sense, but also matches the reality of our circumstance. Many of our parks reflect an intertwining of the natural and cultural, and yes, the recreational. My personal view is that it is unfortunate that the discipline of cultural geography was not embraced by the National Park Service when it began to be developed during the 1920s. Instead of looking at individual resources, we could have been looking at systems of resources and appreciated how the natural historically affected the cultural and how the cultural naturally affected the natural. We now know that almost every place we manage was altered in some fashion by human hands prior to our coming on the scene. There are no vignettes of a primitive America. New England was practically denuded of trees by the middle of the 19th century and had been altered extensively prior to 1620. Yosemite was manipulated by fire prior to European exploration.

Our management policies now are, I think, (I hope, since we are revising them this year) less combative between the resources than in the past. Our battlefields and other cultural landscapes are places where the various disciplines come together for common purpose, and that model is being implemented elsewhere, even here in the Guadalupe Mountains. The Vail Agenda suggests that the National Park Service is being looked at as an international model of "conservation and preservation management—a model that can teach valuable lessons to a world increasingly concerned with environmental degradation, threats to wilderness values, and rapid cultural and historical change." To meet that challenge, we must acknowledge the connections between the natural and cultural spheres and manage them as wholes, not parts.

I would like to conclude with three thoughts—all borrowed. The first comes from William Cronon in his introduction to *Uncommon Ground: Rethinking the Human Place in Nature*. Cronon writes, "A cultural tenant of modern humanistic scholarship is that everything we humans do, our speech, our work, our play, our social life, our ideas of ourselves and the natural world, exist in a context that is historically, geographically and culturally particular and cannot be understood apart from that context." The National Park Service is a political entity created by congress 82 years ago. It continues to be shaped by that legislative body. To be effective, we must understand the context of the time in which we were created and understand the context of the times in which we work.

Part of what makes our work so challenging and exciting is that we all don't come to the table with the same set of perceptions, knowledge, and sensibilities. We manage our parks and our resources between and around differing interpretations of the past, different sensibilities of our policies, and differing understandings of our missions. It is those places where disparate points of view rub together—the spaces between—that I and others find so interesting and enlightening. Barbara Kingsolver, author of *High Tide in Tucson: Essays from Now or Never* and many other books, enjoys those conflicting belief systems—those spaces between—between men and women, North and South, white and non-white, communal and individual, and I would add, natural and cultural. It is through our better understanding of, and respect for, the spaces between that we will be able to manage our lands for the benefit of America in the 21st century. It is within this broader social and intellectual framework that the National Park Service reflects the "land, the cultures, and the experiences that have defined and sustained the people of the nation in the past and upon which we must continue to depend in the future."

Part of what makes our work so challenging and exciting is that we all don't come to the table with the same set of perceptions, knowledge, and sensibilities.

Finally, I will turn to Joseph Sax, who in his superb analysis of the origin of the national park idea concluded, "To speak of man as the measure of all things is not only a cliché but to describe a world in which the rhythm of life is tuned only to the pace of human enterprise. It is not that we are necessarily going too fast but that we risk losing contact with any external standards that help us to decide how fast we want to go. It is the function of culture to preserve a link to forces and experiences outside of the daily routine of life. Such experiences provide a perspective—in time and space—against which we can test the value, as well as the immediate efficacy, of what we are doing." Historians function at the intersection of the natural rhythm of life and the cultural context of human enterprise. They bring the historical perspective of our natural and cultural worlds to the National Park Service's management table. That table, we now understand, is large enough to accommodate a wide range of perspectives and professions. And we are better managers because of it.

Chapter 42

Eyewitness Details and Perspectives: The Value of Oral History at Guadalupe Mountains National Park

ROBERT J. HOFF has served at Carlsbad Caverns National Park for the past 12 years; he is the park historian. He has held positions in interpretation and visitor services throughout his 27-year career with the National Park Service.

Voices from the past. Voices of people who went before us—and who now consent to share with us what they experienced and felt. The historian who conducts oral history interviews "captures" on tape—and later through transcription—the stories, insights, and perspectives of "people who were there;" actual eyewitnesses to a period of history interesting to that particular historian and to others.

Many of these voices from the past do nothing less than enlarge the horizons and understandings of those of us in the present. Don't we often understand and enjoy more about a historical place or time or person when we take the opportunity to listen to those with personal connections with those places, eras, and people?

In his 1985 book *Oral History for Texans* Baylor University Professor, Thomas L. Charlton, wrote:

> Who can argue against the potential good that lies in capturing the accounts and voices of people employing their memories as they describe their personal and social experiences? Who could possibly oppose the preserving of first-person recordings that may help overcome the growing shortage of personal diaries, elaborate correspondence, and other primary sources which, until recent years, were standard items in families, businesses, and other elements of society?

Charlton, who has been in charge of the Baylor University Institute of Oral History since 1970, notes elsewhere: "Oral history holds out some hope that information thus gathered informally about the past will enable both living and future generations to grasp what it was like to be alive during any given past era." Certainly oral history is a good opportunity to "grasp what it was like to be alive during any given past era."

Many of these voices from the past do nothing less than enlarge the horizons and understandings of those of in the present.

Let me admit right here that oral history is but only one way to understand the story of Guadalupe Mountains National Park. In 1990 Judith Fabry published *Guadalupe Mountains National Park: An Administrative History*, a very thorough, well-organized, and interesting historical account of the park. In addition, Professor Hal K. Rothman is currently preparing a well-researched historical resources study for Guadalupe Mountains National Park and Carlsbad Caverns National Park.

If such historical studies exist, why should historians bother with conducting more oral history interviews? For several reasons, oral histories have their own value.

1. Oral history interviews often result in fresh "points of view" or perspectives that illustrate an historical topic from a different angle.
2. Oral history interviews often reveal "choice" specific details never before revealed in other sources. Such details may result in some historical person or event coming into better focus; such details may also result in

some new connection being made between a Cause A and an Effect B, between Person A and Person B, or between Motivation A and Behavior B.

3. A person mentioned in an interview often becomes a historical source to be contacted later by the interviewing oral historian. These unexpected “leads” sometimes prove to be rewarding in separate research value themselves.
4. Oral history interviews often present historians with contrary points of view, a reminder that every issue has an array of perspectives, and that all perspectives must be weighed and considered in interpreting history.

“Oral history is as reliable or as unreliable as other research sources. No single piece of data of any sort should be trusted completely.”
—Donald Richie

Historian Donald Richie declares that “oral history is as reliable or as unreliable as other research sources. No single piece of data of any sort should be trusted completely, and all sources need to be tested against other sources.”

Recently I did an oral history interview with Carlsbad Caverns Management Assistant Bob Crisman. With the help of several others, we conducted 15 interview sessions, lasting a total of 20 hours. Known for his keen interest in history, for his attention to detail, for his marvelous history files kept over 40 years in the National Park Service, and for his devotion to National Park Service goals and ideals, Crisman proved to be a knowledgeable, willing, interesting, and articulate oral history interviewee.

Crisman worked at Carlsbad Caverns National Park from 1957 to 1960 and from 1970 to 1996. He split the 1960s decade about in half working at Montezuma Castle National Monument in Arizona and Fort Davis National Historical Site in Texas. During the period 1972–1987 when Guadalupe Mountains National Park was administered by Carlsbad Caverns National Park, he served first as a staff interpreter and from 1974 on as the management assistant. During these 15 years, he worked directly in the operations of Guadalupe Mountains National Park.

During the interview, Crisman recalled that the bill to authorize the park was signed on October 15, 1966, by President Lyndon Baines Johnson (who himself was the subject of a wonderful 1980 oral history work entitled *Lyndon: An Oral Biography* by author Merle Miller) six years before the park was established. Before the park could be staffed and opened, land and mineral rights had to be acquired.

In those six years before the park would be established (1966–1972), Crisman said, “it was kind of a nebulous period in there; we were getting public use even though we weren’t officially opened.”

Actually National Park Service involvement in the area had started in 1959 when Wallace Pratt, a highly respected petroleum geologist and conservationist who first came to the Guadalupe Mountains area in 1921, bestowed the first of three donations totaling 5,600 acres in McKittrick Canyon; that land was administered as a detached section by Carlsbad Caverns National Park, like Rattlesnake Springs is today. In the early 1960s, rangers had started living in the Pratt house near McKittrick Canyon with the picturesque name of Ship-on-the-Desert.

In September 1997, the park celebrated the 25th anniversary of its September 30, 1972, dedication. Crisman recalled that at the original 1972 dedication the count was 2,424 people, and “I remember myself and others having to make a lot of phone calls to help generate that crowd. We got a lot of school kids from Van Horn and Dell City out there.” Julie Nixon Eisenhower was the principal speaker; Crisman recalled writing suggested material for her to use if she cared to use it. Congressman Richard White, Senator Ralph Yarborough, and Assistant Secretary of the Interior for Fish, Wildlife, and Parks Nathaniel Reed were present. Also present was Caverns Superintendent Donald Dayton and one of Dayton’s predecessors, former Caverns Superintendent “Colonel” Tom Boles (1927–1946), age 90, ailing, and in a wheelchair.

Crisman also noted that the Cavern Supply Company provided a free barbecue lunch for over 2,400 people—a very generous gesture. Cavern Supply was formed in 1927 at the Caverns, the same year that Colonel Boles arrived to take charge.

I asked Crisman if the proposal for national park status for Guadalupe Mountains had been opposed. He replied that, "Beginning in the 1960s, I think people recognized the national significance of the reef and the reef formation. Of course, initially back in the 1930s NPS officials Roger Toll and later Ben Thompson proposed that the Carlsbad Caverns National Park boundary be extended all the way down to Guadalupe Peak and El Capitan, and include all that area including Big Canyon." He added, "In the 1920s and 1930s, Judge J. C. Hunter, Sr., who lived in Van Horn, Texas, had started talking about a state park in that area from McKittrick, El Capitan, and Guadalupe Peak…it was from Judge Hunter's son, J. C. Hunter, Jr., that we later bought the bulk of the land for the park…. So initially this area was looked at as an addition to Carlsbad Cave National Monument, but other folks were looking at it as a state park. But my impression is that by the 1960s many [people] pretty well recognized that the land was probably national park quality."

Once dedicated, the new national park faced major development concerns: water was needed, housing was required, and visitor facilities were essential. The first building was acquired from the FAA buildings at Salt Flat and moved up to the park and became the Frijole information station with Ranger John Hollingsworth living in a back room. On June 6, 1972, when Ranger Hollingsworth was not home, someone tried to burn it down. A motorist passing at 4:20 a.m. reported the blaze and a quick response by firefighters saved this building from total destruction. A can with flammable liquid was found in the building, but no perpetrator or perpetrators were ever caught.

Later a double-wide trailer was moved in as a temporary visitor center. The actual building of a permanent visitor center was much farther down the road than anyone might have suspected. For example, in 1977, according to Crisman, visitation was continuing to climb and reaching 91,878 visitors that year. The Frijole visitor contact room remained just 10-feet-by-15 feet, with one restroom. And one particular day the park hosted 1,000 visitors trying to compete for that one restroom and 10-by-15 room. Crisman said, "we were beginning to get a little desperate for a visitor center by then."

At one point, the amount of money being spent on the National Visitor Center, a railroad station in Washington, seemed to be drawing much negative criticism from congress. At this time the name "visitor center" seemed to be a lighting rod for congressional criticism. In response Crisman reported that they changed the name "visitor center" on all the official paperwork to "operational headquarters." This semantic slight of hand had even a slighter result—nothing.

In 1986, the visitor center reached a turning point when Congressman Ron Coleman, who had replaced Congressman Richard White, secured a $250,000 budget add- on which enabled drawings and specifications to be finished for the visitor center.

In December 1987, congress appropriated $3.65 million to construct a 10,000 square foot visitor center. The long awaited and much needed visitor center was finished in the late 1980s. If the six years which passed between the authorization of the park in 1966 and the dedication of the park in September 1972 had seemed long, the 16 years waiting for a permanent visitor center must have seemed like an eternity. Crisman recalled that on several occasions in reports and other correspondence, officials at the park penned the phrase, "the lack of public use facilities in the new park, coupled with rapidly increasing public use of the area, has created serious problems."

In the 1930s NPS officials Roger Toll and later Ben Thompson proposed that Carlsbad Caverns National Park boundary be extended all the way down to Guadalupe Peak and El Captian.

Crisman noted a serious problem: the lack of a proper contact station actually posed a safety issue, for the park lacked a place to give out safety messages to hikers headed for the backcountry.

The visitor center wasn't the only development worry facing the determined staff. Housing had to be secured. In the beginning, housing consisted of leftover trailers from the FAA. Recently, I E-mailed a questionnaire to Bruce Fladmark, an area manager at the Guadalupe Mountains in the 1970s. Fladmark wrote me that the trailers were "pre-wornout." Worsening the situation of the poor quality housing in the early years was the incessant wind. Crisman reported that a maintenance boss named Herschel Fowler arrived and had to unload his own stuff into a trailer during 100-miles-per-hour winds. Crisman recalled that Fowler, a particularly gruff, but effective boss, didn't stay at Guadalupe Mountains too long. Crisman conceded that maybe Fowler "had to be a tough guy for tough conditions."

The wind underscored life almost on a daily basis at Guadalupe Mountains.

The wind underscored life almost on a daily basis at Guadalupe Mountains. The unrelenting wind seemed to underscore the harshness of the climate and the remoteness of the region. Crisman told several stories about the wind, including that the wind was once clocked in excess of 110 or 120 miles per hour at Guadalupe Mountains. In February 1979 the wind blew over an 18 wheeler truck and the park's radio antenna. It also blew over two camper vehicles belonging to visitors. Fladmark told me that on the same day Superintendent Donald Dayton and his staff had traveled to Guadalupe Mountains "to speak to the employees and answer questions (quell discontent)." Fladmark added, "The noise of the wind was so loud in our maintenance shed that neither questions nor answers could be heard, so the meeting at least demonstrated adverse living and working conditions to park management. Later that day the wind picked up enough rock to destroy the windshield of my park pickup. I was driving at the time." Once, high winds blew a maintenance employee into a fence, breaking his wrist and dislocating his shoulder. Another time the wind turned the McKittrick Canyon contact station trailer on its side.

The park needed water sources. Several wells were drilled in the main housing and visitor contact area, several unsuccessful before workable wells resulted. In several cases like Pine Springs and Signal Peak, wells were drilled several thousand feet. Dog Canyon required four wells before adequate water supplies were reached.

Water wasn't always in short supply at Guadalupe Mountains. In September 1974, the park got more water than it wanted when McKittrick Canyon flooded, running four feet deep and 100 feet across.

The early efforts for shelter, water, and visitor facilities seemed always tougher because of the wind. Fladmark remarked, "We spun our wheels a lot just to exist there."

"Waiting and more waiting" seemed to be the theme at Guadalupe Mountains National Park in the 1970s and 1980s. Crisman said, "The National Park and Recreation Act of 1978 passed on November 10th, officially designating 46,850 acres of wilderness. Of course, this was six years after the recommendation had gone to Congress, so it did take quite a while to get that approved."

If wilderness preservation in 1978 was part of the big picture at Guadalupe Mountains, an important part of that picture was the protection of the mountain lions residing in the national park. Crisman reported that "Ranger Harry Steed made the big discovery of illegal trapping; he found some traps that were stamped with New Mexico Department of Game and Fish markings, probably set by some area rancher. These people were taking the lions illegally out of the Dog Canyon–West Dog Canyon area and transporting them across the state line. Apparently some [lions] were found skinned, but I don't think anyone ever made a case for convicting anyone. But I think the publicity, the discussions, and the interviews had a deterrent effect. I think that was the last incidence of anyone, as far as we know, trapping in the park. Of course, our concern was not only losing the lions, but with visitor safety; some of these traps were not far off of visitor trail routes where a visitor could have been injured.

I asked Crisman if that was typical for the New Mexico Department of Game and Fish to give people traps like that? He replied that, "they would sometimes loan out traps to ranchers in known depredation cases resulting in livestock losses. Harry Steed was in the middle of that situation; of course, tensions increased with the neighbors because of his discovery. Harry was completely businesslike. He was a very professional law enforcement person, though he didn't have that friendly rapport with the neighbors that some of the other rangers had, but he was good at his job. Later on, we switched Harry over to Rattlesnake Springs and replaced him with Roger Reisch, partly to ease the strained tensions with the neighbors.

Crisman shared a lighter story about wildlife in the area. He said, "There was another incident that you may have come across. I thought it was interesting. A black bear, after he was discovered in a nearby alfalfa field, was treed on a power pole down near Dell City. Of course people were standing all around, trying to get him to come down. And, of course, he wasn't coming down until all the people dispersed. Once the people were removed, he came down and headed off toward the park and up toward the mountain."

Crisman also shared an unusual law enforcement story. He said, "In 1980 [there] was the incident about the greyhound bus, one of the law enforcement incidents. I didn't get involved in that, but I did find it interesting in reading and hearing about it. This greyhound bus was traveling through Guadalupe Pass and there was an emotionally disturbed man on board and he decided he was going to attack the driver; there was a Catholic nun on board, who was able to pull him off the driver until the driver could get the bus stopped. Then the guy jumped off the bus and apparently fell about 70 feet there in that Guadalupe Pass area, was knocked unconscious, and the rangers had to get involved and rescue him. I guess they ended up flying him by Fort Bliss helicopters to El Paso. I never did hear the outcome of him or what happened, but at least that got the problem out of the park for somebody else to deal with. [Laughs]"

The following year, a different challenge was posed in an unusual incident. He recalled, "In 1981 a lot of construction going on over at Dog Canyon with many utility trenches opened up. A big old elk had fallen in a utility trench and landed upside down, with his feet up in the air, and with his back and bottom in the trench. Ranger Roger Reisch wasn't sure how he was going to get the elk out of the trench; he went to get rancher Marion Hughes and some of the other neighbors. With the trucks and ropes, the rescuers were able to pull this big elk out of that trench. Apparently the elk wasn't hurt and went on his way after being pulled out; Roger and the others also went on their way."

"And then there was a turkey trapping and relocation incident: Bob Stockwell, who was the county manager at that time, kept reporting to us about these overly aggressive wild turkeys over at Dog Canyon. I think they may have been some that had been fed, and so they'd come up to visitors expecting handouts. So the turkeys were starting to chase the campers around, and the campers couldn't chase 'em back. I think Roger ended up catching several of them with some help. They packed the turkeys by horseback from Dog Canyon over to the McKittrick Canyon area somewhere and turned 'em loose. Later, Roger put his horse in for a performance award." (The horse received a sack of oaks.)

The Guadalupe Mountain National Park stories in Crisman's oral history interview continue, revealing increasing details about life at Guadalupe Mountains.

The Guadalupe Mountain National Park stories in Crisman's oral history interview continue, revealing increasing details about life at Guadalupe Mountains in the 1970s and 1980s, but this paper must come to an end. Other topics discussed in Crisman's interviews include the proposal for the tramway; the wheelchair-bound visitors who climbed to Guadalupe Peak; the building of backcountry trails; the intermittent search and rescue efforts of lost victims, including three wilderness study groups; the development of a park's interpretive program; the preserving of historic structures; and more—all against the backdrop of high winds.

For understanding the history and uniqueness of Guadalupe Mountains National Park, Bob Crisman is a voice from the past, a voice who can enlarge our horizons and understandings about an incredibly beautiful and special place. All we have to do is listen.

Interpretation

Chapter 43

The cave impact monster: an environmental education skit for classrooms

RANSOM TURNER is the cave resource specialist for the Guadalupe Ranger District of the Lincoln National Forest. He has been at this location for 13 years and has developed an environmental education program about cave resources.
Other authors: CYNDI MOSCH, JACKIE TURNER, and SUSAN HERPIN

Introduction
Having recognized education as being essential to the protection of cave resources, the Lincoln National Forest, Guadalupe Ranger District, has developed a diverse educational program. Cave visitors receive this education through brochures and interaction with U.S.D.A. Forest Service cave specialists leading them on cave tours and volunteer projects. The long range education goal, however, is for the public (including children) to become aware of and grow to appreciate the intrinsic values and benefits derived from cave and karst resources.

To this end, the original "impact monster" skit was developed by Jim Bradley of the Eagle Cap District on the Wallowa Whitman National Forest in the 1970s. It has been used by rangers to convey minimum impact messages in an effort to improve visitor behavior. This skit has been adapted to a variety of geographic areas and management issues. The Guadalupe Ranger District has modified the skit to become the "cave impact monster." This will be used to increase the awareness and understanding of cave and karst resources with a target audience of elementary school children. Audience participation is a fundamental component of the skit.

Script: the cave impact monster

Characters:
A Sleepy Bat
A Curious Bat
Cave Cricket One
Cave Cricket Two
Sal the Salamander
Tall Stalagmite
Short Stalagmite
Stella Stalactite
Stanley Stalactite
Fragile Cave Flower
Mighty Microbe
Cave Ranger
Speleologist
New Caver
Cave Impact Monster

Narrator: [Introduce yourself.]
Did you know that caves are fragile? Today, we'd like to help you learn more about caves and how to protect them. We're going to do this with a special activity in which everyone gets to participate.

[Introduce other three Forest Service participants, briefly, by name only.]

Who knows what impact means? ["Change" is the word we are looking for.] A good example of an impact is a baseball being hit through a window. The window breaks from the impact, and unless it is fixed, there will be changes inside: dust can blow in, temperature can change, etc. One small change in a cave can also cause other things to change. Impacts bring changes, both good and bad. In caves, the biggest changes are often made by visitors. There are three basic types of impacts: temporary, long term, and permanent. During this skit, try to notice these different types of impacts.

Narrator: Today we will visit a special cave, one that hasn't seen many visitors.

Having recognized education as being essential to the protection of cave resources, the Lincoln National Forest, Guadalupe Ranger District, has developed a diverse educational program.

[If time allows have the group select names for the cave: Shall we choose a name for this special cave? Take a vote on the best of three suggestions. The cave name will go on a banner near the cave entrance. What do you think belongs in this cave? Audience makes suggestions and each is rewarded with roles for each part in the cast.]

Speaking roles [cards with lines are given to participants]:
Cave fauna:
- A Sleepy Bat
- A Curious Bat
- Cave Cricket One
- Cave Cricket Two
- Sal the Salamander
- Mighty Microbe

Speleothems:
- Tall Stalagmite
- Short Stalagmite
- Stella Stalactite
- Stanley Stalactite
- Fragile Cave Flower

Cavers:
- Cave Ranger
- Speleologist
- New Caver
- Cave Impact Monster

Props [If time allows have members of the audience put prop in place and then sit down.]:
- Pool
- Cave Pearl Nest
- Flagged Trail

[Speleothems and cave fauna are now assembled on stage.]

Narrator: Wait, we're missing something! What else is characteristic of a cave? ["Darkness" is the word we are looking for.]

[Dim house lights when darkness is mentioned.]

Narrator: Tall Stalagmite, what can you tell us about yourself?

Tall Stalagmite: [Very confidently] I'm a VERY tall stalagmite, and I'm very old. Fast water dripping on top of me for thousands of years has helped me grow up tall. Listen as I grow.

Cue Card for Audience: [Repeat quickly] DRIP-SPLASH, DRIP-SPLASH.

Narrator: What about YOU, Short Stalagmite?

Short Stalagmite: I'm as old as my taller friend, but the drops on me were slowwww. If you listen carefully, you will hear how slow I grow.

Cue Card for Audience: [Repeat very slowly] DRIP…SPLASH, DRIP…SPLASH.

Short Stalagmite: You know we grow at different rates, but there is more you need to know; we are both afraid of impacts. Oily hands that touch us can stop our growing. Muddy hands leave stains. Dust stirred up by a hurrying caver will dull our shine so please don't rush or touch us, and we'll be just fine.

Narrator: And, who are the two of you?

Stella Stalactite: We're VERY beautiful stalactites, can't you tell!?

Stanley Stalactite: We grow from the ceiling. Crystals grow inside water drops stuck to the ceiling, before they drip to the floor. You can remember us because we have a "C" in our name and we hang from the ceiling.

Narrator: Stella, what are those unusual round speleothems below you?

Stella Stalactite: Why they're cave pearls, and my drips have helped them tumble and polish. Aren't they beautiful and round?

Narrator: And what's that delicate speleothem there? It looks like a flower!

Fragile Cave Flower: I am lovely, am I not? I'm a gypsum flower! I grow where the air dries the moist clay under me.

[The Cave Ranger, Speleologist, and New Caver all arrive at the cave entrance.]

Narrator: Look, everyone. We have visitors at the entrance to the cave.

[Introduce the three new characters.]

Cave Ranger: Are you both ready to go caving? New Caver, I'm glad you could come with us today. To safely enter a cave takes a minimum of three people. And even then, you should always let someone else know where you're going. Plus, I know you'll enjoy the trip today. Caves are such beautiful and interesting places to visit. Do we have the right equipment?

New Caver: I think I brought everything you asked me to, but let's check to make sure.

Cave Ranger: Helmets? [Point to helmet.]

Cue Card for Audience: Check.

Cave Ranger: We can't let our skin touch the formations or they won't grow any more. So does everyone have gloves? [Hold up gloves.]

Cue Card for Audience: Check.

Cave Ranger: Headlamps, extra lights, and batteries? [Hold up backup light source.]

Cue Card for Audience: Check.

Cave Ranger: Food and water? [Hold up water bottle.]

Cue Card for Audience: Check.

Cave Ranger: And if any of you need to go, you better do it now, outside the cave or you'll have to go in a bottle. [Hold up pee bottle.]

New Caver: Oh!

Speleologist: I have my field notebook for taking notes on what we find inside.

Cave Ranger: I have my trail marking tape to replace some of the old flagging tape, to help make a low impact trail that is easier to follow. When we found this cave, the first thing we did was to put in a well marked trail. That way, all of our impact is limited to a small area, and not spread all over the cave, or over very fragile formations.

New Caver: I think I'm dressed warmly enough. I know caves can be cool. I also checked my boots on a rock, like you asked me to. I wouldn't want to leave black boot marks in this cave. It's sure a good thing to go for the first time with someone who's been to a cave before, and who can give me such good advice.

Cave Ranger: Turn on your lights. Let's go! Now remember to move carefully and slowly.

[They turn on lights and enter the cave.]

Speleologist: Be sure to let your eyes adjust to the dark! Be careful where you step here—I see some crickets on the floor by these rocks.

Cricket One: Gee, I'm glad these guys are being so careful. My uncle got squished last week by some careless people—they didn't even look where they were stepping!

Cue Card for Audience: AWWW!

Cricket Two: Oh my, that's awful! Let's go see if we can find some yummy molds to eat.

[The crickets crawl off to eat, wiggling their antennae.]

Cave Ranger: This flagging tape is getting old and starting to crack. We'll replace it. It was good thinking to keep the trail this far away from those stalagmites so they don't turn brown from dust kicked up by people's feet.

Cue Card for Audience: [Applause] Yeah!!

New Caver: Look at those GORGEOUS long stalactites!

Speleologist: Be careful not to bump them with your helmets. Oh! By the way, there is a lovely nest of cave pearls here,

The original "impact monster" skit has been adapted to a variety of geographic areas and management issues.

too! This area hasn't been impacted at all. Everything looks clean.

[Speleologist stops and takes notes.]

New Caver: Look at this beautiful blue pool. Wow! There's a salamander here! He must like it here where it's nice and moist.

Sal the Salamander: I sure do!
I am Sal. Sal I am.
Sometimes I'm called slimy—it's true my skin is cool and wet.
I really hate it dry.
I like to hide beneath the rocks, when I'm feeling shy.
Other times, I'm King of the Pool.
And it's a nice little pool, it's clean, and it's neat.
The water is pure, and there's plenty to eat!

Speleologist: Look! There are some bats over there. Be extra quiet while we're near them and be sure not to shine your lights at them, since it would hurt their eyes.

[Bats are asleep. Bats make snoring noises.]

Cave Ranger: Good work with the trail, everybody. Shall we have lunch?

Cave Team: Yes! We're hungry!

Cave Ranger: Let's move over here away from the pool.

Speleologist: Yes, that's a good idea. We don't want to impact the animals living near or in the pool.

New Caver: Like the salamander?

Speleologist: Yes, and millions of animals that you can't see, like the tiny cave microbes.

New Caver: Microbes!?

[Cave Team looks toward the pool.]

Mighty Microbe: I'm a mighty microbe,
And yes, I'm mighty small.
I live here joined by millions more
In this cave, and that's not all.

We live deep down in cavern pools,
And some other places too.
And if you get to know us,
You'll find what we can do.

Scientists find us helpful
Solving problems people face.
Like fighting pollution, curing cancer,
Or understanding life in space.

Please don't wade in pools or sneeze and drool,
Tie back your hair, and please take care.
We're in the air and everywhere!

New Caver: Gee, I didn't know about cave microbes.

Speleologist: Microbes are very important to scientists. That's one reason we need to be extra careful in caves. We could be having an impact on creatures so small we can't even see them. Microbes are the reason we asked you to make sure all of your clothes and gear you wore into the cave was clean.

New Caver: I had wondered about that.

Speleologist: Bacteria from the surface can hitch a ride into the cave hidden in dirt or mud on cavers' clothing or gear. These surface bacteria can then kill all the microbes in a cave.

[Cave team moves over towards cave flower.]

Cave Ranger: Shall we sit down over here?

Fragile Cave Flower: Wait, I'm here!
I'm a fragile gypsum flower,
My curvy, shiny crystals,
Sparkle in your light.
Please don't stir up dust or crush me,
Or I'll be a sorry sight.

Cave Ranger: Oops! Excuse me. We'll move over here.

[The cave team moves over, away from the gypsum flower. They take out their large plastic bags to eat over.]

Speleologist: Be sure to eat your food over the bags. We don't want to upset the food balance for the animals that live here by spilling crumbs. The creatures in a cave are specially adapted to live on very limited food supplies.

[All eat quietly and carefully. The spele-ologist takes more notes.]

Narrator: Meanwhile, we have ANOTHER visitor at the cave entrance. It's the Cave Impact Monster!

[The Cave Impact Monster arrives, carrying his/her hand lantern and not wearing a helmet.]

Cave Impact Monster: [loud, excited voice] Wow! It was a long hike up here, but I'm sure excited to check out this cave I found last week! I couldn't go in then, because it was DARK, but I brought a GOOD light with me this time and LOTS of string to help me find my way out.

[Cave Impact Monster comes into the cave, unrolling string behind him/her.]

Cave Impact Monster: Hmm, looks like this is a trail. But I'm here to explore! It's got to be more interesting off of this trial.

[Cave Impact Monster leaves footprints on floor.]

Narrator: [Shakes head.] Look at all those footprints he's leaving everywhere.

Cue Card for Audience: Boo!

[Cave Impact Monster walks up to stalagmites. He touches them, leaving a hand print on each.]

Cave Impact Monster: Oooh, these are wet and smooth! The floor is sure slippery here!

[S/He slips and falls. While returning to his/her feet, his/her head knocks Stella Stalactite.]

Stella Stalactite: Ouch! [Stella drops to the floor, on her side.]

Stanley Stalactite: Oh, no!
Stella Stalactite hung from the wall,
Till a clumsy caver caused her to fall.
And all the hard work the Cave Team puts in,
Can't put Stella back together again.

Cue Card for Audience: AWWWW!

[Cave Impact Monster slips again, falling on the cave pearl nest, sending the pearls rolling.]

Cave Impact Monster: What are these, marbles? I can't seem to step anywhere without slipping! Maybe I better go back to the trail.

[S/He moves quickly, stirring up dust (flour).]

Cave Impact Monster: How did it get so dusty here all of a sudden? Oh, I see. [And he stomps to send up another cloud of dust.] Look how far these clouds of dust go. I'm a regular dust devil!

Fragile Cave Flower: I sure hope the dust s/he's kicking up doesn't make it over here, it'll ruin me!

Cave Impact Monster: This caving is hard work. I sure am hungry!

[Cave Impact Monster pulls out a package of crackers, and drops one along with pieces of the wrapper on the floor near pool. S/He takes out another cracker and eats, OBVIOUSLY spilling crumbs. The crickets move in on the crumbs.]

Cricket One: Can you believe all of this?

Cricket Two: [Burps] I won't have to eat again for quite a while!

Sleepy Bat: [Grumpy] What's all that noise? I don't feel like waking up yet! It isn't dark yet is it?

Audience participation is a fundamental component of the skit.

The long range education goal is for the public to become aware of and grow to appreciate the intrinsic values and benefits derived from cave and karst resources.

Curious Bat: It sure is noisy! It looks like we have a visitor to our cave—and a careless one too! Can't s/he see where s/he's going? Oh yeah, s/he doesn't have echo-location like we do. Poor human! What's that strange stuff s/he's eating? Doesn't smell like bugs.

Cricket One: Ohhhhh! My tummy hurts.

Cricket Two: I feel really sick! And we didn't eat very much of this stuff.

Cricket One: Let's go hide until things quiet down. [Groans]

[The two crickets move off to the side and lay down.]

Cave Impact Monster: What's that moving around up there?

[S/He shines his/her bright light toward the bats.]

Sleepy Bat: Ouch! What's that light—it's so bright it hurts my eyes!

[Sleepy Bat tries to hide his/her face in his wing. Curious Bat hands him/her a pair of sunglasses, after putting on a pair of his/her own.]

Curious Bat: Here, try these. I found these near the entrance the last time we had intruders.

Cave Impact Monster: [Shrieks] Yikes! Bats!

Sleepy Bat: It used to be so nice and quiet around here. If this keeps up, we'll have to find another cave to live in. Don't these humans realize how important we are to them, and that they should show us a little respect. After all, we eat insects, and pollinate some of their favorite fruits.

Curious Bat: [lamenting] We can't take any chances hibernating here. If we were interrupted again like today, we would die of starvation! It's going to be hard to find another cave as good as this one.

[The bats fly off to another part of the cave.]

Cue Card for Audience: AWWW!

Narrator: Poor bats.

Cave Impact Monster: [Panics] The bats are flying! I've got to get out of here!

[Cave Impact Monster turns around and runs toward the pool. S/He slips and falls into the pool with a big splash.]

Cue Card for Audience: Splash!

[Cave Impact Monster holds his/her ankle as if it's hurt, then limps off.]

Cave Impact Monster: [Shivers] I'm freezing! And my ankle hurts. I better go back to the entrance and build a fire to warm up.

[S/He moves toward the entrance.]

Sal the Salamander: There goes the neighborhood!
It WAS a nice little pool, till S/HE fell in
It WAS clean and neat, but NOW, it's all polluted,
By dirty caver feet….Poor microbes!

Mighty Microbe: That's it for me. [Microbe falls over dead.]

Cave Ranger: Did you hear that splash? I wonder what caused that?

New Caver: Yes, it DID sound like a splash. Maybe we better go and investigate.

[Meanwhile, at the entrance, Cave Impact Monster has started a big fire. Smoke begins to pour into the cave.]

Speleologist: Do you smell smoke?

[Cavers, speleothems, and cave life all begin coughing and gasping.]

Cave Ranger: Look at all of these footprints everywhere! And that stalactite is broken! How did this happen? This cave is going to need some serious restoration work.

[They move toward the entrance, still coughing.]

Speleologist: There's a fire! That's what's causing all of this smoke! Cave entrances are a bad place to build fires, because when air moves into the cave, the smoke goes into the cave, too, and it impacts everything inside.

[They turn toward Cave Impact Monster.]

Cave Ranger: What happened to you?

Cave Impact Monster: [frantically] I saw bats in the cave and got scared and ran away, but I slipped and fell in the pool. If I had hurt my ankle any worse, I'd have probably died in there. No one would have known I was here. I'm sooo cold. [Shivers.]

Cave Ranger: You shouldn't be afraid of bats. They're not only harmless, but extremely helpful. We'll help you get warm, but we have to put this fire out before it hurts the cave any more.

Cave Impact Monster: OK.

Cave Ranger: You should know better than to go caving alone. And you should know that caves on the Lincoln National Forest require a permit for permission to enter them. Do you have a permit?

