Seismological Monitoring of the World's First Nuclear Detonation—The Trinity Shot of 16 July 1945[1]

Seismology played a modest role in the Trinity test, thereby establishing, at the very birth of the "atomic age," a mutual interaction between seismology and nuclear testing that would become of increasing significance to both technologies as the century progressed. Because the Trinity "gadget" was designed to be an atmospherically detonated military weapon for which principal damage effects were expected to be air blast and accompanying ground shock of intensities heretofore unexplored, extensive new effects data were needed to plan military applications. When the need for a full-scale test of the implosion design became clear by late 1944, Los Alamos scientists began to devise field experiments to measure both air blast and ground shock. Also, they wanted to estimate how each would scale with explosive energy release (yield), range, and height of burst within a principal target area (nominally, within about 20 km of ground zero).

In March 1945, Herbert M. Houghton, an exploration geophysicist with Geophysical Research Corporation (GRC) and Tidewater Oil, was recruited to work with Los Alamos physicist, James Coon, to perfect earth shock instrumentation for the 100-ton TNT calibration rehearsal shot of 7 May 1945, as well as the unique multikiloton Trinity nuclear event planned for July. Houghton and Coon modified a dozen GRC Type SG-3 geophones to record both vertical and horizontal-radial components of strong ground motion at ranges between 0.75 and 8.2 km from both the calibration and nuclear shots, which were air bursts suspended on towers. Measurements on both shots revealed that Rayleigh waves were the largest ground motion components, but were of secondary interest for immediate combat applications because the air blast damage considerably exceeded those from ground-shock at all ranges.

During final preparations for the nuclear shot, however, potential seismological problems at distances beyond the immediate Trinity test area became high priority considerations for test leaders. Of great concern was possible damage to surrounding

[1] Appendix author is Dr. Kenneth H. Olsen, GCS International, 1029 187th Place, SW, Lynwood, Washington. Born in northern Utah, Dr. Olsen, after graduating with high honors from Idaho State College (BS physics, 1952), earned MS and Ph.D. degrees in physics/astronomy from the California Institute of Technology. Upon joining the Los Alamos Scientific Laboratory in 1957, he specialized in the modeling of nuclear explosion phenomenology, plus being a contributing editor to the book, *Continental Rifts: Evolution, Structure and Tectonics* (Elsevier Science Publishers, 1995).

civilian areas by freak air blast and ground shock effects or perhaps even by "triggered earthquake." One important question was the effect of ground vibrations on Elephant Butte Dam, 88 km southwest of Trinity ground-zero. Although Los Alamos scientists were confident that probabilities for distant damage were extremely small, it was thought prudent for public safety as well as legal purposes to obtain opinions from the best available outside experts in these fields. At an 18 April 1945 conference between General Leslie Groves and Los Alamos senior staff, L. Don Leet, a Harvard seismologist then doing war work at Harvard's Underwater Sound Laboratory, was chosen as consultant for off-site blast vibration problems.[2,3] Leet was requested to examine the possibility of property damage particularly for several small communities within 100 km of the Trinity site for "shots of 100 tons, 5000 tons and 50 000 tons with their centers of gravity 100 feet above the ground."

With little more than two months to prepare, Leet immediately traveled west arriving about the time of the 7 May 100-ton TNT calibration shot. He toured the Trinity test region, examined topographic and geological maps and cross-sections, and analyzed blast data from the 100-ton test, including Houghton's and Coon's close-in geophone stations as well as seismograms confidentially obtained from Coast and Geodetic Survey instruments at Tucson (a Benioff at 440 km) and El Paso (a Wood-Anderston at 200 km). In his 24 June report to Oppenheimer, Leet confirmed that the range of all 100-ton shot measurements "in no case exceeds those at corresponding distances from 5-tons of standard high explosives buried as in commercial quarrying operations." Applying this "upper-bound" 5% conversion factor to the 5 and 50 kiloton cases and factoring in his extensive experience with ground displacement data from quarry shots approaching 100 tons, Leet predicted that the radius of potential property damage from ground vibrations would not exceed 5000 yards. Leet warned, however, of potential public perception problems due to the airborne shock waves, noting that ordinary observers, especially when in buildings, are often unable to distinguish between the two. In order to document such effects for legal and safety purposes, he recommended that three-component, strong-motion, displacement seismographs be located at several communities surrounding the July nuclear test, and that these instruments be placed inside buildings to show the relationship between ground and air waves.

For the 16 July test, Leet's team operated four three-component portable strong-motion seismographs of his own recent design in four small central New Mexico towns at distances of 45, 55, 80, and 88 km. A fifth unit was operated near the manned bunker at "9000N," which was the northernmost of three main instrument sites at 9000-yard (~8 km) ranges where a full suite of device diagnostic and explosion effects measurements were carried out by Los Alamos scientists. The 9000N seismograph thus bridged the near-source blast and earth shock data, chiefly of military interest, to

[2] Throughout the Manhattan Project, one of Groves's chief concerns was to preserve the extremely tight security regarding the ultimate objective of the far-flung enterprise, a bomb of unprecedented energy. A prime security stratagem was to avoid undue publicity that would result from public lawsuits involving possible damage or safety issues involving nearby civilian facilities.

[3] Before the war, Leet had established himself as a leading expert in measuring quarry blast vibrations with portable seismic instrumentation, particularly in the active quarry mining area of the Northeastern U.S.

ranges pertinent to off-site safety and legal considerations. Even at the closest community (San Antonio, New Mexico), Leet's instruments confirmed that motions due to either earth-borne or air-borne waves were smaller by about a factor of 100 than those necessary to produce even minor damage such as plaster cracks (Leet, 1960).[4]

It is historically significant that Trinity inaugurated the tradition of carefully assessing and documenting the chiefly geophysical, distant-range, public safety and legal issues for all future U.S. nuclear testing programs. Second only to fallout considerations, air blast and acoustic wave propagation effects were important public safety concerns of U.S. atmospheric testing programs throughout the 1950s. But with the nearly total shift to underground testing in the early 1960s, seismological and strong ground-motion effects assumed primary significance, both for off-site safety requirements and for political application to monitoring arms control treaties.

When Leet examined the triaxial seismic record from 9000N in greater detail shortly after the war, he found it contained considerable new information of fundamental seismological interest. In a declassified paper, Leet (1946) opined this seismogram was "one of the most important records in the history of observational seismology," because it revealed for the first time a "new" type of seismic surface wave not predicted by theory. This new wave—which produced the greatest amplitudes on the 9000N record—he dubbed the "hydrodynamic (H) wave" because it was characterized by prograde surface particle motions analogous to those of water waves (in the opposite sense to the retrograde motion of the classical Rayleigh wave). The 9000N seismograms also confirmed the presence of another complex surface wave (C-wave) that Leet had described before the war from quarry blast recordings. Leet's claim for such "unusual" seismic phases, heretofore unknown to the theorists or unobserved on earthquake seismograms obtained at sparsely distributed distant observatories, was greeted with caution and sometimes by skepticism by many seismologists for a number of years. From time to time there was speculation that there might be types of seismic phases unique to explosions. To help clarify the issue, Beno Gutenberg suggested that his graduate student, Benjamin F. Howell, Jr., investigate the subject of seismic waves from explosions for his Caltech Ph.D. thesis.[5] Howell modified the electromagnetic geophysical prospecting seismometers for three-component operation to record waves at 14 locations along a 3-km-long profile produced by shallowly buried, 5-pound TNT charges at a common shotpoint. Howell's triaxial records displayed the detailed evolution of ground motion with distance, confirming the prominent C and H phases as described by Leet, in addition to the previously known Rayleigh and body-wave phases (Howell, 1949).

Leet's and Howell's identification of highly complex surface waves generated by "point-like" explosion sources—heretofore considered rather simple cases for mathematical analysis—emphasized that no completely satisfactory theory then existed for

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[4] The four off-site seismographs were placed in buildings at San Antonio, Carrizozo, Tularosa, and Elephant Butte damsite. Records from Carrizozo, Tularosa, and Elephant Butte failed to register peak ground displacements greater than 0.01 mm, the recording threshold of Leet's low-magnification (× 25), strong-motion instruments.

[5] Ben Howell would go on to a distinguished academic career at Pennsylvania State University as professor, head of the Geophysics Department and dean of the Graduate School.

explaining many types of seismic waves. This state of affairs was not unusual in prewar earthquake seismology; observational proofs of many characteristics of even the classic compressional (*P*), shear (*S*), and Rayleigh waves were still rather qualitative. The early explosion studies such as those by Leet and by Howell pointed up the usefulness of explosion data to assist theoretical development of "inversion" techniques that also could be applied to the more complex but seldom directly observable mechanisms of earthquakes. The practice of mathematically relating details of the pattern of recorded seismic waves to characteristics of the ground motions that generated the waves—a technique known as "seismic source characterization"—has become one of the most powerful tools of modern seismology.[6] Although seismic measurements of Trinity were only a minor part of a larger experiment, they helped stimulate postwar research in both theory and observation using "predictable" high-energy sources that eventually matured to an entirely new scientific discipline, "nuclear explosion seismology," which today is one of the most active fields of seismological science.

[6] Because "H-waves" and "C-waves" were not readily apparent on earthquake seismograms, their nature continued to be debated for a number of years. Over the years occasional theoretical papers have appeared suggesting various ingenious modifications of the elastodynamic equations to explain them. However, today theorists believe that at least the H-waves, first clearly observed at Trinity, consist of higher-mode surface waves produced principally by explosions above, or shallowly buried in low-velocity, unconsolidated, near-surface material.

International Association of Geophysical Contractors†—Membership List October 2000

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Vignettes on the Teaching of Geophysics

There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success than to take the lead in the introduction of a new age.

Niccole Machiavelli (1469–1527)

Comments on the Early Years of the Lamont Geological Observatory—Professor Maurice Ewing[1]

Our program of work at sea started in 1935, when the late Dr. Bowie of the Coast and Geodetic Survey and Professor Richard Field of Princeton came and pointed out to me the importance of making some measurements of the depth to basement rocks off the east coast of the United States. I was then an instructor in physics at Lehigh University and had practically no knowledge of geology.… These men [indicated that there was] the possibility of getting a grant of $2000 from the Geological Society of America to support the field work of this project. The grant was obtained, and we made our first tests on the ship *Oceanographer* of the U.S. Coast and Geodetic Survey. Captain Nicholas H. Heck of the Coast Survey was a keen supporter of this project, and actually made one of the early trips with us. After these first tests, we did further work on the ship *Atlantis* of the Woods Hole Oceanographic Institution in the autumn of the same year. We were able to trace the basement rock from the outcrop near Petersburg, Virginia almost to the edge of the continental shelf.

After this, Professor Field and Dr. Bowie urged us to undertake work in the deep ocean basin. At this time the group consisted of myself and one or two graduate students, and our ship facilities consisted of two weeks each year as guests of the Woods Hole Oceanographic Institute aboard the *Atlantis*. It requires much development of

[1] Extract from an unpublished report, "A Short History of Lamont Geological Observatory," dictated on 19 April 1955 by Professor Ewing and submitted to Mr. Richard Stevens, Resident Representative for the Office of Naval Research. The commentary has been edited to some degree by rearranging the location of several paragraphs to provide improved continuity. The document provides an interesting overview of what a great marine geophysicist thought was particularly important some four decades ago—actions, of course, which, in 1978, led to the SEG's top honorary award being named in his honor and, somewhat coincidentally, awarded that same year to Cecil H. Green, whose vignette follows in Appendix D.

new techniques to get good measurements of the sediment thickness in the deep ocean basins. I was able to devote full time to it for two years by virtue of a grant from the John Simmon Guggenheim Foundation, which enabled me to take leave of absence from Lehigh University. I have always felt that this grant marked the real turning point in my career.… At about this time we also initiated work in photography of the ocean bottom. On a small grant of funds from the National Geographic Society, we built a few cameras that were very successful, and to this day almost all of the photographs of the ocean bottom in depths greater than a few tens of fathoms have been taken by us or with our cameras.

An incident which occurred in the early days of this work is a good illustration of the difficulty we have had in raising the funds necessary to keep the program going. After the first work in 1935 I realized that I had found the kind of work which I would like to do the rest of my life, so I organized a prospectus with a view to submitting it to a number of people in the oil business and getting a small annual grant from each of several companies to support a modest program of research. This proposal received no support whatever, and I was told that work out in the ocean could not possibly be of interest to the shareholder and could not rightfully receive one nickel of the shareholders' money. This was the year 1935 and these were the tidelands that have since become so important in the petroleum business. I can safely say that no project to explore any part of the earth can possibly look more remote from commercial application today than the investigation of the tidelands looked to these leaders in the petroleum industry in 1935.

Just before the outbreak of World War II, the National Defense Research Committee was formed to promote research on projects important for national defense. I took leave of absence from Lehigh and went to Woods Hole to work on one of these contracts. Two of my Lehigh students, A. C. Vine and J. L. Worzel, went with me, and this formed the nucleus of the present team. Our wartime work consisted in the application of underwater sound and photography to problems of submarine warfare. We started out on an anti-submarine project but inevitably were led into some developments that were useful for pro-submarine applications. Toward the end of the war we developed a long-range system of underwater sound signaling for which the Navy made the name SOFAR. It had important possibilities for air-sea rescue purposes, but has always got bogged down in bureaucracy to the extent that no appreciable use has ever been made of it. We were quite fortunate professionally in our wartime experiences in that they involved the use of equipment and methods that were very close to the line of work we had followed before the war and after it.[2]

Toward the end of the war I was offered a chair at Columbia University to initiate instruction and research in geophysics. It turned out that a number of my colleagues there were disappointed when it developed that the bulk of my effort would be devoted to investigations of the oceans. They had rather hoped for a program of work that would apply more directly to the mining industry. But the program has flourished well

[2] Unbeknownst to Ewing, at the time of this writing, the Navy had a major secret operation (CAESAR) underway that would soon utilize his deep sea "sound channel" for monitoring screw noises of maritime shipping, including those of Soviet submarines, via the Sound Surveillance System (SOSUS).

enough that there has certainly been no opposition to it within the University, and it now receives strong encouragement from the administration and from our Department of Geology. This encouragement does not include any assistance with the financial problems. The University was operating in the red at the time we started our program, and had insisted from the start that it could not assume any additional financial responsibilities.