Cave Impact Monster: No. There's so much more to going caving than I thought. Maybe I should have found someone more experienced in caving to go with me.

Speleologist: Yes, that would have been better for both you and the cave. Do you realize ALL of the IMPACT you had on this cave in the short time you were there?

Cave Impact Monster: Impact?

Narrator: [To audience] Let's name all of the impacts made during the Cave Impact Monster's visit.

[Narrator prompts audience to come up with impacts and bad caving practices.]

Cave Impact Monster: Gee, I didn't realize I was making so many impacts. Can any of these impacts be fixed?

Cave Ranger: Some of your impacts are permanent and can never be fixed. Those changes will last forever. But some of your footprints we can clean off. The bats MIGHT come back, and the pool may become cleaner, after a long time.

Cave Impact Monster: I'm sorry. Is there anything I can do?

Cave Ranger: Sure, you can help us with some of the clean up work—but it will take a lot of time!

End.

Narrator leads discussion:
Why should we care about caves?

1. Non-renewable
2. Habitat for creatures important to humans, bats, microbes, etc.
3. Scientific value of unique biology
4. Recreational value
5. Water source

What surface activities impact caves?

1. Dumping trash into cave
2. Disturbing area around entrance

How can each of us help protect caves?

1. Federal Cave Resources Protection Act of 1988
2. Follow safe caving practices
3. Use low impact caving techniques
4. Share what you learned today with others

Chapter 44

A Case Study in Applying Historical Research to the Educational Process: Exploring McKittrick and Discovering Our Heritage

DOUGLAS DINWIDDIE, Ph.D., is a professor of social science at New Mexico State University in Carlsbad where he has taught a wide variety of history, government, and anthropology courses for the past 12 years. He has recently overseen the design of a new degree program at the university, entitled "heritage interpretation," which will provide academic and hands-on training for persons working in the field of historic interpretation.
Other authors: CAROLYN OLSEN, Independent Educational Advisor, Carlsbad, New Mexico, and FROSTY BENNETT, Park Ranger, Educational Outreach Coordinator, Guadalupe Mountains National Park

The educational process—comments by Doug Dinwiddie
This study involves information about a tripartite process of professional guidance through a class experience, research of materials and facts, and producing an educational tool called a traveling trunk to be utilized by educators. Information will be provided about the process beginning at its infancy as an instructor guides the research student. The instructor will continue to provide guidance and critique the final product that is prepared using pertinent research facts.

To quote, "Traditionally, education has relied heavily on texts and lectures, questions and discussions. 'Words' are at the core of the experience. Object-based education focuses the learning experience more on artifacts and primary documents in a manner that taps children's diverse learning styles while stimulating interest and providing a deeper understanding of the subject."

We conclude that carefully prepared object-based education found in sources such as traveling trunks is a successful means of engaging young people and teaching a variety of subjects and skills.

Applying historical research to the educational process—comments by Frosty Bennett

The project we worked on is called, "Exploring McKittrick and Discovering Our Heritage." The goal is to develop a traveling trunk about Wallace Pratt and McKittrick Canyon. We already have a large number of students that visit the canyon yearly. The trunk will be gauged for fourth, fifth, and sixth graders. We will be introducing geology to cover the natural environment, as well as information on Wallace Pratt to cover history of the canyon. The park received a $3,000 grant from Parks as Classrooms. Area teachers will provide most of the work so the trunk can contain curriculum-based material.

Completed example trunks are available from Fort Davis National Historic Site, Everglades National Park, Yellowstone National Park, and a song bird trunk. Objects such as a soldier's hat in the Fort Davis trunk provide the student with a hands-on learning opportunity. Imagine how much more a student will remember about history after wearing a soldier's hat. Hands-on experiences are a better method of learning rather than just reading history from a book. The song bird trunk has entertaining puppets used to convey information about birds.

Traveling trunks going to a classroom provide opportunities for students to learn about resources, especially for the student that cannot visit the parks.

We in the National Park Service know there is a need to assist teachers by providing appropriate educational materials about our national treasures. Our national parks are excellent outdoor learning laboratories, and we need to provide materials and opportunities for students to have quality learning experiences.

Traveling trunks going to a classroom provide opportunities for students to learn about resources, especially for the student that cannot visit the parks. Some students are unable to attend because of physical disabilities and some school districts do not have funding for transportation costs. The bus expense from Carlsbad, New Mexico, to Guadalupe Mountains National Park is $137.50. Our goal with the traveling trunk is to take a small portion of the park to the classrooms. The trunk “McKittrick Canyon and a Man Called Pratt” will be sent to the school prior to the students visiting the park. Imagine how much more students will gain from their field trip experience because of their being introduced to information about Mr. Pratt and McKittrick Canyon.

The project I personally worked on for the “Heritage Interpretation Class” was to put together some “old time children’s games.” I use potato/gunny sacks for three-legged and other race games. I also have hoops and sticks from an old barrel. Children love playing these games whether they are at their school or at the Frijole Ranch in the park. In my school programs I tie in what is happening today, such as recycling. I encourage students to be creative. What someone might think is trash could be used to create an exciting new game or toy. An old bicycle tire could be used for the hoops and sticks game.

Our objective is to interest, stimulate, and excite students.

One problem we have is funding so we need your assistance in developing educational programs for students of all ages. If you have any suggestions or can assist by volunteering please feel free to contact the park.

McKittrick Canyon and a man named Pratt—comments by Carolyn Olson
What do we put in a traveling trunk that would interest, and entertain, and stimulate fourth, fifth, and sixth grade students?

First, we needed a theme—a brief statement that would establish boundaries for our trunk. This theme should indicate to us what we could or could not put in it. How big? How small? What do we include that would provide a hands-on experience and acquaint students with the beauty and wonder that is McKittrick Canyon?

Second, we needed a goal—what do we expect our project to accomplish?

Third, an objective—what are the specific results that we want the students to discover?

And, we needed a format—a unifying “thread” to weave all its contents together.

Also—a most important element—the objects we put in our trunk must either be indestructible or easily replaceable!

So, we start with our theme. The grant application’s program title was “Guadalupe Mountains National Park Traveling Trunk” entitled “McKittrick Canyon and A Man Named Pratt.” We have our theme.

Our trunk will contain the picture of Wallace Pratt, along with a brief story of his life and how he came to acquire the land in McKittrick Canyon, “the most beautiful spot in Texas.” It is important for students to know about Wallace Pratt and his lasting legacy, his gift that became a national park. We could include the tape recording of his voice: the one we hear at the visitor center at the canyon’s entrance.

Most usually, elementary school groups will be making the trip to the canyon in the fall, to see the magnificent colors. We would like the experience to be more than just a “field trip”—an opportunity to get out of school all day! Our goal is to acquaint the students with the confluence of diversity that is McKittrick Canyon.

Our objective is to interest, stimulate, and excite students so they will anticipate the hike, looking for “markers” along the way. We could produce a video—one that would include these markers for the children to discover—along with other samples and examples in our trunk. This will be our thread.

Let's pack a map of the canyon and compasses in our trunk. Most field trip groups will be hiking the 2.3 miles to the Pratt cabin, eat their lunch, and return.

How about a picture or a model of Pratt's stone house and a description of how it was built in the 1930s? It was constructed entirely of wood and stone. The stone was brought from the base of the Capitan reef front outside the canyon. The stone slabs came from the rock beds and varied in thickness from a fraction of an inch up to six or eight inches. These rocks were already weathered out and lay, half-exposed, on the surface. They were hauled to the site from four miles away with an old half-ton pickup. Some out-of-work cowboys with their saddle horses and ropes dragged the stones up an inclined plane to build the roof as well as the walls. There is a one-piece stone picnic table in the yard of the cabin. One of Mr. Pratt's grandsons built a fire under it and the heat caused one of the corners to break off—another marker for our students.

Pratt said in an interview in 1974, "McKittrick Canyon cuts a marvelous transverse section squarely across the axis of the Capitan barrier reef. This cross section of a fossil barrier reef displays in its walls, the one thing that makes McKittrick Canyon so special." He was a geologist. He saw the importance of bringing other geologists to these Guadalupe Mountains to study the reef. "There are many other fossil reefs in the world, but few are as well displayed and accessible as in the Guadalupe Mountains." Illustrations of the reef would be helpful, along with the description of how the reef was formed. Fossil samples or models and magnifying lenses would be good teaching tools because the students probably would not be making the hike along the Permian reef trail.

What about the flora and fauna of the canyon? If the trip is made in the fall, students can spot the bigtooth maple by its vibrant red- orange colors. Pictures or possibly dried maple leaves could be included. The distinctive bark of the alligator juniper tree could be intriguing to students. The berries of this tree feed mule deer, black, bear, gray fox, as well as ringtail cats, quail, and jays. Students may not see any animals but will be able to spot the scat. And, of course, pictures of the Texas madrone should be included: the tree Pratt mistakenly identified as the manzanita.

The teacher might want to have a time to "look and listen" for the 40 plus species of birds that nest in the canyon. Pictures of these should be in our trunk as well as possible recordings of their songs. It will take a monumental effort on the teacher's part to entice the students to be quiet and listen while on the trail. How many birds can the students identify by their calls? And, how many can they recognize by sight? Ecology and conservation are two familiar subjects to elementary students. Let's introduce them to the peregrine falcon and the Mexican spotted owl, both on the endangered species list. Areas of the upper canyon are closed during the nesting season of one of the fastest birds on wing—the peregrine falcon.

Other pictures or posters may include the hog-nosed skunk, the javelina, and the mountain lion. There are also the red-spotted toad, the black-necked garter snake, the Chihuahuan spotted whiptail lizard. And let's not forget rattlesnakes and tarantulas!

As for flora, coloring pages can be packed in our trunk of the soaptree yucca, the New Mexico state flower, which grows in the canyon. There are the sotol and the desert spoon. How do they differ? How are they alike? Let's include the mescal, the main food source of the Mescalero Apaches who once called this area their home. The park abounds in burnt rock rings, evidence of their culture.

"There are many other fossil reefs in the world, but few are as well displayed and accessible as in the Guadalupe Mountains."
—Wallace Pratt

A disposable camera could be packed so students would have a "memento" of their adventure. Copies of these pictures may be added to our collection for others to see, giving credit to the student who took the picture.

Children crossing the bed of McKittrick Creek could make a "discovery" game. Instead of "Don't step in the water, don't step on the dry creek bed, you must not…," leaders should try, "Let's count the stones as we cross this dry creek bed," or "Isn't it great that the rangers have set these stones so we don't have to get our feet wet!"

And so, our trunk turns into a vehicle for an adventure! It is our hope that our trunk will help our "hunters" to walk happily down the trail, look eagerly for the markers, and learn to value McKittrick Canyon and a man named Pratt.

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Social Science

Chapter 45

Postmodern Deconstruction and the Role of Science in National Park Management

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So, what the Sam Hill is "postmodern deconstruction?" Well, I've read the books and the Cliff Notes, and I still can't tell you for sure, but I've got an idea. Neil Evernden, of Canada's York University, helped jump-start the deconstructionist approach to "Nature" (capital "N") with his landmark book *The Natural Alien* back in 1985. He followed up with a sequel called *The Social Creation of Nature* in 1992. American conservation biologist, Michael Soulé, jumped into the fire with *Reinventing Nature*, co-authored by Gary Lease, in 1995. Soulé, chair of environmental studies at University of California, is the founder of the Society for Conservation Biology. And Gary Lease is dean of humanities at the University of California at Santa Cruz.

So, what's all the fuss about? Kent Redford (Soulé and Lease 1995) of The Nature Conservancy said: "we must all become aware of what could be called the politics of naturalness…a wave of relativistic anthropocentrism originating in the humanities and social sciences with clear implications for a wide range of biodiversity conservation policies and actions."

J. Baird Callicott (Soulé and Lease 1995), the environmental philosopher and writer, said: "A concerted response to this impending catastrophe (human overpopulation and overconsumption) is thwarted by the fashionable new deconstructive ecology and critical theory."

Paul and Anne Ehrlich, in their 1996 book *Betrayal of Science and Reason*, wrote: "a diverse group of individuals and organizations…With strong and appealing messages…have successfully sowed seeds of doubt among journalists, policy makers, and the public at large about the reality and importance of such phenomena as overpopulation, global climate change, ozone depletion, and losses of biodiversity."

So, it's quite clear—some top drawer experts are really concerned about "deconstruction"—but what is it?

The word "unnatural" denotes a condition caused predominately by humans.

Well, most of you are aware of the "duality" of the term "Nature." It is often used to include everything in the universe, as most dictionary definitions attest. But, in its adjective form, "natural," it is often used to differentiate between the works of God and the works of Man—the former being "natural" and the latter being something else. The National Park Service *Management Policies* (1988) make reference to "unnatural" concentrations of animals as being undesirable. In this context, the word "unnatural" denotes a condition caused predominately by humans. As such, it is implied that human actions must be considered "unnatural."

Gary Lease says: "the idea that nature needs protection from humankind's onslaught begs the definition of the boundary and turns our attention to contesting constructions of nature and to competition among human groups for access to resources and power…. Deconstruction insists that we must not ignore these cultural questions (e.g., whose paradigm will prevail), even in the formerly exclusive provinces of science and conservation."

Put succinctly, deconstructionists simply denounce and demean the various "constructions," or contrived paradigms of living nature. Soulé identified at least nine such constructions, but cautioned that there could be many more. Among them were:

- Wild kingdom: the venue of trophy, camcorder, and life list
- Wild other: wild nature that has no concern for human beings except when other animals perceive us as a dangerous predator or as a possible food item
- Gaia: the view that living nature is homeostatic and self-regulating—sort of a Second Law of Thermodynamics for Nature
- Biodiversity: the living nature of the contemporary western biologist

The deconstructionists argue that none of these constructions has any leg up on any other and that none are any more valuable than any other, or even more valuable than history, in teaching truths about living nature. They claim that there is an infinite amount of knowledge (i.e., knowable facts) in the universe, and modern humans now know little more of it than their ancestors did 100 or even 1,000 years ago. And, perhaps most significant of all, they claim we cannot expect to know nature at all because of our insidious cultural, sensory, and intelligence biases and limitations.

By attempting to separate human influences from other ecological processes we may be fostering the most unnatural living nature paradigm.

Some argue that since humankind has always been a part of nature, it is more unnatural to exclude indigenous people from newly protected areas (e.g., nature preserves and parks) they have long inhabited, than to include them. And some argue convincingly that the genomes of many, if not most terrestrial species (especially the large mammals), have been shaped over hundreds of thousands of years by interactions with the dominant species—man—through the basic Mendelian and Darwinian processes we were taught as gospel. By attempting to separate human influences from other ecological processes we may be fostering the most unnatural living nature paradigm in the last three or four million years of evolution.

Convinced yet? Well, there's a pretty steep learning curve to this stuff; that's why we have so many classic ecologists and conservation biologists cautioning us about it; but that is also why we still have a "natural regulation" management policy in many large national parks. I, like most ecologists trained in the 1960s and 1970s, was steeped in classic Clementsian ecology. That is, we were taught that ecological processes tend toward a climax situation, which was usually characterized as being more diverse, stable, and in equilibrium than the other successional stages. We were taught that species coexisted in discrete communities and ecosystems. We were shown herbaria containing examples of plant species which we could always expect to find in romantic-sounding alliances such as tallgrass prairie, aspen-birch-willow communities, or maple-basswood forests. And we were escorted to the field to peruse living examples of—lo-and-behold—those exact same species, which further imprinted upon us the immutable paradigm of nature in balance.

Boy, have times changed!

Michael Soulé, writing in *Reinventing Nature*, jolts us into the 21st century by stating:

- "The real biological world little resembles the rose…-tinted television portrayal"
- "Certainly the idea that species live in integrated communities is a myth"
- "biotic communities, a misleading term, are constantly changing in membership"
- "species occurring in any particular place are rarely convivial neighbors; their coexistence…is better explained by…tolerances"
- "the much more common kinds of interactions are competition, predation, parasitism, and disease"
- "Most interactions between individuals and species are selfish, not symbiotic"
- "Homo sapiens [are] no exception"
- "the idea that living nature comprises…altruistic, mutualistic symbioses has been overstated"

Wow! Powerful or what!? And this is all in one paragraph! But the following paragraph has the real kickers for National Park Service management policies, including:

- "living nature is not equilibria…on a scale that is relevant to the persistence of species"
- "Homeostatic systems (do not) buffer life on a relevant spatiotemporal scale"
- "the science of ecology has been hoist on its own petard by maintaining…that natural communities tend toward equilibrium"
- "Current ecological thinking argues that nature…has never been homeostatic"
- "Therefore, any serious attempt to define the original state of a community or ecosystem leads to a logical and scientific maze. The principle of balance has been replaced with the principle of gradation—a continuum of degrees of human disturbance."

With two paragraphs of his book, Michael Soulé has "deconstructed" the ecology most of us in this room were taught. But this is a poor pun, because Soulé is so far ahead of us. He accepts the facts above as the late-20th century construction for living nature but goes on to document the insidious, and rapidly growing, "hegemony" of man over the rest of nature. Hegemony—what a word!—meaning "preponderant influence or complete dominance" has been widely used by conservation biologists, probably because of its poetic impact—"onomatopoeia," I believe it's called—to denote the significance of anthropogenic influences on living nature. So, it's man's hegemony that is driving Callicott's "impending catastrophe." And Soulé does an excellent job of illustrating that fact. Man's growing spatial and material dominance, fueled by uncontrolled growth, is clearly unsustainable. We either turn this phenomenon around by design, or wait for it to occur through chaos.

Soulé aptly quotes from Dan Botkin's *Discordant Harmonies* (1990): "We talk about spaceship Earth, but who is monitoring the dials and turning the knobs? No one."

So, to sum up: deconstructionists are seeking to discredit the objectivism, which is the basis for modern science. They claim that the relationships among ecosystem components disclosed through research are artificial, prejudicially and culturally biased, or temporal at best—at the very best. Objectivist-constructionist scientists see the relationships disclosed by research as real and knowable and profess that scientific research gradually increases our knowledge of them. They—we—would argue that while science generated the once highly regarded concepts of mid-20th-century Clementsian ecology, subsequent science debunked the falsehoods in those concepts and moved us forward. Deconstructionists argue that just as we have now rejected many of the fundamental mid-20th-century ecological concepts, our newer, more modern ones will, likewise, be disproved and replaced in time. So, to get too serious about them is a waste of time and, possibly, an impediment to the intellectual advancement of our culture and to the economic advancement of many other human cultures. Soulé equates this approach to "nihilistic monism" and boldly asserts that society can only advance incrementally and that scientific baby-steps are required to move us ever closer to knowing that illusive true nature of the universe. And, even more importantly, unless we turn around the well-documented unsustainable aspects of human population growth and consumption, we will never survive to truly know Nature at all.

We must admit that our national parks, per se, are indeed constructions—and some pretty creative ones at that.

So, what are the implications here for scientific management of national parks? First, we must admit that our national parks, per se, are indeed constructions—and some pretty creative ones at that. Our Servicewide natural resource management policies would seem to drive management toward a more consistent construction, or model, except for the fact that congress has often provided for specific management prescriptions for individual units which may, or may not, comply with Servicewide policies. We have parks with prescribed hunting, sport fishing, commercial fishing, trapping, cattle grazing, oil and gas exploration and extraction, hard rock mining, and a variety of subsistence activities. We have parks bisected with interstate and local highways, mainline railroads, bus lines, navigable rivers, commercial shipping lanes, regional trail systems, scenic and commercial airline routes, and we even own and manage lands occupied by commercial, private, and defunct airports. Some parks occupy habitats created entirely by humans for other primary purposes, such as water impoundments. In specific locations, we have statutory direction to preserve populations of non-native animals such as longhorn cattle, horses, ponies, and striped bass.

Many of us in this room would like to think one of our more altruistic missions—preservation of biodiversity—should be our hallmark, but it is actually that hegemony thing that greets observant park visitors with a cacophonous wake-up call. In the middle of the 20th century, national parks were thought of as monuments to some amoral, equilibrium, natural condition that was once thought to have existed before European contact, or possibly earlier, before any human contact. But our national parks did not evolve like so many plant communities or ecosystems; they were created by human society—American human society—and, as such, they clearly reflect American cultural history and values of the 20th century. In other centuries they would, no doubt, have reflected different ones. And today, the national parks of other countries often do.

We are managing a construct of American society admittedly for societal values.

All this is to say, simply, we of the National Park Service have no need to quarrel with the deconstructionists. We should not be attempting to manage national parks to some God-given—or Mother Nature–given—standard. Yes, we are managing a construct of American society admittedly for societal values: be they endangered species recovery; harvestable wildlife and fisheries; valuable and useful minerals; life-enhancing water, wildness, and wilderness; photosynthesis and carbon fixation; or ecosystems whose most outstanding characteristic is that they are not manipulated for deterministic purposes; and—almost everywhere—sustainable visitor enjoyment. When societal values change, the constructs will change, and most probably, so will the national parks.

So, it doesn't matter even if the deconstructionists are correct. What difference does it make if other individuals or institutions have variant constructs for national parks? They already do. The animal rights folks want to end all hunting, fishing, and trapping on the parks. The livestock industry would like us to do more to reduce predation, depredation, and competition with the cattle industry outside the parks. The timber industry makes continuous inquiries about the availability of old growth Sitka spruce and Douglas-fir for harvest in Olympic and other national parks. RV manufacturers want wider roads and larger, better equipped campgrounds. Airlines want longer runways and larger terminals. And the list goes on.

But congress has defined the national parks for us through their written word and intent. It is up to us, as good stewards, to develop and implement management objectives which optimally blend the specific congressional direction with the more general direction provided by our *Management Policies* (1988). Such work requires that professional proficiency prevails over religious rhetoric. And professionalism requires good science.

Science is absolutely necessary for two major reasons. First, we need scientific information to accomplish the proactive management objectives established for individual parks. Like maintaining healthy, viable populations of elk and bison at levels which don't gradually degrade their habitats thus threatening their very survival. Like how to restore extirpated species without undue conflicts with park neighbors. And like determining what population levels of a mandated exotic species (e.g., horses) can be maintained without forcing extirpation of cohabiting natives.

Second, we need information to determine when undesired influences of our own management, or from sources outside the parks, threaten to compromise or obviate our management objectives. Like how to stop contemporary invasions of alien plants that threaten to upend park ecology. And like how to prevent the offal of American affluence, e.g., our degraded water and air resources, from poisoning park biota.

Science = to accomplish the influences we desire on park ecosystems, and to detect and mitigate those we do not. Without it, one might as well take a lesson from the "deconstruction manual":

Step 1: Describe park ecosystem

Step 2: Define park management objectives to equal that description

Step 3: Declare victory

Surefire recipe for success—eh?—but only if your constituencies are deconstructionists. The rest of us prefer definable standards—admittedly not God-given, and, perhaps, no longer revered as the proverbial "Laws of Nature." But they're the best we'll have until the Rapture.

Thank you.

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Chapter 46

The Role of Cooperating Associations in the Development of Tourism in National Parks

RICK L. LOBELLO has been the executive director for the Carlsbad Caverns Guadalupe Mountains Association since 1992. He is the project coordinator for the award-winning CD-ROM, Carlsbad Cavern and Guadalupe Mountains, as well as Hiking Carlsbad Caverns and Guadalupe Mountains National Parks. He is also coordinating the publication of Wildflowers of the Chihuahuan Desert and a new documentary video on Guadalupe Mountains National Park.

Today I would like to speak to you about one of the most important non-governmental organizations influencing both conservation and tourism in our national parks. Commonly known as cooperating associations or natural history associations, here in the Guadalupe Mountains at Guadalupe Mountains National Park and Carlsbad Caverns National Park we like to think of the Carlsbad Caverns Guadalupe Mountains Association (CCGMA) as one of the best friends our two parks ever had.

When I first visited Guadalupe Mountains National Park in 1975 the park was barely three years old and the National Park Service was working out of a white trailer near Pine Springs. Having worked my first summer as a seasonal park ranger at Big Bend National Park I was fairly familiar with the flora and fauna of the Chihuahuan Desert, but if it wasn't for our trip leader, renowned botanist Dr. Barton Warnock of Sul Ross State University, I would have been hard pressed for information about the park's flora and fauna. Twenty-three years later times have changed considerably with the completion of a state-of-the-art visitor center near the park's south entrance and a series of publications produced by the Carlsbad Caverns Guadalupe Mountains Association plus a handful of other publishers who have helped to provide critically needed educational materials for both the visiting public and the scientific community.

When I first walked into the Panther Junction Visitor Center at Big Bend National Park in 1974, I was overwhelmed with questions. I wanted to know what kinds of animals inhabited the park, what kinds of trails were available, what were some of the main sights to see, and basically answers to dozens of other questions about this large and unfamiliar national park.

After picking up a free brochure and talking with the ranger attending the information desk, many of my questions were answered. Later he sold me several publications that I felt would help me better understand the park. My purchase included a road guide and three wildlife checklists: one on the birds, one on the mammals, and one on the reptiles and amphibians. Inside each publication I found the words "Published by the Big Bend Natural History Association in cooperation with the National Park Service."

Cooperating associations were developed in response to visitor needs for inexpensive guides, pictures, maps, and other interpretive literature not otherwise available through the use of federal funds.

The Big Bend Natural History Association, of which I served as executive director from 1986 to 1992 is one of 69 independent cooperating associations serving nearly every unit of the National Park System. Cooperating associations such as Big Bend Natural History Association and the Carlsbad Caverns Guadalupe Mountains Association, where I work today, originally were developed in response to visitor needs for inexpensive guides, pictures, maps, and other interpretive literature not otherwise available through the use of federal funds. Each association is not only a nonprofit but also a tax-exempt organization authorized by congress in 1946 to produce and provide theme-related materials for the National Park System areas they serve. All associations operate book sales outlets or small bookstores where both National Park Service employees and association employees also dispense free information and answer questions about individual parks. When it comes to helping to educate the visiting public before, during, and after the visit, cooperating associations are at the forefront.

The first cooperating association developed in Yosemite National Park in 1920. Chief Naturalist Ansel Hall desperately wanted to build a museum in the Yosemite Valley. At the time, the National Park Service was just four years old and little funding was available for interpretive projects. As a result Hall sought the help of the private sector. He contacted local business people in the San Francisco–Oakland Bay area who soon agreed to form an organization called the Yosemite Museum Association. After raising $9,000 from the public and receiving a large gift of $75,000, the museum was built. As the museum and its visitation grew, the need for suitable free and sales interpretive literature increased dramatically. The logical vehicle to provide this service was the cooperating association, which was reorganized and expanded into the Yosemite Natural History Association.

The completion of the Yosemite Museum was a significant event for it set into motion an idea which has grown into one of the most important friends groups benefiting the National Park Service today.

During ensuing years cooperating associations were established in Zion and Rocky Mountain national parks in 1931 and in Yellowstone National Park in 1933. The completion of the Yosemite Museum was a significant event for it set into motion an idea which has grown into one of the most important friends groups benefiting the National Park Service today.

Each association must be incorporated under the laws of the state in which it has a resident office. Carlsbad Caverns Guadalupe Mountains Association's articles of incorporation define its purpose as follows: (a) to provide for the visitor to Carlsbad Caverns National Park and Guadalupe Mountains National Park, every possible means of excellence in the interpretation of the parks' stories, (b) to assist in providing to the traveling public accurate information concerning the Carlsbad Caverns and Guadalupe Mountains national parks, and lands related to them in Texas and New Mexico, (c) to stimulate interest in the educational activities and encourage scientific investigation and research in the fields of geology, zoology, botany, history and related subjects, (d) to assist in the establishment, preparation and development of museums, observation stations, trail-side exhibits, and other interpretive and educational devices, (e) to assist in the development and maintenance of library facilities for the use of park personnel, students, research scientists, and interested persons, (f) to assist in obtaining photographs, slides, movie film and other materials for explaining the exhibiting facts relating to the history, earth sciences and life sciences as illustrated in the parks, (g) to publish, in cooperation with the National Park Service and other conservation organizations and agencies, various popular and technical papers and booklets dealing with the various fields of related science as may be needed for better public understanding, (h) to buy, sell, and handle government and private publications, and visual aid items dealing with informational and interpretive subjects related to the Carlsbad Caverns and Guadalupe Mountains national parks or the National Park Service, the profit from these transactions to be used for printing, stationery, miscellaneous supplies connected therewith, and to assist in obtaining equipment, materials and supplies to accomplish the purposes of this Association and (i) to employ such persons as may be necessary and pay salaries chargeable as items of expense for services actually performed in order to achieve the objectives of the Association.

Carlsbad Caverns Guadalupe Mountains Association was originally designated the Carlsbad Caverns Natural History Association on May 2, 1957, by Carlsbad Caverns National Park Superintendent R. Taylor Hoskins. To start up the organization the association received a $500 two year interest free loan from the Petrified Forest Museum Association. During the first year the association was able to donate an $8 volume of the AOU checklist of North American Birds and $2.10 for the development of a roll of film. During its first year the organization also approved its first publication, a nature trail guide at Carlsbad Caverns that would retail at $0.10. The road we have traveled over the past 40 years has been an uphill climb ever since.

Like other cooperating associations, Carlsbad Caverns Guadalupe Mountains Association is governed by a board of directors made up of businessmen, educators, and scientists. Most of them live in southern New Mexico and Texas and are well aware of the organization's role in promoting the park. Cooperating association guidelines including policies and standards are outlined in a document called NPS -32. Originally adopted by the National Park Service in 1986, the guidelines are based on years of experience shared by cooperating association managers from across the nation. NPS -32 includes legal authorities, delegations of authority, cooperating association agreements, and policies. In addition to a board of directors, each association is managed by an association manager, usually the executive director. The association in turn cooperates with the National Park Service in maintaining a distinct separation in the management and operation of each other's activities.

Most cooperating associations are members of a national organization recently renamed the Association of Partners for Public Lands (APPL). Directed by a board made up of individual association managers and board members, the conference is led by an executive director who serves as a liaison between individual associations and the National Park Service on both the regional and national levels. Last year the national organization opened its membership to include nonprofits serving public land agencies other than the National Park Service; in the years to come we can expect to see many more government land agencies represented, including some that are already involved such as the U.S.D.A. Forest Service, Bureau of Land Management, and the U.S. Fish and Wildlife Service. APPL also publishes monthly and quarterly newsletters, sponsors training opportunities for association personnel, and hosts a biennial convention. Our most recent convention was held last month in Gatlinburg, Tennessee, located just outside Great Smoky Mountains National Park. Over 900 people registered for the convention.

National Park Service managers from the national, regional, and individual park levels serve as cooperating association coordinators. Association coordinators act as liaisons between the National Park Service and individual associations. The Servicewide coordinator working with the director of the National Park Service serves in a broad review and advisory capacity. Regional coordinators serve as the primary contact between cooperating associations and regional directors. Individual park cooperating association coordinators, like the chief of interpretation at Guadalupe Mountains National Park, work as partners with association managers on the park level. They also serve park superintendents as review officers and advisors on all association activities.

As of 1998, Carlsbad Caverns Guadalupe Mountains Association has produced nearly 100 different publications.

As of 1998, Carlsbad Caverns Guadalupe Mountains Association has produced nearly 100 different publications including general information park brochures, trail guides, maps, posters, postcards, guidebooks, wildlife checklists, videos, a CD-ROM, and a park newspaper called *The Capitan Reef*. These publications are available as free handouts or as sales items throughout the parks and at local retail outlets in Carlsbad, New Mexico. Profits from these sales are later turned back into visitor services including free publications, visitor information desk staffing, exhibits, equipment for park interpretive programs, research grants, and environmental education programs.

The total contribution to the National Park Service since 1957 from Carlsbad Caverns Guadalupe Mountains Association now exceeds $1.6 million, bringing the grand total of aid from all 69 cooperating associations to over $180 million.

Association priorities are geared more to giving back directly to the parks than in tooting their own horns.

Projects funded at Guadalupe Mountains National Park, in addition to funding for new publications, have included sponsorship of the Guadalupe Mountains National Park Junior Ranger Program, camera equipment, color slide film, dark-room supplies, slide storage systems, museum supplies, computers and software, audio-visual equipment including projectors and tape recorders, binoculars, road and trailside exhibits, sign making equipment, library books, subscriptions to natural history publications and scientific journals, and funding for a number of research projects.

Most projects funded by cooperating associations could not be funded in the regular budget of the National Park Service. For example at Lincoln Boyhood National Memorial in Indiana they needed "one whole hog" for their living history demonstration. At Death Valley National Monument they needed someone to publish the proceedings of their first annual Death Valley History Conference. At Grand Teton National Park they needed assistance in constructing exhibits at the Moose Visitor Center and at Yellowstone National Park they needed a sponsor for a wildlife film festival. As a result of these projects, associations have provided a service that has greatly enhanced the overall objectives of the both the Department of the Interior and the National Park Service. Examples of other projects underwritten through this nationwide effort include funding for new park visitor centers, acquisition of historical objects, supporting special Servicewide interpretive, educational, and scientific programs (including presentations and demonstrations), providing logistical support for neighboring conservation and educational organizations, information services by association sales personnel, foreign language translations, honorariums for lectures by outside professionals, land acquisitions, and funding for staff training, Volunteers in the Parks, and Student Conservation Association programs.

All of this assistance has greatly enhanced the ability of individual national parks to draw larger numbers of visitors. For example, when a park visitor takes home a Carlsbad Caverns Guadalupe Mountains Association publication such as a colorful poster, booklet, video, or calendar the park becomes further publicized to friends and relatives back home. In Guadalupe Mountains National Park, for example, visitation has increased from less than a thousand visitors in 1972 to over 200,000 in 1997. With this increase in visitation has come greater tourism dollars for not only the association but also for many small communities throughout the area.

Although increased visitation can have detrimental effects on park resources, the National Park Service is mandated by law to set carrying capacities to prevent overcrowding. As long as National Park System areas continue to be carefully managed, cooperating associations will play major roles in establishing and maintaining continued public support.

To the American public, cooperating associations like Carlsbad Caverns Guadalupe Mountains Association are largely uncelebrated for the role they play in helping to both conserve and promote our national parks. This is largely the result of below average marketing efforts where association priorities are geared more to giving back directly to the parks than in tooting their own horns. But as competition for the environmental dollar increases in the years ahead, more thought and effort will have to be put into making associations more aggressive if they are to maintain the current level of support given to our national parks. It is also plain to see in 1998 that there will continue to be a growing need for the National Park Service to be more dependent on association-generated funds.

So today I have come to spend some time tooting the horn of Carlsbad Caverns Guadalupe Mountains Association, touching a little upon how the organization plays a significant role in supporting conservation—both directly in helping to educate the visiting public when they get here and indirectly in helping them to decide to come. It is a great horn to play and one that I hope many of you here will want to lend some energy to. We are always looking for more members, ideas, and support of almost any kind. Just give us a call and let us know that you're out there. Forty-one years of support for our two great parks has made Carlsbad Caverns Guadalupe Mountains Association a true friend of the Guadalupes as the park celebrates 25 years of cultural and natural resource stewardship.

Chapter 47

Guadalupe Mountains National Park Visitor Use Survey Results (1996-1997)

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Introduction
This report describes the results of a survey distributed to visitors of Guadalupe Mountains National Park. Researchers from the University of Texas at El Paso conducted this study and distributed visitor surveys for three different time periods: July 27 to August 3, 1996 (summer), October 24 to November 3, 1996 (fall), and March 14 to 22, 1997 (spring).

Methodology
This survey was designed with questions drawn from an approved list of questions from the Office of Management and Budget. Although the majority was fixed choice questions, visitors were asked five open-ended questions to ensure a chance for them to express their views on issues not anticipated by the researchers. By park management estimates, visitation was down during the summer period compared to other years. Park managers and the researchers speculated that the Summer Olympics were the cause, and several visitors told us they were coming from these events in Atlanta. The fall survey period was extended from the original design to include two peak fall color weekends: October 24–27, 1996, and November 1–3, 1996. The spring survey period (March 14–22, 1997) was scheduled during spring break for several area colleges. During this survey period prescribed burns were being conducted to decrease fuel loads in McKittrick Canyon, El Centro Draw, and Cherry Canyon.

Questionnaires were distributed at five different points in the park. Survey sites identified by signs were posted at the trailhead in the Pine Springs campground, the main visitor center, Frijole Ranch–Smith Spring trailhead, McKittrick visitor center, and the Dog Canyon ranger station. Visitors were given their choice of completing the survey right away, completing it at a later time and dropping it off at the survey sites, or returning the survey by mail.

Visitors were approached by research assistants with identification badges as they passed each survey site. The main visitor center survey site was open during visitor center hours; the other sites had a rotating schedule of operation.

For the summer period, 341 surveys were distributed over seven calendar days. A total of 269 surveys were returned for a response rate of 78.9%. During the fall, 900 surveys were distributed and 505 returned for a response rate of 56.1%. For the final spring survey period a total of 768 surveys were distributed and 381 returned for a response rate of 49.6%. Overall, 2,009 surveys were distributed during the three waves and 1,155 returned for an average response rate of 57.5%.

Because the sampling was not random, the results are not representative of all visitors to the park. However, results are consistent with the expectations of the park staff (there were few surprises) and conducting the research during the three peak seasonal periods was done to help ensure that a variety of visitors was represented.

Results summary: visitor perceptions

Crowding. Answering a yes or no question, 9.1% of visitors on average indicated that they felt crowded during their visit to the park. In response to a five point scale, 9.4% reported feeling either a little more crowded or a lot more crowded than expected. In backcountry campgrounds only 2.5% of visitors reported feeling crowded, compared to 21.1% at the main Pine Springs campground. Fourteen percent of visitors to McKittrick Canyon and 8.7% at Guadalupe Peak reported feeling crowded.

Solitude. Almost 40% of visitors reported solitude/quiet as one of their reasons for visiting the park. Solitude was specifically mentioned by 16.1% of summer visitors, 9.9% of fall visitors, and 7.9% of spring visitors in open-ended responses to the question "What did you and your group like most about your visit to Guadalupe Mountains National Park?"

Satisfaction. Sixty-three percent of visitors indicated that they were "very satisfied" with their visit to the park. Thirty-three percent were "satisfied" and 2.9% were neither dissatisfied nor satisfied. Only 1.1% of visitors indicated any dissatisfaction with their visit to the park—a total of 12 people.

Information. Most visitors obtained their information about the park from maps or brochures (38.5%), followed by travel guides and tour books (31.1%) and advice from other people (30.1%). On average, 42.4% of visitors reported the park as their primary destination. Approximately 60% of visitors reported a first-time visit. The most frequent reason visitors reported for being at the park was to view the wilderness/scenery and to hike.

Access. Very few visitors had any difficulty finding their way around the park. Only 8 respondents in both summer and fall and 13 spring visitors indicated having difficulties finding their way around the park. Backcountry trail signage accounted for most of the comments.

Park entry site. Most visitors entered the park at the main visitor center and found adequate information there. Only 5.4% reported getting less information than they wanted.

Trailhead registers. Almost 70% of visitors read regulations and information posted at trailheads, and almost 50% of visitors signed the trail registers before hiking.

Day users vs. overnight backcountry users. Overall day-use visitors mentioned needing such things as vending machines and food. Summer day-users also mentioned showers. Showers were the most cited need for overnight backcountry users (54.5% summer, 39.5% fall, and 37.1% spring).

Visitor composition. About 10% of visitors were from foreign countries, 55% were Texans and the rest were from other states. The average group was composed of a middle-aged respondent and four other family members. The average dayhiker was at the park for 4.6 hours, while the overnighters spent an average 1.4 days.

Strengths and weaknesses. Most visitors cited nature (i.e., scenery, wilderness, wildlife, views) as what they liked most about visiting the park, followed by facilities and services. The reverse is true for perceived weaknesses about the park. Lack of facilities and services were most likely to be mentioned in response to the question about what visitors liked least about their visit, followed by complaints about nature—factors over which the park has no control (i.e., heat, wind, and insects). Almost 30% of visitors reported that they were entirely satisfied with the services and facilities at the park. Approximately 64% of visitors expressed a need for more services or facilities. The most common requests were for a source of food/drink and gasoline closer to the park. Other requests were for such things as showers and other improvements to the camping facilities.

Resource concerns. In response to a question about planning for the future of the park, most visitors mentioned trail, facility, and service improvements. Some visitors even advocated limiting access to the park. However, many visitors felt no changes would be necessary.

Results

Visitors in the summer and spring were most likely to report that they got their information about Guadalupe Mountains National Park from a map or brochure. In contrast, fall visitors got their information from other people or a previous visit (Figure 1). Experience and advice are important information sources, especially for fall visitors.

Visitors were asked to estimate the amount of time they spent at the park (Figure 2). The average amount of time spent at the park for summer visitors was 4.2 hours for day visitors, which were the majority of visitors (72.1%) and 0.96 days for overnighters (20.4%). Fall day visitors (73.6% of visitors) spent an average of 4.5 hours at the park and overnighters (21.1%) reported staying an average of 1.56 days. Spring day visitors (66.3% of visitors) reported spending the most time at the park, 5.1 hours on average, with overnighters (29.7%) staying almost two days on average (1.79). The majority of visitors for all seasons at the park are day visitors. Visitors camping overnight are about 20% of visitors during the summer and fall seasons, with overnight visitors increasing to almost 30% of visitors for the spring break period. Both day and overnight visitors spent more time in the park in the spring, followed by fall and then summer.

Most visitors were at the park with other family members regardless of what season they were visiting the park. Summer visitors reported an average group size of only 3.4 people, while both fall and spring visitor groups were larger at 6.0 and 6.8 respectively. Approximately 10% of visitors to the park reported coming from foreign countries. England, Germany, Canada, and Mexico accounted for the majority of foreign visitors (Table 1, Figure 3). About 55% of visitors were native Texans and the rest were visiting

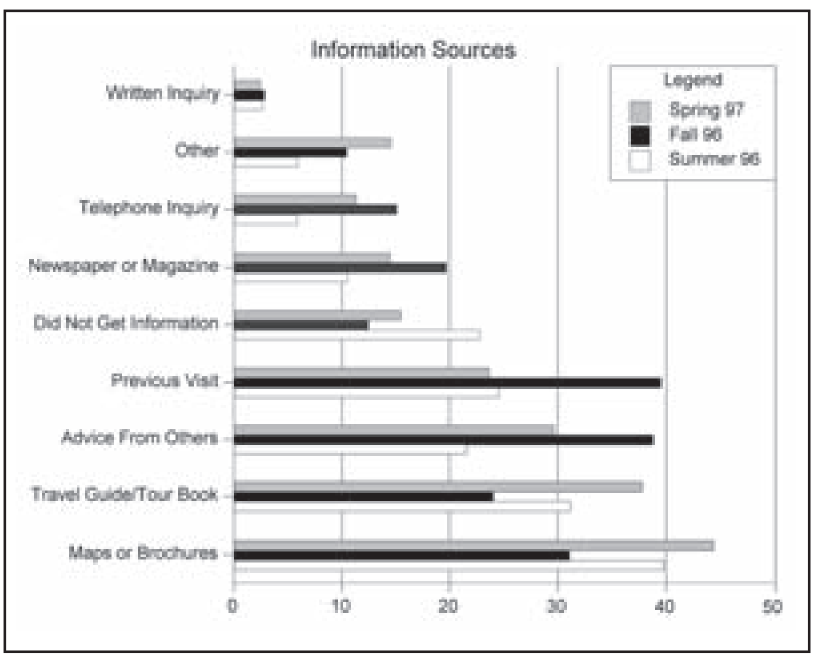


Figure 1

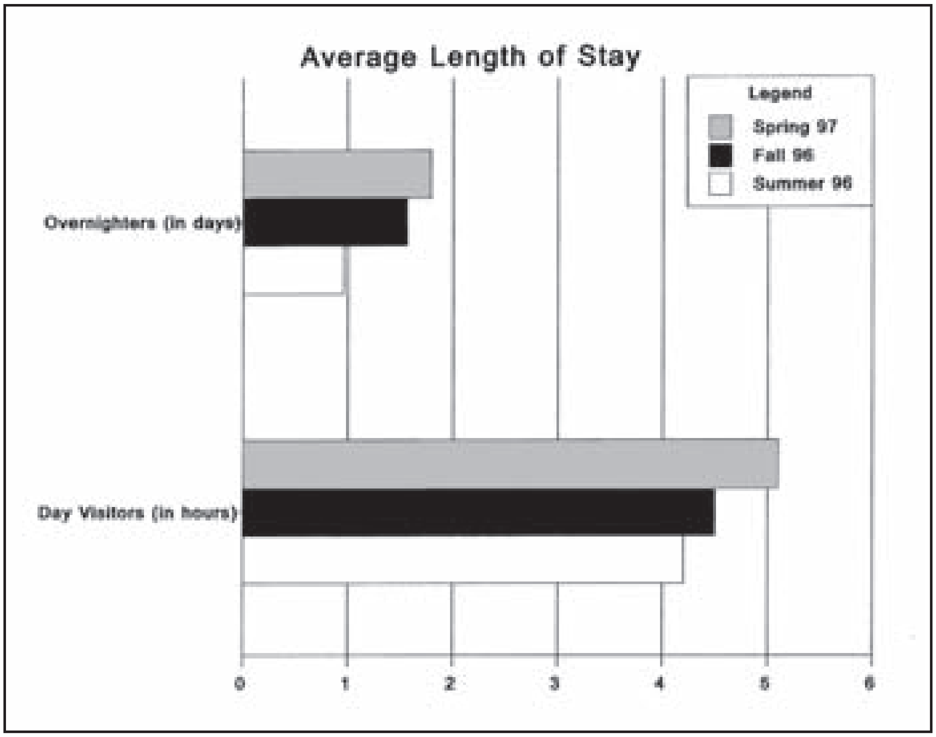


Figure 2

Country	Summer 1996	Fall 1996	Spring 1997	Total
	Number (%)	Number (%)	Number (%)	Number (%)
England	10 (12.5)	30 (41.7)	30 (30.6)	70 (28.0)
Germany	15 (18.8)	17 (23.6)	18 (18.4)	50 (20.0)
Canada	3 (3.8)	1 (1.4)	31 (31.6)	35 (14.0)
Mexico	8 (10.0)	10 (13.9)	0 (0.0)	18 (7.2)
Australia	2 (2.5)	2 (2.8)	9 (9.2)	13 (5.2)
Switzerland	6 (7.5)	4 (5.6)	2 (2.0)	12 (4.8)
Netherlands	7 (8.8)	2 (2.8)	0 (0.0)	9 (3.6)
Costa Rica	7 (8.8)	0 (0.0)	0 (0.0)	7 (2.8)
China	5 (6.3)	0 (0.0)	0 (0.0)	5 (2.0)
Austria	4 (5.0)	0 (0.0)	1 (1.0)	5 (2.0)
Denmark	4 (5.0)	0 (0.0)	0 (0.0)	4 (1.6)
Finland	0 (0.0)	3 (4.2)	1 (1.0)	4 (1.6)
Sweden	2 (2.5)	1 (1.4)	0 (0.0)	3 (1.2)
Japan	2 (2.5)	0 (0.0)	1 (1.0)	3 (1.2)
Norway	0 (0.0)	0 (0.0)	3 (3.1)	3 (1.2)
France	2 (2.5)	0 (0.0)	0 (0.0)	2 (0.8)
Czech Republic	2 (2.5)	0 (0.0)	0 (0.0)	2 (0.8)
Spain	0 (0.0)	1 (1.4)	0 (0.0)	1 (0.4)
Belgium	1 (1.3)	0 (0.0)	0 (0.0)	1 (0.4)
New Zealand	0 (0.0)	1 (1.4)	0 (0.0)	1 (0.4)
Russia	0 (0.0)	0 (0.0)	1 (1.0)	1 (0.4)
Philippines	0 (0.0)	0 (0.0)	1 (1.0)	1 (0.4)
Total	**80 (100.3)**	**72 (100.2)**	**98 (99.9)**	**250 (100.0)**

Table 1. Visitors by country of residence.

Figure 3. Approximately 10% of visitors to Guadalupe Mountains National Park reported coming from foreign countries.

from other states (Tables 2, Figure 4). Most people reported that they had been to the park at least once before their current visit.

Most visitors to the park come from Texas or New Mexico, although 46 of the 50 states were represented (Table 2, Figure 4). Only Hawaii, Mississippi, South Dakota, and Wyoming residents failed to visit the park during any of the three survey periods.

Sixteen percent of respondents reported that they did not look for information at the first location they visited at the park. This suggests the park is doing a good job of providing information. Of those that did seek information, the majority (94.1%) found that information adequate.

For the 5.9% of visitors who indicated that they found less information than they wanted, most requested more detailed information on the existing maps and documents provided at the park.

Most visitors had no difficulty finding their way around the park. Almost 96% said “no” to the question “Did you have any difficulty finding your way around in the park?” A similar high percentage reported no impairments limiting their ability to visit the park (94.1%). Very few visitors had difficulty finding their way around the park. Eight visitors in both the summer and fall waves and 13 spring visitors indicated they had difficulty. Those who reported difficulty tended to be confused about trails.

Only 37 parties reported impairments that limited their mobility. Most responses were complaints about physical problems with backs and knees that limited their ability to hike on the trails. Only three responses indicated that wheelchair access at Frijole Ranch was desired. (Please note that the current accessibility ramp was completed after these responses were collected.)

Fall visitors were most likely to report Guadalupe Mountains National Park as their primary trip destination (Figure 5), followed by spring visitors. Summer visi-

State	Summer 1996	Fall 1996	Spring 1997	Total
	Number (%)	Number (%)	Number (%)	Number (%)
Texas	383 (56.2)	660 (58.3)	406 (50.8)	1,449 (55.4)
New Mexico	34 (5.0)	237 (20.9)	73 (9.1)	344 (13.2)
California	37 (5.4)	28 (2.5)	13 (1.6)	78 (3.0)
Arizona	16 (2.3)	13 (1.1)	38 (4.8)	67 (2.6)
Colorado	2 (0.3)	26 (2.3)	22 (2.8)	50 (1.9)
New York	23 (3.4)	7 (0.6)	15 (1.9)	45 (1.7)
Ohio	11 (1.6)	6 (0.5)	24 (3.0)	41 (1.6)
Pennsylvania	18 (2.6)	4 (0.4)	19 (2.4)	41 (1.6)
Florida	15 (2.2)	12 (1.1)	10 (1.3)	37 (1.4)
Wisconsin	8 (1.2)	7 (0.6)	19 (2.4)	34 (1.3)
Illinois	16 (2.3)	2 (0.2)	12 (1.5)	30 (1.1)
Missouri	5 (0.7)	17 (1.5)	6 (0.8)	28 (1.1)
Kansas	9 (1.3)	4 (0.4)	12 (1.5)	25 (1.0)
Washington	5 (0.7)	7 (0.6)	12 (1.5)	24 (0.9)
Oklahoma	14 (2.1)	4 (0.4)	4 (0.5)	22 (0.8)
Minnesota	2 (0.3)	3 (0.3)	15 (1.9)	20 (0.8)
Massachusetts	6 (0.9)	2 (0.2)	12 (1.5)	20 (0.8)
Alabama	0 (0.0)	10 (0.9)	8 (1.0)	18 (0.7)
Michigan	1 (0.1)	5 (0.4)	10 (1.3)	16 (0.6)
Indiana	6 (0.9)	3 (0.3)	5 (0.6)	14 (0.5)
Alaska	3 (0.4)	4 (0.4)	6 (0.8)	13 (0.5)
Puerto Rico	0 (0.0)	10 (0.9)	2 (0.3)	12 (0.5)
Louisiana	1 (0.1)	8 (0.7)	3 (0.4)	12 (0.5)
Utah	0 (0.0)	4 (0.4)	8 (1.0)	12 (0.5)
Washington, D.C.	9 (1.3)	0 (0.0)	3 (0.4)	12 (0.5)
Iowa	4 (0.6)	3 (0.3)	4 (0.5)	11 (0.4)
New Jersey	2 (0.3)	4 (0.4)	5 (0.6)	11 (0.4)
Virginia	9 (1.3)	0 (0.0)	2 (0.3)	11 (0.4)
Maine	0 (0.0)	5 (0.4)	5 (0.6)	10 (0.4)
North Carolina	5 (0.7)	5 (0.4)	0 (0.0)	10 (0.4)
Nevada	8 (1.2)	2 (0.2)	0 (0.0)	10 (0.4)
Oregon	1 (0.1)	5 (0.4)	4 (0.5)	10 (0.4)
Arkansas	3 (0.4)	0 (0.0)	6 (0.8)	9 (0.3)
Nebraska	8 (1.2)	0 (0.0)	1 (0.1)	9 (0.3)
Montana	1 (0.1)	2 (0.2)	5 (0.6)	8 (0.3)
Tennessee	0 (0.0)	6 (0.5)	1 (0.1)	7 (0.3)
Vermont	3 (0.4)	2 (0.2)	2 (0.3)	7 (0.3)
Maryland	4 (0.6)	2 (0.2)	1 (0.1)	7 (0.3)
Kentucky	4 (0.6)	2 (0.2)	0 (0.0)	6 (0.2)
Georgia	1 (0.1)	2 (0.2)	2 (0.3)	5 (0.2)
New Hampshire	0 (0.0)	3 (0.3)	1 (0.1)	4 (0.2)
South Carolina	2 (0.3)	1 (0.1)	0 (0.0)	3 (0.1)
Connecticut	0 (0.0)	1 (0.1)	2 (0.3)	3 (0.1)
Idaho	0 (0.0)	2 (0.2)	1 (0.1)	3 (0.1)
West Virginia	2 (0.3)	0 (0.0)	0 (0.0)	2 (0.1)
Delaware	0 (0.0)	2 (0.2)	0 (0.0)	2 (0.1)
Rhode Island	1 (0.1)	0 (0.0)	0 (0.0)	1 (0.0)
North Dakota	0 (0.0)	0 (0.0)	1 (0.1)	1 (0.0)
Total	**682 (99.6)**	**1,132 (100.4)**	**800 (100.5)**	**2,614 (99.9)**

Table 2. Visitors by state of residence. States without representation during the survey: Hawaii, Mississippi, South Dakota, and Wyoming.

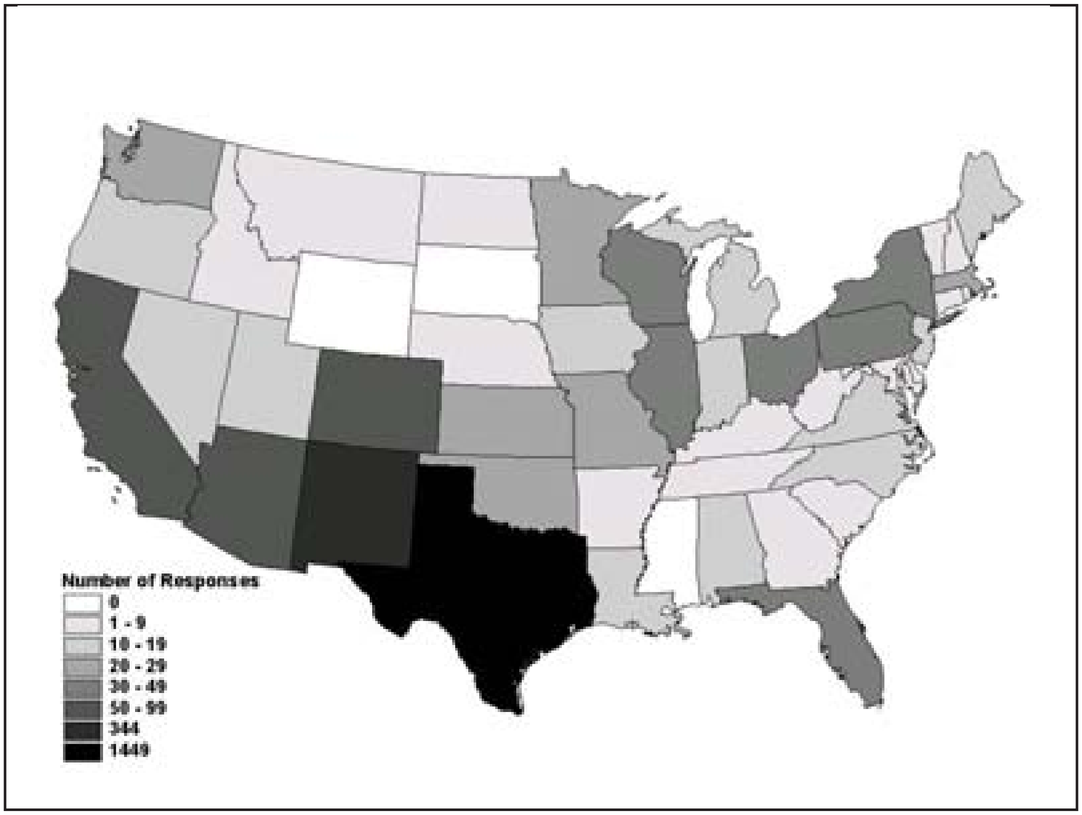


Figure 4. Visitors came from 46 of the 50 states in the United States.

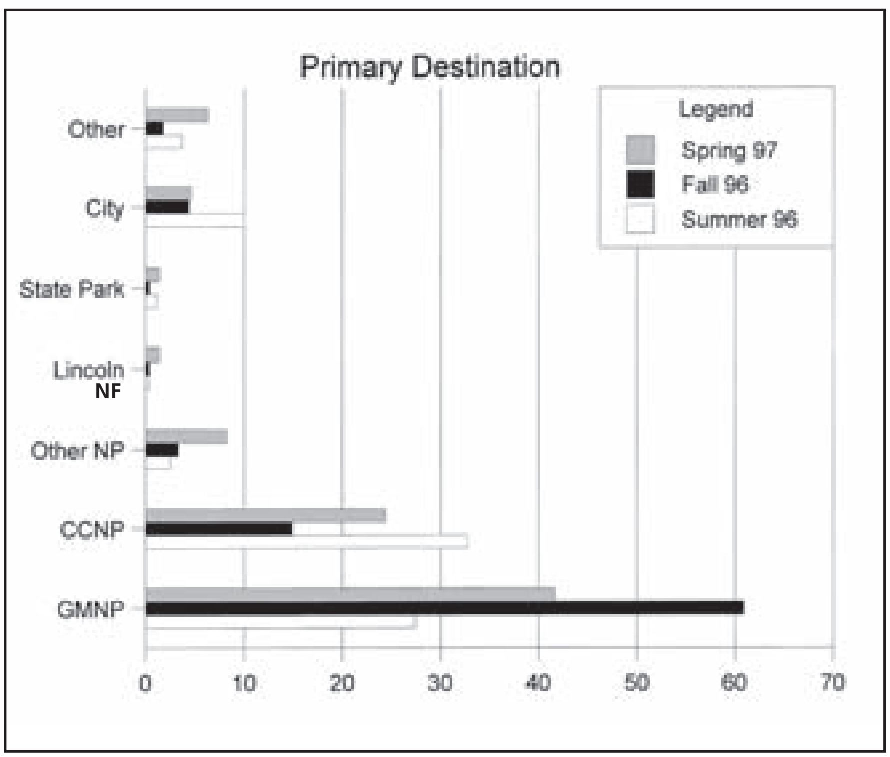


Figure 5

tors were least likely to report Guadalupe as their primary destination; instead, their goal was Carlsbad Caverns National Park.

Visitors were asked to indicate which sites they visited and in what order they visited them. Almost 76% of visitors complied: the Pine Springs visitor center was the site of most first contact with the park; 35.0% reported this as their first stop. McKittrick Canyon handled the next largest percentage of initial visitor stops with 21.7% reporting it as their first stop. Full staffing of the McKittrick Canyon visitor center should be considered as it is the first contact at the park for one in five visitors.

Visitors were asked to check all the options that applied as reasons for visiting Guadalupe Mountains National Park. For all three seasons, the most frequently selected reason was for the wilderness/scenery. Fall visitors indicated that hiking was their reason for visiting the park and McKittrick Canyon was their destination. The item coded "view nature" (Figure 6) was listed in the questionnaire as "view park plants, fall colors, wildflowers" and it can easily be seen that the fall visitors indicated they were at the park to view fall colors. Summer visitors were more interested in viewing wildlife than visitors in other seasons; this is probably a reflection on the typical summer party, i.e., a family group with children. Spring visitors were most likely to report they were at the park to view the geologic features, for the solitude/quiet, for camping, because it was a national park, to climb Guadalupe Peak, and to do some backpacking. This is consistent with predominantly college-student visitors in the spring break season.

Visitors were also asked about their activities from a checklist of 14 items (Figure 7). Fall and spring visitors reported hiking as their primary activity. Summer visitors, on the other hand, reported going to the Pine Springs visitor center as their primary activity. Visitors also frequently cited photography, picnicking, and tent camping as activities. All other activities had frequencies less than 10%.

Visitors were also asked about their activities on previous visits to the park. The frequencies of activities from previous visits to the park are very similar to visitors' current activities at the park (Figure 8).

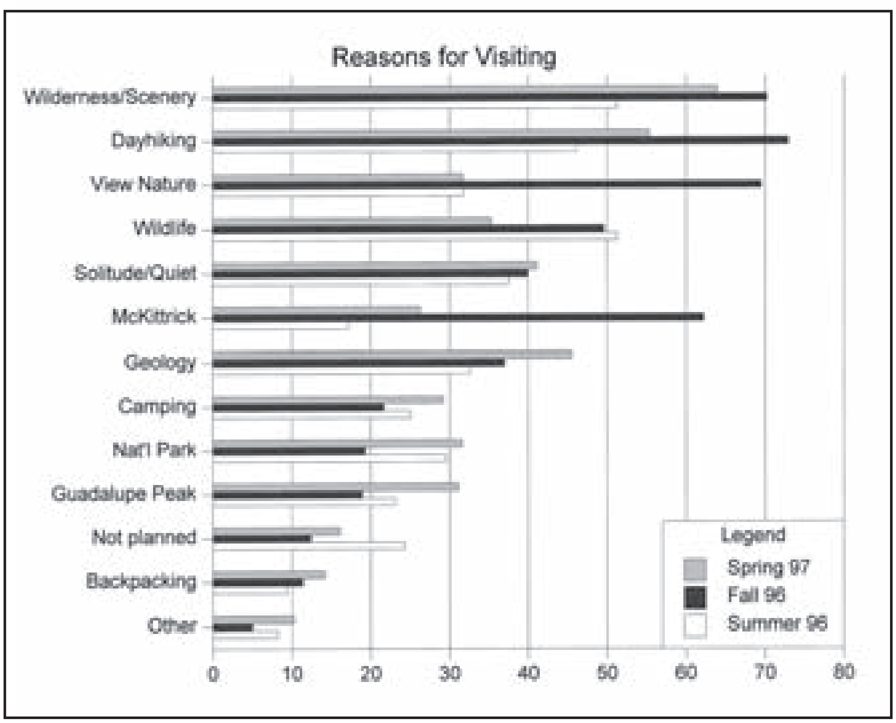


Figure 6

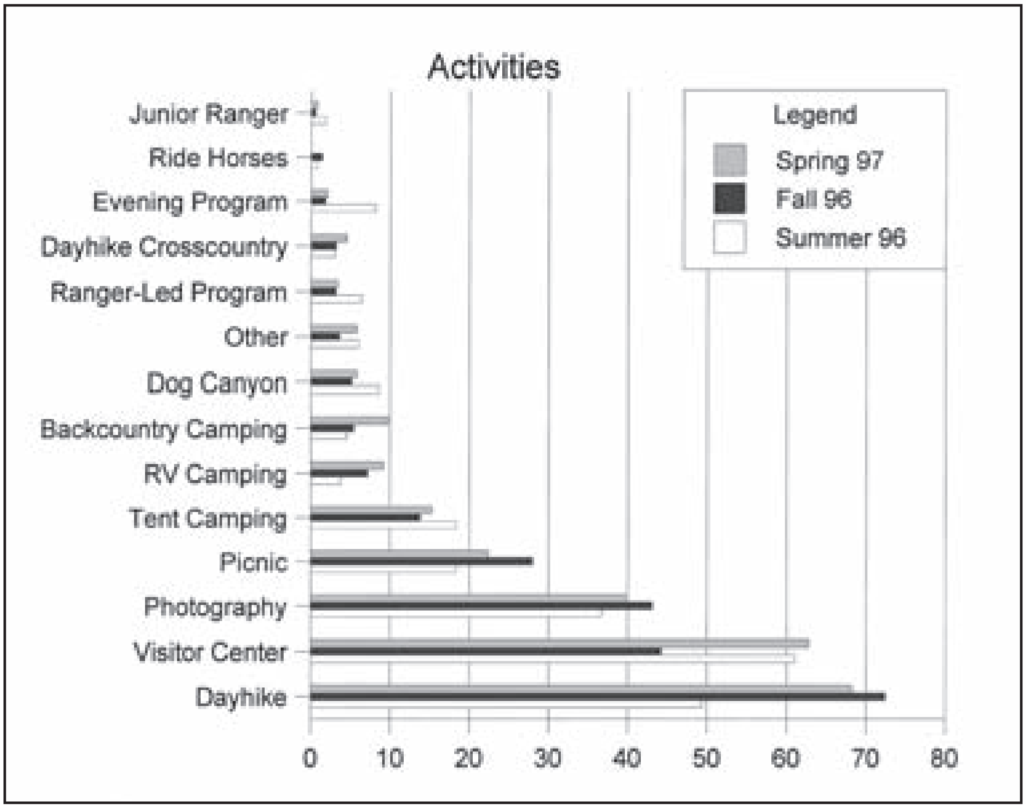
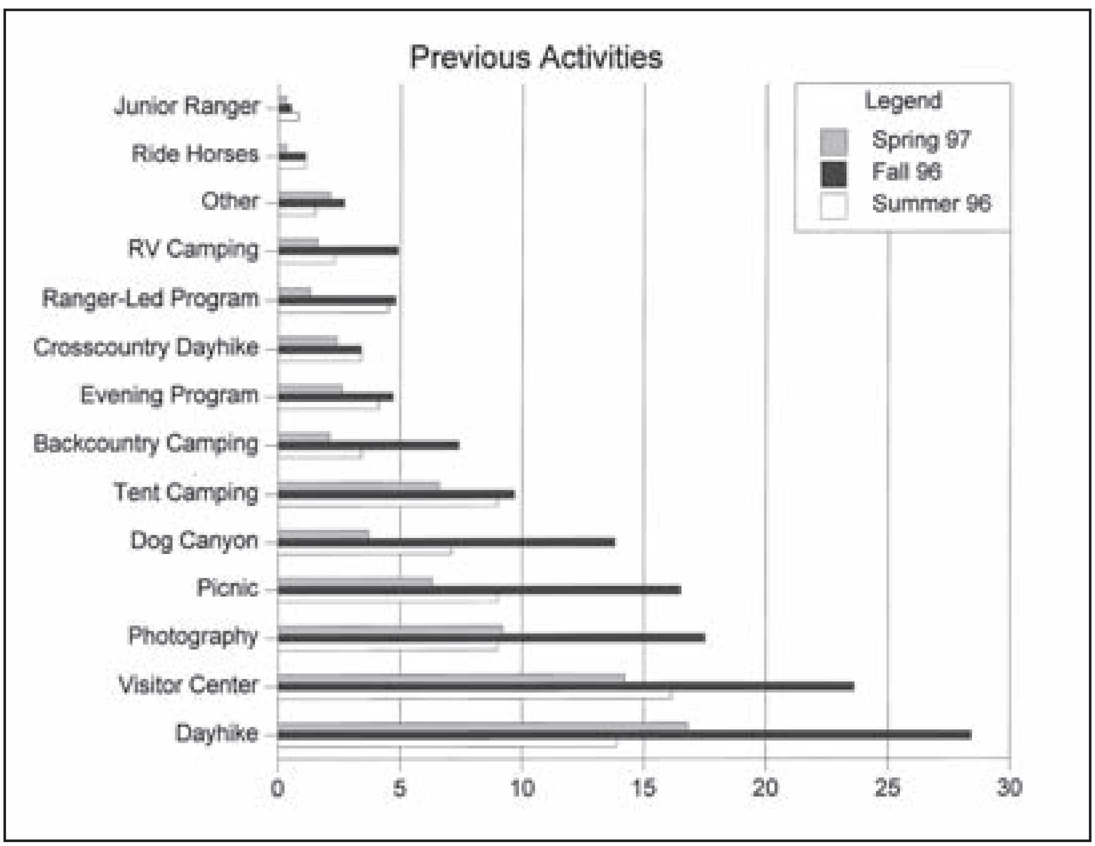


Figure 7



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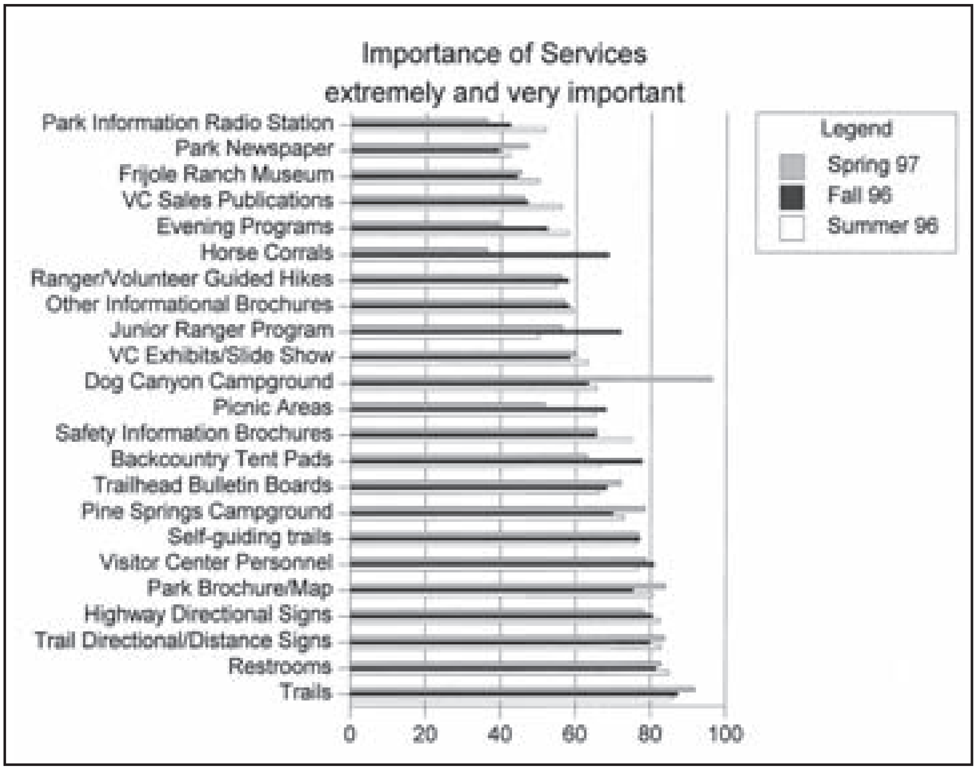


Figure 9

Visitors were asked to rank on a scale from one to five the importance of 23 services available at the park. Summer and fall visitors indicated that trails were the most important service at the park, while spring visitors rated Dog Canyon campground as the most important service (Figure 9).

Visitors were also asked to rate on a five-point scale the quality of the same 23 services (Figure 10). Visitor center personnel got the highest percentage quality rating for all three seasons.

A comparison of importance of services and quality of services can be made. For example, trails were rated by visitors as the most importance service (rank = 1) and were rated fifth on the quality scale (rank = 5). Comparing rank position from importance of service to quality of service, trails would receive a rank score of negative four (-4) indicating visitors felt trails were important but the quality did not match their importance. Conducting the same analysis for the other services, several items of note become apparent (Table 3).