The move to Columbia marked the beginning of a marvelous growth in our program. Mr. Worzel had come to Columbia as a graduate student at the end of the war, and continued to serve as the nucleus of the team while obtaining his Ph.D. degree.… The team has been very largely built up of our own graduate students and, as a result, is remarkably coherent and cooperative. We succeeded in measuring the thickness of sediment in the ocean basin at a number of places and found it to be only about 2000 feet. Unexpectedly we were able to measure the thickness of the basaltic layer beneath the sediment and show that it was only about two miles in thickness. This constitutes the entire crust of the earth under the ocean basin, and the contrast between this thin crust and the crust twenty miles thick or so which underlies the continents, amounts to proof of the permanence of the ocean basins. The transition zone between continent and ocean is the difficult part to investigate, and we are now working on that by several different methods and believe that by understanding it we will understand the mechanism by which continents have grown from nothing, or from small nuclei to their present size.[3]

The demonstration that the total accumulation of sediment in the ocean basins is only about 2000 feet and that this sediment is unconsolidated sets up a very challenging project which promises results of the greatest importance in almost every field of science. This is the project for penetrating the 2000 feet of sediment beneath the three miles of water and sampling it from the ocean floor to the underlying basaltic rock. This should contain a very complete record of the evolution of life with very conspicuous changes in sediment character corresponding to the first development of animals which could concentrate calcium carbonate shells, the first development of plants which would produce free oxygen in the atmosphere, and give clues about the most primitive forms of life through their chemical and biochemical activity. Beneath this, at the very bottom of this sediment, should be clear evidence of the kind of earth we had at the time when water first began to accumulate in the oceans. To date, this question has been the subject of much high-level mathematical study. Very divergent conclusions have been reached, and the consequences of definite information about this point would affect fields as far apart as astronomy and biology.

The project is entirely feasible. To date we have developed a sampling apparatus which penetrates as much as 60 feet into these unconsolidated sediments and has brought together the greatest collection of submarine sediment samples in the world—a total of about 1500 long cores of sediment from the deep sea. The research team which we have got together now includes slightly over a hundred people. A

[3] Although Ewing was a major holdout in subscribing to the Hess-Dietz concept postulated in 1961–62 that continents were permanent lithospheric blocks and oceans temporary features, by 1968 many of his proteges, including J.R. Heirtzler, B. Isacks, J. Oliver, X. Le Pichon, and L. R. Sykes had presented seminal papers proving the existence of what is today called, "plate techtonics."

number of these are part-time students, and a number of them are clerical, technical, and mechanical technicians, but it requires a large team like this to undertake the large problems of the character of that just mentioned.

Our work in measurements of gravity at sea has gone on primarily under the leadership of Dr. Worzel, and if we get continued support in this line, we hope to have, within the next decade, enough of these measurements to permit a new determination of the figure of the earth, in addition to definitive information about many important geological features such as the edges of continents and the volcanic island arcs.

The next big turning point in our affairs came in 1949, when the Lamont Geological Observatory was founded through a gift of property by the late Mrs. Thomas W. Lamont. At that time we were provided with an operating fund of $400 000 which was to constitute our assured support for the first six-year period. We have just completed that six years, and have produced a very gratifying series of scientific reports on work accomplished during the time.

At about the time the Observatory was established, we felt it necessary to begin the study of earthquake seismology, and since then have built up what we consider to be the best seismological observatory in the world. We have concentrated on study of the propagation of surface waves along continental paths, and the contrast between these and the waves which have traveled over oceanic paths. From this study we have been able to demonstrate conclusively that the results about the oceanic crust found in the relatively small area which we could investigate by actual voyages are typical of the oceans of the world. Our work in seismology has received wide recognition. It started primarily as a project between Frank Press, then a graduate student, and myself, but like the other things, it has grown.

A considerable group of our people is now working in what we call model seismology. Laboratory-size scale models of various geological formations and ultimately of the whole earth are put together, and the propagation of vibrations through these is used as a guide to what happens in earthquake- and explosion-generated waves.

We are finding wonderful results in our study of the sediment cores from the deep sea. There is a clear record here of the end of the last glaciation, and a demonstration that it was an abrupt event, as far as the oceans were concerned. The opinion formed by all of those who have studied evidences of glaciation on land was that it was a transitional event, probably still in progress. The discovery that it was abrupt, as far as the ocean is concerned, will certainly prove a most valuable clue to the eventual discovery of the reason for these glaciations. At present we have only speculation, much of it of the wildest possible type, about the cause of those enormous changes in climate.

We have added a group under the leadership of Professor J. L. Kulp which works on the general problems of geochemistry. In addition to a considerable program of measuring the ages of rocks from various radioactive analyses, this group is, in my opinion, the leading one in the world for definitive studies on the changes in the level of radioactivity due to experiments in fission carried out throughout the world, and I am certain that the leadership of this group will be well recognized when the expected change in classification of information makes it possible for them to publish their results.

We have been studying changes in the earth's magnetic field over the oceans by towing behind our research vessel a magnetometer which measures the total strength of the earth's magnetic field. This is an adaptation of the airborne magnetometer which has been of importance in exploration for minerals in the past few years. It is my belief that we will produce truly revolutionary results from these studies within the next two years. We [also] have a fine program of work in submarine topography which has led to the discovery of abyssal plains and an explanation of their origin. The North Atlantic has been divided into new physiographic provinces, ordinary submarine canyons shown to extend to depths greater than two miles, and a new type of mid-ocean canyon discovered on it.

Under a grant recently awarded by the Rockefeller Foundation, we are about to undertake a study of the productivity of food materials in the ocean. Dr. Gifford Pinchot, now at Yale University, plans to come here and head up this work. We believe this program of work will expand and will constitute a positive action in response to the prolonged outcry about the necessity for developing additional sources of food if the population of the earth is to continue its growth. In addition, the study of the distribution of small organisms in the present-day ocean will be of great advantage to us in interpreting the climatic changes of the past as recorded in the fossil remains of these organisms.…

I believe that we have built up here a unique team of scientists, unique in the diversity of techniques which it can bring to bear on problems and in the fundamental importance of the problems in which the group is interested. It can truly be said that practically every project in this laboratory—certainly every major project—has a direct and important bearing on all others, and that there is the fullest cooperation between people working on the various projects. In fact, there is much overlapping and interlocking of personnel, so that the group can work almost as efficiently as a single individual could do.…

I believe that this integrated group of scientists, this group of facilities which includes the ship, the chemical laboratory, the collection of sediment cores, and the great seismograph station constitute a facility comparable with the greatest cyclotron or the greatest telescope, and it is unique. It is as though there was just one cyclotron in the world and we had control of it, or just one big telescope in the world and we had control of it. It is true that there are other groups in the general field, but none has a comparable integration of personnel and techniques, or such concentration on the major problems.

Learning Geophysics from Professor George P. Woollard—Ned A. Ostenso[4]

George Woollard was a refreshingly irreverent person. His vast reservoir of sanctity for the human spirit and human feelings did not spill over to human foibles and institutions.[5] I first met George quite by accident in the winter of 1952, and our association has been a vignette of hundreds of others who share the rare opportunity to be associated with him. It all began with my need for a final elective three-credit course with-

[4] Remarks of Dr. Ostenso, Director, Sea Grant Program Office, National Oceanic and Atmospheric Administration, at a Memorial Service for Professor Woollard on 19 April 1979.

[5] He and his wife, Eleanore, having four natural children, adopting five others, and supporting 18 foster children, indicate Woollard's special compassion for children.

in the Department of Geology to meet the minimum requirements (which were my maximum requirements) for a baccalaureate degree in what I fondly hoped to be my terminal semester of college. A necessary requirement for my selection was that the course not start at 7:45 a.m. The selection was rather limited because geology professors tend to be early starters, and I had taken all the easy courses. Seemingly, the least distasteful choice was a relatively new course called "Geophysics," taught by a guy called George Woollard. Although his personal class attendance can be most charitably described as spotty, he completely transformed my views of science, the earth, and myself. Rather than a dry compilation of facts, textbooks became frameworks for structured questioning. The printed word did not square with what he and Brackett Hersey observed a couple of years ago off the Carolina Coast. If Statements "A" and "B" are both true, then how can we possibly have "C"? For example, the Charleston, North Carolina earthquake, which was one of the greatest ever recorded in North America, occurred thousands of miles from areas of normal earthquake activity. Why? "We've just got a proposal funded, Bill Bonini and some of the boys are going to try to find the answer, and we're looking for help." Parenthetically, I might add that some months later, while sitting in a Columbia, South Carolina jail, Bill, Don Plouff, Jack Mack, and I had time to discuss the pluses and minuses of providing George with "help"!

The sepia-and-celluloid-collared scientists that stared bloodlessly from the textbook pages were replaced by the exploits of the Ewing Brothers, Dick Geyer, Teddy Bullard, Bert Crary, and Walter Munk—to mention but a few of the happy and hapless adventurers who filled our lives through George Woollard's special style of "nonteaching." We were encouraged to wonder about all the wondrous things for which we had never given a single thought. Why are there continents and ocean basins? Why have all continents been seas at various times in their history, whereas there is no evidence that an ocean has ever been dry land? Why does the Earth have an internal magnetic field and why does this field exhibit certain dynamic properties? What is the internal constitution of the Earth? Why earthquakes? And so on. We were given all the scanty and conflicting evidence and challenged to evaluate it, to propose experiments to test it, and most exciting of all, tantalized by the prospects of participating in the grand adventure.

Half-way through the semester, I was committed to go on to graduate school and approached George on the subject. Let me be explicit here in stating that at this point in time my academic credentials were less than stellar. My first semester as a freshman at Eau Claire State Teachers College was spent marking time awaiting my appointment to Annapolis. My social life was straight A's! My second semester was spent brooding over having failed the Academy physical examination and trying to punish my parents for making me stay in college when I wanted to join the Marines. That semester I even flunked social life. The following summer I continued my higher education working in the local canning factory. The hours were long and the pay 75¢ per hour. The niceties of time-and-a-half for overtime and double-time for Sundays and holidays had not yet been invented. The work was wet and miserable for us all—except for the guys who walked around with clipboards. They weren't wet and haggard. They looked pretty well fed, rested, and seemed to be actually enjoying themselves.

Right then, I decided that the clipboard job was the job for me—enough of stuffing lids into canning machines—and I fancied that a college degree was the surest and shortest way to a clipboard job. It was with nothing more than a clipboard in mind that I set my academic sights as I moved on to the Madison campus and began in earnest the delicate balancing act of selecting the easiest courses that did not start too early in the morning. The ensemble of this highly selective process led me *de facto* towards a degree in geology and the aforementioned encounter with George Woollard. My singular lack of collegiate performance to date did not bother George one whit. I was willing, I had the blush of new-found youthful enthusiasm, and he figured I would work cheap. That was good enough for George, and the niceties of getting me admitted to graduate school and accepted by the Department were, like sex and religion, something gentlemen didn't discuss.

Through some mysterious combination of his awesome gall and guile, George got me into graduate school, and I found myself crammed into his outer office in the basement of Science Hall. My first encounter was a mothy vintage bearskin suspended from the ceiling and the greater part of two-thirds of a dried-out rattlesnake. These proved to be the most benign denizens of that room now so hallowed in many of our memories. There were also Bob Meyer, John Rose, Bill Black, Rodger Chapman, Bill Heinze, Phoebe Pierce, Ed Thiel, and John Behrendt, to name but a few. This rich zoological mix had certain experiences in common which was a strong uniting force: none of us ever took a course from George that we didn't end up teaching ourselves; we all wondered where George was; we all became infected with George's working habit which was to keep going 'till you dropped—and then start over again when you came to; and most importantly, the exhilarating sense that we were inventing as we were learning.

My first "official" act as a new graduate student was to enter George's inner office where I was astonished to see him dancing about the floor strewn with bits of paper. This ritual, I was informed, had nothing to do with geophysics but rather a ceremony in honor of the University's business office. It was called "aging" receipts. Of all the things that have and could be said of George Woollard, he has never been accused of being organized. The orderly collection and retention of receipts from his multitudinous travels represented management acumen to which he never aspired. His system of doing travel accounts had, like the common pyre, the elegance of ultimate simplicity. He knew how much he left with and he knew how much he came back with—the difference is what he spent. To satisfy the less elegantly minded accountants, at the end of each trip he would pass out a motley array of scraps of paper to his students who had to produce two receipts each—one with the right hand and one with the left hand. We were graded on our originality! These receipts were then aged under foot.

In addition to serving as George's sanctum sanctorum, we found his inner office a convenient place to store dynamite left over from or in anticipation of seismic experiments. The only bowing I have seen George do to higher authority was when he started stashing the explosives under his desk and some of the more nervous of the custodial force complained to buildings and grounds management. Looking back now, those were primitive days without the headlines of the new global tectonics, earthquake prediction, satellites, upper-mantle projects, and so forth. Nevertheless, they were truly exciting days—I think mainly for three reasons.

First, there was a sense of self-sufficiency. What we had was pretty much what we made. There were no Academy committees or international consortia to generate research ideas. There were few companies to supply the instruments we needed even if we could afford "store-bought" stuff. There was no support staff of technicians and data processors. And there were few research grants. The grant that supported my Master's thesis research was the generous loan of George's personal gasoline credit card—I suspect [his wife] Eleanore actually paid for it.

Secondly, and somewhat in contrast, there was a strong sense of togetherness in George's basement room plus a feeling of common purpose and kinship that drew from the strength of George's character. This was an aura that was shared with Woods Hole and Lamont by virtue of his association with these institutions. The fortunate amongst us remember the annual (in those days one didn't have to specify Spring) AGU meetings in Washington when we would all descend on the old Gordon Hotel. The Gordon was a masterful statement of what hotels were meant to be—cavernous rooms that could be rented for $8.00 as a double and into which an additional six sleeping bags would easily fit. The management dignified the then unknown expression—"benign neglect." Frank Press, George Sutton, Jack Nafe, Paul Pomeroy, John Ewing, Chuck Drake, Joe Worzel, and others would join us there. We drank in the good fellowship and shared sense of discovery along with the more tangible spirits of the Hay-Adams Hotel Bar. We couldn't afford to stay at the "Hay" but we liked to drink in style—the ol' Woollard élan.

Thirdly, George shared with his students the rich array of his personal friends: Sam Worden, Nelson Steenland, Cecil Green, Louis Slichter, Louie Nettleton, Lucien La Coste, Teddy Bullard, and others. These were truly pioneers. We stood in their awe and were privileged to be in their presence. Wherever we traveled throughout the world our identification with George Woollard opened doors and hearts.

My story could go on for hours, and thousands more could be told by others whose lives have been touched by George. But I cannot stop without a final comment on the indelibility of that touch. Once one became a member of the Woollard "family," it was a lifetime affair. For instance, while doing my Army service in Alaska, it seemed perfectly natural that I should spend my weekends and leave-time doing a gravity survey of the then "territory." Somehow, he got me one of Sam Worden's meters, and I "gumshoed" the jeeps, planes, and boats to do the job. Later, while gainfully employed with Geophysical Service Inc., looking for oil in the Gulf of Mexico, George volunteered my services for a year-and-a-half tour in the interior of Antarctica. It never occurred to me that I shouldn't go. The only surprise was when I learned, two days before we sailed, that I was actually going to get paid for going—$1800 a year yet!

More significantly, George set the standards against which I have measured my judgment and performance since we first met over a quarter of a century ago. The lessons he taught were the lessons of life, not just the relative significance of a Bouguer versus a free air anomaly. That such a great heart has stopped beating is more than pause for reverence—it is also pause for concern. We must take stock of a world without George Woollard and wonder what a poorer place it must be unless someone else picks up the trace. We must look to ourselves. To achieve George's stature most surely exceeds our reach. But if we strive, the many of us who have known and been influenced by him and come even half way to the mark, can, together, perpetuate his greatness for another generation—and maybe others to come. This is our challenge.

Appendix D

Vignettes on Geophysical Prospecting

Reflections on the Field of Exploration Geophysics—Cecil H. Green[1]

My long career in exploration geophysics and electronics has entailed only a faint line of separation between work and pleasure. At this later time in life, I have reached the important conclusion that success in life is mainly a function of one's state of mind—or in a single word—"happiness." This, in turn, is tied to a second important word, "accomplishment." Just how and why did I get started in exploration geophysics in the first place? After all, I had grown up in far-away British Columbia and had then graduated as an electrical engineer at MIT in New England. However, it turned out that, in 1930, I was associated in Palo Alto, California as a production engineer with Charles V. Litton in the electronics shop of the Federal Telegraph Company, a subsidiary of the International Telephone and Telegraph Company (ITT). I soon admired Litton as one of the smartest young men I had ever met.[2] He could go into the machine shop, take over from the best toolmaker, proceed to show him how to do a job better, and then return to his own office to perform a mathematical analysis of some other problem on the blackboard. At the same time, while designing and building 20-kilowatt transmitting tubes for ITT's overseas radio system, Charlie had become one of the most capable glass-to-metal technologists in the United States.

I mention this detail because this is where a new company, named Geophysical Service Inc. (or GSI for short), first entered the picture. Charlie's preferred daily work regime with molten glass and metal was from late afternoon until long after midnight. I became greatly intrigued and understudied him after my regular work schedule, with the result that I found myself putting in far too many 12–15-hour days. Quite naturally, Ida, my wife, got just a little discouraged with her loneliness and so expressed herself in correspondence with Helen, the wife of Roland F. Beers, with whom I had worked on a previous research assignment with Raytheon back in Cambridge, Massachusetts. When I had left for the West Coast, Roland transferred first to Submarine Signal Corp. and then to Geophysical Research Corp. (GRC), a subsidiary of Amerada

[1] Presented on 3 November 1980 to the Dallas Society of Exploration Geophysicists, Mr. Green's remarks are based on having spent 50 years in petroleum geophysics dating back to 1930.

[2] Litton went on to found the firm which eventually became a conglomerate, Litton Industries, and the owner of the Western Geophysical Company until 1994.

Petroleum Corporation. Then, in early 1930, when J. C. Karcher and Eugene McDermott elected to leave GRC to launch GSI as a completely independent seismic exploration service company, several other GRC associates, such as Roland Beers, H. Bates Peacock, Ken Burg, Henry Salvatori, and Chalmers Pittman, left as well to become party chiefs for the new firm based in Dallas, Texas. In spite of the great depression, prevailing at that time, business was so good that additional party chiefs had to be recruited. Because of our previous association in the Boston area with Raytheon, coupled with his knowledge via our two wives that I had become a workaholic out in Palo Alto, Roland purposely mailed me a glowing account of the exciting life of a petroleum explorationist. Ida was, of course, quite amenable and so I succumbed to an attractive job offer from Eugene McDermott—a letter which I still have in my memorabilia file.

I included Charlie Litton in my notice of resignation from Federal Telegraph and I still hear his friendly, but harsh, criticism and his reference to the utter folly of looking for new oil because all storage tanks were already overflowing. But the die was cast! Ida and I drove our Oldsmobile from Palo Alto to Seminole, Oklahoma, where I understudied Roland Beers as Party Chief on his crew under contract to Pure Oil. His visiting geologist, Ira Cram, was most cooperative. Then, on 1 October 1930, I became party chief of GSI's tenth field party, headquartered 12 miles away in the big town of Maud, Oklahoma, population 275, and under contract to Twin States Oil Company, a subsidiary of Sun Oil Company. My observer was Bill McDermott and computer, Chester Donnally. I experienced many interesting adventures during the next 12 months as we moved at frequent intervals to such Oklahoma towns as Seminole, Prague, Stillwater, Perry, and Guthrie. Seismic energy was, of course, provided by 2½ inch diameter sticks of Hercules 60% nitroglycerine sticks of dynamite.

Since this was before the advent of truck-mounted drill rigs, shotholes were obtained with bucket augers built by the Hall Company. You real old-timers will recall this hole-digging process as "Bear down and turn to the right!"[3] This was accomplished by three-men labor crews—two men to turn the auger handle, while the third sat on the handle to provide necessary weight as successive 4-foot pipe extensions were added until the hole reached its desired depth of 19 feet. Six closely spaced holes had to be drilled at each shot point, designated ahead of time by the crew surveyor with a stake decorated with yellow flagging. As many as six holes per shot were necessary, since the amplifiers of that early day did not feature automatic volume control, so successive charges of dynamite, of varying size per hole, had to be detonated in order to obtain the optimum reflection amplitude.

Water from a truck-mounted tank was used for tamping each charge. A telephone line over the length of the spread of 1500 to 3000 feet between the layout of six seismometers and shotpoint provided communication between the observer and shooter. The shooter would advise by telephone when each charge had been pushed to the

[3] One of GSI's newer employees, Edward Fain, was promptly assigned to hand auger duty. In the process of grumbling about it, he asked a partner on what device he had been hired as. The answer was simple—"President," for the individual was no less than J. C. Karcher! Fain became a topflight observer, but still was noted for his complaining. Wherever his crew happened to be was the world's worst place, while the last place they had been was usually termed the world's best.

bottom of its hole and tamped with water. The observer would then start hand cranking the four-inch record through the camera as he told the shooter to fire; the shooter then quickly pushed down the handle of his old-fashioned blasting machine to detonate the charges. The instant of detonation was transmitted automatically from the blaster via the telephone line to be recorded as a "time-break" at the beginning of the reflection record. The surveyor's distance from shotpoint to each of the seismometers at the recorder's set-up was then checked by means of a blastphone—the time taken for the air wave generated by a very small charge, detonated at the surface, to travel at an air velocity of 1100 feet per second.

The small number of seismometers was offset by their size and weight. They were our so-called S-2 "jugs"—cylindrical, 6 inches diameter, 15 inches tall, 30 lbs weight, and comprising a stationary coil and moving magnet mounted on leaf springs—such heavy moving system being properly damped by the right weight of oil. Each of these cylindrical jugs had to be buried in hand auger holes in order to minimize wind disturbance. At the same time, set-ups near trees were avoided in order to avoid wind noise transmitted by nearby roots.

The essential unit in the recording camera was the so-called "harp"—comprising five 0.00065-inch-diameter gold wires, stretched between two ivory bridges. In the bright light of a properly focused optical system, each of these five small wires, whether stationary, or moving in response to an amplified signal from its particular seismometer, produced a so-called trace on 4-inch-wide photographic paper as it was hand-cranked through the camera by the observer. The camera also included a miniature sized hand-started synchronous motor driven by an electrically actuated tuning fork—the ten tines on its small fly wheel casting timing lines at 0.01-second intervals across the recording paper, so that the reflection arrivals on each of the five traces could be timed to the nearest 0.001 second by the party chief in his field office—that is, after the record had been developed, fixed, and dried by the observer's helper as he caught the exposed record with his hand in the developer box located beneath the camera.

Interpretation in the field office by the party chief, with an assistant as a computer, was a process of identifying reflection patterns and correlating same throughout the particular area, or prospect. Corrections for reflection traveltime through the weathering, near-surface material, was measured at each seismometer by the observer who recorded shallow refraction traveltimes using very small dynamite charges detonated in shallow auger holes beyond each end of the seismometer array. After thus correcting for weathering, as well as the surveyor's surface elevation data, reflection arrival times were then converted to depths utilizing a chart based on time versus depth information from nearby velocity profiles or from direct measurements in a nearby dry oil well in the general area. In the case of our central Oklahoma work, the prime reflection horizon was an Ordovician limestone known as the Viola. I still recall the wonderment of our crew's wives and their speculations that, since their men talked so much about Viola, she must obviously be quite a girl.

In correlating the reflection patterns in a new prospect, the initial reconnaissance objective was, of course, to discover any reversal from normal regional dip for the prime reflection horizon. Unless such reversal was discovered fairly early, the prospect would be abandoned. On the other hand, an indication of reverse dip would then warrant additional or fill-in reflection profiles to outline a hoped-for anomaly for a subsequent test well. One can't help remembering the aggressive acts of field scouts paid by oil companies other than one's client firm. Indeed, it became very much a game to do one's best in leading scouts astray in order that they would not be aware that interest was intensifying in a given prospect as the need arose to do fill-in profiling.

I would make a personal observation at this point. After starting my professional career as an electrical engineer in both research and production, I had come to the conclusion that exploration seismology gave me the greatest measure of pleasure and satisfaction for the field comprised a wonderful combination of technology and people. I was also impressed that people in exploration rate highest in both personality and integrity. I learned also that Mother Nature can be coy and inconsistent so that whenever you feel you have her completely discerned, she is then ready to throw you a curve. So, in line with this experience, I finally concluded that whenever you meet a geologist, or a geophysicist, who is an egotist, you can be quite sure that you are listening to a beginner. Back in those days of the 1930s, before there were rigid controls on the number of hours worked, our prime objective was to satisfy the client company with a daily level of good information. If breakdowns occurred or trucks were mired overly long on muddy roads, a crew might then find itself working in the field by moonlight, but this could be offset by returning to town in the middle of the afternoon on other days if everything had worked perfectly.

That was also back in the days of Prohibition, so alcoholic stills were very prevalent in the wooded hills of central Oklahoma. One afternoon I elected to visit my field crew, hoping that as I walked from my car through the woods I would not be shot as a possible "revenooer" by some trigger-happy "moonshiner." I found the crew eventually, but instead of working, the observer and his men were asleep in the shade of the recording truck. On awakening them with a few kicks, I then listened to a plausible story: Thus, while the hand auger crew was drilling its six 19-foot holes at the surveyor's stake with its yellow flagging in a creek bed beneath a large cottonwood tree, a farmer came over the brow of the nearby hill. He was Mr. Snow, the owner of that particular land, and wanted to know why holes were being dug there and, of course, the answer was, "We are fixing to set off a little dynamite in order to find some oil." His quick response was, "Dynamite! Hell, I have six kegs of whiskey buried right there. Could you move up or down the creek?" Since the crew felt that the surveyor was probably not "exacting," they very willingly moved the shotpoint about 100 feet up the creek. In return for their ready cooperation, my crew explained to me that Mr. Snow then insisted that they walk over the hill to enjoy his hospitality, which consisted of "corn squeezings" fresh from the spigot of his still. "Mr. Green, since we are on his land, how could we refuse his kind hospitality?" I agreed, especially since our client representative had not happened on this sleepy situation before I did.

As I was beginning to regard Oklahoma as my newly adopted home, the East Texas oil field suddenly came on stream in mid-1931, resulting in a panic price drop in oil to as low as 10–15¢ per barrel, which resulted in an equally sudden cancellation of seismic exploration. Karcher and McDermott urged as many of us as possible to please get off the payroll for awhile by either returning to some previous job or to graduate studies. I elected to help out by communicating with my old friend, Charlie Litton. "Sure, come on back to your old job, now that you have probably learned your lesson." Very soon after I had returned to Palo Alto, ITT announced that its Federal

Telegraph operation would be moved back to Newark, New Jersey. Charlie elected to resign rather than move back East with the result I had no other choice than to take his place as manager of the Electronics Lab back in Newark. This seemed like retrogression to me, but Eugene McDermott came to my rescue 12 months later when, in July 1932, he telephoned that the depressing effect of the East Texas field was beginning to be absorbed. "Would I please come back to my job as party chief, especially since a small anomaly I had mapped just south of Perry, Oklahoma was now a new oil discovery?" I said "yes" and then tackled the task of telling Mr. Clements, Chief Engineer of Federal Telegraph, that I planned to resign. His immediate response was, "Cecil, if this is your strategy for getting a raise in pay, the answer is no!" He was flabbergasted when I told him that I was completely serious about leaving. So his next response was, "Where can you possibly go for another job in this great depression?" He followed that by giving Ida and myself a very pleasant farewell dinner.

We were soon on our way to Corning, New York, after loading six S2 seismometers in my car trunk obtained from Erik Jonsson, then in charge of a small GSI shop in nearby Elizabeth, New Jersey. My first job upon returning to GSI was shooting a small prospect at nearby Campbell, New York, with W. W. "Ike" Newton as observer, J. W. Thomas, computer, and Phil Gaby, driller, on a portable spudder rig. The client was a small independent operator who drilled a test well on our resultant anomaly—then the following year he brought Karcher and me back into a Brooklyn Court because his well turned out to be a dry hole instead of a gas producer. The judge soon dismissed the case since seismic exploration is certainly not a direct oil-finding method, nor could the absence of geologic structure be verified by one lonely test well.

The next four years were full of interesting experiences in many small towns throughout Kansas, Oklahoma, Texas, and Northern Louisiana. Thus, while working for Seaboard Oil Company, I recall mapping a structure at Indian Gap, Hamilton County, Texas. A test well revealed the presence of gas rather than oil for which I received a friendly "bawling-out" by Chief Geologist, Ray Stehr—his criticism being, "What good is gas when we want oil?" Another structure was mapped for Seaboard, south of Minden, North Louisiana, which was drilled to the Woodbine sand—a dry hole! I had no trouble getting permission to run a velocity survey before the well was abandoned. Schlumberger cables were not then available so it meant taping about 5000 feet of lamp cord to a simple acid bottle line. Fortunately, we made our velocity measurement as we lowered the seismometer to the bottom of the well, because as we started to raise the seismometer through the heavy mud, the small steel line broke. So we obtained our velocity information, but at the cost of our geophone. Ray Stehr laughingly stated that we had done a good job of helping to fill a useless well! A year later, Stehr changed his mind completely. Seaboard had decided to resume drilling, and he worried about the possible difficulty of drilling through our lost geophone. He also noted in a friendly way that we might be sued in case of blockage. As might be expected, the geophone was merely pushed into the sidewall as the well was carried on down to the Pettit zone where it became a distillate producer.

On being promoted to the position of supervisor, life became even more exciting because of continued adventures but on a worldwide basis. An episode in Southern California is worth mentioning. While headquartered in Los Angeles, I tried to add to our client customers by calling repeatedly on the Chief Geophysicist of the Superior Oil Company. I finally caught up with him at a social gathering. When he admitted that he had been avoiding me at his office, I told him that I was anxious to talk to him about a possible contract with GSI. His response was "Over my dead body!" Naturally, I asked him why. His answer was straightforward, "When I was about to graduate from O.U. ten years ago, I wrote your dear Dr. Karcher asking for a job. I am still waiting for an answer." I have remained forever mindful of that important lesson in people relations.