Trail directional/distance signs and the Pine Springs campground were two services that were ranked high in importance and low in quality. Picnic areas and restrooms also showed similarly large differences between importance and quality. Printed material from the park, such as the visitor center sales publications, informational brochures, the park newsletter, and the park brochure/map, were considered low in importance but were ranked highly in quality. Also considered low in importance but high in quality were the visitor center exhibits/slide show and the evening programs.

Visitors were asked if they signed in and out at the trail registers (Figure 11). Overall, only a little over half of visitors reported signing in and out at the trail registers (51.9%). Trail register use did vary by season. Fall visitors were the most likely to report using the registers (58.0%), followed by spring visitors (52.7%). Summer visitors were the least likely to use trail registers (39.5%), but they were also the least likely of all visitor groups to use the trails.

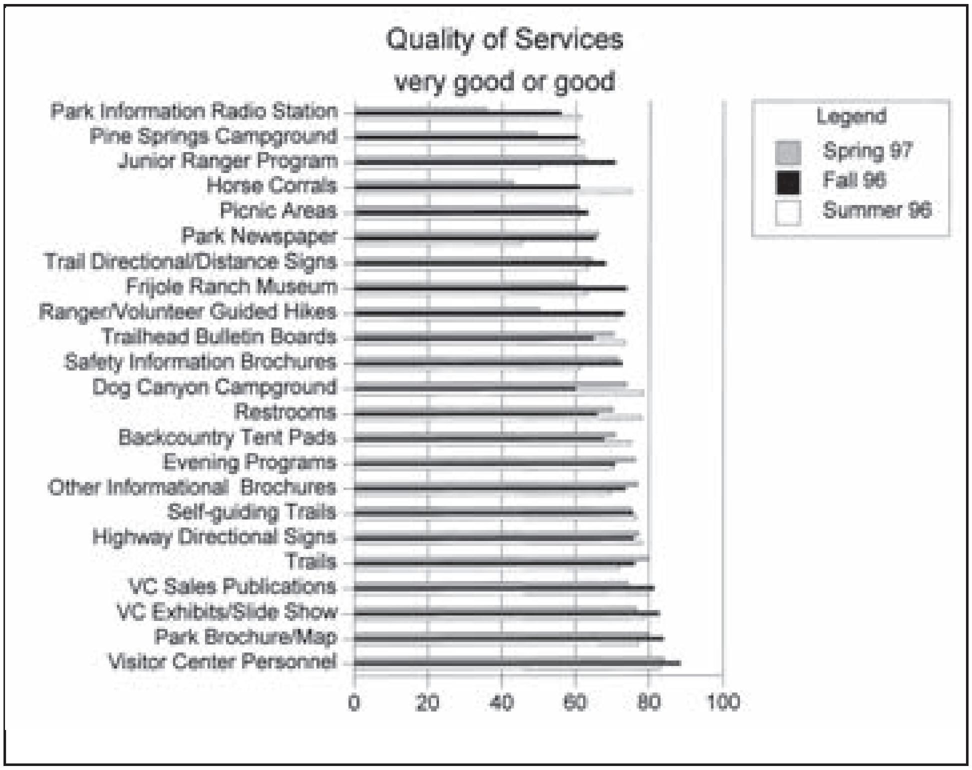


Figure 10

Importance Rank	Quality Rank	Difference	Service
20	4	16	Visitor Center Sales Publications
14	3	11	Visitor Center Exhibits/Slide Show
19	9	10	Evening Programs
6	1	5	Other Informational Brochures
6	1	5	Visitor Center Personnel
21	16	5	Frijole Ranch Museum
22	18	4	Park Newspaper
5	2	3	Park Brochure/Map
17	15	2	Guided Hikes
13	12	1	Dog Canyon Campground
7	7	0	Self-Guiding Nature Trails
10	10	0	Backcountry Tent Pads
23	23	0	Park Information Radio Station
4	6	-2	Highway Directional Signs
11	13	-2	Safety Information Brochures
1	5	-4	Trails
9	14	-5	Trailhead Bulletin Boards
15	21	-6	Junior Ranger Program
12	19	-7	Picnic Areas
2	11	-9	Restrooms
3	17	-14	Trail Directional/Distance Signs
8	22	-14	Pine Springs Campground

Table 3. Analysis of services by importance and quality.

Just because visitors weren't registering at the trailhead does not mean they were not reading the information available there. Visitors were much more likely to report having used the information displayed on the trailhead bulletin boards than to have utilized trail registers (Figure 12). About 20% more visitors viewed the bulletin board information than signed the trail registers. Information about why it is important to register may help increase compliance with trail register use. In the meantime, any use of the information from these sources should take into account the fact that only about half of visitor groups use the registers.

Visitors were asked a series of questions to determine the level of crowding that they perceived while at the park (Figure 13). They were first simply asked if they felt crowded during this visit to the park. Fall visitors were the most likely to report feeling crowded, followed by spring visitors, with summer visitors reporting very little feeling of crowding. Spring is the peak visitation period for Guadalupe Mountains National Park, but unlike fall when visitors are concentrated into a single area (McKittrick Canyon for fall colors), spring visitors are more spread out over the various areas of the park; hence, they experience less crowding. Overall, only about 10% of visitors reported feeling crowded during their visit.

Visitors were then asked to rate their experience of crowding on a five-point scale. They were asked how the number of people they saw at the park compared with what they expected to see (Figure 14). The majority of fall and spring visitors experienced about as much crowding as they expected. Summer visitors were most likely to report that the park was a lot less crowded than they expected.

Visitors were also asked about how crowded they felt in specific areas of the park (Figure 15, Figure 16, Figure 17). Analysis by season indicates that there were definite differences between the groups in perception of crowding by specific park site. Backcountry camp 1, backcountry camp 2, trail 1, and trail 2 do not equate to any particular camp or trail, but respondents were given opportunity to make specific comments on up to two camps or trails. For visitors in the summer and spring, Pine Springs camp-

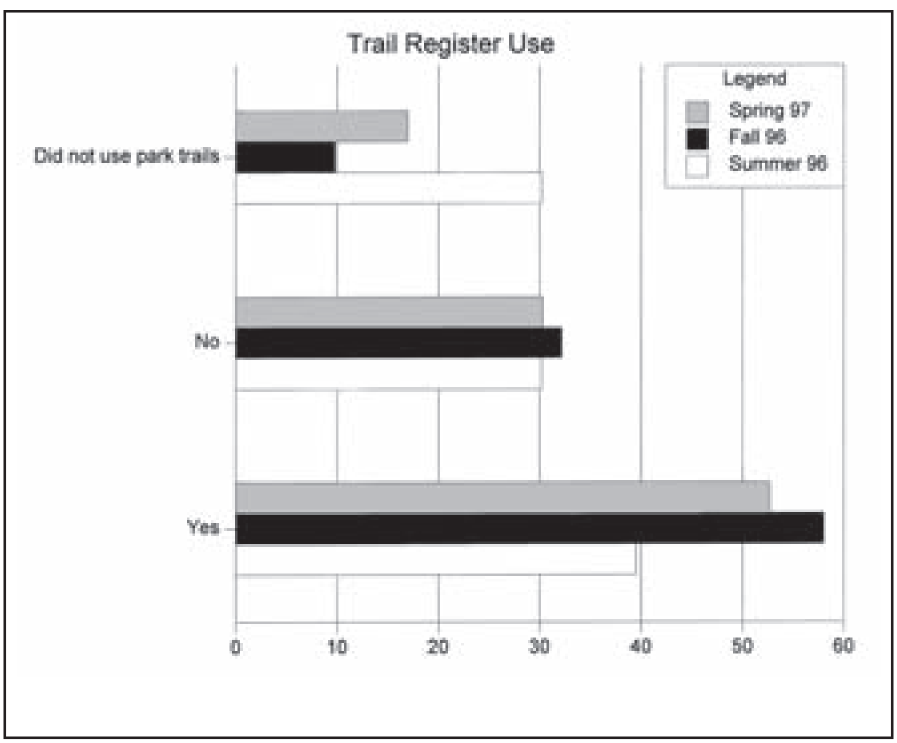


Figure 11

ground was perceived as most crowded. During the fall season, McKittrick Canyon was named as both the most crowded and the least crowded! Summer visitors found Frijole Ranch to be the least crowded and spring visitors named McKittrick Canyon as the least crowded. Examination of median values shows that for all locations the majority of visitors indicated that their experience was that the site was either "about as crowded as I expected" (McKittrick Canyon, Guadalupe Peak, Pine Springs campground, and Pine Springs visitor center) or "a little less crowded than I expected" (Frijole Ranch, Williams Ranch road, Dog Canyon, backcountry trails and camps). For each season, visitors had the option on this crowding question of writing in the name of backcountry trails and camps and indicating the level of crowding. Summer visitors had the fewest complaints about crowding in the backcountry. Fall and spring visitors were more likely to have complaints about crowding in the backcountry, but relative to the number of visitors surveyed, the number of visitors experiencing crowding in the backcountry was quite small.

Two summer visitors indicated that the Bowl trail was a little more crowded than they expected; three mentioned the Tejas trail, and one mentioned the Juniper trail. One fall visitor indicated that the Devil's Hall trail and another that the Bowl trail were a lot more crowded than they expected, and two mentioned the Tejas trail as being a little more crowded than expected. Three spring visitors indicated that the Devil's Hall trail was a lot more crowded than they expected, and one mentioned the Smith-Manzanita Spring trail as being a little more crowded than expected along with three visitors on the Tejas trail. Two spring visitors also indicated they felt crowded on the Bush Mountain trail. Regarding crowding in backcountry camps, Guadalupe Peak camp was mentioned as a little more crowded by three visitors (one summer and two spring visitors) and one summer and one fall visitor mentioned Tejas campground. One spring camper indicated that the Pinetop campground was a lot more crowded than he/she expected. Overall, it appears that backcountry trails and campgrounds are less crowded than visitors expect.

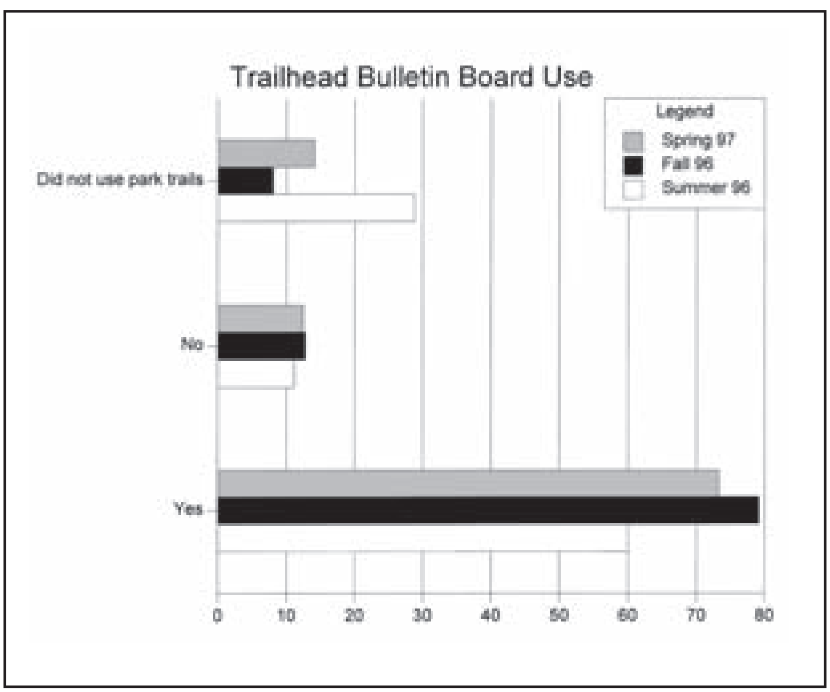
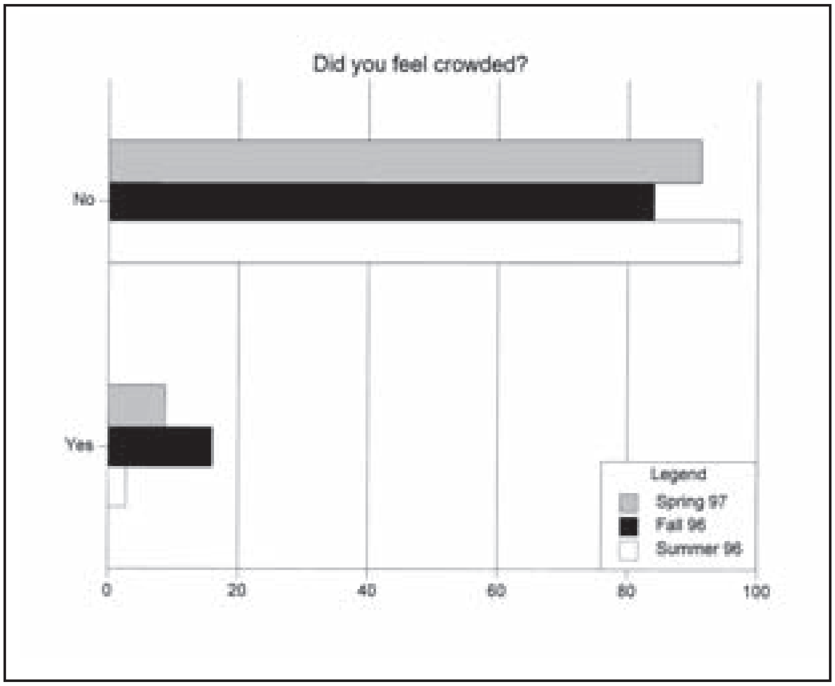


Figure 12



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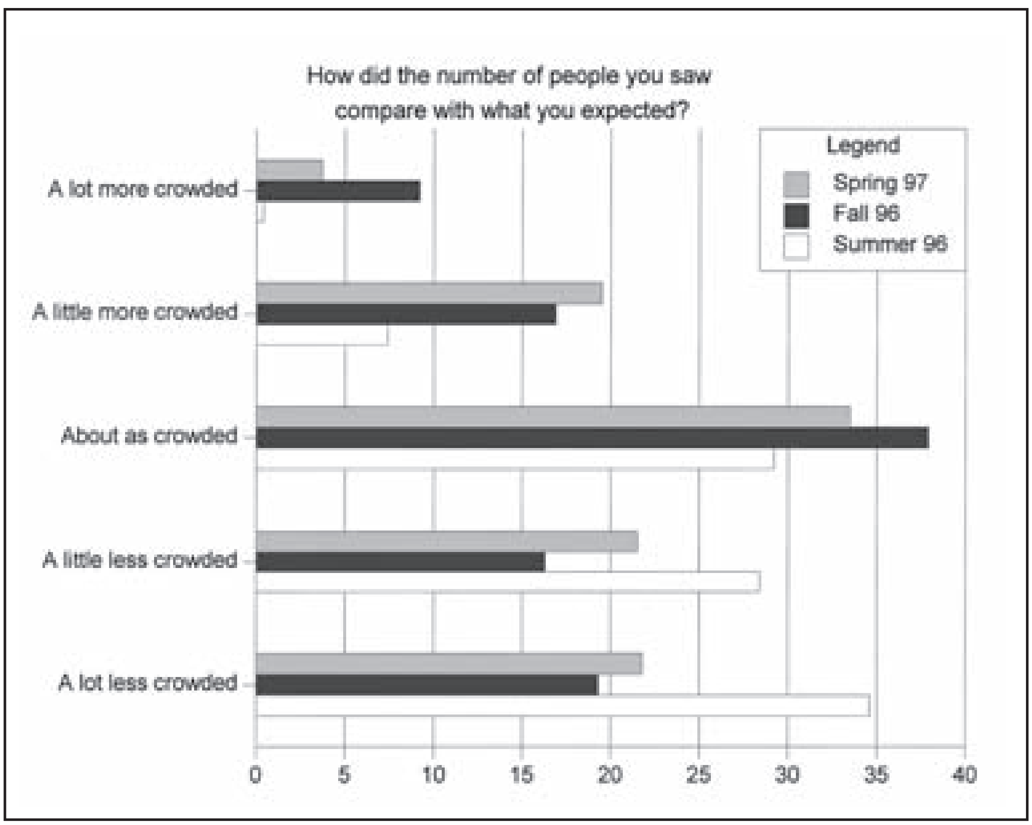

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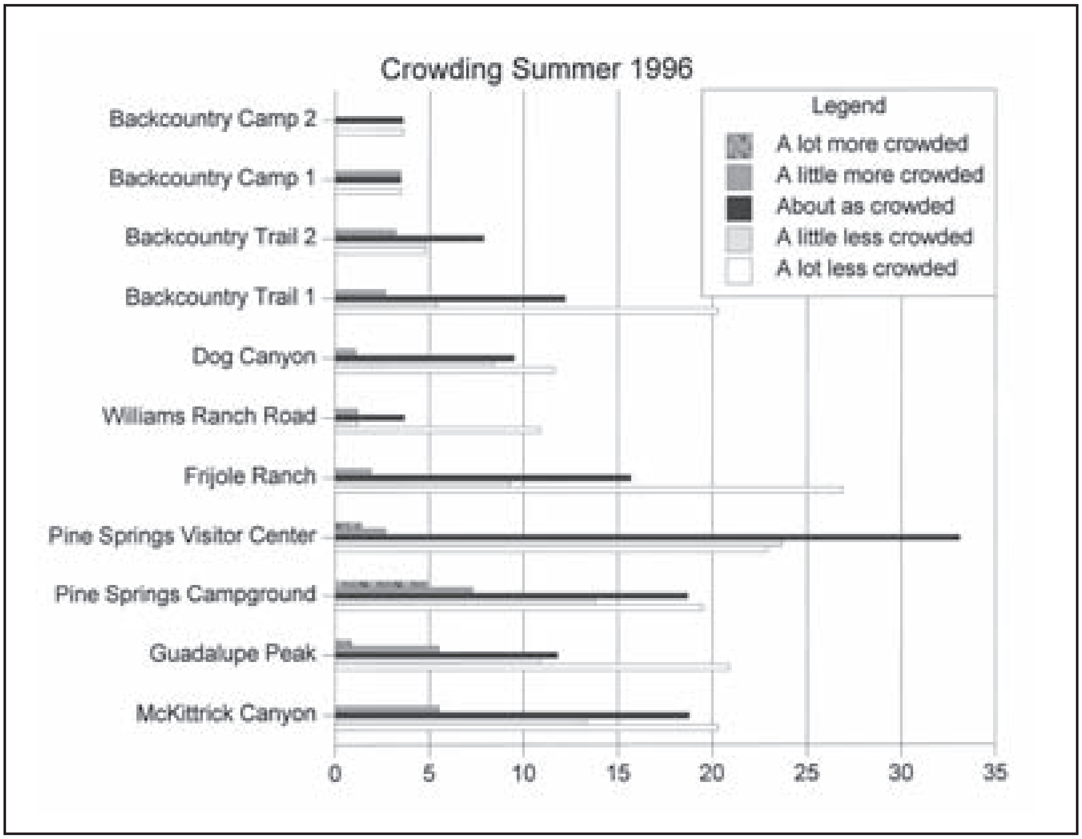

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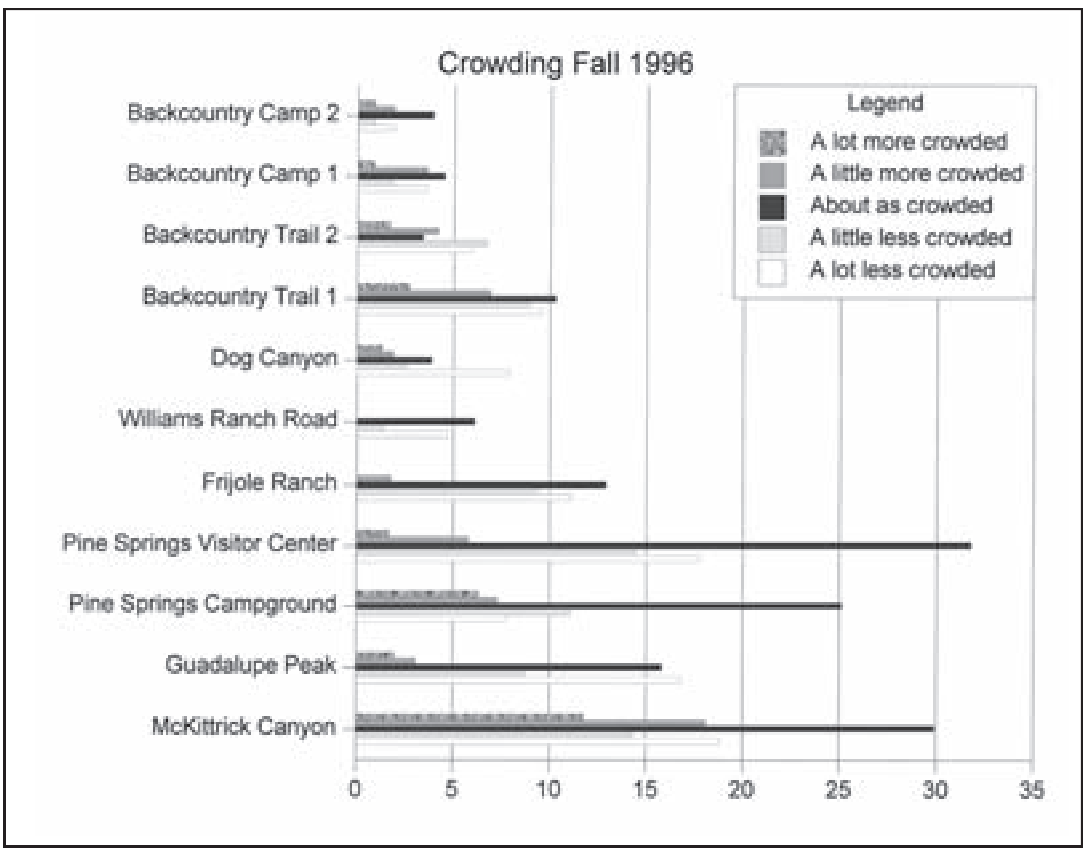


Figure 16

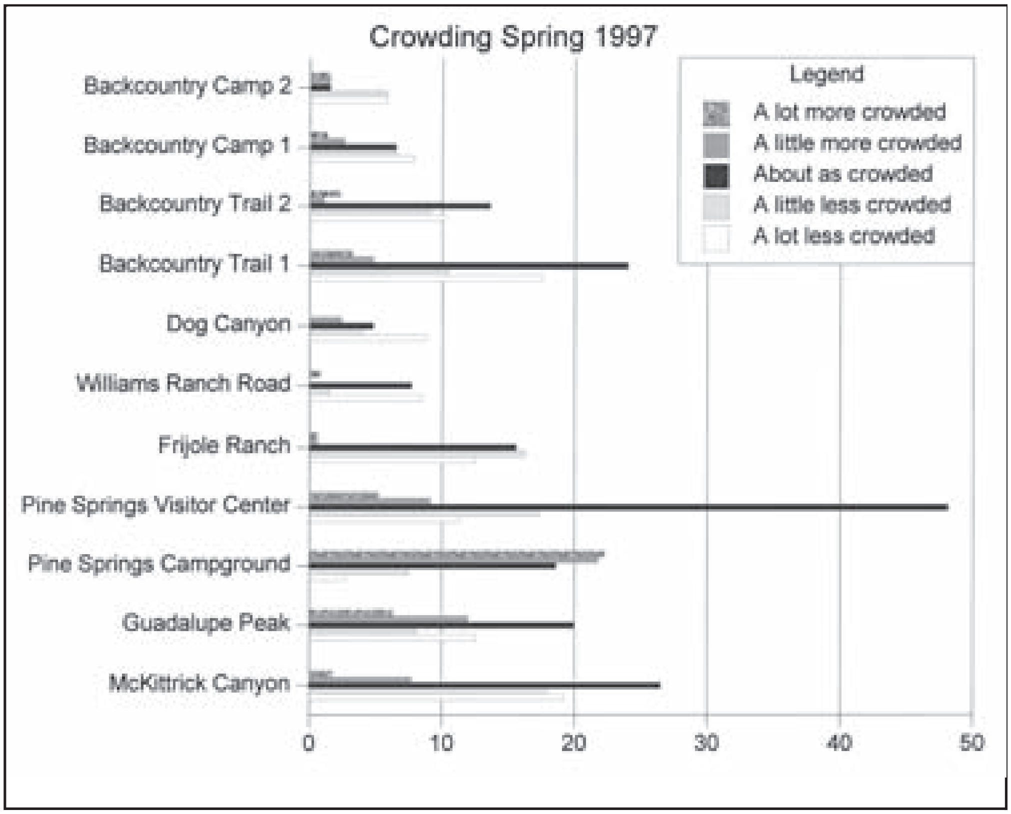


Figure 17

Visitors were asked if they thought the park should have a camping reservation system (Figure 18). The majority of visitors had no opinion on this topic, indicating that it is not a salient issue. Spring visitors were the most in favor of a camping reservation system which is probably because these are the visitors most likely to camp. Fall visitors were the most likely to say "no" and summer visitors were the most likely to have no opinion on the subject.

Visitors were asked if there were any services, facilities, or programs that were not available in the park that would have added to their enjoyment of their visit. Only about 30% of visitors replied "yes" to this question, indicating visitor satisfaction. Visitors made comments to an open-ended question (Figure 19). Analysis of their comments indicates that the seasonal activities people were enjoying at the park drove their desires for specific services or facilities. Showers were the most requested addition to park services and facilities, with summer visitors showing the most interest of the three visitor groups. Perhaps this indicates a need for more interpretation to park visitors about the scarcity of water in the desert and the need for conservation of this resource in the park.

Visitors were asked, "Overall, how satisfied were you with your visit to the park?" Most respondents were satisfied with their visit (Figure 20). Fall visitors expressed the most satisfaction of all three groups, followed by spring visitors. Very few visitors expressed dissatisfaction with their visit to the park.

Respondents were given the opportunity to respond to four open-ended questions about their park experiences. Visitors were asked, "What did you and your group like most about your visit to the park?" Some element of nature was the most mentioned favorite aspect of visiting the park (Figure 21).

Visitors were also asked to indicate what they least liked about their visit to the park (Figure 22). Summer and fall visitors were most likely to complain about

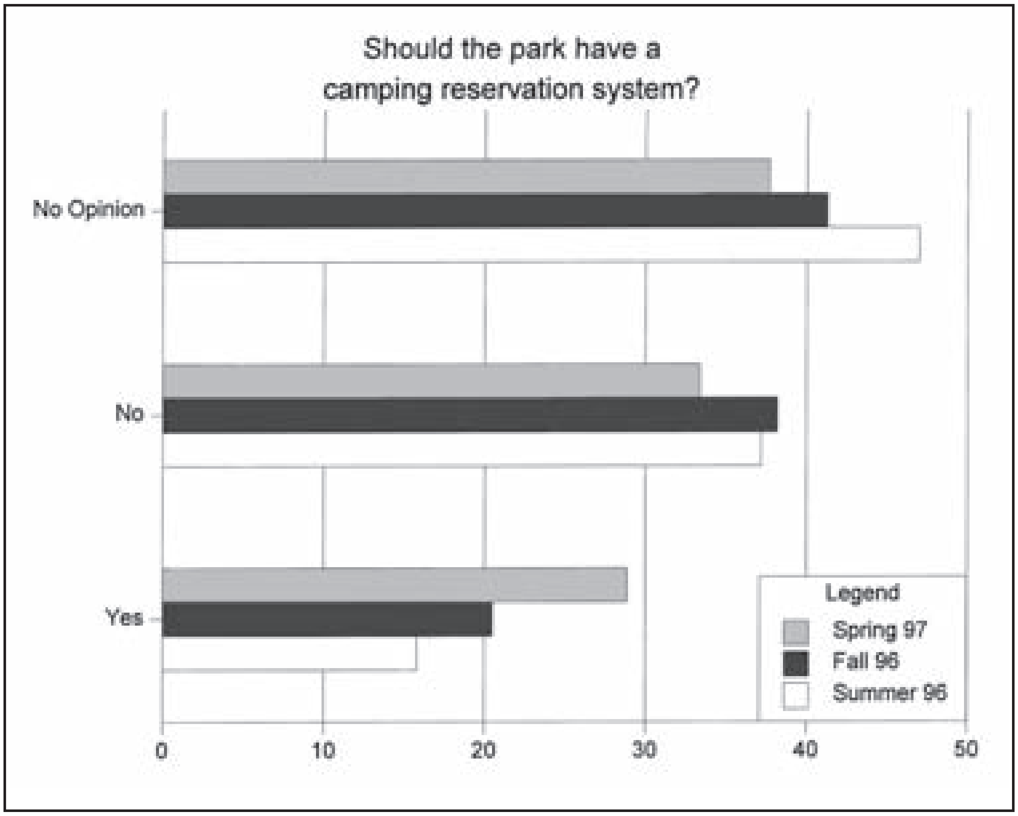


Figure 18

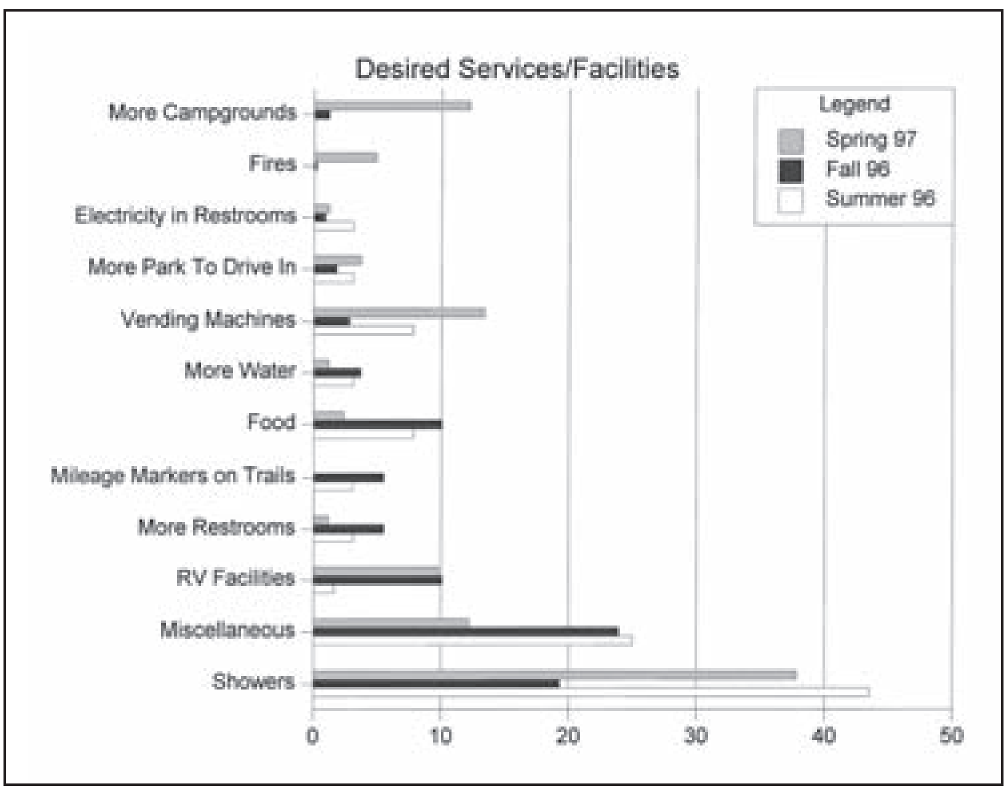


Figure 19

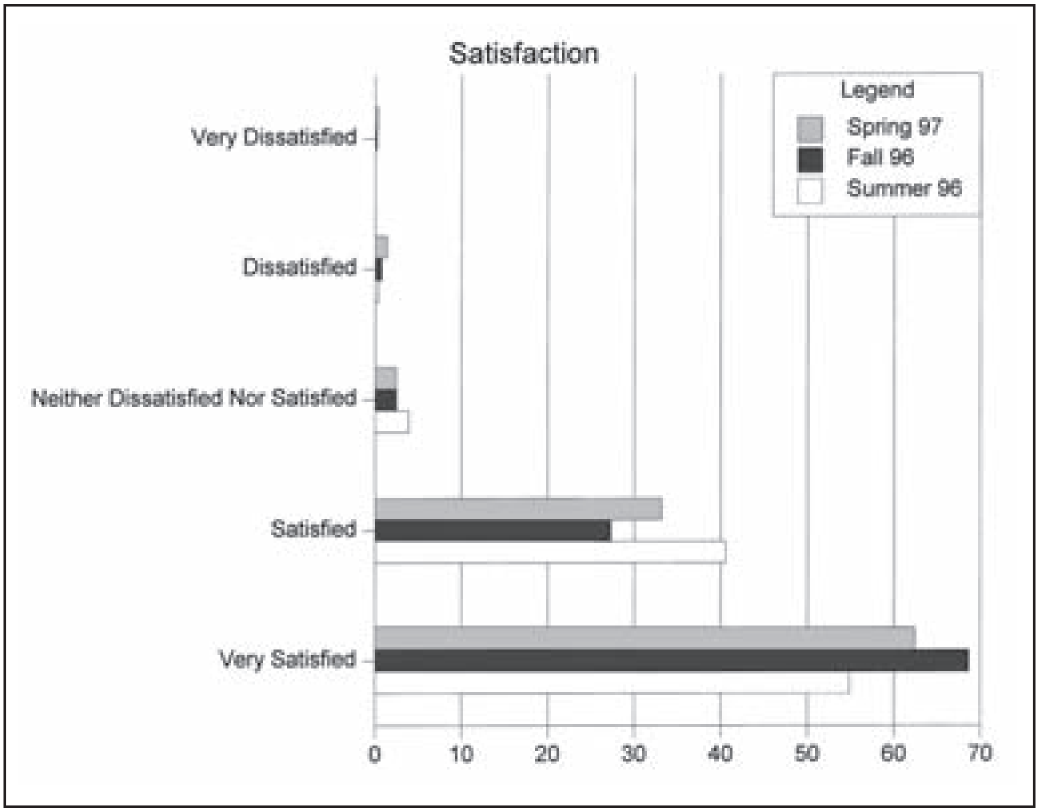


Figure 20

the facilities/services (usually something they felt was absent, not complaints about existing facilities or services). Fall visitors were those most likely to have no complaints at all. Summer visitors were the most likely to complain about aspects of nature beyond park control, such as the heat; spring visitors tended to complain about the wind. In the category of "not relevant" were such complaints as one visitor expressing disgust at hunting being allowed at the park, when in actuality rangers were looking for a deer that had been wounded in an encounter with a car. Other examples in this category were such things as complaints about travel time to the park and personal lack of physical conditioning.

Visitors were asked the question, "If you were a manager for the future of Guadalupe Mountains National Park, what would you propose?" (Figure 23). The largest category for most spring and summer comments was a suggestion for facilities and services at the park. In contrast, fall visitors were the most likely to propose no changes be made at all. Trails were frequently mentioned in this section. Visitors expressed the need for better trail signage and maintenance.

The final question in this survey was, "Is there anything else you and your group would like to tell us about your visit to Guadalupe Mountains National Park and the surrounding area?" The most frequent type of response to this question was a compliment about the great job that the National Park Service is doing at Guadalupe Mountains National Park (Figure 24).

Note: At present (2003), Jacqueline Bergdahl is a professor in the Department of Sociology and Anthropology at Wright State University, Dayton, Ohio.