Accompanying George M. Cunningham, the Chief Geologist for Standard Oil Company (California), around the world during 1939–40 provided more experiences. GSI was then conducting our first seismic marine survey in the Persian Gulf—one off Bahrain Island. This was much before the advent of seismic streamers. Fortunately, the water was only 20 feet deep—also crystal clear because of the bottom material being a smooth white marl. We were able to use a vertical spread comprising four Type-S10 seismometers on either side of the shot point. Each seismometer was dropped overboard from a small Arab dhow at marked intervals. They generally settled upright on the bottom because of being surmounted by a small metal parachute. Before shooting began, it was necessary to check visually from the surface to make certain each geophone was in an upright position. In case of any being on their side, one of the Arab helpers with pearl-diving experience would dive down to it, for which he was glad to receive a one-rupee bonus. We did not know enough to detonate charges in the water, so shot holes drilled beneath the bottom, with casing reaching to the surface for easy loading, were provided by a barge-mounted rotary drill rig. Surveying was by sight triangulation with towers on frequent islets and coral reefs.

One night, when I was on the headquarters barge, a strong seasonal gale from the north (a "shamal") not only caused us to drag our anchors over the smooth marl bottom but, more seriously, the Arab dhow carrying our supply of dynamite disappeared. Knowing the direction of the previous night's wind, it was easy for our observer and a retired British Navy officer to find the dynamite dhow on a beach in the nearby sheikdom of Dhofar. Our men were very relieved to find the dynamite intact in the dhow. After apologizing to some of the local Bedouins for defiling their beach with the uninvited dhow and its unsavory cargo, our men promised to return the next day with a larger craft to remove both the dhow and its cargo. This announced plan was, of course, a real mistake, because the local Bedouins very quickly surmised that anything worth coming back for must be valuable in spite of the fact that, on tasting a slice from one of the dynamite sticks, it did not seem a palatable food. So when our men returned the next day, the dhow was on the beach, but its cargo had disappeared. Without mentioning the word, dynamite, our men tried to scare the local Bedouins by describing the cargo as very unhealthy and therefore undesirable to retain in their country. By that time the local sheik had taken full possession and, on being propositioned, he demanded a preposterous ransom equivalent to $25 000. There was only one thing left to do, which was to seek the counsel and aid of the British Political Agents of Bahrain and Dhofar. The Bahrain agent agreed to help by first stating that marine law would apply wherein anyone who salvages a ship's cargo is entitled to only half its market value. Our estimate was $5000, so in quick time the two British agents obtained the release of the dynamite with our payment of $2500.

At that time, the California–Arabian Standard Oil Company (CASOC), the predecessor to the Arabian–American Oil Company (ARAMCO), was very unhappy that a test well drilled on seismic data known as Abu Hadrya Number One in the northeastern part of Saudi Arabia near the Neutral Zone was giving indications that it would be a dry hole. The well had already penetrated without result all of the known Jurassic producing zones identified in the Damman Dome to the south of Dhahran, but it also had reached the unheard of depth (for foreign areas) of 2900 m. Everyone in CASOC's Producing Department wanted to abandon the well and, at the same time, use this as a good reason for getting rid of the misleading geophysicists. However, the drilling superintendent had a peculiar feeling, based on his imagined smell of sulphur in the returning mud, that he might strike some new and deeper oil-producing zone. So it was agreed that he continue drilling until he either struck basement or ran out of drill stem or casing.

This was the unhappy situation when George Cunningham and I left for Karachi, India. While we were together visiting a seismic party, an overnight train ride up the Indus River Valley, George received two cablegrams, one from San Francisco and the other from Dhahran. He decided to open the San Francisco message first because of it probably being from his boss, Clark Gester, the SOC vice president for production. Sure enough, it was, and the cryptic instruction, "Please return to Saudi Arabia before going on to Indonesia for the express purpose of making a post-mortem study re the loss of $1.5 million on the dry hole at Abu Hadrya." While still moaning about such a disappointing message, I suggested that he read the second cablegram. It was also a cryptic message signed by Chief Geologist, Max Steineke at Dhahran, that Abu Hadrya had just struck oil at a depth of 10 200 feet and at a rate of 15 000 barrels per day. My next remark was to suggest that this was a very appropriate time to order up a cold beer!

Soon after World War II, I found myself visiting Richmond Petroleum headquarters in Bogota, Colombia, before taking off on an unusual travel excursion to visit a seismic crew in the upper Magdalena River Valley. I was accompanied by the GSI Party Chief, Martin Linwell, by "Chuck" Ramsden, a field geologist for Richmond, and by a Colombian medical student, known as a "praciticanti," who was carrying a thermos bottle of yellow fever serum to inoculate our crew because of the reported threat of a yellow fever outbreak. We first traveled by DC-3 aircraft from Bogota to Bucaramonga in the coffee-bean country, then by a small rail car powered by a Kalamazoo one-cylinder gasoline engine downgrade to Puerto Wilches on the Magdalena River, followed by moving on down the river by outboard-engine-powered canoe to Bocas del Rosario. Horses had been scheduled to meet us there for a ride via jungle trail to our houseboat on a nearby tributary of the Magdalena. While waiting in the town plaza for our horses, we decided to have a beer in a small grocery store. While the store owner was expressing his regrets for not having any *Cervesa* (a beer), Chuck opened the door of the refrigerator and found it fully stocked with beer as well as Coca Cola. The manager was full of apologies as he pointed to the heads of several peons who were watching us through the half open front door. He pleaded with us to accept Coca Cola instead of Cervesa because if he sold beer to us then he would have to sell beer to the watchful peons. Since their pockets were full of money, it being pay-day, they would drink too much, get terribly drunk, and wreck his store. We, of course, were willing to cooperate until we walked over to the waiting horses and found our "practicanti" missing. Very soon we saw him approaching us, carrying his thermos bottle plus a brown paper sack, and wearing a big smile. When asked as to the contents of the sack, he produced four cold bottles of Cervesa. We asked, of course, "Where did you get them?" His reply "In the store you have just left." Naturally we asked, "How come, when we were turned down?" "Ah, but Senors, you offered money, while I asked if he would like an inoculation as protection against a bad yellow fever epidemic that is about to break out?" Naturally, our regard for our young Colombian friend increased tremendously in those few moments.

In 1955, I had occasion to visit a seismic party near Exmouth Gulf in Western Australia. I had heard a year or so previously that CALTEX, in partnership with Western Australia Petroleum Company (WAPET), had acquired a new concession in that area. In response to my inquiry concerning seismic service, I was informed that the prime feature of the concession was a very prominent surface anticline, about 30 miles long, two or three miles wide, with 500 feet of relief and known as Rough Range. So all they really had to do was drill. As expected, oil was struck in the first well. At this juncture the market price of WAPET stock down in Perth escalated overnight from 10 shillings to 10 pounds per share. A north offset location was then drilled and it was dry, clearly a case of advancing in the wrong direction. Obviously a south offset was prescribed, but horrors, it was dry also! Then, much in desperation, offset locations both east and west were drilled and tragically were also dry. By this time, the common stock of WAPET had descended back "into the basement." Our seismic task became twofold. The first step was to resolve this enigma. In this instance, the seismic data seemed to indicate a situation of complicated faulting with no apparent relation between the subsurface structure and the prominent surface anticline. The other portion of our assignment was for me, as a so-called "outside expert," to go down to Perth and explain to news reporters why this peculiar and expensive operation was not just a mean maneuver by WAPET and CALTEX to "fleece" the gullible public who had put their savings into what turned out to be an unfortunate gamble for everyone concerned.

In closing this musing, I would like to express my admiration and high esteem for the job that the Society of Exploration Geophysicists has done during the first half-century of its existence. During my term as the Society's president in 1947–48, we were able to convert the Tulsa headquarters, run as an informal office for several years by the devoted efforts of Elizabeth Stiles, into a formal business one directed by Colin C. Campbell. Moreover, the concept of "Local Sections" came into being then. This concept not only has stood the test of time but has grown to include sections in Australia, Canada, and Peru. As a result, our professional group is more than living up to the hopes of its founders that it be truly THE Society of Exploration Geophysicists and know no national boundaries when it comes to improving the economic and social welfare of mankind.

Conception of the Common-depth-point (CDP) Method of Seismic Surveying—W. Harry Mayne[4]

In late 1949 or early 1950, I made a field trip from the San Antonio office of Petty

[4] Courtesy of Petty-Ray Geophysical Operations, Inc., Houston, Texas, a Geosource, Inc., subsidiary.

Geophysical Engineering to an area somewhere in South Texas to assist in the startup of a new crew. As I recall, the area turned out to have a massive caliche surface that produced severe surface noise (ground roll) of unusually high velocity. Analysis of the noise indicated that extremely long (600 to 1000 ft) arrays would be required to satisfactorily attenuate this noise. Unfortunately, this solution was not considered permissible because the objective of the survey was a search for low-relief structure accompanied by small faulting. The "smearing" effects of such long arrays were thought to be so serious that the desired definition could not be obtained.

Consequently a marginally acceptable choice of array length was made, and the survey proceeded with data of dubious quality. I was far from satisfied with the results obtained with this expedient solution, and continued to think about the problem after returning to San Antonio. How might such long wavelength noise be attenuated without smearing the subsurface? The search for an answer to the question led to the basic concept of CRP (also CDP). To do this, an array was formed by summation of the recordings from a series of source-receiver pairs with progressively greater source-to-receiver distances, but with all having a common midpoint. With the concept in hand, a patent was drafted and filed in July 1950.

At this time, however, there were two major deterrents to routine application of the technique. First, no field-worthy system for making electrically reproducible recordings was available at the time. Second, no acceptable way of applying the normal move-out corrections to the electrical signals prior to summation existed. As a matter of fact, the only way in which I visualized the method could be implemented was by purely graphical means. In 1950 this represented the only viable solution, and the method would probably have remained a scientific curiosity had not other parallel developments taken place.

The Patent Office processed applications in leisurely fashion in those days, and issuance of the patent was not ensured until late 1955 with final publication in January 1956. By this time, of course, magnetic tape recording had become established as a field-worthy recording system, but was limited to routine filtering and trace-mixing playback options. The only missing link was the lack of transcription correction capability.[5] This remaining deficiency began occupying more and more of my attention by mid-1955 as it became increasingly apparent that significant patent coverage would probably be obtained.

All of the geophysical instrument manufacturers were approached with an outline of the requirements for processing equipment that could perform the necessary correcting, transcribing, and summing operations. With the exception of one company, the Texas Division of Brush Electronics, no one could understand the need for transcribing the corrected data to another tape and refused to consider making such a machine. After considerable negotiation, Brush prepared preliminary specifications and submitted a price quotation on a suitable machine, and Petty entered into a development contract in late 1955. Brush was a newcomer in the geophysical instrument business, and not fully aware of the high standards required by the industry. I suspect that their education was a rather painful engineering and financial process. In any case, after two years' elapsed time, considerable engineering trauma, and price escalation to

[5] GSI's magnetic disc system did not have enough capacity to handle the CDP requirements

2½ times the original price quotation, they developed quite a competent machine.

Unfortunately, the geophysical business had suffered a severe recession in the interim, and Petty, as a relatively small contractor, was dubious about the business wisdom of risking $250 000 (the final purchase price) on an untried instrument designed to perform a process which had not yet been accepted by the industry. It was a classic case of the chicken and the egg. We could not demonstrate effectiveness of the CRP method without the machine, and we didn't want the machine unless the method proved to be economically viable. All this against the backdrop of a widespread "it will be too expensive even if it works" expression of opinion from a large segment of the industry.

Consequently it was with some relief that we received an inquiry from a major oil company requesting us to relinquish our order for the machine to them. Negotiations were completed between the three parties at the SEG Annual Meeting in Dallas in 1957, and they assumed our order and subsequently took delivery on the first machine of its type. It should be gratifying to all concerned that this particular machine continued to perform creditably until displaced by digital processing in the mid-sixties. Then once again it was back to the drawing board!

To regress a bit, we had realized shortly after conception of the idea that it had the capability of significantly attenuating multiple reflections[6] as well as generally improving the signal-to-noise ratios. Since this could not be accomplished by any other means at the time, we decided to emphasize this advantage in trying to gain industry acceptance. It also happened that at least two oil companies, Phillips Petroleum Company and Shell Oil, had independently conceived the same idea prior to publication of my patent and had been separately developing it on a proprietary basis. Quite logically then, they became the first licensees under the patent, and this acceptance helped to strengthen our commitment to the idea. Shell, in fact, later bought several data-processing units patterned after the prototype which was originally designed and built for us, but delivered to another oil company.

Thus is was that as late as early 1958, Petty was still unable to implement the method and was desperately searching for an alternative data-processing unit which we thought we could afford. About then just such a unit was introduced by Techno Instrument Company in the form of the Dekatrak® auxiliary unit for their mechanical move-out corrector. The first of these units, manufactured under license from Continental Oil Company, was delivered to us in mid-1958, and we were finally in a position to fully implement the CRP method. General industry acceptance was still some time away, however, and the first clients who supported this early work were the Texasgulf Producing, Pure Oil, and El Paso Natural Gas companies. Through the interests of these companies, we were able to develop a considerable body of experience in a variety of areas, and confirm our hopes that the method offered significant potential for data-quality enhancement in most problem areas. This information was gradually percolating through the industry, and a great deal of interest was apparent by late 1960

[6] These are secondary reflections which have been reflected more than once, either between the surface and one or more subsurface horizons, or between two subsurface horizons. They are frequently mistaken for bona fide primary reflections and hence make accurate interpretations difficult.

®A registered trademark of the Techno Instrument Company at the SEG Annual Meeting in Galveston. As evidenced by licensing activity and the proliferation of specialized data-processing equipment designed for the method, interest increased rapidly from 1960 through 1963, and the last major remaining skeptics had finally accepted the method by the end of the 1960s.

Paralleling a part of this period, another technical development was gaining momentum, namely the digital recording and processing revolution. This was also a fortuitous circumstance because the CDP method and digital processing were mutually synergistic. The wide-spread use of the CDP concept also provided the masses of data required to make digital processing attractive, and digital processing soon developed the capabilities of routine velocity analysis and automatic determination of static corrections. Both of these latter capabilities enhanced both the effectiveness and the convenience of the CDP method. One other synergism between apparently unrelated technical developments can be cited between the CDP technique and the development of non-dynamite sources, both land and marine. The development of these inexpensive and effective new sources also undoubtedly impacted acceptance of the CDP method by notably improving its cost-effectiveness.

The Way It Really Happened—The Invention of the VIBROSEIS® System—John M. Crawford[7]

Bill Doty had just returned from a seminar at Massachusetts Institute of Technology and was reporting to me concerning the new mathematical concepts on information theory which had been presented. He laid the June 1950 copy of the journal *Electronics* on my desk. It was open to page 86 where an article by Lee and Wiesner discussed the principles of "auto-correlation" and "cross-correlation." Bill said something like this, "Here is a principle which we should be able to use in our business, but I don't yet know how."

After he left my office, I scanned the article briefly and we got together again. We agreed that this principle would allow accurate measure of the traveltime of a seismic wave through acoustic material *if* we could provide a signal which was "unique" (did not repeat itself) and *if* we had an accurate copy of the signal as transmitted.

The article taught a "white noise" signal as usable but we knew of no available equipment for transmitting such a signal with sufficient power to be of much interest. Again Bill left me to my own devices for a short time. I then recalled an earlier conversation with Bill about his experience as an officer on a minesweeper during World War II. He had described the "bumblebee" signal, which the minesweeper transmitted as a seismic wave through the water in an attempt to detonate acoustic mines that were sensitive to certain sound frequencies. The signal varied continuously in frequency from high to low to high, etc., hopefully hitting the triggering frequency in the process.

It occurred to me that here was our unique signal. That is, it would match itself only at one time-phase relationship during a single frequency excursion or "sweep."

® Registered trademark of the Continental Oil Company.

[7] Reprinted from the company journal, *Mertz World*, of March 1982 by courtesy of Mr. Don Mertz, President

Also, I remembered an article in the *Oil and Gas Journal* from several years back which had described an old principle for making a mechanical vibrator. Counter-rotating, off-center weights were geared together in such a way that horizontal forces were canceled and vertical forces added in combination. To make a sweep signal, all we needed to do was to continually speed up or slow down the driving engine or motor.

When Bill returned, he agreed that we had a system with possibilities. From these and other conversations between Bill and me the ideas flowed thick and fast. With Frank Clynch's help we came up with a mechanical vibrator, driven by a borrowed gasoline engine and held in contact with the earth by driving a loaded water truck (also borrowed) up on some pads rigidly attached to the vibrator. A seismic detector fastened to the vibrator furnished the sample of the sweep signal as transmitted.

With this vibrator and a bunch of electronic gear assembled from some very unlikely sources by some highly effective electrical engineers, we were able to get our first modest field results, and the rest is history. [Thus] the basic invention was made in a single working day by two people—each contributing vital building blocks from mostly unrelated fields. The principle building blocks were not original with either Bill or me, but the combination and adaptations were ours by means of a cooperative effort. It is quite probable that neither of us, working by ourselves, would have come up with the system.

Some Contributions by Cecil and Ida Green to Their Fellow Man

In Cecil and Ida Green's biography,[1] Robert Shrock referred to them as philanthropists extraordinary. At the writing of the biography in 1988, they had contributed over $150, 000, 000. This included a variety of gifts including parcels of land, buildings, endowed chairs, student awards and fellowships, and other equipment. The Cecil and Ida Green Foundation continues today and will perpetuate the spirit of these philanthropists extraordinary.

Global

Project "IDA," which allows "International Deployment of Accelerometers" at some 20 points to study worldwide effects of earth oscillations, with the data center at Scripps Institution of Oceanography, La Jolla, California. During 1987, this helped found the International Federation of Digital Seismograph Networks, which became highly useful during negotiations prior to the Comprehensive Test Ban Treaty of 1996.

By the end of 1987, 32 different professors had held distinguished endowed chairs in 15 institutions; more than 300 scholars had received limited appointments at six colleges and medical institutions, and more than 150 undergraduate and graduate students were able to start or continue their college education.

Buildings

Fifty academic, medical, and civic buildings were wholly or partially funded by them. Following is a list of 18 which were also named for them.

- St. Mark's School of Texas (Dallas)
  Cecil H. and Ida Green Library Study Center (1958–86)
- Massachusetts Institute of Technology
  The 20-story Cecil H. and Ida F. Green Center for Earth Sciences (1959–64).
  Ida F. Green Hall for female graduate students (1983).
  Cecil H. Green Center for Physics.

[1] *Cecil and Ida Green, Philanthropists Extraordinary* by Robert R. Shrock, MIT Press, Cambridge, Massachusetts, 1989.

- Colorado School of Mines

  Cecil H. Green Geophysical Observatory (1962).

  Cecil H. and Ida Green Graduate Professional Center (1972)

- University of British Columbia

  Cecil Green Park, including a 24-room mansion housing the University's Alumni Association (1967).

- Austin College, Sherman Texas

  Ida Green Communication Center (1972)

- University of California at San Diego

  Cecil and Ida Green Piñon Flat Geophysical Observatory (1978).

  Cecil H. and Ida Green Faculty Club Building (1988)

- Stanford University

  The principal donation for expansion of the main library, now called the Cecil H. Green Library (1980).

  Cecil H. and Ida M. Green Earth Sciences Research Building (1987).

- Scripps Clinic and Research Foundation, La Jolla, California

  New health care center on Torrey Pines Mesa, including the Cecil H. and Ida Green Hospital (1972–75), plus other improvements.

- University of Texas

  Health Science Center at Dallas and its Southwestern Medical School

  The Cecil H. and Ida Green Science Building (1975)

  Partial funding of the 9-story Cecil H. and Ida Green Biomedical Research Building (1986)

- YWCA at Dallas, Texas

  The principal donation for construction of the new Dallas Community YWCA and an additional donation for construction of the Ida Green Natatorium (1972–75).

- National Academy of Sciences, Georgetown, Washington DC

  Funding of the Cecil and Ida Green building, the principal building at the new site of the Academy's National Research Council (1987).

- Oxford University, England

  Donations to the construction fund for buildings in the Cecil H. Green College (1978–80).

Other Notable Contributions

(Joint Donations by the Greens (Cecil and Ida), the McDermotts (Eugene and Margaret) and the Jonssons (Erik and Margaret)

- Massachusetts Institute of Technology

  When the McDermotts learned of the Green's large donations to MIT, they established a fund in the amount of $1 218 000 to give young men and women of Texas and the Southwest opportunities to receive an MIT education (1960).

  The McDermotts also provided funds to commission the famed sculptor, Alexander Calder, to create a suitable sculpture (The Big Sail) for the area fronting the Green building. They also paid for beautifying the area now called McDermott Court.

- Southern Methodist University

  The Greens, Jonssons, and McDermotts contributed equal amounts to finance construction of SMU's Science information Center (1961). At this time, the Center became the headquarters for construction of the TAGER TV educational network, a project to which the Greens made very substantial contributions of both time and money.

- University of Texas at Dallas

  The Greens, Jonssons, and McDermotts donated 1200 acres of land and the Founders' Building to the Graduate Research Center of the Southwest (1961) prior to its conversion to university status in 1969.

- University of Texas Health Science Center in Dallas

  McDermott gave an amount equal to the Green's pledge to construct a second building, the Eugene McDermott Administration Building (1972). The gardens were financed by Erik and Margaret Jonsson.

- Dallas Arboretum and Botanical Gardens

  The core property (house and gardens) for the Dallas arboretum and gardens was the home of the most famous oil finder in the world, Everett DeGolyer (1885–1956). He and his wife, Neli Virginia Goodrich of Norman, Oklahoma, had the Spanish colonial house designed and built when they returned with four children in 1936 for DeGolyer to complete his degree in geology at the University of Oklahoma. Eventually, the house and grounds were purchased by the city of Dallas in 1975, but the DeGolyer library was retained by SMU. The Greens made a major challenge donation of $300 000 in 1984 to develop the Arboretum and Botanical Gardens, causing the first garden inside the main entrance to be named after them.

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References

The Prologue

Bolt, B. A., 1976, Nuclear explosions and earthquakes — The parted veil: W. H. Freeman & Co.

Evans, B., 1997, A handbook for seismic data acquisition in exploration: Soc. Expl. Geophys.

Howell, B. F., 1990, An introduction to seismological research: History and development: Cambridge Univ. Press.

Mayne, W. H., 1989, 50 years of geophysical ideas: Soc. Expl. Geophys.

Sweet, G. E., 1978, The history of geophysical prospecting, vols. 1 and 2, 3rd Ed.: Science Press.

Tucker, P. M., 1990, Reflections of a seismic interpreter: Soc. Expl. Geophys.

Ward, S. H., editor, 1990, Geotechnical and environmental geophysics (vols. I-III): Soc. Expl. Geophys.

Chapter 1

Brush, S. G., 1980, Discovery of the earth's core: Am. J. Sci., **48**, 705–721.

Ewing, M., and Worzel, J. L., 1948, Long range sound transmission, Memoir 27: Geol. Soc. Am.

Fay, H. J. W., 1963, Submarine signal log: Submarine Signal Div., Raytheon Co.

Herbert-Gustar, L. K., and Nott, P. A., 1980, John Milne: Father of modern seismology: Paul Norbury Pub., Ltd.

Kevles, D. J., 1978, The physicists: Random House, Inc.

Lyman, J., 1948, The centennial of pressure-pattern navigation: U.S. Naval Inst. Proc., **74**, 309–314.

Macelwane, J. B., 1950, Jesuit seismological association, 1925–1950: Central Station, Saint Louis Univ.

Silverman, S., 1998, First congress of the United States tackles geophysics in 1789: EOS, **79**, 257–260.

Stanton, W., 1975, The great United States exploring expedition of 1838–1842: Univ. of California (Berkeley) Press.

Chapter 2

Allaud, L. A., and Martin, M. H., 1977, Schlumberger, the history of a technique: John Wiley & Sons.

Asquith, G. B., 1980, Log analysis by mini-computer: PennWell Publ. Co.

Barton, D. C., 1938, Tech. Pub. 950: Am. Inst. Min., Metall., Petr. Eng.

Bates, R. L., 1941, Review of internal constitution of the earth by B. Gutenberg et al.: AAPG Bull., **25**, 172–174.

Bigelow, H. B., 1931, Oceanography: Its scope, problems and economic importance: U.S. Natl. Ac. of Sci.

Blau, L. W., 1941, Review of "Exploration geophysics," by J. J. Jakosky: AAPG Bull., **25**, 170–171.

Bolt, B. A., 1979, Perry Byerly — A memorial: Bull., Seis. Soc. Am., **69**, 928–945.

Bullard, E. C., and Gaskell, T. F., 1941, Submarine seismic investigations: Proc., Roy. Soc. London, Ser. A, **177**, 476–499.

Clark, R. D., 1983, Sidney Kaufman: The Leading Edge, **2**, No. 7 22–27.

Eckhardt, E. A., 1940, A brief history of the gravity method of prospecting for oil: Geophysics, **5**, 231–242.

Gutenberg, B., editor, 1939, Internal constitution of the earth: McGraw-Hill.

Heiland, C. A., 1940, Geophysical exploration: Prentice-Hall.

Iselin, C. O'D., 1959, Environmental factors influencing the performance of naval weapon systems — An introduction: Sponsored by Woods Hole Oceanographic Inst.

Jakosky, J. J., 1940, Exploration geophysics: Times Mirror Press.

Jeffreys, H., 1924, The earth, its origin, history and physical constitution, 6th Ed.: Cambridge Univ. Press.

Johnson, C. H., 1938, Locating and detailing fault formations by means of the geo-sonograph: Geophysics, **3**, 273–294.

Johnson, H. M., 1962, A history of well logging: Geophysics, **27**, 507–527.

Karcher, J. C., 1987, The reflection seismograph, its invention and use in the discovery of oil and gas fields: The Leading Edge, **6**, No. 11, 10–19.

Knopoff, L., Holzer, R. E., and Kennel, C. F., 1979, Memorial to Louis B. Slichter: Bull., Seis. Soc. Am., **69**, 655–657.

Leet, L. D., 1938, Practical seismology and seismic prospecting: D. Appleton-Century.

Natl. Academy of Sciences, 1930, Final Report: Committee on oceanography. (Mimeographed version only.)

Nettleton, L. L., 1940, Geophysical prospecting for oil: McGraw-Hill Book Co.

Raitt, H., and Moulton, B., 1967, Scripps Institution of Oceanography — First fifty years: Ward Ritchie Press.

Revelle, R., and Munk, W., 1948, Harald Ulrik Sverdrup — An appreciation: J. Mat. Res., **7**, 127.

Rosaire, E. E., 1940, A perspective of exploration for petroleum: Geophysics, **5**, 259–271.

Sargent, P., 1979, The sea acorn: Printed privately by Peter Sargent.

Schlee, S., 1973, The edge of an unfamiliar world — A history of oceanography: E. P. Dutton & Co.

Sheriff, R. E., and Geldart, L. P., 1982, Exploration seismology: Cambridge Univ. Press.

Slotnick, M. M., and Geyer, R., 1959, Lessons in seismic computing: Soc. Expl. Geophys.

Sverdrup, H. U., Johnson, M. W., and Fleming, R., 1942, The oceans: Prentice-Hall, Inc.

Tinkle, L., 1970, Mr. De: Little, Brown & Co.

Chapter 3

Bates, C. C., 1949, Utilization of wave forecasting in the invasions of Normandy, Burma and Japan: Ann. New York Acad. Sci., **51**, 545–569.

Bennett, G., 1975, Naval battles of World War II: David McKay.

Born, W. T., 1941, The future of geophysics: Geophysics, **6**, 213–220.

DeGolyer, E., 1942, Notes on the present status of problem of exploration: AAPG Bull., **26**, 1214–1220.

Field, R. M., 1941, Geophysics and world affairs: a plea for geoscience: Trans. Am. Geophys. Union, **22**, 225–234.

Gilmore, M. H., 1947, Tracking ocean storms with the seismograph: Bull., Am. Meteor. Soc., **28**, 73–86.

Goldstone, F., 1943, Maintaining an adequate level of geophysical exploration: Geophysics, **8**, 237–243.

Gutenberg, B., 1946, Interpretation of records obtained from the New Mexico atomic bomb test, 16 July 1945: Bull., Seis. Soc. Am., **36**, 327–329.

Jakosky, J. J., 1947, Whither exploration?: Geophysics, **12**, 361–368.

Johnson, E. A., and Katcher, D. A., 1973, Mines against Japan: U.S. Naval Ordnance Lab.; also Govt. Printing Office.

Sverdrup, H. U., and Munk, W. H., 1944, Wind waves and swell; principles in forecasting: U.S. Navy Hydrographic Office Misc. 11275.

Vajk, R., 1949, Geophysical developments in Europe during the war: Geophysics, **14**, 101–108.

Whiting, C., 1996, Massacre at Malmedy: Pen & Sword Books Ltd.

Wilson, R. E., 1941, Petroleum and the war: AAPG Bull., **25**, 1264–1282.

Wyckoff, R. D., 1948, The Gulf airborne magnetometer: Geophysics, **13**, 182–208.