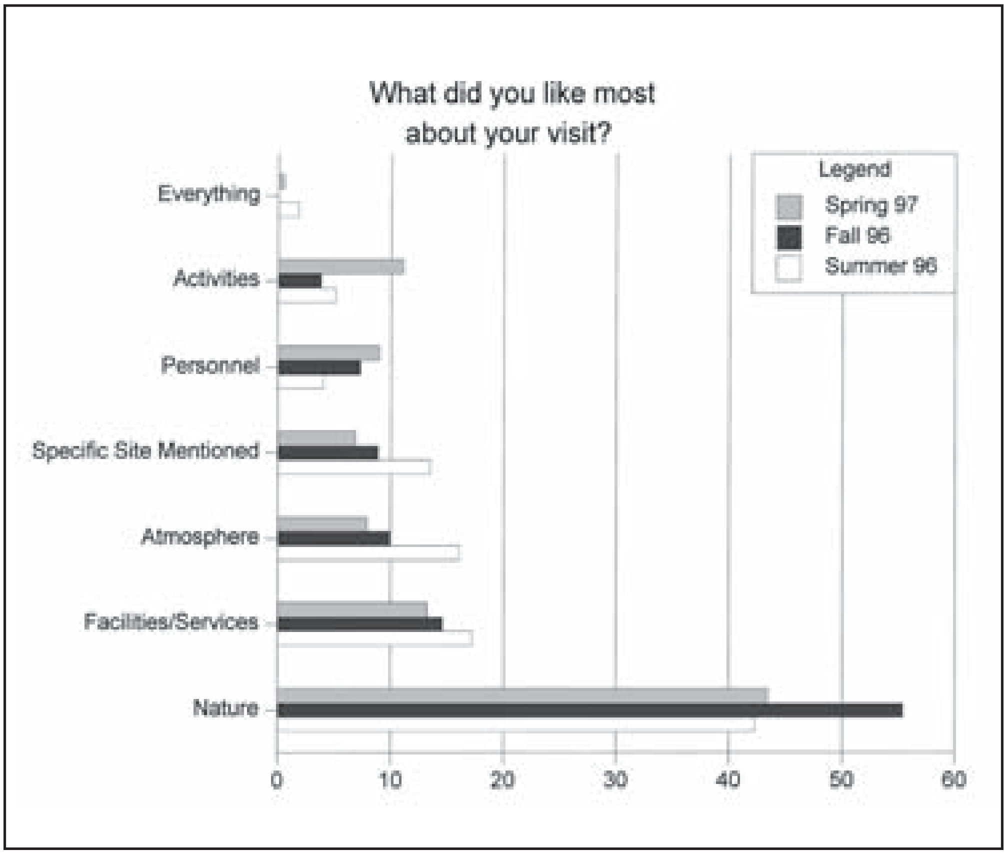
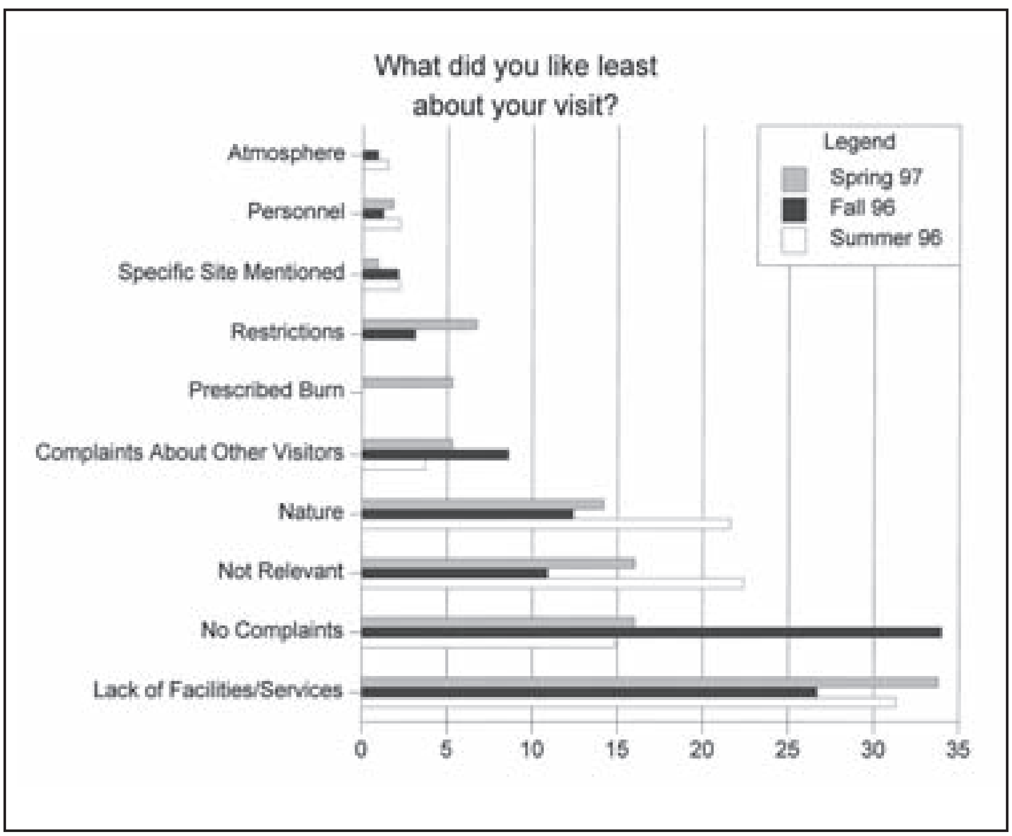


Figure 21



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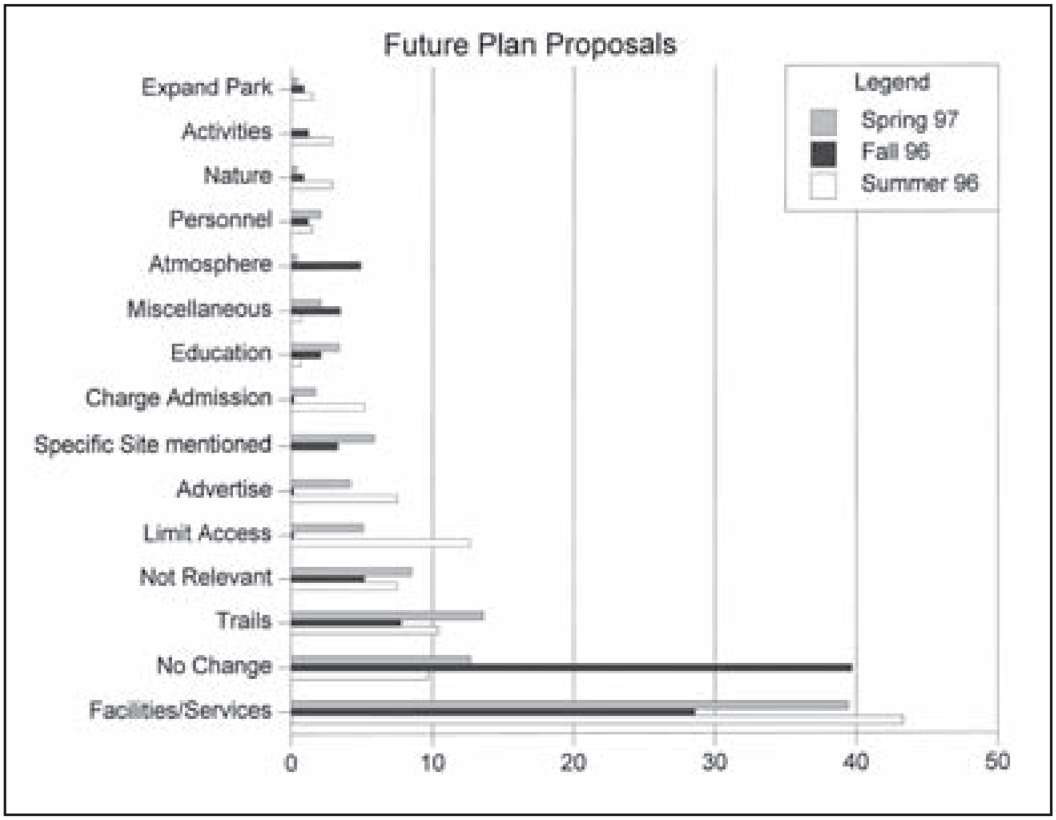

Figure 23

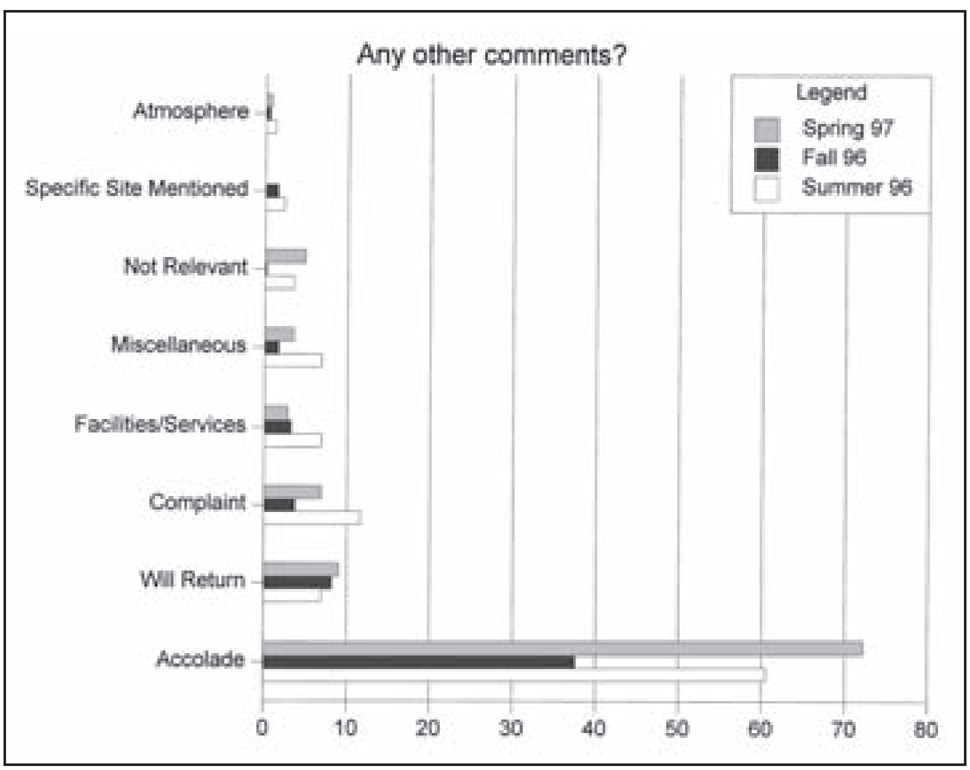

Figure 24

Chapter 48

Legislative Mandates, Cultural Affiliation, and Guadalupe Mountains National Park

ADOLPH M. GREENBURG, Ph.D., is a professor of anthropology with Miami University in Oxford, Ohio. He compiled an ethnographic overview of the Mescalero Apache and Ysleta del Sur tribes.
Other authors: GEORGE S. ESBER, JR., Miami University, Oxford, Ohio and formerly with the NPS Southwest Regional Office ethnography program; and JOE SIERRA, Tigua Indian Tribe, Ysleta del Sur Pueblo

A few years ago, a top-level official in the federal government with authority over the National Park Service made the comment that none of the western parks contained cultural resources. Presumably, the underlying thinking was that in the eastern United States there are a number of places having historical significance that reflect the cultural heritage of the nation: places such as presidential homes, Civil War battlefields, monuments to figures of national importance, and other places to commemorate events in United States history. Thus, it is a reasonable supposition that many of the parks in the East preserve the historical and cultural heritage of the United States. In this view parks in the West are seen as places of scenic monumentalism represented by examples such as Yellowstone, the Grand Canyon, and Carlsbad Caverns. They are magnificent landscapes. However, they too, contain cultural resources as this paper will illustrate.

People of the Euro-American tradition, holding a position of dominance, readily disregard other cultural traditions that are an equally important part of the country. In fact, many of these "other" traditions have the added significance of greater antiquity than those of the more recent immigrants to North America. In parks such as Mesa Verde National Park, Petroglyph National Monument, Pecos National Historical Park, Bandelier National Monument, Chaco Culture National Historical Park, Aztec Ruins National Monument, and Wupatki National Monument, to name but a few, cultural resources are preserved in parks specifically because each preserves a cultural heritage. Contrary to much of the information disseminated through archaeological interpretations, through our educational system, in textbooks, and indeed, in the nations' mythology, present day Indians have neither disappeared nor ceased to function as dynamic, viable communities. A typical fallacy, for example, has allowed students of excavation to make the claim that the Anasazi, a presumed culture fictitiously created in the first place, mysteriously vanished, while in reality, Pueblo Indian descendants from these cultural traditions continue to function as communities as they have for centuries. Many of the Arizona and New Mexico parks have appropriated and preserved the Puebloan cultural heritage for the nation and only incidentally for the Pueblo peoples. Needless to say, the government official made a hasty retraction, but nevertheless, this incident is worthy of note because it bears on heritage issues facing ethnic communities, especially those of Native American Indians.

Traditionally, as sites are authorized as parks and come under the stewardship of the National Park Service, they are managed according to the mandate of the Organic Act of 1916, which charges the National Park Service "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by means as to leave them unimpaired for the enjoyment of future generations." In the Organic Act, there is no mandate to seek advice from or consult with peoples having traditional associations with the resources of the park. Translated into practice, parks like Guadalupe Mountains National Park would typically be managed without consideration for the ties that contemporary communities have with some of the resources in the park, not to mention how some of those relations might have significance for peoples with regard to their freedom of religion, need for medicinal plants, concerns about the treatment of resources by parks, or how information about those resources was presented to the public through interpretive or educational programs.

Beginning in the Civil Rights era, certain legislative acts were passed having implications for how federal agencies, including the National Park Service, perform their responsibilities. The National Historic Preservation Act of 1966 (NHPA), the National Environmental Policy Act of 1970 (NEPA), the American Indian Religious Freedom Act of 1978 (AIRFA), and more recently the Native American Graves Protection and Repatriation Act of 1990 (NAGPRA) are but a few examples of laws that require federal agencies and others to consider American Indian concerns and to consult with American Indians when they are affected by policy implementation. While each of these laws carries its own directives, their net effect was to create an atmosphere whereby the National Park Service found it necessary to formalize procedures for involving American Indians and other ethnic communities in consultations with the parks where traditional associations were a concern.

The initiative for developing policies for ethnographic work originated with the senior anthropologist in the Washington Office of the National Park Service, Dr. Muriel Crespi, who over the years, worked to establish ethnography programs in each of the parks' regions. As a consequence, regional ethnographers were hired in some of, what were at the time, the ten regions of the National Park Service. Although a reorganization of the National Park Service has since taken place, the regional ethnography programs remain with ethnographers in positions to initiate research programs and to assist in implementing their findings in park operations. Ethnographic research collects data about peoples' associations with parks, and is used to establish consultations with associated peoples regarding the stewardship, management and interpretation of cultural resources significant to them. In this capacity Dr. George Esber served as the first regional ethnographer for the Southwest Region and initiated some of the first research in the regional ethnography program.

An ethnographic study was conducted at Guadalupe Mountains National Park to determine which communities had traditional associations to the cultural resources in the park, to learn the nature of the resources they were concerned with, and to ascertain their level of interest in and desire for involvement with the National Park Service. The services of Dr. Adolph Greenberg were contracted to conduct the research.

According to the NPS-28 Cultural Resource Management Guideline (1994), an ethnographic overview and assessment represents an initial comprehensive background study of types, uses, and users of a park's ethnographic resources. The study calls for a review of existing information and the identification of new data needs. The meaning and importance of specific locales and resources in the Guadalupe Mountains to the Mescalero and other contemporary American Indian communities remains at the level of historic and ethnohistoric documentation. Previous studies by the National Park Service identified the need to understand the historic period of Mescalero economic, religious, and military use of the Guadalupe Mountains. In addition, there exists oral commentaries and written documentation pertaining to recent Mescalero use of the area for religious purposes, as well as Mescalero solicitations to the National Park Service for permission to collect sotol and/or mescal fruit for ceremonies. For the most part, such documentation does not contain Indian commentary or narratives on the meaning of the Guadalupe Mountains to their people. Oral commentary revealed through ethnographic interviews and observations can inform park management of places that may require special attention or protection by the National Park Service. Moreover, the establishment of ongoing consultations with those affected Indian communities holds the potential to enhance not only the management of the park but its interpretative story.

A major component of the study was to establish a consultation relationship with the Mescalero Apaches because there is substantial historic documentation that they regularly used the resources of the Guadalupe Mountains during the 1700s and 1800s. However, their interest in the area continues today, although no ethnographic overview and assessment of their traditional and continuing association with the resources of the park—including significant natural and cultural areas, traditional use areas, sacred sites and locales, access trails, and access needs—had been undertaken until this project.

Ethnographic research to obtain this information demands the recognition of American Indian tribal sovereignty as their communities are more than ethnic entities. They, unlike other ethnic communities, are self-governing with sovereign authority over their members and their lands and are recognized as such by the United States government. As a National Park Service project, the ethnographic overview and assessment proceeded accordingly and maintained a government-to-government relationship. After initial meetings with the staffs of Guadalupe Mountains National Park and the Southwest Regional Office of the National Park Service, Greenberg began the process of establishing official contact with the Mescalero tribal government. Because of a number of unforeseen events and issues with which the tribe was involved, official contact via a meeting with the vice president of the tribe did not occur until some 13 months into the project. The tribal official was amenable to the project and felt it desirable that the tribe participate as they have a deep-seated, continuing interest in the Guadalupe Mountains. However, before the project could be considered by the tribal council, the scope of the project along with its implications for the tribe would have to be discussed in the tribe's cultural affairs and museum committees. Meanwhile, the contractor produced and sent a videoletter introducing the project, park staff, and the park to the tribe. After a reasonable period of time, the contracting officer's technical representative from the regional office determined that the project would have to be drawn to a conclusion, although that would not preclude the park and the National Park Service from continuing in their contacts with the Mescalero. As a consequence, this ethnographic study did not involve official ethnographic interviews or on-site visits to the park involving the Mescalero tribe. The final report relied on existing documentation regarding Mescalero interest and involvement in Guadalupe Mountains and as such there are noticeable and critical gaps in the existing database. Subsequent contacts have been made by the National Park Service with the tribal government and hopefully these will spur the development of ongoing consultations with the Mescalero tribe.

In addition to the Mescalero associations, National Park Service staff at Guadalupe Mountains National Park speculated about ongoing Tigua presence in the general vicinity of the Guadalupes. Official contact with the Tigua tribe of Ysleta del Sur Pueblo was made and the tribe agreed to participate in the project. Subsequent discussions, documentary research, ethnographic interviews, and an on-site consultation visit to the park revealed the extent of Tigua links to the lands now under National Park Service administration and most notably to the Guadalupe Salines on lands immediately adjacent to the park. Ethnographic interviews with the Tigua revealed a long-term association with the west slope of the Guadalupe Mountains, including the salt basin, gypsum dunes, and specific plant resources.

The final report (Greenberg 1996) for this project included recommendations for further consultations with the Mescalero and continuing consultations with the Tigua including a response to Tigua concerns about protection of and tourist access to the west-side sand dunes and to archaeological sites. The Tigua representatives were unanimous in their request that they be consulted regarding any changes in the disposition of the sand dunes relative to protection issues and tourist access and visitation. Tigua representatives were also of one mind in their willingness to assist the park staff in adding accuracy to the ethnographic interpretative story of Guadalupe Mountains National Park. They are opposed to any further excavations of the archaeological sites in the west-side boundary area and have recommended that the site be closed to the public. Finally, the Tigua noted that access to the area is important to the tribe and should be the subject of further negotiations.

What the legislative mandates and the project itself reveal is the critical need to recognize that an ethnographic component enhances the management of park resources and does so in a culturally-informed manner. The accomplishment of this goal requires transferring the mantle of authority about cultural knowledge from archaeologists, ethnographers, and historians to the rightful owners of traditional cultural properties and knowledge, who in this case are the identified American Indian communities. When this happens, the parks will be effectively and appropriately decolonized with respect to management and interpretation.

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Chapter 49

Guadalupe Mountains National Park: A 1920s Attempt at Preservation

FRED MACVAUGH is a graduate student in history at the University of Texas at El Paso, where he is writing his Master's thesis on the establishment, early administrative history, and socio-cultural significance of Carlsbad Caverns National Park.

Congress authorized Guadalupe Mountains National Park in 1966; the National Park Service dedicated the park in 1972. Attempts to set the area aside as either a national park or monument date back to 1924, if not earlier.

Anglo-Americans had known of the Guadalupe Mountains by the mid-1800s. Spanish explorers and Mexicans knew of them centuries earlier. Native American awareness, habitation, and use of the mountains and their hidden resources predated Columbus' discovery of the "New World." Yet, except for small numbers of Native Americans, few people settled in the Guadalupe Mountains or surrounding desert until the last decades of the 19th century. Spanish explorers and settlers, and their later Anglo-American counterparts, mostly bypassed the region. For certain, Anglos passed through the region on their way to California, or in some cases, for the Rio Grande valley. Anglo settlement in the Pecos Valley and Guadalupe Mountains area did not begin in earnest until the 1870s; thereafter, settlement slowly and steadily increased.

One fascinating element about the Anglo-American exploration and settlement of the Guadalupes is the way in which the people interpreted the landscape and region. It is a process still very much occurring today in Guadalupe Mountains National Park and Carlsbad Caverns National Park. In fact, that is the reason for my interest: I am researching for and in the process of writing a thesis dealing with Carlsbad Caverns' history. I am looking at why Carlsbad Caverns came into the National Park System in 1923 as a national monument (Carlsbad Cave National Monument). It was not until seven years later, in 1930, that congress upgraded the monument to national park status.

The way people interpreted the landscape and, in particular, the way Americans defined themselves (as a society) according to landscape and the West is extraordinary. Indeed, this is a trend readily visible at Guadalupe Mountains' sister park, Carlsbad Caverns. Names of cave formations—the way they were described and labeled in the 1920s and the way they are still identified and explained today—originate with cultural constructs prevalent in 1920s American society. These in turn can be traced back to Judeo-Christian philosophies—all the way back to the Greeks. Evidence of this trend is found throughout the entire Guadalupe Mountains–Carlsbad Caverns region.

Writing about the history of national park units cannot be confined to the area within park or monument boundaries alone.

Hence, writing about the history of national park units cannot be confined to the area within park or monument boundaries alone. Individual park histories are about the parks, yes, but they are also the stories about the surrounding regions and communities, stories about the people who first settled in a given region, stories, too, about the people who passed through while making their way elsewhere. For all of these people left their mark: maybe physical remains such as structures or inscriptions on canyon walls, maybe published or unpublished accounts of their travels and impressions, or, perhaps they named features encountered during their ventures and those names stuck.

The Delaware Basin is a perfect example; it includes the land stretching south from the Guadalupe escarpment. The mountain chain due south of El Capitan is called the Delaware Mountains. Both get their name from the Delaware, or Lenni Lenape, Indians who emigrated (due to increasing Anglo-American population pressure) from the Delaware–New Jersey–Pennsylvania area. These people slowly pushed west into Ohio and Illinois, then to Arkansas, Texas, Oklahoma, and beyond, where eventually they served as guides for United States military expeditions passing through the Guadalupe Mountains region in the mid-1800s. People such as Jim Shaw, John Connor, and Black Beaver (all Delaware) earned reputations as peerless guides, hunters, and negotiators. Black Beaver, perhaps the most famous, led Randolph B. Marcy's 1849 expedition in search of the most practical route between Fort Smith, Arkansas (now a National Park Service unit), and Santa Fe, New Mexico. Marcy's return trip brought him across what is now the Delaware Basin. Whether the basin is named in honor of Black Beaver is unknown; nonetheless, it is named for his people in commemoration of their knowledge of and ability to successfully lead Anglo-Americans through this area.

Clearly, the Guadalupe Mountains had been known for a long time. Apache habitation and use of the mountains predated the Anglo-American arrival in the area. (The mountain chain due south of the Delawares is named Apache Mountains.) All previous knowledge and use of the Guadalupes notwithstanding, the first genuine interest in setting them aside as a national park emerged in 1924.

Lee judged the area worthy of inclusion in the National Park System. Basically, he considered the rugged mountains and canyons on par with some of the other crown jewels of the 1920s National Park System.

The previous September, U.S. Geological Survey geologist Willis Thomas Lee visited Carlsbad to inspect some of the Bureau of Reclamation dam sites along the Pecos River because they were not holding as much water as expected or wanted. In hopes of developing a better understanding of the region's geology from within, he inspected Carlsbad Cave, then called the Bat Cave. After returning to Washington, D.C., Lee recommended that the cave be made into a national monument. His scientific rational for preservation—later quoted in a letter from Secretary of the Interior Hubert Work to President Calvin Coolidge—clinched it, and Coolidge signed the Carlsbad Cave National Monument proclamation on October 25, 1923. At the same time, Lee proposed a more extensive exploration of the cave. Wisely, Lee cautioned against limiting the expedition to the cave alone; he felt the surrounding country with its numerous caves, some reportedly as spectacular as the Bat Cave, needed to be explored as well.

By the 1920s, Lee was a recognized authority on the geology of the Southern Rocky Mountains. He had studied them for years; in 1912 he had recommended that Capulin Volcano be reserved as a national monument. (Although his superiors at the U.S. Geological Survey rejected his recommendation, the National Park Service did preserve Capulin Volcano as a national monument in 1916.) Lee also wrote a very popular history of Rocky Mountain National Park published in 1917. In recommending a thorough exploration of the Bat Cave and Guadalupes, Lee had two equally important justifications: first, he wanted to study how the cave and its stalactites, stalagmites, and other formations had formed; second, he believed he might find caves containing remains of hitherto little or unknown prehistoric peoples who had inhabited the Guadalupe Mountains. He also cited possible botanical, faunal, and geographical discoveries as equally important reasons for such an exploration and study.

The National Geographic Society approved Lee's proposal and allocated $16,000 for a six-month expedition, which commenced in March 1924. For the first half of the expedition, Lee and other expedition participants such as James "Jim" Larkin White (the man recognized as the first major explorer of Carlsbad Cave) and Carl Livingston (a local attorney and amateur archaeologist) chiefly worked at the cave. Toward the middle of the expedition, with the bulk of the photographic and surveying work in the cave completed, Lee turned his attention to the Guadalupe Mountains. With White, Livingston, and others, Lee rode on horseback through many of the canyons such as McKittrick and Gunsight canyons. As a result of these excursions, Lee judged the area worthy of inclusion in the National Park System. Basically, he considered the rugged mountains and canyons on par with some of the other crown jewels of the 1920s National Park System; consequently, he advocated their reservation as a national park or, at the least, a national monument.

Texas officials enthusiastically greeted Lee's proposal. In fact, during the summer of 1924, Texas Governor Pat Neff, the state's newly created state parks board (1923), and the state's highway commissioners joined New Mexico's governor and highway commissioners at Carlsbad Cave National Monument. After touring the cave, Lee took them to the Guadalupe Mountains, where he and others, such as Judge J.C. Hunter of Van Horn, stressed the importance of reserving the Guadalupe Mountains as a state or national park. Lee even went so far as to propose an interstate national park incorporating both Carlsbad Cave and the Guadalupe Mountains.

Today, the questions are: What impressions did people have of the Guadalupe Mountains? How did they describe them? What did they compare them to? What value did they ascribe to them? People equated exploration of Carlsbad Cave with conquest of the West—meaning, the West of myth as much as the West of reality. While understandable, it is nonetheless surprising, for Carlsbad Cave is a cave. Nevertheless, the entire western experience—contact, exploration, description, conquest, and preservation—is defined within the cave and its development as a park unit. People equate Jim White with the western experience, for instance; he is compared with and revered as much as America's explorers and pioneers. Most telling is the persistent image of White as a cowboy despite his having worked as a guano miner for 20 years prior to the federal government's creating the monument.

Definition and description of the Guadalupe Mountains landscape similarly consisted of identifying it with the West of popular conception: of a heroic and violent place where individual men triumphed over savagery, where outlaws assumed the guise of heroes, where men (and women) persevered and survived in spite of an unforgiving desert. Hence, the parks represented the West and, by extension, America. Even Lee, an erudite eastern scholar and respected geologist, couched his descriptions of the mountains and desert in these terms. "It is the Wild West," Lee wrote, "the land of adobe shack, of range cattle and goats." He also wrote that this is an area where sombrero-hatted cowboys are common sights. Once, it was the land of gunfighters and gold seekers, where the whitened bone of oxen that perished on the long stretches between watering holes along the Butterfield Trail are remembered by old timers. Other writers in the 1920s, including guidebook author Blanche Grant, portrayed the Carlsbad region as a land infested with desperate outlaws such as Billy the Kid and Geronimo. Blood had run free, she wrote, during many a showdown in the town of Old Phenix (near Carlsbad), which by the 1920s was no more than crumbling adobe ruins. Such portrayals shaped peoples' perceptions of and experiences in southeastern New Mexico and west Texas, including the Guadalupe Mountains and Carlsbad Cave.

Lee even went so far as to propose an interstate national park incorporating both Carlsbad Cave and the Guadalupe Mountains.

By the 1920s, the "frontier" as defined by historian Frederick Jackson Turner had been "closed" for little more than 30 years. Still, many Americans, particularly easterners, looked to the West to recapture some essence of the imagined American identity of rugged individualism, strength, and democracy. At the same time, these people sought escape (if only momentarily) from an oppressive, corporate-controlled East. In searching for the defining elements of American character, either real or imagined, they sought spiritual rejuvenation. As Turnerian as this description seems, it is the way people understood themselves and their place in the world in the 1920s. Turner did not create the civilization versus savagery or garden versus wilderness dichotomies. No, one can find these ideas in Greek writings. They are in the Bible. No doubt, these are social and cultural constructs that have existed in one manner or another from the time of man's cognitive beginnings. Turner just proclaimed wilderness and the frontier as democratic-making conditions, as original American ideas. He was the most recognized, most authoritative champion of a heroic America, and as a result people identified, and continue to identify, individualism, strength, and democracy as separate and distinct American characteristics.

One wonders why neither Congress nor the National Park Service set aside the Guadalupe Mountains until 1966 despite interest as early as 1924.

In view of this, and given the fact that Americans set aside other National Park System units (e.g., Yosemite, Yellowstone, and Grand Canyon) for similar reasons, one wonders why neither Congress nor the National Park Service set aside the Guadalupe Mountains until 1966 despite interest as early as 1924. This is a 40-year gap. How did other writers and the media describe the Guadalupe Mountains–Carlsbad Cave West, and how did these portrayals change between the 1920s and 1960s? How did peoples' perceptions of wilderness change?

Roderick Nash, among other scholars, has written about wilderness in America and its significance in American society. Still, I am interested in seeing a comparative analysis written in which attitudes toward the Southwest in the 1920s are contrasted with those 40 years later. Then one should compare these attitudes with those which led to Carlsbad Cave National Monument's creation, for the cave was compared as much with western landscape and the West-as-experience as it was with lesser caves such as Mammoth Cave in Kentucky or Luray Caverns in Virginia. How do these, in turn, compare and contrast with those [attitudes] underpinning Guadalupe Mountains National Park's establishment?

There are several reasons why I think the Guadalupe Mountains were not incorporated into the National Park System in the 1920s. First, they were too inaccessible for many tourists. Paved roads did not exist in this region; indeed, few roads at all existed in the region. Highway 62-180 between El Paso and Carlsbad, which passes just south of the mountains, was not opened until the late 1920s. (Both Texas and New Mexico developed the road because of Carlsbad Cave and the interest in expanding it into a national park. Businessmen in the region, including El Pasoans, wanted to ensure that tourist dollars flowed into their coffers. At the same time, many merchants wanted the road as a more direct access route to markets; discovery of potash and oil in the region in the mid-1920s only expedited development.) Roads between Van Horn and Carlsbad or Pecos and Carlsbad similarly did not serve as "major" automobile arteries until after the creation of Carlsbad Cave National Monument. If the region's inaccessibility was one cause for the Guadalupe Mountains not being set aside as a national monument or park in the 1920s, it is ironic. Why? Because the majority of tourists who visited Carlsbad Cave during the 1920s and 30s drove from central and east Texas.

Second, the absence of concerted state or local support in Texas may also explain why Guadalupe Mountains National Park was not authorized until 1966. Although Lee and others expressed interest and commitment to preserving the Guadalupe Mountains, little appears to have been done toward that end either on the federal or state level. In Texas, at least, greater emphasis appears to have been placed on establishing parks nearer the state's more populated east. Similar to the dearth of popular support was a lack of commercial support from the railroads, which historically played a central role in the development of early national parks. (Carlsbad Cave itself was the subject of much publicity from the railroads, especially the Santa Fe Railroad.) Indeed, the railroads continued to have enormous influence on park development and publicity through the 1940s, at which time automobiles surpassed trains as the principal means by which tourists traveled to national parks. Regardless, it appears that the railroads paid little attention to the Guadalupe Mountains.

A third factor that may have delayed creation of Guadalupe Mountains National Park is Congress' penny-pinching, which in turn made National Park Service administrators wary of proposed parks, many of which were of questionable, pork-barrel-politics quality such as Wind Cave. And since the Guadalupes were similar to yet smaller (in size) than other existing mountain parks, they may have been viewed as "second class" when compared to the Grand Tetons, Mount Rainier, or Mount Olympus. When Congressman John Morrow of New Mexico requested an increased appropriation for Carlsbad Cave National Monument in the early 1920s, Louis Cramton, chairman of the subcommittee on Interior Department appropriations, explained that the National Park Service should be thankful to get any money at all for monuments. Congress was trying to cut back on expenses, he added, and developing the crown jewels of the system—Yosemite and Yellowstone, for example—superseded the creation of new parks. Only once the National Park Service adequately developed these parks would Congress consider creating and funding new parks. As can be seen, then, there was insufficient support in Washington, D.C., for new parks or, perhaps, even for additions to existing parks or monuments.

To an even greater extent, the lack of a concrete scientific rationale may have thwarted efforts to preserve the Guadalupe Mountains. Little about the region was known in the scientific community prior to the National Geographic Society's six-month expedition led by W.T. Lee; in fact, the region's geology, paleontology, and archaeology was all but known. Granted, Lee made inroads, publishing articles about and lecturing throughout the East on Carlsbad Cave and the Guadalupes. He even proposed a second National Geographic Society expedition to the Guadalupe Mountains. Unfortunately, Lee died in 1926 before anything further came of his proposal. And with Lee's death, genuine scientific interest (for the gain of knowledge rather than money) in southeastern New Mexico appears to have receded for many years. Consequently, another 40 years passed before Americans, the National Park Service, and Congress recognized the scientific, natural, and educational uniqueness inherent in the Guadalupe Mountains.

Again, what did transpire during those 42 years between Lee's 1924 expedition and 1966 which eventually culminated in the creation of Guadalupe Mountains National Park? How did the National Park Service change? How did America change? And how did peoples' perceptions of the Guadalupes change? Without an understanding of these changes on local, state, regional, and national levels, no one can rightfully claim to understand the history of Guadalupe Mountains National Park. This, then, is the task that lies ahead: to learn and write about Guadalupe Mountains National Park as an individual park unit and as a product of an ever-changing, ever-modifying American society. A thorough history of the park, therefore, should help readers understand the park's history; more importantly, perhaps, it should help readers understand American history in its broadest sense.

Congress was trying to cut back on expenses and developing the crown jewels of the system—Yosemite and Yellowstone, for example—superseded the creation of new parks.

Bibliographical note

Many scholars have studied and written about nature, wilderness, and the West in the hopes of better understanding their roles and significance in America's history. Among the most notable scholarly works are Hans Huth's *Nature and the American: Three Centuries of Changing Attitudes* (Berkeley: University of California Press, 1957) and Roderick Nash's *Wilderness and the American Mind* (New Haven: Yale University Press, 1982, 3rd edition).

Other scholars have examined singular facets of nature, wilderness, or preservation in American history. Often, these scholars study and write for the purpose of providing a more detailed yet broadly applicable understanding of Americans' attitudes toward nature, the past, and preservation. Two excellent examples are Alfred Runte's *National Parks: The American Experience* (Lincoln: University of Nebraska Press, 1979) and Hal Rothman's *Preserving Different Pasts: The American National Monuments* (Urbana: University of Illinois Press, 1989).

National Park Service historians or contract historians hired by the National Park Service likewise research and write about the histories of individual park units and/or the regions in which park units are located. Judith K. Fabry's *Guadalupe Mountains National Park: An Administrative History* (Santa Fe: Department of the Interior, National Park Service, Southwest Region, Southwest Cultural Resources Center, 1988) and Mark Hufstetler's and Lon Johnson's *Watering the Land: The Turbulent History of the Carlsbad Irrigation District* (Denver: National Park Service, Rocky Mountain Region, 1993) are pertinent examples. Presently, Hal K. Rothman is finishing a historic resources study of the Carlsbad Caverns–Guadalupe Mountains region for the National Park Service.