Chapter 4

Ben-Menahem, A., editor, 1990, Vincit Veritas: a portrait of Norman Abraham Haskell (1905-1970): Am. Geophys. Union.

Dobrin, M., 1976, Introduction to geophysical prospecting, 3rd Ed.: McGraw-Hill Book Co.

Eckhardt, E. A., 1948, Geophysical activity in the oil industry in the United States in 1947: Geophysics, **13**, 529–534.

Joint Task Force One, 1946, Operation crossroads — The official pictorial record: William H. Wise & Co.

Knudsen, V. O., Redfield, A. C., Revelle, R., and Schrock, R. R., 1950, Education and training for oceanographers: Science, **111**, 700–703.

Paul, C. K., and Mascarenhas, A. C., 1981, Remote sensing in development: Science, **214**, 139–145.

Proffitt, J. M., 1991, A history of innovation in marine seismic acquisition: The Leading Edge, **10**, No. 3, 26–30.

Reford, M. S., and Sumner, J., 1964, Review of aeromagnetics: Geophysics, **29**, 482–516.

Rice, R. B., 1953, New seismic computing method fast and efficient: World Oil: **137**, No. 2, 93–98, 104.

Rice, R. B., 1955, Additional notes on the resolved-time computing method: Geophysics, **20**, 104–122.

Weeks, L. G., 1949, Highlights of 1948 developments in foreign petroleum fields: AAPG Bull., **33**, 1029–1124.

Wyckoff, R. D., 1944, Geophysics looks forward: Geophysics, **9**, 287–298.

Chapter 5

Amer. Geol. Inst., 1951, Policy statement regarding status of geological and geophysical manpower.

Barth, K-H., 1998, Science and politics in early nuclear test ban negotiations: Physics Today, 34–39.

Bascom, W., 1961, A hole in the bottom of the sea: Doubleday & Co., Inc.

Bates, C. C., 1958, Current status of sea ice reconnaissance and forecasting for the American arctic: Polar atmosphere symposium, Agardograph, **29**, No. I, 285–322. Pergamon Press, Inc.

Bolt, B. A., 1976, Nuclear explosions and earthquakes — The parted veil: W. H. Freeman & Co.

Carlowicz, M., 1997, New data from Cold War treasure trove: EOS, **12**, 93–94.

Chapman, S., 1959, IGY — Year of discovery: Univ. of Michigan Press.

Crawford, J. M., Doty, W., and Lee, M. R., 1960, Continuous signal seismograph: Geophysics, **25**, 95–105.

Dobrin, M. B., and Van Nostrand, R. G., 1956, Review of current developments in exploration geophysics: Geophysics, **21**, 142–155.

Dunbar, M., 1954, The pattern of ice distribution in Canadian arctic seas: Trans. Roy. Soc. Canada, **48**, No. III, 9–18.

Eckhardt, E. A., 1951, Geophysical activity in 1950: Geophysics, **16**, 391–400.

———1952, Geophysical activity in 1951: Geophysics, **17**, 441–451.

Gaskell, T. F., 1954, Seismic refraction work by HMS Challenger in the deep oceans: Proc. Royal Soc. (A), **222**, 356–361.

Gaskell, T. F., Swallow, J., and Ritchie, G. S., 1953, Further notes on the greatest oceanic sounding and the topography of the Marianas Trench: Deep Sea Research, **1**, 60–63.

Green, C. H., 1953, A cooperative plan in student education: Geophysics, **18**, 525–529.

Gutenberg, B., and Richter, C. F., 1954, Seismicity of the earth, 2nd Ed.: Princeton Univ. Press.

Haskell, N. A., 1959, The detection of nuclear explosions by seismic means: Geophysics Research Directorate Technical Note 60-632.

Hubbert, M. K., 1955, Discussion On "An educational program in geophysics" by G. P. Woollard: Geophysics, **20**, 681–682.

Jaffe, G., Wittman, W., and Bates, C. C., 1954, Radioactive hailstones in the District of Columbia area, 26 May 1953: Bull., Am. Meteor. Soc., **35**, 245–249.

Kean, C. H., and Tullos, F. N., 1948, Acoustic impedance logging: Oil & Gas J., **47**, 95.

Killough, J. R., 1953, Petroleum exploration on our public lands: Geophysics, **18**, 201–211.

Leary, W., and Leschack, L., 1996, Project COLDFEET: Secret mission to a Soviet ice station: Naval Inst. Press.

Lill, G. G., 1971, Oceanographic activities in the Geophysics Branch, Office of Naval Research, 1950–1959: Proc. Royal Soc. Edinburgh (B), **72**, 253–261.

Linehan, D., 1956, A seismic problem in St. Peter's Basilica, Vatican City, Rome, Italy, *in* Lyons, P. L., Ed., Geophysical Case Histories: Vol. 2, Soc. Explor. Geophys., 615–622.

Longwell, C. R., 1955, In support of the Am. Geol. Inst.: Geophysics, **20**, 683–687.

Loper, G. B., and Pittman, R. R., 1954, Seismic recording on magnetic tape: Geophysics, **19**, 104–115.

Lyons, P. L., 1951, A seismic reflection quality map of the U. S.: Geophysics, **16**, 506–510.

Macelwane, J. B., 1954, Annual survey of geophysical education, 1953–1954: Geophysics, **19**, 549–564.

Mayne, W. H., 1956, Seismic surveying, U.S. Patent 2 732 906. (Abstracted in Geophysics: **21**, 856.)

———1962, Common reflection point horizontal data stacking techniques: Geophysics, **27**, 927–938.

Peterson, R., 1960, Investigation of proposed use of large seismometer arrays in the U.S.S.R. for the detection of underground explosions: Testimony presented to Joint Committee on Atomic Energy, U.S. Congress on 21 April 1960, Part I, 318–335.

Richter, C. F., 1958, Elementary seismology: W. H. Freeman & Co.

Richards, P. G., and Zavales, J., 1996, Seismological methods for monitoring a CTBT: The technical issues arising in early negotiations, *in* Huseby, E. S., and Dainty, A. M., Eds., Monitoring a comprehensive test ban treaty: Kluwer Academic Publishers, 53–81.

Robinson, E., 1967, Predictive decomposition of time series with application to seismic exploration: Geophysics, **32**, 418–484.

Shrock, R. R., 1966, A cooperative plan in geophysical education — The GSI student cooperative plan, 1951–1965: Geophys. Service, Inc.

———1982, A history of the geology department, Massachusetts Institute of Technology: MIT Press.

Silverman, D., 1967, The digital processing of seismic data: Geophysics, **32**, 988–1002.

Sterne, W. P., 1954, New seismic tool: Oil & Gas J., **52**, No. 2, 106–107.

Sullivan, W., 1961, Assault on the unknown — The international geophysical year: McGraw-Hill Book Co.

Summers, G. C., and Broding, R. A., 1952, Continuous velocity logging: Geophysics, **17**, 598–614.

Teller, E., and Griggs, D., 1956, Deep underground test shots: Univ. Calif. Lawrence Radiation Laboratory (Livermore) Report 4659.

U.S. State Department, 1959, The need for fundamental research in seismology: Report of the Panel on Seismic Improvement, Dr. L. V. Berkner, Chairman.

U.S. State Department, 1961, Geneva conference on the discontinuance of nuclear weapons tests — History and analysis of negotiations: Dept. of State Publication 7258 (Disarmament Series 4).

Vogel, C. B., 1952, A seismic velocity logging method: Geophysics, **17**, 586–597.

Voss, E. H., 1963, Nuclear ambush — The test-ban trap: Henry Regnery Co.

Weatherby, B. B., 1959, An appraisal of the present state of geophysical activity: Oil & Gas J., **57**, No. 32, 48–49.

Williams, M. D., 1998, Submarines under ice: the U.S. Navy's polar operations: Naval Inst. Press.

Wilson, J. T., 1961, IGY — The year of the new moons: Knopf.

Woollard, G. P., and Godley, V. M., 1980, The new gravity system: Changes in international gravity base values and anomaly values: Hawaii Inst. of Geophysics Report 80–1, Univ. of Hawaii.

Chapter 6

Am. Assn. Petr. Geol., 1928, Theory of continental drift — A symposium on the origin and movement of land masses.

Bark, E. V. D., and Thomas, O., 1980, Ekofisk: First of the giant oil fields in Western Europe: Memoir 30: Am. Assn. Petr. Geol., 195–224.

Belderson, R. H., Kenyon, N. H., Stride, A. H., and Stubbs, A. R., 1972, Sonographs of the sea floor: Elsevier North-Holland.

Benkert, W. M., 1965, Statement concerning "Oceanographic research vessels exemption," HR 3419 and HR 7320. Serial No. 89–8 Print for Committee of Merchant Marine and Fisheries, U.S. House of Representatives. (Hearings of 4–5 May 1965.)

Ben-Avraham, Z., 1981, The movement of continents: Am. Sci., **69**, 291–299.

Ben-Avraham, Z., Nur, A., Jones, D., and Cox, A., 1981, Continental accretion: From oceanic plateaus to allochthonous terrances: Science, **213**, 47–54.

Bolt, B., 1976, Nuclear explosions and earthquakes — The parted veil: W. H. Freeman & Co.

Bradley, M. A., 1998, Why they called the Scorpion "Scrapiron": Naval Inst. Proceedings, **124**, No. 7, 30–38.

Bullard, E., Everett, J. E., and Smith, A. G., 1965, The fit of the continents around the Atlantic: Philos. Trans. Royal Soc. London, Series A, **258**, 41–51.

Carpenter, E. W., 1965, An historical review of seismometer array development: Proc. Inst. Electr. and Electron. Eng., **53**, 1816–1820.

Clancy, T., 1994, Submarine: Berkeley.

Clegg, J. A., Almond, M., and Stubbs, P. H. S., 1954, The remnant magnetism of some sedimentary rocks in Britain: Philosophical Magazine, **45**, 583–598.

Cox, A., Doell, R. R., and Dalyrumple, G. B., 1964, Reversals in the earth's magnetic field: Science, **144**, 1537–1543.

Dickson, G. O., Pitman III, W. C., and Heirtzler, J. R., 1968, Magnetic anomalies in the South Atlantic and ocean floor spreading: J. Geophys. Res., **73**, 2087–2099.

Dietz, R. S., 1961, Continent and ocean basin evolution by spreading of the seafloor: Nature, **190**, 854–857.

Dobrin, M., 1962, Exploration geophysics: Today and tomorrow: Geophysics, **27**, 109–110.

Friedman, N., 1991, U.S. submarines since 1945: Naval Inst. Press.

Greenberg, D. S., 1967, The politics of pure science: The New Amer. Library.

Harris, G., 1962, How Livermore lab survived the test ban: Fortune, **65**, 127, 236–241.

Heirtzler, J. R., Le Pichon, X., and Baron, J. G., 1966, Magnetic anomalies over the Reykjanes Ridge: Deep Sea Res., **13**, 427–443.

Herrin, E., and Taggart, J., 1962, Regional variations in P_n velocity and their effect on the location of epicenters: Bull., Seis. Soc. Am., **52**, 1037–1046.

Hess, H. H., 1962, History of ocean basins: Petrologic Studies, Geol. Soc. Am., 599–620.

Hornig, D., 1965, The atmosphere and the nation's future: Bull., Am. Meteor. Soc., **46**, 438–442.

Isacks, B., Oliver, J., and Sykes, L. R., 1968, Seismology and the new global tectonics: J. Geophys. Res., **73**, 2565–2577.

Iyer, H. M., Pakiser, L. C., Stuart, D. J., and Warren, D. H., 1969, Project EARLY RISE: Seismic probing of the upper mantle: J. Geophys. Res., **74**, 4409–4441.

Jeffreys, H., 1976, The Earth, its origin, history and physical constitution, 6th ed.: Cambridge Press.

Kelly, E. J., 1966, LASA on-line detection, location and signal-to-noise enhancement: Tech. Note 1966–36, Lincoln Laboratory.

Kisslinger, C., 1971, Science and public policy — Lessons from Vela Uniform: EOS, **52**, 939, 967.

Latter, A. L., LeLevier, R. E., Martinelli, E. A., and McMillan, W. G., 1959, A method of concealing underground nuclear explosions: Report 348, RAND Corp.

Laughton, A. S., 1981, The first decade of GLORIA: EOS, **62**,

Levin, F., Bayhi, J. F., Grieves, W. A., Watson, R. J., and Webster, G. M., 1966, Developments in exploration geophysics, 1962–1965: Geophysics, **31**, 320–325.

Lewis, L., 1967, One of our H-bombs is missing: McGraw-Hill Book Co.

Manchee, E., and Cooper, W. D., 1968, Operation and maintenance of the yellowknife seismological array: Seismological Series 1968-2, Dominion Observatory, Ottawa.

Mansfield, R. H., and Evernden, J. F., 1966, Long-range seismic data from the Lake Superior seismic experiment, 1963–1964, *in* Steinhart, J. S., Ed., The Earth beneath the continents: Geophys. Monograph, **10**, 249–269: Am. Geophys. Union.

Maxwell, A. E., Von Herzen, R. P., Hsü, K. J., Andrews, J. E., Saito, T., Percival, S. F., Jr., Milow, E. D., and Boyce, R. E., 1970, Deep sea drilling in the South Atlantic: Science, **168**, 1047–1059.

Moores, E. M., 1981, Ancient suture zones within continents: Science, **213**, 41–46.

Morley, L. W., and Larochelle, A., 1964, Paleomagnetism as a means of dating geological events, *in* Osborne, F. F., Ed., Geochronology in Canada, Royal Soc. Canada, Spec. Pub. No. 8.

Oliver, J., 1996, Shocks and rocks: Seismology in the plate tectonics revolution: Am. Geophys. Union.

Pakiser, L. C., and Mooney, W. D., Eds., 1989, Geophysical framework of the continental United States: Geol. Soc. Amer., Memoir #172.

Peterson, J., and Orsini, N. A., 1976, Seismic research observatories — Upgrading the worldwide seismic data network: EOS, **57**, 548–556.

Pomeroy, P. W., Hade, G., Savino, J., and Chander, R., 1969, Preliminary results from high-gain wide-band long-period electromagnetic seismograph systems: J. Geophys. Res., **74**, 3295–3298.

Rice, R. B., 1962, Inverse convolution filters: Geophysics, **27**, 4–18.

Rocard, Y., 1962, Le signal du sourcier: Dunod.

Rockwell, D., 1967, The digital computer's role in the enhancement and interpretation of North Sea seismic data: Geophysics, **32**, 259–281.

Rodean, H. C., 1971, Cavity decoupling of nuclear explosions: Report 51097, Lawrence Radiation Laboratory.

Romney, C., and Beyer, C., 1960, U.S. offers aid to seismographic stations participating in global net using standardized equipment: Science, **131**, 1877.