Despite the abundance of books, monographs, and articles written about the history of nature, wilderness, the West, and the National Park Service, little has been written about the Carlsbad–Guadalupe Mountains West. And much of what has been written deals with narrowly defined subjects. Fabry's history on the Guadalupe Mountains is a case in point. Primarily, she writes about the history of Guadalupe Mountains National Park from the time of its establishment to the 1980s. Her treatment of early attempts to establish the park—either by addition to Carlsbad Cave National Monument or as a separate and distinct park or monument—is cursory at best.

To gain any understanding of interest in and efforts to establish Guadalupe Mountains National Park prior to the 1960s, one must look to the primary documents that exist. Such documents can be found in various locations. First and foremost, the local newspapers—the *Carlsbad Current* and the *Carlsbad Argus* (later combined and published as the *Carlsbad Current–Argus*)—contain scores of articles which detail early interest in and efforts to establish a state or national park in the Guadalupe Mountains. The El Paso and Van Horn newspapers in all likelihood published similar articles.

A second place where one can find information is in records relating to Willis Thomas Lee and the National Geographic Society's expedition. These records can be found in several places: (1) the Carlsbad Caverns National Park library and archives, where several of Lee's Carlsbad Caverns manuscripts are housed in addition to newspaper and magazine articles gathered since the 1920s; (2) at the National Geographic Society archives in Washington, D.C., where Lee's expedition proposals, correspondence, and reports are housed; and (3) in the Carlsbad Caverns records maintained in Record Group 79 (Records of the National Park Service) at Archives II, National Archives and Records Administration, in College Park, Maryland.

Note: At present (2003), FRED MACVAUGH is the regional archivist for the National Park Service's Midwest Region. His presentation was a spur of the moment addition to the symposium, which filled in for another presenter who was unable to attend.

Abstracts

Chapter 50

Abstracts—Presentations

Note: Abstracts of papers presented during the Guadalupe Mountains Symposium are arranged in alphabetical order by the primary author's last name. The number in parenthesis following the title denotes the number of the paper in the table of contents and its order in the symposium volume.

ADAMS, JIM W.
The Butterfield overland stagecoach through Guadalupe Pass (38)
The discovery of gold in California accelerated the clamor in congress for a stagecoach line linking that state with the rest of the union. Early western railroad surveys conducted by the Army came through Guadalupe Pass and recommended that route. John Butterfield, an owner of stagecoach lines and railroads in New York, preferred a northern route but he recognized that the snows of the Rocky Mountains and the Sierra Nevada were formidable obstacles to regular service. The postmaster general was from the South, and he insisted on a route through Texas, New Mexico, and Arizona. Butterfield won the $600,000 per year mail contract by suggesting a compromise route: two eastern origins, one at Saint Louis and another at Memphis joining each other at Fort Smith, Arkansas. His route then snaked southwestward through Indian Territory to Texas and westward over a warm weather southern route. Only three villages existed between Saint Louis and San Francisco: Franklin (El Paso), Tucson, and a town of some 6,000 souls called Los Angeles. Nobody besides John Butterfield thought he could meet the 25-day contract for this 2,795 mile journey, the longest stagecoach line in the world. Existing freight wagons took much longer than that. But he was a terrific organizer. He spent $2 million the first year on supplies, horses, mules, and new stagecoaches. He also built 150 way stations where fresh mounts and meals could be secured. He put lamps on the coaches, and they traveled day and night. On September 14, 1858, the first Butterfield stagecoach left San Francisco, and two days later, John Butterfield carried the first bag of mail out of Saint Louis headed westward. This first coach stopped for a lunch of venison pie and baked beans at the Pinery camp in the Guadalupe Mountains on September 28th. After a hair-raising descent of Guadalupe Pass, the first westbound stagecoach passed the first eastbound coach on the flats below majestic El Capitan Peak. So far as we know, the Butterfield stagecoaches never once exceeded the 25-day travel time specified in their contract. For 11 months, these colorful stagecoaches rumbled through Guadalupe Pass. The postmaster general died, and his replacement requested that the route be changed to bring mail service to Fort Davis and Fort Quitman, so the coaches no longer ran through the Guadalupes. The Butterfield overland mail was brilliantly successful for 2½ years until severed by Texas confederates in March 1861.

ADAMS, JIM W.
The career and contributions of Wallace E. Pratt (40)
Wallace Pratt was born in 1885 and raised on a farm in northern Kansas. Being number six of 10 children, he had to earn his own way through college. He graduated from the University of Kansas with a B.A. in 1907 and a B.S. in 1908. He was unable to find a job as a geologist, so he stayed in college and received a M.A. in 1909. He signed on as a geologist with the Division of Mines of the Philippine Islands. As he said, "I had to go halfway around the world to find a job." Actually, he became Chief of the Division of Mines for four years. When he returned in 1915, he took a job with The Texas Company in old Mexico, where he was thrown in jail and rescued with other Americans by gunboats. He began his long successful career with the newly-

formed Humble Oil & Refining Company in early 1918. As their first geologist, he was named chief geologist and later became a director and vice president. Wallace Pratt's success as an oil-finder came chiefly through his brilliant mind and his capabilities as an organizer. He quickly hired a staff of 10 geologists; he insisted on their being closely associated with all drilling wells. He started a research laboratory where they could study cores and well samples. He cleverly integrated oilfield scouts, landmen, geologists, and geophysicists into his exploration department, so when any of these people got a lead on a new prospective area, the Humble Company could move quickly to acquire valuable leases at low cost. His thinking frequently ran contrary to prevailing geologic prejudices of the day. First, for example, he discovered that faults frequently form oil traps (they were thought to always leak). Second, Texas faults are not always vertical. Because of this, Humble leased valuable acreage at Mexia and other fields in 1920 that had been left by other mistaken operators. Third, south Texas was thought by others to be a wildcatters' graveyard. Pratt noticed that it had a thick section of marine sedimentary rocks. On the belief that oil and gas are natural constituents of marine rocks, he talked the management at Humble into leasing one million acres of the King Ranch in the depths of the Great Depression. This acreage later yielded more than 1,000 producing wells. Fourth, while many oil companies were laying off geologists during the Great Depression and dropping many leases, Wallace Pratt took a directly opposite strategy: he sold Humble management on the idea that salaries were low and lease costs were low; therefore, it was an ideal time to expand geologic and geophysical staffs and greatly increase lease acquisitions. Wallace Pratt and his exploration team were so successful that between the years 1930 and 1937, they increased Humble's reserves nine times to 2 billion barrels of oil, more than twice that of their largest domestic competitor. In 1920 Pratt and friends drove across country on unpaved trails in a Model T Ford to see "the prettiest spot in Texas: McKittrick Canyon in the Guadalupe Mountains." He was enamored by the enchanted beauty of this canyon. With several partners "and largely on borrowed money," Wallace Pratt started accumulating a ranch there that eventually totaled 20,000 acres. Wallace and Iris Pratt built two homes there of native flagstone. They brought in a stonemason from Sweetwater, Texas to construct the cabin deep in McKittrick Canyon in 1930. Throughout his long career, he was an outspoken proponent of conservation of reservoir energy and resources. This carried over to their ranch. He said, "I never hunted or fished on the ranch, and I never let anyone else do this either." He was an environmentalist before the word was even invented. In 1937 Pratt was promoted from Humble to a director and vice president of the associated Standard Oil Company of New Jersey. His comment was: "Over the years, I have become wary of any enterprise that required a new suit." They moved from Houston to a flat overlooking Central Park in downtown Manhattan. After World War II in 1945, Wallace and Iris Pratt retired to their McKittrick Canyon ranch and built their second flagstone house on the lines of an oil tanker, the famous Ship-on-the-Desert. They had no telephone and were 10 miles from the nearest neighbor. They bought his and hers Mercedes Benz automobiles and daily flew in their open-cockpit airplane from the ranch to their office in Carlsbad. Every professional honor possible came to Wallace Pratt from a respectful, grateful oil industry. In typically modest manner, he denigrated his success by saying, "I was lucky. The time just happened to be ripe for someone with my bag of tricks to come over the pike." A truer statement was made by Everette L. DeGolyer when he presented Pratt with the first American Association of Petroleum Geologists Sidney Powers Medal Award: "he has raised the profession of petroleum geology to an eminence and a dignity which it would not otherwise have attained." In 1960, Wallace and Iris Pratt moved to Tucson, Arizona, to better treat her arthritis. He turned naturally to the National Park Service to best preserve McKittrick Canyon in the pristine condition that he had enjoyed keeping it. In three installments, he and his heirs conveyed 5,632 acres toward the establishment of Guadalupe Mountains National

Park. It was their gift to all of us. He departed Earth as gently as he lived, on Christmas Day 1981, at the age of 96.

ARMSTRONG, FRED R.
An overview of the resource management program at Guadalupe Mountains National Park (4)
With each passing year, the collective bank of human knowledge about the world in which we live doubles. The knowledge about the resources at Guadalupe Mountains National Park provides no exception. Since the park was authorized, nearly 250 research permits have been issued to increase our awareness of park resources ranging from microscopic fungi to landscape-scale geologic structures. Many of the research projects that were initiated to collect baseline data about the cultural and natural components of the park have been carried on by park staff as a means of periodic monitoring of the resources. Current resource management activities could be categorized as cooperative programs, carryover programs, condition assessments, and federally mandated monitoring. Much remains to be learned about the cultural and natural resources within the Guadalupe Mountains. The strength of our program will continue to rely on a multi-faceted approach utilizing independent research, university programs, and National Park Service staff to contribute to the wealth of knowledge and the ultimate conservation of park resources.

BAKER, ROBERT J.
Archiving the future (keynote address) (6)
Archive is a noun and it means to hold in trust. This presentation will discuss the concept of holding things in trust and where the scientific and the conservation communities are going as they archive biological specimens. There are almost 90 species of mammals that are known from Texas and more than half are known from the Trans-Pecos of Texas. Faunal records for the last 150 years have described 65 species of mammals from the Guadalupe Mountains, nine of which have been extirpated. The museum at Texas Tech University contains an extensive depository of state and world mammal tissues and study skins which have been, and will continue to be, instrumental in tracking disease patterns and environmental health among mammal populations. Recurring research in natural population banks, such as the Guadalupe Mountains, will provide scientists with data against which to measure environmental change.

BERGDAHL, JACQUELINE, MICHAEL R. NORRIS, and MARCELLA JONES
Guadalupe Mountains National Park visitor use survey results (1996–1997) (47)
A survey was distributed to visitors of Guadalupe Mountains National Park during three different time periods by researchers from the University of Texas at El Paso. Findings indicate that the visitors during each season (summer, fall, and spring) have distinct characteristics. Summer visitor groups are making a stop at Guadalupe Mountains National Park with their families in a series of national park visits in the geographical area. Fall visitors come specifically to see the fall foliage in the McKittrick Canyon area of the park. During the busiest season, spring, visitors come to camp, hike, and backpack into the backcountry. Each group has opinions and desires for services that are tied to their distinctive activities at the park.

Ten to 15 percent of visitors were from foreign countries, about 40% were Texans, and the other half was from out of state. The average group was composed of a baby boomer and four other family members. The average day visitor was at the park for 4.6 hours, while the overnight visitors spent an average 1.4 days.

Most visitors (93.7%) reported they were satisfied with their visit. Almost 30% of visitors reported that they were entirely satisfied with the services and facilities at the park (29.5%). Approximately 64% of visitors expressed a need for more services or facilities (63.8%). The most common requests were for a source of food/drink and gasoline closer to the park. Other requests were for shower facilities and other improvements to the camping facilities.

BROWN, ALTON A.
Orientation of synsedimentary folds in carbonate basin and slope deposits, Permian Guadalupe Mountains, west Texas (35)
Synsedimentary folding occurs in the basal shear zones of slides and slumps in Delaware Mountain Group strata. Folding is most common in basal shear zones of large translational slides 1–6 kilometers from the contemporaneous shelf edge. These basal shear zones are from 0.2 to about 1.5 meters thick and form units approximately parallel to bedding. The unusual feature of these folds is that their fold axes are oriented parallel to the dip of the paleoslope and parallel with the inferred direction of slide movement. Synsedimentary fold axes are normally interpreted to be statistically perpendicular to dip of the paleoslope with axial surfaces dipping in the upslope direction, or randomly oriented. These recumbent folds fit neither of these models, as axis orientation data form tight clusters consistently parallel to the downslope direction.

I interpret the orientation of the folds to result from shear alignment. Initial shear in the basal zone due to slide translation will form folds with axes parallel to the paleostrike of the slope and an axial surface dipping away from the direction of transport, just as earlier studies propose. Such folds are occasionally documented in the basal shear zones of rotational slumps in the toe-of- slope setting higher on the Capitan paleoslope. As the slide continues to move, axial surfaces rotate to a position parallel to bedding and the fold axes rotate to a position parallel to the dip of the slope.

BRYAN, KELLY B.
Recent changes in the breeding avifauna of four southwestern mountain ranges in Texas and Coahuila (8)
Almost 25 years have passed since Wauer and Ligon undertook a significant task to compare the differences in the breeding avifauna of four southwestern mountain ranges in their book *Transactions of the Symposium on the Biological Resources of the Chihuahuan Desert Region, United States and Mexico* (1974). Species known or suspected to breed above 5,500 feet elevation were analyzed and compared for four mountain "islands": the Guadalupe, Davis, and Chisos mountains in Texas, and the Sierra del Carmen in Coahuila, Mexico. Within a composite list of 99 species, 81 were listed for the Guadalupe Mountains, 73 for the Sierra del Carmen, 71 for the Davis Mountains, and 63 for the Chisos Mountains. Since 1974, 17 species have been added to the composite list, which now stands at 114. One species listed previously, yellow-billed cuckoo, was deleted, and two species, house wren and brown-throated wren, were lumped into one. Species added include common black-hawk, greater roadrunner, white-eared hummingbird, dusky flycatcher, gray flycatcher, black phoebe, dusky-capped flycatcher, barn swallow, red-breasted nuthatch, mountain bluebird, loggerhead shrike, black-throated gray warbler, MacGillivray's warbler, green-tailed towhee, lark sparrow, bronzed cowbird, and red crossbill. Additionally, status changes were applied to 28 species within one or more of the four ranges analyzed. Current information reflects the following breakdown per range: 102 species for the Davis Mountains, 92 for the Guadalupe Mountains, 81 for the Sierra del Carmen, and 68 for the Chisos Mountains. In light of recent declines in selected songbirds, especially neotropical migrants, and with significant additions to the overall list (11 of which represent first known/suspected breeding records for the entire region) further detailed investigations are warranted in these ranges that regionally reflect an intricate mixture of breeding birds from the Rocky Mountains, Sierra Madre Oriental, and Sierra Madre Occidental.

DAYTON, DONALD A.
A new national park: research needs and challenges in the 1970s (2)
After many years of combined effort on the part of leaders in Texas and New Mexico, Guadalupe Mountains National Park was born in the late 1960s and early 1970s. Its birth came at a time of controversy and upheaval in the National Park Service with regard to the emphasis and management of a fledgling scientific research program for that agency. The complex and fragile ecological relationships found in the new park along with alterations brought about by years of livestock grazing in the Guadalupes

made the need for immediate scientific research critical to the future management of the area as a national park. Biological, geological, and cultural resource studies conducted by research professionals from several universities and other research entities in the early stages of park planning were instrumental in providing for comprehensive basic resource data essential for the future protection and interpretation of the unique park resources. These data were of great value in the preparation of a variety of resource management plans, operational management plans, wilderness area management plans, development plans, and interpretive plans—all required for a new national park.

DINWIDDIE, DOUGLAS, CAROLYN OLSON, and FROSTY BENNETT
A case study in applying historical research to the educational process: exploring Mckittrick and discovering our heritage (44)
This study involves information about a tripartite process of professional guidance through a class experience, research of materials and facts, and producing an educational tool (i.e., a traveling trunk) to be used by educators. Information will be provided about the process beginning at its infancy as the research student is guided by an instructor. The instructor will continue to provide guidance and critique the final product, which is prepared using pertinent research facts.

To quote, "Traditionally, education has relied heavily on texts and lectures, questions and discussions. 'Words' are at the core of the experience. Object-based education focuses the learning experience more on artifacts and primary documents in a manner that taps children's diverse learning styles, while stimulating interest and providing a deeper understanding of the subject."

We conclude that carefully prepared object-based education found in sources such as traveling trunks is a successful means of engaging young people and teaching a variety of subjects and skills.

GALLAGHER, KELLY G., and BROOK G. MILLIGAN
Are small populations of columbines more vulnerable to inbreeding depression? (15)
Only in recent years have botanists recognized the need to assess rarity and vulnerability of plants based on biological processes rather than only on patterns of geographic distribution. Of those biological processes affected by small population size, inbreeding depression has received special attention by conservation biologists. In particular, small populations are generally regarded as exhibiting increased inbreeding depression or decreased heritability relative to large populations. However, this proposition has rarely been tested and quantified in natural populations. Measuring and monitoring fitness in sensitive plant species may be the most reliable approach to predict levels of inbreeding depression. To test this idea empirically, work is currently in progress to quantify several key processes, including inbreeding depression and heritability, for the threatened plant species *Aquilegia chrysantha* var. *chaplinei,* commonly referred to as the Chapline's columbine. The known, limited distribution of Chapline's columbine is endemic to the Guadalupe Mountains, within Eddy County, New Mexico, and adjacent Culberson County, Texas. Our study will enable biological, process-based management necessary for the conservation of this rare plant. Significantly, this will be the first study to do so using measurements of quantitative genetics in field environments.

GARDNER, MICHAEL H.
Application of the Permian Brushy Canyon Formation in Guadalupe Mountains National Park as an outcrop analog for deep-marine petroleum reservoirs (34)
Sedimentary rocks buried in basins host nonrenewable fossil fuels, our primary source of energy. The original depositional environment and post-depositional history of ancient deposits forming reservoir and source rocks determine hydrocarbon distributions. Resource optimization of petroleum reserves requires characterizing the class of reservoir hosting hydrocarbons and

designing strategies that maximize discovery and recovery. An important way to decrease uncertainty and risk in this analysis is to increase the geologic knowledge and information used to make exploration and development decisions.

Surface outcrop exposures of deposits that form hydrocarbon reservoirs provide the only direct view of reservoir architecture. In exceptionally large outcrops, reservoir distributions can be mapped. Outcrop analogs establish different types, or classes, of reservoirs and provide calibration to subsurface seismic and borehole data. Such outcrops form templates for visualization of reservoir architecture, generate conceptual geologic models for frontier exploration, and provide quantitative information on reservoir dimensions and heterogeneities that govern recovery efficiency.

The western escarpment of the Guadalupe Mountains in Guadalupe Mountains National Park exposes the Brushy Canyon Formation, one of the best outcrop exposures of ancient deep-marine clastic deposits in the world. Geoscientists from the Colorado School of Mines are conducting multidisciplinary research on the Brushy Canyon Formation to help optimize resource recovery from the challenging class of deep-marine clastic reservoirs present in offshore continental margins and in deep-marine basins. Because the Brushy Canyon is the target of active exploration in the nearby Delaware Basin, we are relating outcrop results to nearby subsurface production to generate general models that may be applied to other deep-marine basins worldwide. Study results are being used as analogs for Gulf of Mexico, offshore Africa, and North Sea deep-marine basins.

GEHLBACH, FREDERICK R. presented by LARRY HENDERSON
Interpreting desert regions, deserts, and regional indicator plants (7)
Topographic and vegetative features are used to name vegetation-types (plant formations) such as upland succulent and lowland shrub deserts. The public easily understands that such features, descriptive of landscape position and plant lifeform, are similar and easily identified in all regions. The adjectives Chihuahuan, Sonoran, Mohavean, and Great Basin are used only with the subject word, region, when interpreting regionally restricted (indicator) species that identify local plant associations. Desert is dropped from the epithet, since regions have vegetation-types besides deserts, and local areas in each region lack deserts. Desertscrub is not used because it is incorrect in that desert plants are not necessarily scrubby (unable to attain mature stature).

Vegetative and topographic features are used to name vegetation types (plant formations) such as upland succulent and lowland shrub desert, or evergreen and deciduous woodland, because the public readily understands that descriptive plant features are the same or similar everywhere, and the same vegetation types are present in all regions.

GLENISTER, BRIAN F., BRUCE R. WARDLAW, and LANCE L. LAMBERT
Guadalupian Series: international standard for Middle Permian time (30)
Reference sections for the major subdivisions of the last half- billion years of geologic time were designated over 150 years ago; most are in western Europe. Problems in establishing precise correlation to many of these standards have served to justify proposal of a plethora of regional or local geographic standards that discourage development of a single international language for the subdivisions of geologic time. However, over the past 50 years, the International Commission on Stratigraphy has made great progress in recognition and designation of those stratigraphic successions that collectively serve best as international standards.

The Permian System of sedimentary rocks and corresponding Permian time period were defined in 1841 with references in the Perm area, Ural Mountains, Russia. The southern Urals continue to serve effectively as international standards for the Lower Permian Cisuralian Series, whose base is dated at 292 million years ago. However, upward shallowing of the seas progressively excluded the marine organisms needed to effect time correlation, so that references for younger intervals of Permian time have been sought elsewhere. Southwest North America has been selected as the international standard for the Middle Permian Guadalupian Series, but upward shoaling in the area necessitated designation of the Upper Permian as the Lopingian Series of south China. The middle of the Guadalupian has been dated as 264 million years ago, and the top of the Lopingian Series and Permian System at 251 million years ago.

The global stratotypes for the Guadalupian Series and ascending Roadian, Wordian, and Capitanian component stages lie within Guadalupe Mountains National Park. They will be the subjects of a symposium poster and a field trip.

GOSS, JAMES A.
The Apache cultural landscape in Guadalupe Mountains National Park (21)
The Mescalero Apache cultural landscape project is four-pronged. It involves: (1) library and archival research on the resources of the Guadalupe Mountains area and archaeological, ethnographic, and historic records of Apache adaptation to those resources; (2) the reconstruction and mapping of potential plant and animal resources of the Guadalupe Mountains area; (3) actual ethnographic field work with living Apaches who still remember or are still practicing utilization of traditional resources; and (4) the testing of predictions of where prehistoric and protohistoric resource utilization camps and sacred sites should be. The Apache–Guadalupe Mountains cultural landscape project provides a model for understanding and interpreting the natural and cultural tapestry of Guadalupe Mountains National Park, as seen through Native American eyes.

GREEN, TIM
Distribution of aquatic invertebrates in Mckittrick Creek (11)
McKittrick Creek of Guadalupe Mountains National Park is a discontinuous creek flowing both above and below ground through McKittrick Canyon. Invertebrates of the creek were sampled over a two-year period from September 1987 through June 1989. Various physical and chemical parameters were measured during each visit to compare with distributions of aquatic invertebrates inhabiting the creek. During the two years of sampling, 87 taxa were collected using a Surber sampler, of which 44 were of sufficient population size to be used in cluster analysis and 24 were of sufficient population size to determine their distribution based on the various physical and chemical parameters that were measured. Cluster analysis was used to compare species makeup within the branches of the creek. ANOVA and multiple linear regression analysis were used to determine invertebrate distributions and factors affecting distributions. Statistical results suggest that interspecific interactions, habitat, location along the creek, and a few physical-chemical variables combine in the determination of distributions. McKittrick Creek was divided into three sections for comparison, north McKittrick, south McKittrick, and lower McKittrick. South McKittrick was determined to be the most diverse branch of the creek and held the highest populations of aquatic invertebrates within the system. McKittrick Creek as a whole represents an exception to the river continuum concept due to its discontinuous nature.

GREENBERG, ADOLPH M., GEORGE S. ESBER and JOE SIERRA
Legislative mandates, cultural affiliation, and Guadalupe Mountains National Park (48)
Several legislative acts have required federal agencies of the United States to respond to needs and voices of Indian tribes in the Southwest and in particular acknowledge at least a sense of tribal cultural interest in National Park System units and associated resources. Examples from an ethnographic overview and assessment of Guadalupe Mountains National Park are discussed along with Native perspectives on this new legislative thrust.

GRISWOLD, TERRY
The native bee fauna of Guadalupe Mountains National Park (13)
The native bee fauna of Guadalupe Mountains National Park appears to be a rich assemblage of pollinators based on only three limited sampling periods: two in the spring and one in the fall. More than 140 species of bees, including

13 new species, were present in these samples. One third of these bees are new to Texas. I estimate that more than 300 species will be found when a complete survey has been made. Diverse faunal elements are represented among Guadalupe's bees. Most of the species are widespread in the Southwest (54%). Other faunal components include Great Plains (5% of species), eastern (2%), and transcontinental (14%). *Dufourea boharti,* a bee described from central Mexico, is here, recorded for the first time from the United States. There may be species endemic to this region; several of the new species are so far known only from the park. The bee fauna is characterized by strong seasonality, a diversity of nesting sites, and distinct habitat preferences. Most species are solitary. Preliminary evidence suggests floral specialization by some bee taxa. The impact of the advent of the Africanized honey bee on native bee populations and on the pollination services that they provide for the native flora is unknown.

HAECKER, CHARLES M., and NEIL C. MANGUM
Historical and archaeological investigations of Apache war sites, Guadalupe Mountains National Park (22)
During the late fall and early winter of 1869–1870 a troop of Third Cavalry troopers, led by Lieutenant Howard Cushing, successfully attacked and destroyed three Mescalero Apache encampments within the Guadalupe Mountains. Manzanita Spring, located a few miles east of the Guadalupe Mountains National Park visitor center, has been interpreted as the location of the final fight of December 30, 1868. However, a review of historical documents suggested that the entrance of McKittrick Canyon was, in fact, the correct location. An archaeological survey produced sufficient evidence indicating that our hypothesis was correct.

HARVESON, LOUIS A., WILLIAM T. ROUTE, FRED R. ARMSTRONG, NOVA J. SILVY, and MICHAEL E. TEWES
Mountain lion ecology and population trends in the Trans-Pecos region of Texas (17)
The mountain lion (*Puma concolor*) was once the most wide-ranging large predator in the western hemisphere ranging from Canada to South America. Present distribution of the mountain lion in the United States is restricted to the western states (west of 100th meridian). The ecology (food habits, age distribution, mortality patterns, and density estimates, and home ranges) of the Trans-Pecos mountain lion has been studied extensively on public lands of west Texas. Mountain lions consume a variety of prey with mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and javelina (*Tayassu tajacu*) comprising the majority of their diet. The leading cause of death for mountain lions in the Trans-Pecos region is man-related (e.g., predator control efforts). Mountain lion density estimates in the Trans-Pecos region have ranged from 0.21 to 2.32 mountain lion per 100 square kilometers. Annual home ranges for male and female mountain lions ranged from 207 to 1,032 square kilometers and 59 to 1,032 square kilometers, respectively. Three mountain lion population trends are available for the Trans-Pecos region and include the number of reported sightings, the number of reported mortalities, and a track survey. Since 1982 the Texas Parks and Wildlife Department has been collecting information on mountain lion reports. Both mountain lion population indices have demonstrated an increase in reports from 1983 to 1988 and then a leveling off from 1989 to 1996. Conversely, the track survey (conducted in the Guadalupe Mountains) demonstrated a decreasing population from 1987 to 1997.

HILL, CAROL A.
Geology of the Guadalupe Mountains: an overview of new ideas (27)
This presentation will trace the geologic history of the Guadalupe Mountains from Late Permian to the present by discussing a number of new ideas which have emerged over the last decade. In Late Permian (Guadalupian) time the Capitan reef encircled the Delaware Basin except for where seawater entered the basin. The traditional location for this inlet channel has been the Hovey Channel in the Glass Mountain area, but interpretation of new evidence indicates that it was located between the

Guadalupe and Apache mountains. Other evidence supports the view that the Guadalupe Mountains first became exposed and subjected to karsting (Stage 1 fissure caves) in Ochoan (Castile) time when the channel became closed off and a shallow- water basin became desiccated.

In the Mesozoic Era the area was low lying. Much dissolution took place during this time, both in basin evaporite rock and also in the Capitan reef (Stage 2 spongework caves). In Early Cretaceous (Comanchean) time, low-gradient rivers and a sea transgressed over at least part of the Guadalupe Mountain area, leaving behind gravels, which still cover parts of the summit plain. At the end of the Cretaceous, the Laramide orogeny caused the area to be uplifted above sea level almost to its present height.

In the early Tertiary there was a transition from Laramide compression to regional extension. Volcanism occurred in the Oligocene, and Basin and Range block faulting began. As the Guadalupe block began to uplift, hydrogen sulfide migrated from the hydrocarbon-rich basin into the Capitan reef, and Mississippi Valley-type (MVT) sulfide deposits formed within the reduced zone. High heat flow (approximately 50°C/km) in the Miocene caused convective fluids to deposit calcite spar in the reef, along fault zones, and in Stage 3 thermal caves. During this main uplift stage, the water table dropped and hydrogen sulfide became oxygenated to sulfuric acid, which dissolved out the large Stage 4 cave passages. In the Pliocene-Pleistocene, Stage 4 caves continued forming from the southwest to northeast along the Guadalupe Mountain front. The last major lowering of the water table in these caves may have occurred about 600,000 years ago when the Ancestral Pecos River breached the Capitan aquifer at Carlsbad.

HOFF, ROBERT J.
Eyewitness details and perspectives: the value of oral history at Guadalupe Mountains National Park (42)
In the summer of 1996, Carlsbad Caverns Park Historian Bob Hoff and others conducted an oral history interview with Management Assistant Bob Crisman, a 40-year veteran of the National Park Service. The 20-plus hours interview included reminiscences of the period 1972–1987 when Carlsbad Caverns National Park staff administered Guadalupe Mountains National Park, and Crisman was a staff member at Carlsbad Caverns. Hoff will present excerpts from Crisman's personal recollections of the development and operations in Guadalupe Mountains National Park during this period.

Besides noting the value of oral history interviews in understanding the history of Guadalupe Mountains National Park, Hoff will also emphasize other reasons for such interviews.

HOUSE, ROBERT
Felix Mckittrick in the Guadalupe Mountains of Texas and New Mexico (39)
Felix McKittrick came into west Texas and New Mexico as trail boss of one of John S. Chisum's herds in the late 1860s, and he remained in the area nearly 20 years before relocating to a ranch in Arizona. Memories of the colorful McKittrick linger with a number of landmarks bearing his name, including a canyon in Guadalupe Mountains National Park.

During McKittrick's career as a Texas and New Mexico cattleman, he lived through the Lincoln County Wars, and came into contact with many of the principal combatants. Yet he stayed relatively neutral, counting among his friends and neighbors big stockmen like Chisum and members of the Seven Rivers faction, like the Joneses and Beckwiths.

A veteran of the Mexican War, McKittrick's real battle lasting the balance of his life, was with the United States. His claims under the Indian Depredations Act would be pending at the time of his death in Arizona. Livestock reported stolen by the Mescaleros and the claim for the stock would be the only assets of McKittrick's estate, though he once possessed a sizable amount of property in Denton County, Texas.

Cattleman? Rustler? Noted character? All descriptions seem to fit Felix McKittrick, depending on the source.

This paper will attempt to correlate material only recently collected and examined on a man who left a lasting imprint on the history of the Guadalupes.

HUFF, DAN
Postmodern deconstruction and the role of science in national park management (45)
National Park Service policy calls for the preservation of "naturally evolving ecosystems." Ecosystems are considered to be evolving "naturally" if they are comprised of all "native" species and protect "natural ecosystem processes." This policy requires that the terms "native" and "natural" be definable. Both are often attributed to the characteristics of some pre-European-contact reference period. The role of aboriginal humans (Native Americans) in the evolution of those conditions has traditionally been considered to be minimal, or "natural," as opposed to the obviously more dramatic impacts of European immigrants. This paradigm has been questioned in recent years. The counterargument holds that aboriginal humans were the most dominant ecological factor in pre-Columbian American ecosystems and that their absence from national parks precludes the restoration and maintenance of "natural" ecosystems. The deconstructionist viewpoint complicates the issue by claiming that, first, the current exclusion of traditional aboriginal hunter- gatherer activities from national parks does, indeed, render them artificial, regardless of park-specific management paradigms. But the deconstructionists go on to claim that this situation should not be problematic, if understood and duly noted, because (1) contemporary humans are only slightly more capable of perceiving and understanding the absolute nature of the universe than humans of previous centuries, (2) our understanding is limited by our language and our culture, and (3) science is of no more value than history in our meager and incremental advancement in intellectual accomplishment.

JAGNOW, DAVID H.
History of sulfuric acid theory of speleogenesis in the Guadalupe Mountains (28)
The theory that the caves of the Guadalupe Mountains were dissolved primarily by sulfuric acid (rather than carbonic acid) was controversial when Egemeier and Jagnow originally proposed it in the early 1970s. Cave morphology and cave deposits of gypsum and sulfur provided the initial clues to this theory. By the late 1970s, Hill's sulfur isotope determinations of gypsum blocks in Carlsbad Cavern had verified that the isotopically light gypsum had not come from the Castile gypsum in the Delaware Basin. Endellite clay deposits were also recognized as products of sulfuric acid solution. During the 1980s scientists performed additional studies on gypsum and sulfur deposits and realized that the chert deposits beneath the massive gypsum in the Big Room of Carlsbad Cavern also reflected sulfuric acid speleogenesis. Hill related the sulfuric acid to the underlying hydrocarbon deposits and Mississippi Valley-type (MVT) sulfide-ore deposits. More recently studies of endellite, alunite, natroalunite, tyuyamunite, and other unique minerals all point to basinal degassing of hydrogen sulfide as the most likely source of the sulfuric acid solution. Currently Polyak and others are determining the age of formation of the Guadalupe caves based on $^{40}Ar/^{39}Ar$- dating of alunite. Because the alunite deposits are byproducts of H_2S–H_2SO_4 speleogenesis, these ages date the formation of the caves. The oldest Guadalupe caves (12.3 million years old) formed high in the Guadalupe block, toward the western end, as it began to rise. Younger caves (4.0 million years and younger) formed eastward as the water table subsequently dropped, accompanying the continued structural uplift of the Guadalupe Mountains.

JOHNS, RONALD A., and BRENDA L. KIRKLAND presented by COURTNEY TURICH
Sponge diversity in the middle Capitan reef, Guadalupe Mountains, Texas, and their environmental implications (33)
The Permian reef geology trail in Guadalupe Mountains National Park of west Texas provides an excellent section through the middle Capitan reef and associated facies. The Massive Member of the middle Capitan contains numerous

sphinctozoan and inozoid sponges, many of which have not been described in taxonomic detail since 1908.

Samples were collected from the Capitan Massive at regular intervals of four to five meters along the Permian reef geology trail, beginning at the outer shelf–reef transition, the shallowest part of the reef, and continuing downward. These samples reveal a dramatic change in sponge diversity at a point approximately 10 meters below the outer shelf–reef transition: an inferred water depth of at least 10 meters. Between the outer shelf–reef transition and a position about 10 meters below, samples exhibit high sponge diversity, with at least eight genera being common. Samples collected from that part of the reef between 10 and 140 meters below the outer shelf–reef transition were overwhelmingly dominated by *Lemonea,* a sphinctozoan sponge that is also very common within the upper Capitan.

In modern open marine environments, the diversity of heterotrophic sponges is greatest at about 20 meters; diversity in shallower waters is limited because of turbulence. Interpretation of our data implies that other ecological factors were influencing the distributions within the Capitan. It is possible, but unlikely, that increased amounts of fine sediment or decreased light levels may have influenced the species distributions. More likely explanations include a more rapid drop in oxygenation or a more rapid increase in salinity with depth than has been previously suggested. It is significant that *Lemonea* both inhabited the deeper parts of the reef and also survived into the upper Capitan. We suggest that the abundance of *Lemonea* in both situations indicates that it thrived in stressed conditions that other sponges could not tolerate.

KATZ, SUSANA R., and PAUL KATZ
Archaeological resources of Guadalupe Mountains National Park (20)
A single theme runs through the impressive record of the southern Guadalupe Mountains. For 12,000 years people have been visitors here, coming on a short-term basis to gain something from the region's unique natural resources. The ancient big-game hunter, late Prehistoric gatherer, salt collector, ore and guano miner, and today's park visitor have all benefited from the diversity of available resources. Past and present, the activities of the people have left little more than footprints. The challenge of locating, describing, and interpreting these activities has been the focus of our quarter-century relationship with the Guadalupe Mountains. Archaeological evidence relating to resources, exploitative activities, sites, and the people who used them through time will be discussed.

LAMBERT, LANCE L., BRUCE R. WARDLAW, and BRIAN F. GLENISTER
Defining the base of the Guadalupian Series—the world standard Middle Permian—in its type area, Guadalupe Mountains National Park (31)
The Guadalupian Series (based largely on rocks exposed within Guadalupe Mountains National Park) has been selected by the International Union of Geological Sciences, Subcommission on Permian Stratigraphy, to be the world reference standard for the Middle Permian—a major unit of the geologic time scale. The first occurrence of the conodont *Jinogondolella nankingensis* defines the base of the Guadalupian Series. *Jinogondolella nankingensis* evolved from *Mesogondolella idahoensis* through a brief mosaic paedomorphocline. The point within this transitional cline that is to mark the inception of *J. nankingensis sensu stricto* is proposed at the first post-juvenile retention of serrated anterior platform margins. Such specimens have been recovered from samples 42.7 meters above the base of the Cutoff Formation in Stratotype Canyon—a portion of Guadalupe Mountains National Park set aside as a geological preserve with dedicated international scientific access.

LOBELLO, RICK L.
The role of cooperating associations in the development of tourism in national parks (46)
During the past 78 years, cooperating associations have become one of the driving forces in the development of tourism in national parks. Profits from the sales of theme related publications are donated to park areas in the form of free publica-

tions, exhibits, visitor services, research grants, training opportunities, and equipment. While enhancing the interpretive programs of the National Park Service, cooperating associations do a great deal in creating favorable park publicity that results in increased visitation and loyal supporters of national parks.

MACVAUGH, FRED
Guadalupe Mountains National Park: a 1920s attempt at preservation (49)
Congress authorized creation of Guadalupe Mountains National Park in 1966, 36 years after neighboring Carlsbad Caverns National Park (1930). Proposals for the Guadalupe Mountains as a national park or monument, however, date back to 1924. In this paper, MacVaugh discusses possible reasons why 43 years passed between creation of Carlsbad Caverns (as a national monument) in 1923 and Guadalupe Mountains National Park. He suggests historians study local, regional, national, and National Park Service attitudes toward nature, the West, and Guadalupe Mountains in the 1920s and 1960s. This sort of history of the Guadalupe Mountains will reveal how residents, businessmen, conservationists, scientists, the public, and federal officials viewed and valued the mountains, what changed, and how American attitudes toward nature and the West evolved in the intervening years.

MILLIGAN, BROOK G.
Integrating genetic information into natural resource stewardship (16)
Management of biological resources commonly involves manipulation or monitoring of the performance of natural populations in order to ensure long-term persistence. Because immediate performance is typically viewed in demographic terms such as reproductive success, growth, or survival, understanding the action of demographic processes is an important component of resource management. This perspective has led to the view that genetic information cannot play a useful role in biological resource management. As my studies on *Aquilegia* demonstrate, however, the action of some demographic processes can only be efficiently recovered through the study of genetic variation. These studies also demonstrate that neither genetic nor demographic studies alone are sufficient to obtain an understanding of the demographic processes needed to wisely manage biological resources.

PARKER, NICK C., CARLOS GONZALEZ-REBELES, T. SCOTT SCHRADER, ANDREA E. ERNST, YONGLUN LAN, KELLY E. ALLEN, ERIC HOLT and SHERI HASKELL
The Texas GAP project: status and potential (10)
The Texas Gap Analysis Project (TX-GAP) is part of a nationwide effort to document the spatial distribution of biodiversity and assess its representation by the current conservation system. The objectives of TX-GAP are: (a) to develop a map of current land cover of Texas from recent Landsat Thematic Mapper (TM) satellite scenes, (b) to estimate potential distribution of Texas wildlife vertebrate species, (c) to depict and map land- stewardship categorized by level of conservation, and (d) to combine the above data layers in a Geographic Information System (GIS) and perform analyses of species richness patterns relative to known levels of land conservation and management. There are 52 Landsat scenes covering the state of Texas. Scenes with pixels representing 30 x 30 meters areas are classified with Spectrum software to label vegetation type in accordance with the Nature Conservancy identification of vegetation at the alliance level. Fifty to 200 points per scene are being used to ground truth scenes in west Texas. Aerial videography provides an additional level of data to interpret the Landsat imagery. Seventeen scenes in west Texas have now been tentatively classified.

Wildlife Habitat Relationships (WHRLs) for Texas vertebrates are being prepared based upon habitat affinities for vegetation type, soil type, precipitation, elevation, temperature, and other abiotic and biotic factors. WHRL databases are approximately 25% complete for mammals, 50% for herptiles, and 50% for birds. We anticipate completion of all vertebrate databases this year. Completed WHRLs are used in the context of a GIS to map the distribution of Texas vertebrates. These maps are then in turn used to evaluate the status of biological diversity in the state and ultimately the nation.

These maps and other data will be available to the public and resource managers through the World Wide Web, computer discs, and published reports.

An initiative from the Biological Resources Division of the U.S. Geological Survey, working through the Environmental and Contaminants Research Center, the Texas Cooperative Fish and Wildlife Research Unit, the National Gap Analysis Program, and with cooperation of the Mexican agency National Commission for the Knowledge and Use of Biodiversity, has been funded to extend TX-GAP into Mexican lands adjacent to the lower Rio Grande (Rio Bravo). The study area proposed involves a region covered by 14 Landsat TM scene areas that span the lower Rio Grande plus six adjacent scene areas wholly in Mexico. This trans-national Rio Grande Gap Analysis Project will cover a buffer area approximately 150 kilometers wide to each side of the border. The project will generate valuable geographic and biological data sets to support binational efforts for conservation and land-use planning, provide opportunities for biological data sharing and the potential standardization of procedures applicable in this region with common ecological characteristics. Maps, data, and products produced in this transnational project will be distributed through the World Wide Web, computer discs, and published reports in both Spanish and English.

PITCAITHLEY, DWIGHT T.
Role of history in managing NPS areas (41)
Our personal experiences, knowledge, ethnicity, social circles, economic status, political outlook, and geographical roots shape our perceptions. And our perceptions shape the way we look at things: the natural world, history, other cultures, our own culture, and the federal government. We don't like to have our perceptions of truth, the present, or the past challenged, however. Nevertheless, if we now recognize the impact of human occupation on the national parks, we realize that historical information provides the beginnings of a framework for understanding the natural processes in these places. It is not surprising to remember, then, that one of the first studies commissioned by the National Park Service at Guadalupe Mountains National Park was a historical overview of human occupation and use. Historians play a major role in managing natural areas through the preparation of administrative histories which focus on how the National Park Service as an agency has managed its resources over time. Historians function at the intersection of the natural rhythm of life and the cultural context of human enterprise. They bring the historical perspective of our natural and cultural worlds to the National Park Service's management table. That table, we now understand, is large enough to accommodate a wide range of perspectives and professions, and collectively, we are better managers because of it.

POOLE, JACKIE M.
An update on the status of rare plants in Guadalupe Mountains National Park (14)
At the last Guadalupe Mountains National Park symposium in 1975, Northington and Burgess presented a paper on the rare and endangered plants of the park. Much has changed since then, including concepts of rarity. This paper will present the current status of the rarest plants occurring in the park and discuss the different classes of rarity and the implications for management.

PRAY, LLOYD C.
Geologic significance of Guadalupe Mountains National Park (26)
Guadalupe Mountains National Park has been, is, and must long continue to be a treasure chest and "magnet" for sedimentary geologists from around the globe. Its fascinating array of Permian geologic features, cited in many geology textbooks and research publications, has brought international fame to the park. Hundreds of geologic professionals and students come annually to see and study its wide variety of features.

The Permian Capitan reef is one of the best exposed and accessible ancient reefs of the globe. Research needs to continue in order to better understand the reef and its wide variety of time-equivalent strata. But the geologic significance of the park is not restricted to the Capitan Formation. Underlying it, best visible along the rugged western escarpment, are several thousand feet of older Permian strata. These strata and their correlatives farther north and south have been of increasing value as analogs in the application of sequence stratigraphy to exploration and exploitation of buried oil and gas resources of the world, including those of the adjacent Permian basin. Many of the newly emerging "sequence" concepts had their birth in research along the Guadalupe Mountains western escarpment.

The park's establishment was initiated by Wallace Pratt's gift of some 5,000 acres at the entrance to McKittrick Canyon. This distinguished petroleum geologist wanted the geologic wonders exposed there to be forever available to other geologists for observation and research. Now, happily, this is possible across the much larger area of the present park. Having the many geologic resources within the park is important because they can be protected, studied, and if research warrants, even sampled, under close National Park Service guidance. Such is essential to make the most of the park's geologic inheritance and mission.

RICHARDS, ELIZABETH N.
Forensic entomology meets the Guadalupe Mountains (12)
Entomological evidence recovered from crime scenes has aided criminal investigations in numerous ways, including evidence of postmortem relocation of human remains. For example, such evidence can lead law-enforcement personnel to the primary crime scene, where additional evidence may be recovered, thereby providing a critical link between victim and perpetrator. Currently, there are two methods used to detect relocation of a corpse. The purpose of the current research was to investigate the potential of a third method, using geographic variation in morphology among populations of blow flies that colonize remains following death. If significant morphological variation, correlated with different geographic regions, exists among populations of blow flies, evidence of relocation may be detected. The secondary screwworm fly, *Cochliomyia macellaria* (F.), was chosen as the research organism due to its documented association with human remains and its abundance in west Texas. Specimens of *C. macellaria* were collected at two sites in each of the following locations: Lubbock (Lubbock County), Junction (Kimble County), and Guadalupe Mountains National Park (Culberson County). Twenty characters were measured from the left wing of 10 flies collected from each of the six sampling locations. Multivariate statistical methods were applied, including principal component analysis, discriminant function analysis, and size-free discriminant function analysis. Significant morphological differences were observed among all six samples. These results have important implications in the field of forensic entomology. This technique may expand the current set of tools available to forensic entomologists and law enforcement agencies.

ROTHMAN, HAL
The last traditional national park: Guadalupe Mountains (1)
The establishment of Guadalupe Mountains National Park came at a crucial time for the National Park Service. Between the authorization of the park in 1966 and its establishment in 1972, the National Park Service and the National Park System underwent radical change. At its 50th anniversary in 1966, the agency still intellectually mirrored its origins to a large degree; it remained committed to the complicated set of ideals that Stephen T. Mather and Horace M. Albright assembled in the 1910s. Despite significant professionalization and the rise of science within the agency, large natural areas with spectacular scenery still formed a preeminent focus of agency acquisition efforts; the National Park Service remained committed to an intellectual and cultural construction that derived from early in the 20th century. The emphasis of Conrad L. Wirth and George Hartzog, Jr.—who together led the agency from 1953 until 1972—on expanding the system, sometimes over the protests of other agency officials who remained committed to an earlier set of ideas, foreshadowed great change in the responsibilities of the National Park Service. From Mission 66 to Parkscape USA, Hartzog's successor program, to the 10-year capital development bonanza that preceded the 50th anniversary of the founding of the National Park Service, the parks seemed to

be changing: from being distant, revered places to proximate, hands-on locales used by everyone. By 1972 the combination of social unrest and cultural turmoil precipitated the new stance. With the establishment of Gateway National Recreation Area in New Jersey and Golden Gate National Recreation Area in San Francisco and the growing emphasis on urban parks and what would come to be called multi-cultural sites, the agency and its value system were in flux.

In this context, Guadalupe Mountains National Park became the symbolic last traditional national park in the lower 48 states. Remote, expansive, and devoted largely to nature and scenery, with only specialized recreation possible, Guadalupe Mountains was conceived without the constraints of successors. Along with North Cascades and Redwoods national parks, both authorized the same year, Guadalupe Mountains joined the small group of the last national parks fashioned from lands not already included in the park system. Such parks stood out as the plethora of areas, which stemmed from changing national goals and aspirations and later from the so-called "park-barreling" process that muddied the meaning of National Park System designation. In the context of a changing agency and even greater alterations in what the public expected from the national parks, Guadalupe Mountains was a throwback to an earlier era.

ROUTE, WILLIAM T., DAVID M. ROEMER, V. HILDRETH-WERKER, and J. C. WERKER
Methods for estimating colony size and evaluating long-term trends of Mexican free-tailed bats (*Tadarida brasiliensis mexicana*) roosting in Carlsbad Cavern, New Mexico (19)
Carlsbad Cavern hosts a colony of several hundred thousand Mexican free-tailed bats (*Tadarida brasiliensis mexicana*). Colony size, behavior, and roost geography have all been problematic for obtaining accurate abundance estimates. Past methods have varied from gross ocular counts to complex calculations using video and still photography. No method has provided a measure of precision nor has any method proven valuable as an index to trends. We are investigating reflective infrared photography (RIP) as a method for routine monitoring of this colony. The RIP method involves taking repeated infrared still-photographs from fixed points in the roost. Colony size is then estimated from the area of cave ceiling covered by bats. Using a roost density of 2,153 bats per square meter and the mean area of ceiling covered with bats, we estimate that in the spring of 1996 there were 193,000 bats (±51,000) increasing to 353,000 (±22,000) in fall. In 1997 we estimated 79,000 bats (±30,000) in spring, increasing to 191,000 (±69,000) in fall. We believe that immigration and emigration in the colony contributed to increasing trends in area estimates in both springs, and a decreasing trend in the fall of 1997. Only the fall 1996 estimate is representative of the resident colony. We believe that with refinements to the RIP method including the use of flight noise recordings, development of a contour map of the cave ceiling, and careful seasonal timing of photography, that this method should provide valid estimates of annual trends.

SERFACE, ROBERTA, and ERIC GILLI
Recording of Earth movements in karst: results of a short trip in southwestern U.S.A. (29)
During a three-week trip in the southwestern United States, we visited caves to observe speleothems that could have been affected by ancient earthquakes. There were no caves near the San Andreas Fault in California. In Arizona it was possible to find evidence of the 1887 Sonoran earthquake in S.P. Cave. The most interesting observations are in New Mexico where caves in the Guadalupe Mountains contain many broken speleothems showing evidence of an old, unknown earthquake.

SIMON, DAVID J.
Research, resource management, and resource protection at Guadalupe Mountains National Park: the next 25 years (5)
The establishment of Guadalupe Mountains National Park in 1972 was a legendary achievement, the product of decades of citizen effort. Over the past 25 years, the diverse value of the park to the nation and world has continued to increase. Scientific value is among the most important benefits of protected ar-

eas and Guadalupe Mountains National Park has made significant contributions to the understanding of natural and cultural resources and human interaction with these systems. Together the National Park Service and a supportive public have also made important strides in improving park management and resource protection, often based on good research. But the price of having a National Park System is eternal vigilance. Despite the importance of research and resource management to the national parks, these vital programs have historically not received—and still do not receive—the support that they deserve. Moreover, myriad management challenges and threats to the integrity of Guadalupe Mountains National Park loom before us. The National Park Service, its supporters, and partners must change all of this. We must have a vision for the future of Guadalupe Mountains—an agenda for the next 25 years—that addresses these fundamental challenges so that the park's 50th anniversary will find this place more secure and more cherished than ever before.

STAHLE, DAVID W.
Tree-ring analysis of ancient Douglas-fir at Guadalupe Mountains National Park (25)
Ancient Douglas-fir (*Pseudotsuga menziesii*) over 450 years old survive in protected microenvironments on Guadalupe Peak, Texas. Tree-ring chronologies of early-wood and late-wood width derived from these ancient conifers provide outstanding proxies of past winter and early summer precipitation, respectively. The early-wood width chronology for Guadalupe Peak is coherent with Douglas-fir early-wood growth over a large sector of southern New Mexico, west Texas, and northern Mexico. These Douglas-fir early-wood width chronologies are significantly correlated with indices of the El Niño–Southern Oscillation (ENSO), and provide a valuable, exactly dated, seasonally resolved record of ENSO influence on regional climate for the last 450 years. The intense and prolonged drought of the 1950s was accurately recorded by the Douglas-fir at Guadalupe Peak, but was equaled or exceeded by the extreme droughts of the 1860s, 1660s, and 1570s. Recent analyses of the 1950s drought indicate that these prolonged droughts have played a major role in the ecosystem dynamics of both grasslands and coniferous woodlands in the southwestern United States and northern Mexico.

STUBBS, TIM
Wildland fire management in the Guadalupe Mountains (24)
This paper presents some of the available literature that supports the wise use of wildland fire and prescribed fire in the Guadalupe Mountains and in the adjacent upper Chihuahuan Desert biome. It is also a collection of personal observations and communications regarding wildland fire in the Guadalupes. After reviewing the paper, it is hoped that readers will understand why the fire management program at Carlsbad Caverns and Guadalupe Mountains national parks supports frequent, low intensity wildland fire in the parks' wilderness areas. The managers of both parks believe that all scientific research and other available evidence supports this management approach as that most closely resembling what nature would be doing, were we not present.

TEPEDINO, VINCENT J., T. L. GRISWOLD, SUSAN M. GEER, and ROBERT FITTS
The reproductive biology of McKittrick pennyroyal, *Hedeoma apiculatum* (Lamiaceae) (18)
We studied McKittrick pennyroyal primarily at the Wilderness Ridge population in Guadalupe Mountains National Park. Bagging techniques that excluded insects from the flowers were used together with hand pollinations to elucidate the breeding system. The flowers are protandrous, with the initial male stage lasting one to two days depending on the weather. Because of their protandrous habit, flowers automatically self-pollinate (autogamy) uncommonly even though they are fully self-compatible. Self-pollinations performed by hand produced as many fruits per flower and as many seeds per fruit as did hand cross-pollinations. Flowers never set fruit parthenogenetically (agamospermy). There was no indication that fruit or seed production was being limited by inadequate deposition of pollen on receptive stigmas. The primary pollinators appear to be a variety of lepi-

dopterans and bees. Experiments which allowed access to flowers only during the day or at night revealed that moths are as important pollinators as are butterflies and bees: there was no difference in fruit and seed production between flowers only open in day or night.

TURNER, RANSOM, CYNDI MOSCH, JACKIE TURNER, and SUSAN HERPIN
The cave impact monster: an environmental education skit for classrooms (43)
Having recognized education as being essential to the protection of cave resources, the Lincoln National Forest, Guadalupe Ranger District, has developed a diverse environmental education program. Cave visitors receive this education through brochures and interaction with Forest Service cave specialists who lead them on cave tours and coordinate volunteer projects. The long range education goal is for the public to become aware of and grow to appreciate the intrinsic values and benefits derived from cave and karst resources. To this end the Guadalupe Ranger District developed the cave impact monster skit. The original impact monster skit was developed by Jim Bradley of the Eagle Cap District on the Wallowa Whitman National Forest in the 1970s. It has been used by wilderness rangers to convey minimum impact messages in an effort to improve visitor behavior. This skit has been adapted to a variety of geographic areas and management issues. This skit is be used to increase the awareness and understanding of cave and karst resources with a target audience of elementary aged children. Audience participation is a fundamental component of the skit. The hands-on experience combined with role playing and having fun have produced outstanding learning outcomes.

WEST, STEVE
Avifaunal changes in the Guadalupe Mountains of New Mexico and Texas (9)
Historic data on bird distribution in the Guadalupe Mountains is scant. The earliest available dates are from the turn of the 20th century and little else until the 1950s. Changes in status in many species have been marked in both increasing and decreasing status. The Guadalupe Mountains are an important transition area in bird distribution between the southwestern mountains and those with more of a tropical origin as found in northern Mexico.

Included in the study area are Guadalupe Mountains National Park, Carlsbad Caverns National Park, the adjacent Lincoln National Forest, and adjacent Bureau of Land Management land. Over 325 species have been reported with varying degrees of certainty. Comparing current information on status with historic data shows many changes with human influence as a large factor. Many species have either become extirpated or extremely limited in distribution. Other species which may have been missed at the turn of the 20th century are now very common. While some of these changes are due to better understanding of the Guadalupe Mountains ecosystem and to climatic factors, many are due to human impacts.

The origin of birds currently noted shows a strong Rocky Mountain influence but also a growing awareness of a larger Mexican element than previously thought. Status, including nesting status, shows the large number of species nesting or suspected of nesting. Many gaps could be filled with better understanding and documentation. The necessity for reestablishing extirpated populations should be a high priority in any regional management plans if the goal is a healthy and stable ecosystem. Agencies need to place biological inventories and reestablishing native populations at a higher priority than is currently done.

WILDE, GARNER L.
Permian extinctions: a fusulinacean's way of life and death (32)
Fusulinaceans enjoyed a relatively long life as a group, covering nearly 100 million years, from the Carboniferous to "End-Permian" time. And then they were gone from Earth forever, the same as many millions of other life forms. End-Permian time marked the greatest extinction period in Earth's history.

Myriad arguments have been offered for the End-Permian extinctions, including superanoxic oceanic conditions, salinity changes, tectonics, extra- terrestrial impact, global cooling, and marine regression, to name a few. Commonly, workers tend to defend with vigor their latest ideas until new evidence, or new ideas lacking real evidence, appear interesting enough to gain new adherents.

What if nearly everyone is correct? And what if signs of the demise of much of Permian life could be anticipated by an examination of data from the Middle Permian Guadalupian, millions of years earlier than End- Permian time?

Sedimentary and tectonic history, including volcanism, and the recorded life and death of fusulinacean foraminifers, have all conspired to reveal a pattern of both gradual and sudden extinctions. The dinosaurs were possibly lucky—it all happened so suddenly according to some workers. Permian life did not fare so well.

WILKINS, DAVID E., and DONALD R. CURREY
Lacustrine paleoenvironments in the Trans-Pecos closed basin (36)
The study of the Trans-Pecos closed basin examines how global paleoclimatic factors and intrinsic geographic controls determine the threshold between states of hydroclimatic equilibria. Geomorphic, radiocarbon, and sedimentologic evidence are used to identify four major highstands for Pleistocene Lake King during the last glacial maximum (LGM). Patterns in the resulting model limnograph for Lake King suggest that runoff contributions from basin catchments to the inundated area were limited by precipitation rather than evaporation; onset of lacustrine environments appears to have been abrupt, with rapid formation of deep-water lakes. Timing of the onset of lacustrine transgressive events corresponds with the latter stages of cooling events recorded in the Greenland ice and North Atlantic deep-sea sedimentary record. Correlation of Trans-Pecos lacustrine environments with North Atlantic cooling implies that full pluvial conditions in the basin were limited to those periods when those cooling events resulted in extreme equatorward shifts of the LGM subpolar winter storm tracks, providing a moisture source to the basin. By comparing timing, intensity, and direction of climate change over a widely spliced array of hemi-arid basins, the global implications of climatic events becomes better understood.

WOBBENHORST, JANICE A.
Stewards of the land: the role of discovery, science, and research—a Guadalupe retrospective (3)
Stewardship is a term that is frequently used today to describe certain land conservation and preservation practices and management philosophies. But what is stewardship and who are the stewards of the land? Historically the land owners, their managers, and others were the stewards of the land we now call Guadalupe Mountains National Park. They managed the land under a different philosophy than we might today, but nonetheless they were the stewards of the land.

The explorers, researchers, scientists, and others who have explored this land also have a role in its stewardship. The information that they have gathered is an important aspect of the stewardship of the land. Without the information that these stewards have provided over the years, we could not manage the resources as well today. A review of this discovery and research will be presented from the first discoveries made through three distinct time periods: the period before park establishment, the period during which initial inventories were conducted, and finally the years since that initial work as the park has matured. The role and responsibilities of research and researchers will be discussed from the perspective that they too are stewards of the land.

WORTHINGTON, RICHARD D., and ARTIE L. METCALF
Fossil assemblages of mollusks as indicators of past communities in the Guadalupe Mountains, Culberson County, Texas (37)
Knowledge of the nature of community changes since the Pleistocene has increased substantially by studies of ancient packrat middens. Packrat middens are seldom found on the lower mountain slopes or bajadas. Mollusk shells are often well preserved in soil horizons on lower mountain slopes. They provide clues as to the composition of past com-

munity structure and change. Two fossil mollusk assemblages from near the Frijole Ranch are reported and interpreted. The two assemblages suggest a radically different environment during the Pleistocene that consisted of woodland, perhaps dominated by ponderosa pine, but with sufficient hardwoods to form enough rich leaf litter to support the snails. These data are in general agreement with the results from studies of packrat middens that document life zone depressions during the Pleistocene and postulate woodlands extending well out onto the bajada of the Guadalupe Mountains.

ZOOK, BARBARA
Celebrating the historic architecture of Guadalupe Mountains National Park
(23)
The majestic Guadalupe Mountains have attracted rugged individuals for over 6,000 years. This presentation focuses on the architectural features of Guadalupe Mountains National Park which remain as symbols of the unique individualism of former residents and visitors who historically ranched, mined, drilled, studied, enjoyed, settled, and traveled through the austere and powerfully beautiful landscape.

This presentation will explore the 34 remaining architectural features which significantly weave together the story of past historic human interaction with the park's powerful landscape. The presentation will introduce those rugged individuals who were architects and builders, explaining why they chose to settle in this remote, isolated area. Each of the 34 architectural features will be characterized.

The author will explain how the National Park Service has honored these architectural symbols through inventory, research, documentation, and evaluation over the past 25 years. The National Park Service's stewardship through stabilization, restoration, and rehabilitation projects will be discussed.

Those interested in sharing in the National Park Service's stewardship of this rich architectural legacy will be challenged with a list of potential future projects. A vision for the preservation of these valuable cultural resources over the next 25 years will be proposed.

Chapter 51

Abstracts—Poster sessions

Note: Abstracts of posters presented during the Guadalupe Mountains Symposium are arranged in alphabetical order by the primary author's last name.

ARMSTRONG, FRED R., National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas, and TERRELL H. JOHNSON Consulting Biologist, Los Alamos, New Mexico
Mexican spotted owl management at Guadalupe Mountains National Park
The Mexican spotted owl, *Strix occidentalis lucida*, was listed by the U.S. Fish and Wildlife Service as a threatened species on April 15, 1993, and a corresponding recovery plan was released in December 1995 in the effort to mitigate habitat loss for this species. One organizational concept of the recovery plan was to develop recovery unit work groups to assist with implementing the recovery plan throughout a significant portion of the bird's habitat. The recovery unit work groups consist of representatives from federal, state, and local government agencies, private organizations, and special interest groups. The resource management specialist at Guadalupe Mountains National Park serves as the representative for habitat and recovery issues on National Park Service lands within the Basin and Range–East Recovery Unit, one of six identified recovery units.

The presence of Mexican spotted owl in the Guadalupe Mountains has been documented since the 1930s to include habitat within what is now Carlsbad Caverns National Park, Lincoln National Forest, and Guadalupe Mountains National Park. Terry Johnson has developed a topographic model for projecting potential spotted owl habitat in New Mexico, and has applied this model to Guadalupe Mountains National Park. The model correlates well with some known nesting and roosting sites within the park and may predict habitat areas which need to be field verified.

BENNETT, FROSTY, and COOKIE BALLOU, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas
Birds: nesting and habitat at Guadalupe Mountains National Park
Birding at Guadalupe Mountains National Park requires time, patience, luck, and hard work. Park elevations range from 3,624 to 8,749 feet, and the park boundaries encompass several life zones, each with its own variety of bird life. Desert lowlands, pine forested mountain tops, deep canyons with their riparian woodlands, and the transition zones between all of these present a variety of habitats. Observe the uniqueness of different kinds of nests built in a variety of habitat. Enjoy birding at Guadalupe Mountains National Park and assist the park to manage birds and their habitat by reporting observations to park personnel.

BENNETT, FROSTY, and JOHN MILLER, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas
Solar electric power systems provide energy to operate communications, remote living quarters, water pumping, remote weather stations, and essential lighting at Guadalupe Mountain National Park
Guadalupe Mountains National Park is using the photovoltaic (PV) system because it is cost effective and supports the worldwide emission reduction program. There are many uses for the electrical power generated by PV systems. The most practical use of solar- generated power is in regions of the world where the sun is not obscured by a lot of cloud cover, such as Guadalupe Mountains National Park.

Remote weather stations with instrumentation that collects and records weather related data, such as wind speed and velocity, precipitation amount, temperature extremes, and in some cases the particulate count of what is blowing in the air are powered by solar energy. Guadalupe Mountains National Park is dependent upon solar power for the operation of remote weather stations.

The park uses solar energy for improved communications by having power to operate a remote radio repeater station. Backcountry ranger cabins and remote living quarters receive solar energy for lighting, a base radio unit and charging of portable radio batteries. Fire fighting personnel, maintenance workers, and rangers all depend heavily on being able to quickly communicate with each other to maintain, protect, and ensure the safety and well being of the park and visitors.

BRADLEY, ROBERT D., ROBERT J. BAKER, CLYDE JONES, NICK C. PARKER, and DAVID J. SCHMIDLY, Texas Tech University, Lubbock, Texas; ANDREW SANSOM, ROBERT L. COOK, RONNIE R. GEORGE, and DAVID H. RISKIND, Texas Parks and Wildlife Department, Austin, Texas
Faunal surveys of state-owned properties
Over the past 2.5 years, researchers at Texas Tech University have collaborated with the Texas Parks and Wildlife Department in conducting faunal surveys on state-owned properties. The focus of these endeavors was to: (1) assist Texas Parks and Wildlife Department with its ongoing baseline inventories; (2) archive voucher specimens (skins and skeletal material) for historical documentation of existing biodiversity and for future reference; (3) archive tissue samples for future studies pertaining to systematics, genetics, ecotoxicology, and emerging viruses (e.g., rabies, hantavirus, and arenavirus); (4) provide GIS localities of traplines for use in habitat preference studies or future baseline studies; and (5) provide data and information to the Texas Parks and Wildlife Department and the scientific community.

As of February 1998, we have conducted surveys on 22 state-owned properties, with a majority of our efforts being focused on wildlife management areas. These surveys generally have focused on small mammal species with the major emphasis being on rodents and bats. The results of these surveys have ranged from producing the first baseline data for poorly studied properties to supplementing and updating existing data for those properties which have been studied in more detail. To date, we have discovered at least 27 county records and several property specific records as a result of these inventories.

We hope that this collaboration will enhance our knowledge of the biodiversity of state-owned properties, as well as serve as an indicator of the biological status of wildlife species across the state of Texas. It has been 100 years since the Biological Survey of Texas was conducted by Vernon Bailey and his colleagues. Not only has a significant amount of time passed, but the land use practices and human activities of Texans have changed significantly since the initial survey. Data such as those being generated through the interactions of Texas Parks and Wildlife Department and Texas Tech University will be instrumental in addressing the current and future issues concerning the biodiversity of Texas.

CWIKLIK, JOHN, and FRED R. ARMSTRONG, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas
Resource monitoring programs at Guadalupe Mountains National Park
This poster will display the current natural resource monitoring programs within Guadalupe Mountains National Park. The park has established monitoring programs for air quality, surface water quality, mountain lions, and peregrine falcons. Air quality monitoring is conducted as a part of the National Atmospheric Deposition Program/National Trends Network and under the Impairment to Protected Visual Environments (IMPROVE) program, which are both long-term monitoring programs. Surface water quality monitoring of McKittrick Creek and Choza Spring was developed as a continuation of sampling programs

initiated by Baylor and Texas Tech universities. The continuation of mountain lion monitoring follows survey protocol enacted by a contract study to determine population trends. Annual peregrine falcon monitoring is conducted to document nesting and fledging success of this federally listed endangered bird.

DOBOS-BUBNO, DIANE and MARK BREMER, National Park Service, Carlsbad Caverns National Park, Carlsbad, New Mexico; WILLIAM ROUTE, International Wolf Center, Ely, Minnesota

Preliminary density and population estimates and mortality tables of the federally listed threatened cactus, *Coryphantha sneedii* var. *leei*, Carlsbad Caverns National Park, New Mexico

Lee's pincushion cactus (*Coryphantha sneedii* var. *leei*), a federally listed threatened species and New Mexico state-listed endangered species, is endemic to the lower elevations of the Guadalupes. Study and population estimates of wild cactus prove problematic due to its small size, clustering distribution, and the difficult terrain it inhabits. At present, no reliable estimate of the current population exists. There is limited knowledge of the habitat requirements, recruitment and mortality schedules, and response to environmental stresses such as fire and drought. Previous attempts to monitor cacti responses to environmental changes include photo-documentation and fire-effects studies. An analysis will be presented covering 11 years of photomonitoring data on 275 plants. Initial assessment of life cycles of individuals within the population will be examined. Preliminary results from the first year of a fire effects study, with resulting preliminary density estimates of this cactus, will also be presented.

DODGE, REBECCA, RAED ALDOURI, and RANDY KELLER, Pan American Center for Earth and Environmental Studies, Department of Geological Sciences, University of Texas, El Paso, Texas

Views of the surface and subsurface of Guadalupe Mountains National Park

The Guadalupe Mountains are a major geologic structure set in the transition of the Basin and Range–Rio Grande rift extensional province and the stable Great Plains province. On the west, the range is bounded by the Salt Flat basin which is the result of a downfaulted block (graben) that has developed in 20 million years or less. Although young faults can be seen in this basin, it contains less than one kilometer (about 3,300 ft) of sedimentary fill. When viewed using imagery from the Landsat Thematic Mapper (TM) instrument, the Salt Flat basin shows up as a bright feature that extends southward to the region around Van Horn, Texas. The Guadalupe Mountains are a prominent V-shaped feature on the image, and the Great Plains which are underlain by the Permian basin extend to the east of the mountains. The rich geologic diversity within the park is revealed in the coloration of the strata shown on the image. In terms of deep Earth structure, the region displays variations that are as strong as those seen on the surface. The gravity anomalies in the area demonstrate this by showing a strong increase in values from west to east across the region of the park. The low values to the west are due to the heating which has lowered the density of Earth down to depths of at least 100 kilometers. To the east, high values are due to the fact that the cool, stable Earth has high density. Thus, both the surface and subsurface structure in the region are interesting and complex.

GAGE, ED V., Texas Museum of Entomology, Pipe Creek, Texas

Insects within the Guadalupe Mountains and surrounding areas

The limestone tiger beetle complex of Texas, Oklahoma, and New Mexico will be discussed. Taxonomic problems will be discussed concerning this complex. Habitat, behavior, and distribution range for each will be discussed. Other selected insect species will be noted for the immediate area of the Guadalupe Mountains. Surveys of this nature are often utilized to develop insect checklists for an area. These lists also lay the groundwork for determining the environmental health of the area. Management techniques which favor some rare species will also be discussed.

HARVESON, LOUIS A., Sul Ross State University, Alpine, Texas; FRED ARMSTRONG, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas; BILL ROUTE, International Wolf Center, Ely, Minnesota; NOVA J. SILVY, Texas A&M University, College Station, Texas; and MIKE E. TEWES, Texas A&M University, Kingsville, Texas

Mountain lion population trends in the Guadalupe Mountains, 1987–1996

In the United States, the mountain lion (*Puma concolor*) is currently limited to the western states and an isolated population in Florida. Recent reports suggest that mountain lion numbers in the West are increasing; however, most estimates are based on biased harvest records, mortality reports, or sightings. Our purpose for the study was to assess mountain lion population trends in two areas within the Chihuahuan Desert using multiple-sign surveys. Transects (76 and 74 km) were monitored in spring and fall during the years 1987 to 1996 in Carlsbad Caverns and Guadalupe Mountains national parks, respectively. Mountain lion sign (tracks, scat, scrapes, kills) was recorded for each kilometer. The amount and type of mountain lion sign in each park differed and was likely related to dominant substrate. A decreasing trend in mountain lion sign was observed on Guadalupe Mountains National Park from fall 1987 to fall 1991, and an increasing trend was observed from spring 1992 to spring 1996. No apparent mountain lion trend was observed on Carlsbad Caverns National Park from fall 1987 to spring 1996. Mountain lion mortalities on adjacent lands may have reduced mountain lion numbers at Guadalupe Mountains National Park. Similar multiple-sign transects may provide a useful tool for monitoring mountain lion populations in other regions of the Southwest.