Romney, C., Brooks, B. G., Mansfield, R. H., Carder, D. S., Jordan, J. N., and Gordon, D. W., 1962, Travel times and amplitudes of principal body phases recorded from GNOME: Bull., Seis. Soc. Am., **52**, 1057–1074.

Rothé, J. P., 1954, La zone séismique médiane Indo-Atlantique: Proc. Royal. Soc. London, Series A, **222**, 387–397.

Runcorn, S. K., 1955, Rock magnetism — Geophysical aspects: Advances in Physics, **4**, 244–291.

Sabins, F. F., Jr., Blom, R., and Elachi, C., 1980, SEASAT radar image of San Andreas Fault, California: AAPG Bull., **64**, 619–628.

Savit, C. H., 1960, Preliminary report: A stratigraphic seismogram: Geophysics, **25**, 312–321.

Shor, G. C., 1976, Interview of 3 July 1976 with R. A. Calvert (filed Texas A&M Univ. Oral History Collection).

Silverman, D., 1967, The digital processing of seismic data: Geophysics, **32**, 988–1002.

Specht, R. N., Brown, A. E., Selman, C. H., and Carlisle, J. H., 1986, Geophysical case history, Prudhoe Bay field: Geophysics, **51**, 1039–1049.

Springer, D., Denny, M., Healy, J., and Mickey, W., 1968, The STERLING experiment: Decoupling of seismic waves by a shot-generated cavity: J. Geophys. Res., **73**, 5995–6011.

Steinhart, J. S., and Smith, T. J., 1966, Preface To: The earth beneath the continents: Am. Geophys. Union, Geophys. Monograph 10.

Sullivan, W., 1974, Continents in motion — The new earth debate: McGraw-Hill Book Co.

Szulc, T., 1967, The bombs of Palomares: Viking Press.

Taylor, D., 1974, Understanding bright spot: Ocean Industry, **9**.

Teller, E., 1979, Energy from Heaven and Earth: W. H. Freeman.

United Electro Dynamics Seismic Data Laboratory Report, **109**.

U.S. Commission on Marine Science, Engineering and Resources, 1969, Our nation and the sea: A plan for national action, 4 vols.: U.S. Govt. Printing Office.

U.S. Navy, 1967, Lessons and implications for the Navy (Aircraft salvage operation, Mediterranean): CNO Technical Advisory Group (chaired by RADM L. V. Swanson, USN), Dept. of the Navy.

Van Melle, F. A., 1964, Editorial note concerning Vela Uniform special issue: Geophysics, **29**, 299–300.

Van Nostrand, R., and Helterbran, W., 1964, A comparative study of the SHOAL event: United ElectroDynamics Seismic Data Laboratory Report 109.

Vine, F. J., and Matthews, D. H., 1963, Magnetic anomalies over ocean ridges: Nature, **199**, 947–949.

Vine, F. J., and Wilson, J. T., 1965, Magnetic anomalies over a young oceanic ridge off Vancouver Island: Science, **150**, 485–489.

Warme, J. E., Douglas, R. G., and Winterer, E. L., Eds., 1981, The deep sea drilling project: A decade of progress: Soc. Econ. Paleont. Mineral., Spec. Pub. 32.

Wegener, A., 1915, The origin of continents and oceans (4th ed.): (English translation, Biram, J., 1966, Dover Publications.)

Wenk, E., Jr., 1972, The politics of the ocean: Univ. of Washington Press.

Wilson, J. T., 1963, Evidence from islands on the spreading of ocean floors: Nature, **198**, 536–538.

———1965, A new class of faults and their bearing on continental drift: Nature, **207**, 343–347.

———1968, Static or mobile earth: the current scientific revolution: Proc. Amer. Phil. Soc., **112**, 309–320.

Wiseman, J. D. H., and Sewell, R. B. S., 1937, The floor of the Arabian Sea: Geol. Magazine, **74**, 219–230.

Chapter 7

Barry, K., 1981, Geophysics is alive and well: Geophysics, **47**, 269–270.

Brice, W. R., 1989, Cornell geology through the years: Cornell University Press.

Carson, R., 1962, Silent spring: Houghton-Mifflin.

Clark, R. D., 1983, Sidney Kaufman: The Leading Edge, **2**, No. 7 22–27.

Cook, R. J., Barron, J. C., Papendick, R. I., and Williams G. J., III, 1981, Impact on agriculture of the Mount St. Helens' eruptions: Science, **211**, 16–22.

Crandell, D. R., Mullineaux, D. R., and Rubin, M., 1975, Mount St. Helens Volcano, recent and future behavior: Science, **187**, 438–441.

Cronan, D. S., Ed., 1999, Handbook of marine mineral deposits: CRC Press.

Domenico, N., 1974, Effect of water saturation on seismic reflectivity of sand reservoirs encased in shale: Geophysics, **39**, 759–769.

Donn, W. L., and Balachandran, N. B., 1981, Mount St. Helens' eruption of 18 May 1980: air waves and explosive yield: Science, **213**, 539–541.

Flowers, B. S., 1976, An overview of exploration geophysics — Recent geophysics and recognition of challenging new problems: AAPG Bull., **60**, 3.

Frank, A. R., 1991, The Bryn Mawr connection: The Leading Edge, **10**, No. 2, 47–48.

Lawyer, L. C., and Kay, B. V., 1984, The challenge of the Sudan: The Leading Edge, **3**, No. 2, 26–28.

Lindseth, R., 1979, Synthetic sonic logs — A process for stratigraphic interpretation: Geophysics, **44**, 3–26.

Lowman, P., and Frey, H. V., 1979, A geophysical atlas for interpretation of satellite derived data: NASA Tech. Memo. 79722, Goddard Space Flight Center.

Marr, J. D., 1971, Seismic stratigraphic exploration, Parts I, II and III: Geophysics, **36**, 311–329, 533–553, 676–689.

McKelvey, V. E., 1980, Seabed minerals and the law of the sea: Science, **209**, 464–472.

Press, F., 1981, Science and technology in the White House, 1977 to 1980: Science, **211**, 139–145, 249–256.

Press, F., and Siever, R., 1974, Earth: W. H. Freeman & Co.

Rice, R. B., 1976, Today's geophysical dilemmas — and challenges: Proc. Southwestern Legal Foundation, Exploration and Economics of the Petroleum Industry, vol. 14.

Rice, R. B., Allen, S. J., Gant, O. J., Jr., Hodgson, R. N., Larson, D. E., Lindsey, J. P., Patch, J. R., LaFehr, T. R., Pickett, G. R., Schneider, W. A., White, J. E., and Roberts, J. C., 1981, Developments in exploration geophysics, 1975–1980: Geophysics, **46**, 1088–1099.

Ritsema, A. R., 1980, Observations of St. Helens' eruption: EOS, **61**, 1201.

Robinson, R., and Iyer, H. M., 1981, Delineation of a low-velocity body under the Roosevelt Hot Springs geothermal area, Utah, using teleseismic *P*-wave data: Geophysics, **46**, 1456–1466.

Savit, C. H., 1960, Preliminary report concerning a stratigraphic seismogram: Geophysics, **25**, 312–321.

Siems, L., and Hefer, F., 1967, Discussion On: "Seismic binary gain switching amplifiers": Geophys. Prosp., **15**, 23–34.

Taylor, S. R., 1975, Lunar science — a post Apollo view: Pergamon Press, Inc.

U.S. Marine Science Commission, 1969, Our nation and the sea: U.S. Govt. Printing Office.

U.S. Office of Technology Assessment, 1980, Ocean margin drilling — A technical memorandum: U.S. Govt. Printing Office.

Ward, S. H., Sill, W. R., Chapman, D. S., Bowman, J. R., Parry, W. T., Cook, K. L., Brown, F. H., Nash, W. P., Smith, R. B., and Whelan, J. A., 1978, A summary of the geology, geochemistry and geophysics of the Roosevelt Hot Springs thermal area, Utah: Geophysics, **43**, 1515–1542.

Wenk, E., Jr., 1972, The politics of the ocean: Univ. of Washington Press.

Chapter 8

Carlile, R. E., 1981, Forecasting worldwide seismic activity, 1980–1984: World Oil, **192**, No. 3, 36–56.

Gardner, J. V., Field, M. E., and Twichell, D. C., Eds., 1996, Geology of the United States' seafloor: The view from GLORIA: Cambridge Univ. Press.

Graebner, R. J., Steel, G., and Wason, C. B., 1980, Evolution of seismic technology into the 1980s, Pt. 1: APEA J., **20**, 110–120.

Halbouty, M. T., 1981, New frontiers where future world oil and gas will be found: Presented at the 51st Ann. Internat. Mtg., Soc. Expl. Geophys.

Hammer, S., 1975, The energy crisis and geophysics — A challenge: Oil & Gas J., **73**, Feb. 3, 140, 145–146.

Henderson, F. M., and Lewis, A. J., editors, 1998, Manual of remote sensing, 3rd ed.: John Wiley & Sons, Inc.

Incorporated Research Institutions for Seismology, 1995, Iris 2000: A science facility for studying the dynamics of the solid earth: The IRIS Consortium.

Jane's Fighting Ships, 1994–95, 1994, 97th ed.: Jane's.

Kerr, A. U., Ed., 1985, The Vela program — A twenty-five year review of basic research: Defense Advanced Research Projects Agency.

Richelson, J. T., 1995, A century of spies: Intelligence in the twentieth century: Oxford Univ. Press, Inc.

Roussel, P. A., Saad, K. N., and Erickson, T. J., 1991, Third generation R&D: Managing the link to corporate strategy: Harvard Business School Press.

Sabins, F. F., 1997, Remote sensing: Principles of interpretation, 3rd ed.: W. H. Freeman & Co.

———1998, Remote sensing for petroleum exploration: The Leading Edge, **17**, 467–470, 623–626.

U.S. Library of Congress Congressional Research Service, 1998, The law of the sea convention and U.S. policy: IB95010, by M. A. Brown.

Chapter 9

Aylor, W. K., Jr., 1998, The role of 3-D seismic in a world-class turnaround: The Leading Edge, **17**, 1678–1681.

Bash, J. F., 1998, University-National Oceanographic Laboratory System research fleet: Sea Technology, **39/6**, 59–64.

Chen, Q., and Sidney, S., 1997, Seismic attribute technology for reservoir forecasting and monitoring: The Leading Edge, **16**, 445–450.

Coffin, M. F., Edholm, O., Stofla, P. L., and Austin, J. A., Jr., 1998, Looking ahead to the future of marine reflection seismology: EOS, 15 Dec. 1998.

Honigman, S. S., and Quinn, J. P., 1998, Navy blue goes green: Naval Inst. Proceedings, **124/8**, 56–59.

Kerr, R. A., and Normile, D., 1998, Ocean drilling floats ambitious plans for growth: Science, **282**, 1251–1252.

Kinsland, G. L., and Houston, L. M., 1998, Minimal effort, time lapse 3-D seismic process: Sea Technology, **39/6**, 96–97.

Leith, W., and Kluchko, L. J., 1998, Seismic experiments, nuclear dismantlement go hand in hand in Kazakhstan: EOS, 15 Sept. 1998.

Lowman, P. D., 1992, Geophysics from orbit: The unexpected surprise: Endeavour, **16/2**, 50–58.

Ratcliff, D. W., and Weber, D. J., 1997, Geophysical imaging of subsalt geology: The Leading Edge, **16**, 115–138.

Richards, P. G., Kim, W-Y, and Ekström, 1992, Borovoye Geophysical Observatory, Kazakhstan: EOS, 5 May 1992.

Richelson, J. T., 1995, A century of spies: Intelligence in the twentieth century: Oxford Univ. Press, Inc.

Rose, P. R., 1999, Taking the risk out of petroleum exploration: The adoption of systematic risk analysis by international corporations during the 1990s: The Leading Edge, **15**, 192–200.

Tatham, R. H., and McCormack, M. D., 1991, Multicomponent seismology in petroleum exploration: Soc. Expl. Geophys., Investigations in Geophysics No. 6.

Thomsen, L., 1998, Optimizing 3-D seismic surveys: Sea Technology, **39/6**, 98–101.

U.S. Department of Commerce, 1998, Year of the ocean: discussion papers: Issued by Office of the Chief Scientist, NOAA.

U.S. Library of Congress, Congressional Research Service, 1998, Nuclear weapons: Comprehensive test ban treaty and nuclear testing, IB92099: by J. Medalia.

U.S. National Academy of Sciences, 1975, Petroleum in the marine environment: Natl. Academy of Sciences.

U.S. National Aeronautics and Space Administration, 1992, Brochure, Laboratory for terrestial physics: Goddard Space Flight Center.

Van Der Vink, G., Simpson, D. W., Hennet, C. B., Park, J., and Wallace, T., 1994, Nuclear testing and nonproliferation: The role of seismology in deterring the development of nuclear weapons: Inc. Res. Institutions for Seismology.

Weimer, P., and Davis, T. L., Eds., 1996, Applications of 3-D seismic data to exploration and production: Soc. Expl. Geophys. Geophysical Developments, No. 5.

Chapter 10

Savit, C. H., 1986, Can we survive the 'oil price crisis'?: Sea Technology, **27/10**, 69.

Sheriff, R. E., 1980, History of geophysical technology through advertising: Geophysics, **50**, 2299–2410.

U.S. Council on Environmental Quality, 1980, The global 2000 report to the President: Entering the twenty-first century: 3 vols.

Chapter 11

Barrington, T., 1982, Cecil Green: The Leading Edge, **2**, No. 6, 16–23.

Dobrin, M. B., Ingalls, A. L., and Long, J. A., 1965, Velocity and frequency filtering of seismic data using laser light: Geophysics, **30**, 1144–1178.

Dobrin, M., and Savit, C. H., 1988, Introduction to geophysical prospecting, 4th ed.: McGraw-Hill Book Co.

Haggerty, P. E., 1965, Management philosophies and practices of Texas Instruments Inc.: Texas Instruments, Dallas, Texas.

Heinrichs, W. E., Jr., and Thurmond, R. E., 1956, A case-history of the geophysical discovery of the Pima Mine, Pima County, Arizona, *in* Lyons, P. L., Ed., Geophysical Case Histories, Vol. 2, Soc. Expl. Geophys, 600–614..

Lawyer, L. C., 1997, From the other side: The Leading Edge, **16,** 322.

Liner, C. L., 1997, On the history and culture of geophysics, and science in general: The Leading Edge, **16**, 939–940.

Loewenthal, D., Lu, L., Roberson, R., and Sherwood, J., 1976, The wave-equation applied to migration: Geophys. Prosp., **24**, 380–399.

Mayne, W. H., 1989, 50 years of geophysical ideas: Soc. Expl. Geophys.

Neidell, N. S., and Taner, M. Turhan, 1971, Semblance and other coherency measures for multichannel data: Geophysics, **36**, 482–497.

Peterson, R. A., Fillippone, W. R., and Coker, F. B., 1955, The synthesis of seismograms from well log data: Geophysics, **20**, 516–538.