HENDERSON, LARRY, and JANICE A. WOBBENHORST, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Western expansion of park boundary—white gypsum and pink quartz sand dunes—a status report

On October 28, 1988, congress authorized the boundary expansion of Guadalupe Mountains National Park by approximately 10,000 acres in order to preserve and open to the public an area of white gypsum and pink quartz sand dunes. The gypsum dunes are the second largest exposure in the United States, and the pink quartz dunes contain numerous remains of Indian campsites and artifacts.

The white gypsum dune field covers an area of approximately 2,000 acres and is the second best example of a gypsum dune field in the Chihuahuan Desert. It consists of about 50% granular gypsum. The parent source of this gypsum is the salt flats to the west of the area. They range from three feet to over 60 feet in height. They are heavily vegetated in the southern and western sections of the dune field, but largely unvegetated in the northern sections where the highest dunes are located. The red quartzose dunes lie to the northeast of the white dunes and cover an area of about 2,500 acres. These dunes are smaller than the white dunes and display a fairly rich vegetative cover. Common plants in the quartzose sands include honey mesquite, snakeweed, creosote bush, giant dropseed, and soaptree yucca.

Besides the dunes themselves, several sensitive and fragile resources are of note. One plant species, gypsum scale broom (*Lepidospartum burgessii*) found in the area is a candidate for endangered species status. One extremely pale form of the lesser earless lizard (*Holbrookia maculata*) is found only at White Sands National Monument and in the west side dunes. Over 20 archeological sites have been identified in the area, with most of these located in the red dunes. Cryptogamic soils—a lichen and fungal association—cover some of the smaller dunes and interdunal areas. These cryptogamic crusts produce soil nitrogen, prevent sheet erosion, and are essential in stabilizing and preparing the soil for other vegetation. This crust is very fragile and simply walking across it can cause erosion.

Of the seven land tracts in the boundary expansion area, all but approximately 5,000 acres owned by CL Ranch and one belonging to the Nature Conservancy have been acquired. Although the CL Ranch owners are willing to sell their acreage, there has been disagreement on the price, because CL Ranch contends that the uniqueness of the resources on their property affords it a higher value than that appraised by the U.S. government. Because the CL Ranch was considering offers to mine the gypsum deposits within the authorized boundary, and in fact had dug test trenches within the area, a condemnation case was filed in February 1995.

A judgment based on a jury verdict was awarded to the CL Ranch in October 1996, and the U.S. filed a Motion To Dismiss the Condemnation and abandon the acquisition for the immediate future. This was based on the fact that the award is excessive and is based upon a premise used by the appraiser, which is not sanctioned by the appraisal organization as a method of appraising property. The Motion To Dismiss was denied by the District Court and was appealed to the 5th Circuit Court of Appeals where it was granted.

At present (April 2, 1998) the Department of Justice, the National Park Service, and the CL Ranch are discussing possible alternatives to resolve this acquisition conflict. Once land acquisition issues are resolved, the National Park Service plans to provide access to the dunes to the public. Careful planning will be completed to insure maximum protection of the dunes and the fragile resources from adverse impact. Additional research and baseline inventory of the dunes is essential to provide information needed for management of the area and to plan for this access.

LEYVA, RAQUEL, Texas Tech University, Lubbock, Texas; NICK C. PARKER and MARKUS PETERSON, U.S. Geological Survey, Texas Cooperative Fish and Wildlife Research Unit, and Texas Parks and Wildlife Department, Lubbock, Texas

Assessment of the scaled quail population dynamics in Texas

Scaled quail (*Callipepla squamata*) populations have declined in most areas of Texas in the past decades. Changes in habitat characteristics may have caused changes in population dynamics of the species throughout its historical range. Research is currently underway to test the hypothesis that long-term habitat changes are not correlated with scaled quail population declines in Texas. Remotely sensed data and other databases are being used to describe changes in the biotic and abiotic habitat composition in areas of scaled quail distribution in Texas. A Geographical Information System (GIS) is being used to assemble all the databases for habitat description. Databases include soil description, scaled quail population surveys, historical climate data, and vegetation description. ArcInfo was used to create a referenced frame using counties as the sampling unit for this study. This frame will be used to overlay the coverages produced with each database. A soil map for Texas has been created as one of the several data layers that will integrate into a spatial model. This model will aid in the description of changes in scaled quail populations in Texas. A second coverage is being created using historical climate data from the late 1800s. This coverage will be created using Geostatistics (i.e., Kriging) and incorporated in the spatial model. A total of 3,860 point locations for Texas have been used to create a climatic map for the entire state. These locations represent areas in which climate stations are located. Population surveys derived from the U.S. Fish and Wildlife Service's breeding bird survey for scaled quail will be incorporated into the GIS and will be spatially correlated with roads from which these surveys were conducted. Completion of this project is expected to provide a tool for the management of scaled quail populations in Texas. The use of remote sensing techniques employed in the project may prove to be important tools in the management of not only scaled quail but also other wildlife populations in the future. Funding for this research was provided by the Texas Parks and Wildlife Department.

MARTIN, LARRY, National Park Service, Water Resources Division, Fort Collins, Colorado

Water resources inventory of Guadalupe Mountains National Park

Springs and seeps at Guadalupe Mountains National Park were inventoried in 1990–1991. Twenty-three springs and seeps were identified and described. Field inventories included estimates of flow rates and sizes of spring pools, hydrogeologic setting, and descriptions of vegetation associated with the springs.

Springs and seeps are important water sources for wildlife and backcountry users.

Inventory and analyses of surface-water quality from EPA's STORET database identified 7,540 observations for 46 separate parameters collected at 33 monitoring stations from 1959 to 1997. All of the monitoring sites are located in the eastern part of the park. Surface waters within the park are generally of good quality with some indications of human activities. Potential anthropogenic sources of contaminants at Guadalupe Mountains National Park are primarily recreational activities and atmospheric deposition.

Obtaining reliable potable water supplies at Pine Springs and Dog Canyon has required drilling several thousand feet to reach the regional water table. At some locations where smaller quantities of water are needed, such as Wallace Pratt Lodge and McKittrick Canyon visitor station, adequate supplies have been obtained by constructing wells in the alluvial aquifer. Old stock wells on the west side of the park generally are unsuitable for potable supplies due to saline water typical of the aquifers underlying the salt flats. Potable water can probably be developed from the alluvium of Bone Springs Draw, should park managers decide to develop facilities on the west side of the park.

MENNING, MANFRED,
GeoForschungsZentrum, Telegrafenberg Potsdam, Germany

First magnetostratigraphic results from the type section of the Guadalupian Mountains (Middle Permian)

In the Permian section of the Guadalupe Mountains, west Texas, two Global Stratotype Section and Points (GSSP) are proposed to define the base and top of the Middle Permian Guadalupian Series (Subcommission on Permian Stratigraphy 1996). The GSSP for the Lower-Middle Permian boundary is planned in the Cutoff Formation of the Stratotype Valley. The GSSP for the Middle-Upper Permian boundary is planned near the top of the Nipple Hill. To achieve these GSSP in the Guadalupe Mountains magnetostratigraphic investigations are claimed from the International Commission on Stratigraphy besides numerous others.

The major aim of our magnetostratigraphic research is to detect the Illawarra Reversal (IR). To date the IR is the only Permian magnetic marker usable for global correlation. At least, the IR is the best magnetic time marker of the Palaeozoic Era. The age of the IR is *265 Ma (million years). At *265 Ma the reversal frequency of Earth's magnetic field changed significantly. During the Carboniferous-Permian Reversed Megazone (CPRM; 305–*265 Ma; Permo-Carboniferous Reversed Superchron–PCRS; Kiaman Magnetic Interval–Kiaman) the number of reversals of Earth's magnetic field (five in maximum) was very low, whereas during the Permo-Triassic Mixed (normal and reversed) Megazone (PTMM; *265–238 Ma; Permotriassic Mixed Superchron–PTMS) the number of reversals of Earth's magnetic field was significantly higher—about one reversal per one million years.

The IR has been found undoubtedly within the lower Tatarian (Upper Permian) of east Europe and within the upper Rotliegend (Lower Permian) of central Europe. The IR may be positioned in the Lower Permian of south China (Maokouan). According to the reinterpreted magnetostratigraphic results of Peterson and Nairn (1971) the IR is expected in the Bell Canyon Formation of the Delaware Group (Menning 1986). Seven-hundred-twenty specimens have been sampled from the Bone Spring Member (Cutoff Formation, Cathedralian stage) at the bottom to the Lamar Limestone (uppermost Bell Canyon Formation, Capitanian stage) at top from the Guadalupe Mountains National Park and its surroundings to confirm the CPRM and to discover the position of the IR undoubtedly. Magnetic cleaning using alternating field and thermal demagnetization has been used to isolate the syngenetic magnetic component and to determine the primary magnetic polarity. Post-diagenetic (secondary) magnetic components have been eliminated as far as possible. The main problem is to detect remagnetization (loss of the magnetic long time memory) undoubtedly in rock specimens investigated. A total remagnetization hasn't been expected because the conodont color alteration index is very low at 1 to 1.5. In many samples there are three magnetic components: component A—viscous remanent magnetization (VRM) of recent/subrecent age, component B—chemoremanent magnetization (CRM) of secondary age carried by goethite or/and haematite, and component C—characteristic remanent magnetization (ChRM) of diagenetic age carried mostly by magnetite and in minor samples by haematite. In most samples a northeast directed magnetic component is stable applying alternating field demagnetization particularly in the sandstone. It is carried by goethite or/and haematite. The thermal demagnetization improves the quality of the results slightly; however, it yields sufficient results only in few specimens. Paleomagnetic tests are used to check the age of the ChRM. The reversal test is positive for most samples with a magnetite-bearing remanence. It means that there is a syngenetic age of the main magnetic component. Only these samples can be used for magnetostratigraphic interpretation. The conglomerate test is negative; a fold test isn't applicable. The Cutoff Formation has reversed or questionable polarity. Normal polarity is missing. Consequently, the proposed global stratotype section and point for the Lower-Middle Permian boundary (Cathedralian-Roadian boundary) is within reversed magnetized sequences of the Stratotype Canyon of the Guadalupe Mountains. The Getaway Limestone and the Manzanita Limestone of the Cherry Canyon Formation (Roadian-Wordian) are reverse polarized. By that the existence of the CPRM is confirmed. To date, few normal polarized samples are found in the Pinery Limestone and Lamar Limestone. Therefore, the IR should be positioned near the Wordian-Capitanian boundary. Sampling should be continued in the Glass Mountains, west Texas, to check the results from the Guadalupe Mountains in a parallel section.

MORSE, DEE, National Park Service, Air Resources Division, Denver, Colorado, and FRED R. ARMSTRONG, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Air quality conditions at Guadalupe Mountains National Park

The National Park Service began monitoring the air quality at Guadalupe Mountains National Park in 1982. The park later became a participant in the National Atmospheric Deposition Program (NADP) to monitor acid deposition in June 1984. Visual range estimates have been calculated using photographs of a target feature on the horizon, Sierra Prieta, at a known distance of 28 miles, and with a transmissometer which calculates the visual range hourly by measuring the scattering and absorption of light over a fixed distance between two stations 4.86 kilometers apart. Best and worst visual range photographs, 193 and 37 miles respectively, and average summer and winter visibility photographs are in this poster. An air corridor map shows the flow of "dirty" and "clean" air into the region, and an isopleth map displays the average summer visual range across the United States. Components that contribute to visibility impairment include sulfates, nitrates, organics, soil, humidity, nitrogen, and oxygen molecules. Acid precipitation monitoring shows that the pH of rainfall in the park has ranged from 4.3 to 6.7. The calcium and carbonates of the Guadalupe Mountains have a certain capacity to neutralize acid deposition. The measured acidity of park rainfall has decreased 46% from 1984 to 1994. Nitrate concentrations increased 57%, yet no significant changes in sulfate and particulate matter concentrations were recorded over this same period. Any effects to organisms or resources in the park due to air quality changes have yet to be studied and determined.

MORTON, TOM, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Backcountry campgrounds and campsites: Guadalupe Mountains National Park, Texas

Guadalupe Mountains National Park, located in west Texas, is composed of 86,416 acres with 46,850 acres being designated as Wilderness in 1978. The park is truly a paradise for hikers and backpackers with approximately 85 miles of designated trails and 10 designated backcountry campgrounds. Approximately 60 individual campsites are contained in the backcountry campgrounds. Over the years, literally thousands to tens-of- thousands of visitors have enjoyed these rustic facilities. Because of the above increasing usage, the park has seen the necessity to change from non-designated campsites (1980s) to designated campsites (1990s). This change has been and is being accomplished following the park's Backcountry Management Plan. Visitor impact is and has been the driving force in decisions regarding the management of the park's backcountry. Today, some of the criteria used to evaluate visitor impact would consist of area disturbance, lack of vegetative cover, and soil erosion.

RATH, RANDY G., National Park Service, GIS Center, Albuquerque, New Mexico; FRED ARMSTRONG, JIM SULLIVAN, VICTOR TIMMONS, and JANICE WOBBENHORST, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Geographic Information System data sets for Guadalupe Mountains National Park, Texas

Geographic Information Systems (GIS) are becoming one of the better mediums to display and query geographical data. Managers at Guadalupe Mountains National Park realize the importance of GIS and have begun to acquire digital data of the park. There are several methods that can be used to display this data. We use ArcView, which is user friendly. The digital data that are used in ArcView are called "themes." Themes exist in several different formats and can be obtained from many sources. The U.S. Geological Survey (USGS) is an excellent source. Some of their data include Digital Elevation Models (DEM) and Digital Line Graphs (DLG). DEMs show the topography of an area and DLGs include boundary and hydrology covers as well as transportation routes. Both DEMs and DLGs can be downloaded from the USGS Internet site in a scale of either 1:100,000 or 1:250,000. Another source of obtaining data is collecting it directly in the park. A Global Positioning System (GPS) can collect point, line, or boundary data to an accuracy of around a meter. GPS units can be used to collect point data on springs, wells, and archaeological sites. Data can also be digitized from an existing accurate map and brought into ArcView as a theme. These digital themes are easily manipulated and viewed in ArcView. The National Park Service's Intermountain GIS Center utilizes some of the existing themes mentioned above and displays them in a poster. Related themes are shown as four separate views that coincide with specific park interests.

ROEMER, DAVID M., National Park Service, Carlsbad Caverns National Park, Carlsbad, New Mexico

Evaluation and mitigation of brood parasitism by cowbirds at Rattlesnake Springs, Carlsbad Caverns National Park, New Mexico

Brown-headed cowbirds (*Molothrus ater*) have significantly expanded their range and have increased in abundance since the arrival of Europeans to North America. Cowbird abundance has increased in relation to improved feed provided by livestock grazing, agriculture, and irrigation. Brood parasitism by brown-headed cowbirds may contribute to the decline of migratory songbirds in the Southwest, where up to 90% of the riparian habitat has been lost since European settlement. The Rattlesnake Springs unit of Carlsbad Caverns National Park provides critical nesting habitat for the New Mexico state-endangered Bell's vireo (*Vireo bellii*), and other migratory birds. Nest monitoring at Rattlesnake Springs in 1996 discovered brood parasitism by cowbirds in nine of 28 (32%) migratory songbird nests where the host species was known, including two of five (40%) state-endangered Bell's vireo nests. In 1997, cowbirds parasitized 19 of 31 (61%) observed nests where the host species was known, including 13 of 15 (87%) of Bell's vireo nests. Cowbirds caused nest abandonment in seven of 17 (41%) total Bell's vireo nests in 1997. Cowbirds also laid eggs in the nests of yellow-breasted chats, blue grosbeaks, house finches, indigo buntings, and unidentified species. Cowbird eggs were addled and replaced in all vireo nests during the two-year study. The 87% parasitism rate on Bell's vireo in 1997 is alarmingly high, and suggests that the continued presence of Bell's vireo at Rattlesnake Springs may be at risk.

SILVY, NOVA J., Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas

Long-term deer trends on Guadalupe Mountains National Park

From January 1987 to March 1988 studies were conducted to provide population assessments of the deer herd within Guadalupe Mountains National Park and to develop census techniques for use in future monitoring of the deer population. A 12-year (1967–1978) pellet-group data set had been collected by National Park Service personnel on Guadalupe Mountains National Park and was analyzed to determine deer trends. Deer density was assessed using road counts (morning, evening, and spotlight) and time-area counts. Sex, age, and species of deer seen were recorded when definite identification was possible. Road counts proved to be effective in monitoring the deer population at Guadalupe Mountains National Park. Spotlight counts followed by evening counts gave the highest density estimates. Time-area counts were considered inefficient due to high man-power requirements. Pellet-group data indicated a general increase in pellet-group density for the entire park during the 12 years. Because of man-power requirements, time effectiveness, and precision of the monitoring technique, spotlight counts are recommended as the most efficient method to assess deer trends on Guadalupe Mountains National Park.

SLATER, LINDA C., National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Status of the prescribed fire program at Guadalupe Mountains National Park

A critical wildland fire hazard exists in the park's riparian zones and conifer forests due to the tremendous accumulation of fuels that has occurred with the exclusion of fire over the past 80 years. Fire exclusion has also contributed to the invasion of grasslands by increasing quantities of shrubs and cactus. These problems are being addressed through the implementation of an ambitious management-ignited prescribed fire program. Park fire crews burned about 450 acres in 1997, including 80 acres in McKittrick Canyon. Two prescribed burns near El Centro Draw and Cherry Canyon have been carried out in 1998 as of April 22. Preparations are underway for burning brush piles in the Bowl.

TINKER, SCOTT W., Marathon Oil Company, Petroleum Technology Center, Littleton, Colorado

Shelf-to-basin sequence stratigraphy of a steep rimmed carbonate margin: Mckittrick Canyon, New Mexico and Texas

Shelf-to-basin outcrop studies in steep-rimmed, shelf-margin settings are uncommon because continuous shelf-to-basin transects are rarely exposed in a single outcrop. Discontinuous or absent stratigraphic marker beds across the shelf margin complicate outcrop studies in this setting. This poster discusses the results of a high-resolution sequence-stratigraphic interpretation of the shelf-to-basin profile along the north wall of North McKittrick Canyon, New Mexico and Texas. In McKittrick Canyon, carbonate-dominated sedimentary rocks associated with the steep-rimmed, Upper Permian Capitan depositional system are exposed along a continuous five-kilometer outcrop face. Measured sections, lateral transects, and geochemical data were synthesized into a digital database and interpreted in conjunction with a digital photomosaic of the canyon wall.

Results of this work include a shelf-to-basin sequence-stratigraphic interpretation with an associated dynamic facies model for Capitan deposition. Emphasis was placed on quantifying data regarding systematic changes in key depositional parameters (e.g., progradation, aggradation, offlap angle, outer-shelf dip, water depth, facies tract width, and distance between facies tracts), prediction of 2-D facies distributions and strata geometries from 1-D sections, and sites and rates of sediment production and accumulation on carbonate shelves.

The subtidal outer-shelf and shelf-margin facies tracts were sites of major sediment production. Accumulation rates across the shelf margin indicate a relatively continuous growth history, with rare periods of non-deposition or erosion limited to the terminal phase of each composite sequence. As a result, the preserved sedimentary record of high frequency and composite sequences in the outer-shelf to upper-slope position is equally proportioned between transgressive and highstand systems tracts. This symmetric outer-shelf to upper-slope record of carbonate accumulation is significantly different from the asymmetric, highstand-dominated middle-shelf accumulation record reported for this and many other carbonate shelves.

Although the massive Capitan reef facies marks the position of the actual shelf-slope break, the following data indicate that the paleotopographic profile was a marginal mound, with Capitan reef facies deposited downdip from the topographically-high shelf crest: (1) a shallow-to-deep facies progression from the shelf crest to the shelf margin; (2) proportional expansion of beds downdip from the shelf crest to the shelf margin; (3) systematic changes in progradation and aggradation, offlap angle, outer-shelf dip, distance to the shelf margin and toe-of-slope, and interpreted water depth (from 15 to 75 m) to the top of the reef; (4) abundance of the shallow reef indicator Mizzia in the upper Yates and Tansill composite sequences relative to the lower Yates and Seven Rivers composite sequence; (5) presence of transported fusulinid grainstones downdip from in situ fusulinid wackestones and packstones; and (6) a decrease in dolomite from the shelf crest to the shelf margin.

Although the paleotopographic profile was a marginal mound, the complete system should not be characterized with a single, static depositional model. The facies distributions, facies proportions, strata geometries, and quantified depositional parameters vary systematically within each high-frequency and composite sequence, and record an overall deepening of the shelf margin during maximum flooding stages and an overall shallowing of the shelf margin during highstand at both the high-frequency and composite-sequence scales. Throughout its history, the Capitan system evolved predictably from a deeper-water margin in the Seven Rivers, to a shallower-water margin in the upper Yates and Tansill, providing testimony to the dynamic nature of this elegant depositional system.

VEQUIST, GARY, National Park Service, Carlsbad Caverns National Park, Carlsbad, New Mexico

Preliminary investigation of bullfrog (*Rana catesbeiana*) at Rattlesnake Springs, Carlsbad Caverns National Park, New Mexico

Large numbers of introduced bullfrogs, a potential destructive non-native species, are present at Rattlesnake Springs. This species is known to be a voracious predator capable of contributing to the decline of other species. In 1997 James Krupa from the University of Kentucky's Center for Ecology, Evolution and Behavior began a study to assess the relative abundance of bullfrogs and their potential impacts. Night counts of adult frogs were conducted, finding a high ratio of adult bullfrogs to adult leopard frogs (*Rana berlandieri*). Amphibian inventory techniques, including trapping and breeding call surveys, did not detect any cricket frogs (*Acris crepitans*). This species may be locally extirpated due to bullfrog predation. Surveys of nearby springs will help to determine the population status of this once abundant species. During the study, bullfrogs were actively removed, photographed, measured, and dissected for sex identification, reproductive state, and stomach contents. It is likely that bullfrogs are reducing the density of native amphibian species; however, direct evidence is currently minimal. Amphibian monitoring and bullfrog removal will continue during 1998.

WOBBENHORST, JANICE A., and KATHY ELMORE, National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

A bibliographical database for Guadalupe Mountains National Park

Sound management decisions must be based on knowledge, research, and baseline information. Good databases and bibliographies are essential tools in taking advantage of the vast amounts of information available. The National Park Service has recognized the need for bibliographical databases as one of the 12 essential data sets needed by all parks.

Guadalupe Mountains National Park has been actively building a park bibliography for the past 25 years. The value of knowing what research has been done and having it available for park management, resource managers, interpreters, and other researchers cannot be overemphasized. Management decisions must be made on the basis of sound research and information. Thus, a bibliography of the park is critical. Bibliographies abound in numerous plans, but until recently a bibliographical database did not exist. Guadalupe Mountains has been actively developing a computerized database using PROCITE software. Two bibliographical databases are being created for the park: (1) NRBIB—a natural resources bibliography and (2) CRBIB—a cultural resources bibliography.

NRBIB. In 1994, investigators scoured the parks in the Southwest Region and the regional office to create an initial resource bibliography for parks in the Southwest. Guadalupe Mountains National Park was included in that project as two investigators, Marilyn Ostergren and Ronnie Hill, spent several months working on a computerized database for the park. They compiled various bibliographies and inventoried documents into one database. The bibliographies of Carlsbad Caverns and Guadalupe Mountains national parks were combined as there is much overlap. The result: over 3,000 entries are included in this combined database. And it is being added to daily.

CRBIB. Unfortunately, while we have many bibliographical lists on the cultural resources, a computerized database has not been done yet. Work is underway to create a cultural resource bibliographical database to complement the natural resource database.

In addition, the park has developed a computerized inventory of the park library reference collection. These databases are presented in this poster with the NRBIB database available on disk (for cost of the disk). Furthermore, researchers are given the opportunity to add to the bibliography and/or park library.

WOBBENHORST, JANICE A., National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Cultural landscapes at Guadalupe Mountains National Park, Texas

Four cultural landscapes associated with historic structures and two ethnographic cultural landscapes not associated with any one historic structure are presented.

Four cultural landscapes that are associated with historic structures have currently been identified at Guadalupe Mountains for management as cultural landscapes. The four historic structures: Frijole Ranch, Wallace Pratt Lodge, the Ship-on-the-Desert, and Williams Ranch, each contribute significantly to the history of the Guadalupe Mountains and the region. The associated buildings, features, scenery, vegetation, and other elements of the area surrounding each building contribute significantly to the integrity of these sites and to their identity. The historic character of each site is closely related to these identified landscapes.

In 1994 Peggy Froeschaur completed a cultural landscape report for the Frijole Ranch cultural landscape. This report provides management information regarding the historical land-use patterns surrounding the Frijole Ranch, a National Register property. From this report, the next step will be to develop a management action plan which will implement appropriate management strategies to protect and preserve this historic setting. The remaining three historic landscapes are presented; each has been identified as in need of cultural landscape reports before preservation treatments can be implemented.

Two cultural landscapes have been identified that are not associated with historic structures but are ethnographic landscapes. These two landscapes are identified by the use, occupancy, and associated features that are remnants of a past land use. They are: Mescalero Apache cultural landscape (or the Mescalero Apache occupancy) and the historic ranching cultural landscape. Each is represented by a scattered assemblage of cultural features found throughout the park.

WOBBENHORST, JANICE A., National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Mudwagons and the Butterfield Trail

For 11 months, from September 1858 until August 1859, the Butterfield overland mail traveled through Guadalupe Pass in the Guadalupe Mountains. The Pinery stage station, located at Pine Springs, Texas, was a meal and mule stop for the Celerity wagons that carried mail and passengers between Saint Louis and San Francisco. A map is presented showing the route of the overland mail through the pass.

Through a generous donation to another park, Guadalupe Mountains National Park has been able to obtain a mudwagon similar to the ones used by the Butterfield overland mail as they went through Guadalupe Pass. It is currently being stored in a donated warehouse facility in Dell City and was moved specially for display at the symposium. The mudwagon is in excellent condition but does need some restoration and preservation work to preserve and maintain it. The park plans to restore this mudwagon and then hopes to place it on display at Pine Springs, near the old Pinery station. This will necessitate building a structure to house the mudwagon before it can be placed on display. The National Park Service is seeking funding through alternative sources such as grants and donations, to enable this to happen.

WOBBENHORST, JANICE A., National Park Service, Guadalupe Mountains National Park, Salt Flat, Texas

Overview of the fire management program, Guadalupe Mountains National Park, Texas

Natural fire is one of the most important environmental factors that influence natural ecosystems in Guadalupe Mountains National Park. Fire must be reintroduced to restore and maintain these ecosystems.

The fire management plan addresses the management of fire as an ecosystem process in the park and is oriented towards allowing natural fire to operate as fully as possible within ecosystem dynamics, while protecting public safety and minimizing the impacts of wildfire on natural and cultural resources. These goals are attained through the use of fire suppression, management of wildfires using the appropriate management response including the use of natural fire by allowing natural ignitions to burn within prescriptions, and the use of prescribed fire. Research and monitoring provide the foundation for application and future refinement of this program.

Factors such as fire effects and fire effects research, fire history, vegetation, fuel types and conditions, fuel loading, weather, climate, etc. are all elements considered in developing the comprehensive fire management program for the park and were included in the fire management plan that directs this program. These components of the fire management plan and how they are used to direct the fire management program are presented.

Forums

Chapter 52

Forums—Biological Resources

moderated by FRED ARMSTRONG

The purpose of the biological resources forum was to generate ideas for current and future biological resource management. A panel of subject matter experts was selected to address questions or generate discussion points. The following bullets are not categorized, but are in the order of the flow of discussion. Some of the items on the list were already being performed at the park or could not be implemented due to law or policy. Those items were posted to the list to not disturb the brainstorming process.

- Complete park biological inventories and follow through with a monitoring program in order to create snapshots in time
- Develop a way for existing park researchers to communicate with each other so they are aware of contemporaneous projects
- Email copies of research results out to all active researchers
- Post a list of active research on the park Web site. This may generate research ideas and connections.
- Require research debriefing meetings with park managers at the end of projects
- Generate an electronic bibliography of research actions. (The National Park Service natural resource bibliography is being reviewed to make non-sensitive material available.)
- Maintain the park research library, including bound copies of all dissertation work
- Develop a comprehensive map of where all past study plots existed. This would reveal heavily studied and under studied areas of the park.
- Imbed photos into an electronic version of this research map to show changes over time. This would require locating photos from past research work.
- Convert paper research data into GIS themes. This would be a potential GIS intern project.
- Geo-reference all known museum specimens and the associated project metadata into the park GIS. This would produce a measure of accuracy for determining future project needs.
- Require researchers to provide specimen locations in UTMs or at a minimum provide a specific collection point on a map
- Recommend that every research site and specimen be photographed and UTM collected
- Post all papers and poster session displays from this symposium on the park Web site to increase exposure of the public to science in the National Park Service
- Distill scientific research information into materials for all audiences: students, casual visitors, Web pages, etc.
- Bioinfomatics is an up and coming field. We should systematically post all our known biological resource information on the Internet.
- Develop virtual tours of restricted areas for visitors to view
- Develop virtual tours to other park communities of interest
- Use university students to develop these projects
- Generate links on the park Web page to associated Web sites of similar interest and for in-depth information
- The park needs to do a better job of making research needs known to the research community
- Researchers need to know what the current park management questions are so they can develop useful proposals and projects
- The park should maintain a prioritized list of research needs
- The park and research community need to recycle research project data into as many useful products as possible: the original project report,

brochures, Web pages, student curricula at all levels, etc.
- Look for people who are passionate about their work to develop cost-share agreements
- Seek subject matter experts to review and aid in the development of resource management project proposals
- Maintain a current priority of resource management projects. There will always be more projects than money.
- Develop an interdisciplinary team of people internal and external to the park to identify the top 10 issues and strategies to meet them. Review this list and progress annually.
- Include the public in the process of developing resource management projects
- Use the Web as an electronic think tank
- Obtain input from all park divisions in the development of resource management projects for improved resource protection
- Build a GIS and make it available to all park managers so they have ready access to seeing sensitive resource areas
- Produce a 1–2 page research project review form that can be sent electronically to willing specialists to review and comment on potential projects. No one has time to evaluate 30 page proposals these days.
- Perform a topic by topic review of entries in the park natural resource bibliography to identify voids in research fields or park habitats
- Correlate the park natural resource bibliography data to a park map to identify under studied areas and temporal gaps

Chapter 53

Forums—Cultural Resources

moderated by LARRY HENDERSON

The purpose of the cultural resources forum was to generate ideas for current and future cultural resource management. A panel of subject matter experts was selected to address questions or generate discussion points. The following bullets are not categorized, but are in the order of the flow of discussion. Some of the items on the list were already being performed at the park or could not be implemented due to law or policy. Those items were posted to the list to not disturb the brainstorming process.

- Produce a list of needed cultural resource projects
- Develop a bibliography of park-related cultural resource materials
- The park should seek cultural resource grant money
- Establish a "friends" (501c. 3) group
- Seek out partnerships with universities where students could accomplish cultural resource projects and receive college credit. Students receive training and the park accomplishes projects. Sample projects could include:
  1. Field verification of previously mapped archaeological sites
  2. Re-surveying archaeological sites with modern equipment
  3. Update archaeological site forms
- Develop a cultural resource advisory group
- The park holds a great potential for additional archaeology, early military, and ethnography work to be done and interpreted
- Cultural resource exhibits should be included in the main visitor center
- Interpret the Butterfield Trail trace through Guadalupe Canyon
- Nominate the Butterfield Trail for inclusion in the National Park Service National Historic Trails program
- Develop relationships with other ethnographic groups beyond the Mescalero
- Complete a written history of the park
- Provide interpretation of the Basketmaker Culture
- Encourage interdisciplinary research projects to cover natural and cultural resources
- Development and execution of cultural resource projects should be performed by an interdisciplinary team to include archaeologists, botanists, wildlife specialists, ethnographers and others
- Submit joint park cultural resource proposals for Guadalupe Mountains and Carlsbad Caverns to make stronger issues for understanding and preserving these regional resources
- Seek a joint park (Guadalupe Mountains and Carlsbad Caverns) archaeological inventory
- Develop a Web page to post needed cultural resource work. Include instructions to recruit capable volunteers.
- Use cost-share agreements and use trained local people on projects
- Establish a human resource list of local people who could write grants and perform specialized cultural resource tasks
- Develop an interactive Web page to recruit skilled help for cultural resource work
- Pursue private sector fund-raising for park cultural resources, e.g., Pratt Lodge, Williams Ranch, Frijole Ranch, etc.
- Pursue the connection between Wallace Pratt–Humble Oil–Exxon–Pratt structures

- Pursue large corporate images and national park connections, e.g., American Express and vacationing in national parks, petroleum companies and protection of the Permian reef, etc.
- Seek grant money that has in-kind matches
- This park has come a long way. Twenty years ago no one would have entertained the thought of holding a cultural resources forum in a "natural" park

Chapter 54

Forums—Geological Resources

moderated by JANICE WOBBENHORST

The purpose of the geology resource forum was to generate ideas for current and future geological resource management. A panel of subject matter experts was selected to address questions or generate discussion points. The following bullets are not categorized, but are in the order of the flow of discussion. Some of the items on the list were already being performed at the park or could not be implemented due to law or policy. Those items were posted to the list under the brainstorming process.

- Geologists must educate the lay public to the significance of geologic resources
- Field trips to the park should permit students to collect working specimens
- There would be no exhausting the sample collection of canyon bottom gravels
- Create virtual field trips to special geologic outcrops
- Educate interpretive staff in geology and geologists in interpretive methods
- The park should address the concern that every field trip wants to collect reference samples
- Develop a complete reference and study collection at the park
- Take advantage of geology interns to help train interpretive staff
- The park geology site bulletins missed the mark in developing guides for the lay person
- Develop layman's guide to park geology, trail by trail
- Develop a layman's guide to Stratotype Canyon
- For the best product, the guides should be developed by a group of geologists
- Develop a photographic slide series for purchase on park geology
- Establish a set of liaisons to aid in critical geology issues
- Develop a geologist staff position
- Develop geology tours to visit type sections
- Develop and present a video on geology for the visitor center and for purchase
- Develop a teacher's manual on park geology for primary schools
- Hire an earth science teacher in a summer intern project to develop geology curriculum
- Develop a park Web site with geology study units
- Incorporate geology into the park junior ranger program
- Adapt existing field guide material, available from several universities, into primary and secondary school materials
- Experts deserve compensation for developing these materials
- The Geological Society of America (GSA) has Partners in Education Program (PEP) which is an email register of geology educators willing to help with projects
- There are programs in Midland, Texas, that would be interested in funding geology education in the Guadalupe Mountains
- Partnerships between the GSA and the National Science Foundation have funded geology education projects
- The park should maintain records of university field trip groups to develop partnerships
- Allow the general public to tag along on college field trips
- Develop a secondary education pre-field trip planning packet for teachers
- Develop a geology page on the park Web site
- Park staff should attend petroleum company field trips
- Geology researchers should give programs to park staff
- Petroleum companies should give park staff training

- Develop an accurate geology base map. The P.B. King map doesn't match when projected onto topographic maps.
- Guadalupe Mountains National Park is probably within the top 10 national parks preserving geologic resources. The park should have top rate geology products for staff and visitor use.
- If the park fills a potential geology position, fill it with an educator
- The park should network with oil research centers