Petty, O. S., 1976, Seismic reflections: Geosource Inc.

Schneider, W. A., 1998, 3-D seismic: A historical note: The Leading Edge, **17**, 375–380.

Schneider, W. A., and Backus, M. M., 1968, Dynamic correlation analysis: Geophysics, **33**, 105–126.

Schrock, R. R., 1989, Cecil and Ida Green: Philanthropists extraordinary: MIT Press.

Sheriff, R. E., 1980, Seismic stratigraphy: Internat. Human Res. Dev. Corp.

———1989, Geophysical methods: Prentice-Hall, Inc.

———1991, Encyclopedic dictionary of exploration geophysics, 3rd ed.: Soc. Expl. Geophys.

Senti, R. J., 1981, Geophysical activity in 1980: Geophysics, **46**, 1316–1333.

Sweet, G. E., 1978, The history of geophysical prospecting, 3rd ed.: Science Press.

Taner, M. T., and Koehler, F., 1969, Velocity spectra — Digital computer derivation and applications of velocity functions: Geophysics, **34**, 859–881.

Taner, M. T., Koehler, F., and Alhilali, K. A., 1974, Estimation and correction of near-surface time anomalies: Geophysics, **39**, 441–463.

Taner, M. T., Koehler, F., and Sheriff, R. E., 1979, Complex seismic trace analysis: Geophysics, **44**, 1041–1063.

Chapter 12

Boone, R., 1998, Distinguished achievement award for Western Geophysical: The Leading Edge, **17/9**, 1246.

Bowker, G. C., 1994, Science on the run: Information management and industrial geophysics at Schlumberger, 1920–1940: MIT Press.

Digicon and Veritas Energy Services, 1996, Joint management information circular of July 19, 1996.

du Castel, D., Pierre-Adolphe, P., Mamoud, M., and Tzanos, G. O., 1995, Journey into the earth: Editions La Sirène.

Gausland, I., and Nordberg, H., 1998, Honorary membership for Anders Farestveit: The Leading Edge, **17/3**, 385–386.

Grant Geophysical, Inc., 1998, Form 10-C report to the U.S. Securities and Exchange Commission of 15 May 1998.

Hughes, S., Barton, P. J., and Harrison, D., 1998, Exploration in the Shetland-Faerce Basin using densely spaced arrays of ocean-bottom seismometers: Geophysics, **63**, 490–501.

Layat, C., Clement, A. C., and Pommier, G., 1961, Some technical aspects of refraction seismic prospecting in the Sahara: Geophysics, **26**, 437–446.

Pieuchot, M., and Richard, H., 1958, Some technical aspects of reflection seismic prospecting in the Sahara: Geophysics, **23**, 557–573.

Savit, C. H., and Siems, L. E., 1977, A 500-channel streamer system: Presented at the 8th Annual Offshore Technology Conference.

Schlumberger, A. G., 1982, The Schlumberger adventure: Arco Publishing, Inc.

Skerl, D., 1998, Carl H. Savit — The human side: Geophysics, **63**, 682–683.

Western Atlas, 1998, Letter to stockholders of July 2, 1998.

Yilmaz, O. and Lynn, W.S., 1997, Maurice Ewing Medal citation for Kenneth L. Larner: The Leading Edge, **17**, 155.

Chapter 13

Biegert, E. K., and Millegan, P. S., 1998, Beyond reason: The new world of gravity and magnetics: The Leading Edge, **17**, 41–42.

Brozena, J. M., 1984, A preliminary analysis of the Naval Research Laboratory (NRL) airborne gravimetry system: Geophysics, **49**, 1060–1069.

Cameron, E. N., 1986, At the crossroads: The mineral problems of the United States: Wiley-Interscience.

Carson Services, 1998, Technical elements and considerations for high quality airborne gravity and magnetic surveys: Advertising brochure.

Chapin, D., 1998, Gravity instruments: past, present, future: The Leading Edge, **17**, 100–112.

du Castel, D., Pierre-Adolphe, P., Mamoud, M., and Tzanos, G. O., 1996, Journey into the Earth: La Siréne.

Fountain, D., 1998, Airborne electromagnetic systems—50 years of developments: Expl. Geophys., **29**, 1–11.

Geyer, R. A., Ed., 1992, CRC handbook of geophysical exploration at sea, 2nd ed.: CRC Press.

Gibson, R. I., and Millegan, P. S., Eds., 1998, Geological applications of gravity and magnetics: Case histories: Soc. Expl. Geophys.

Gumert, W. R., 1998, An historical review of airborne gravity: The Leading Edge, **17**, 113–116.

Guzman, J. C., 1988, Comments concerning an aerogravimetric survey of eastern Venezuela: Proc. Fourth Geophys. Congress.

Hammer, S., 1982, Airborne gravity is here: The Leading Edge, 1, No. 5, 69–72.

Jeansonne, D. A., 1998, Annual Report for 1997, OMNI Energy Services Corporation.

Jensen, H., 1986, Virgil Kauffman — A memorial lecture: Photogrammetric Engineering & Remote Sensing, **52**, 973–977.

LaCoste, J. B. L., 1934, A new type long period vertical seismograph: Physics, **5**, 178.

LaFehr, T. R., 1980, Gravity method: Geophysics, **45**, 1634–1639.

McCollum, E. V., 1941, Water prospecting with the gravity meter: World Petroleum, June, 74.

Nettleton, L. L., 1940, Geophysical prospecting for oil: McGraw-Hill Books, Inc.

Nettleton, L. L., LaCoste, L. J. B., and Harrison, J. C., 1960, Tests of an airborne gravity meter: Geophysics, **25**, 181–202.

OYO Geospace, 1997, Annual report for shareholders.

Rice, R. B., Allen, S. J., Gant, O. J., Jr., Hodgson, R. N., Larson, D. E., Lindsey, J. P., Patch, J. R., LaFehr, T. R., Pickett, G. R., Schneider, W. A., White, J. E., and Roberts, J. C., 1981, Developments in exploration geophysics, 1975–1980: Geophysics, **46**, 1088–1099.

Chapter 14

Clark, D., 1998, Introduction: Is this a good time to talk about careers in geophysics?: The Leading Edge, **17**, 786.

Domenico, S. N., and Silverman, D., 1980, Our society: Geophysics, **45**, 1800–1818.

Ingram, J., 1998, SEG salary survey: The Leading Edge, **17**, 1220–1224.

Lawyer, L. C., 1999, From the other side: The Leading Edge, **18**, 10.

Russell, B. R., 1999, Around the world in 49 days: The Leading Edge, **18**, 12, 15.

Appendix A

Howell, B. F., Jr., 1949, Ground vibrations near explosions: Bull. Seis. Soc. Amer., **39**, 285–310.

Leet, L. D., 1946, Earth motion from the atomic bomb test: Amer. Sci., **34**, 198–211.

———1960, Vibrations from blasting rock: Harvard University Press.

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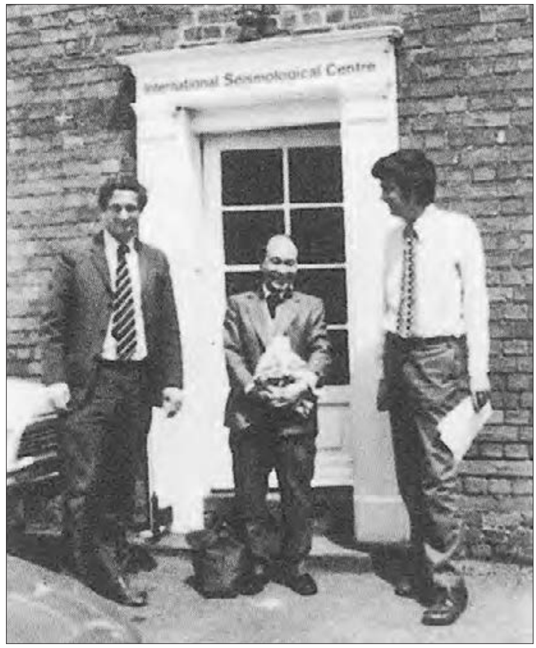
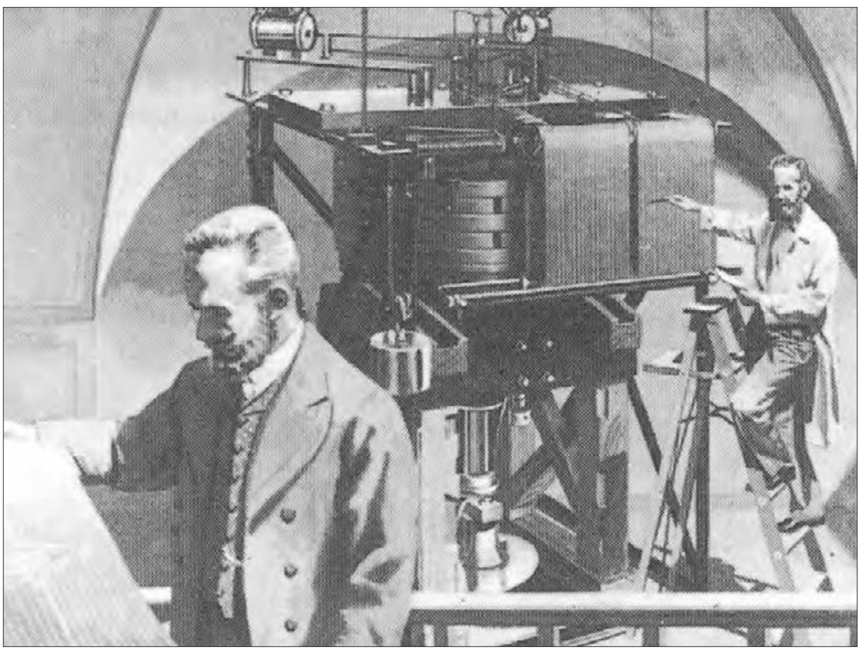
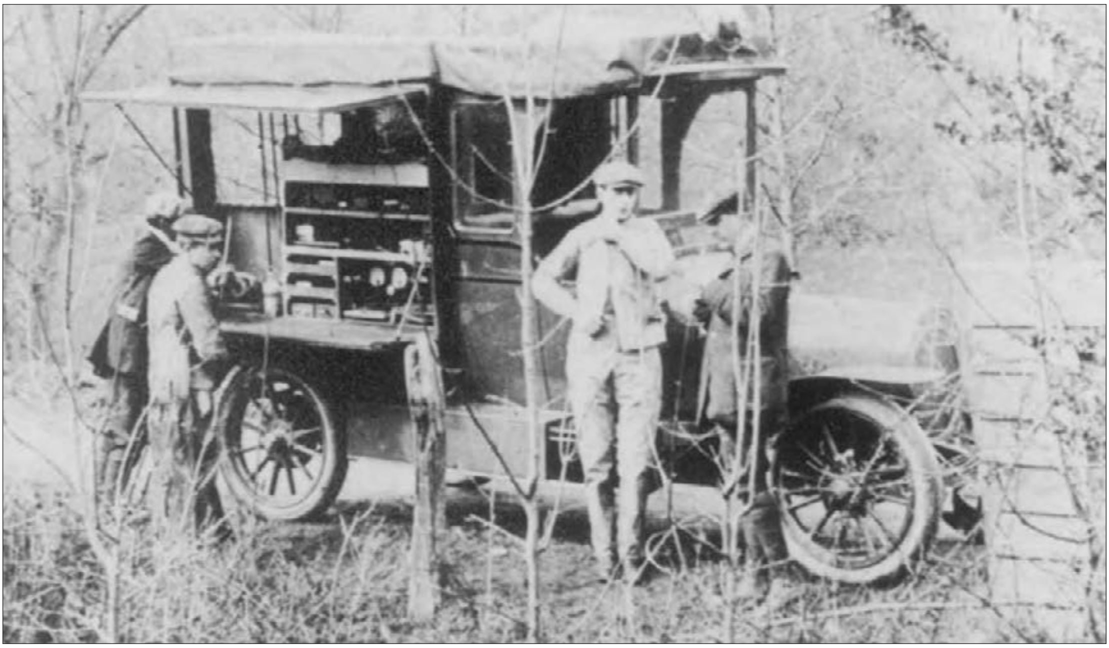




ABOVE LEFT–Baron Roland von Eötvös, inventor of the first field-worthy torsion balance (1890) (courtesy J.E. Sweet).
ABOVE RIGHT–International Seismological Centre entrance near Reading, England (1981) (courtesy Inter. Seis. Center).
BELOW–Weichert-type mechanical seismograph with central mass ranging up to 21 tons (circa 1900) (courtesy of Texas Instruments).

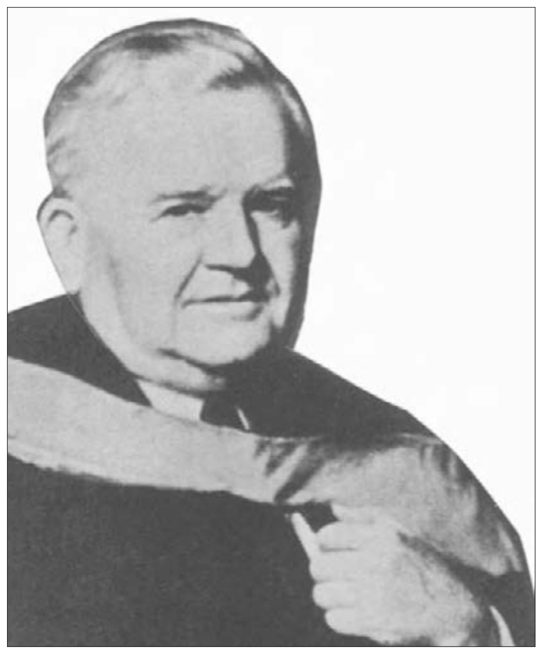
ABOVE LEFT–Prof. Reginald Fessenden, holder of reflection seismology's basic patent (courtesy Raytheon Corporation).
ABOVE RIGHT–World War I naval vessel's hydroacoustic array installation (courtesy Raytheon Corporation).
BELOW LEFT–Utilizing binaural headset in World War I underwater water signal detection (courtesy Raytheon Corporation).
BELOW RIGHT–Captain Lawrence Bragg, chief of Sound Ranging, British Army (1915–18) (courtesy J.E. Sweet).

ABOVE LEFT–Lt. Charles Bazzoni, chief of Sound Ranging Section No. 1, American Expeditionary Force (1917–18); later Sun Oil's chief geophysicist (courtesy J.E. Sweet).
ABOVE RIGHT–Dr. Ludger Mintrop, initiator of sound ranging by the German Imperial Army (1917) and later, first to locate oil rich salt domes by seismic refraction (1924) (courtesy J.E. Sweet).
BELOW–Captain Conrad Schlumberger, one of the French pioneers in reparage par le son *circa 1916 (courtesy Clarisse Doll Lebel).*



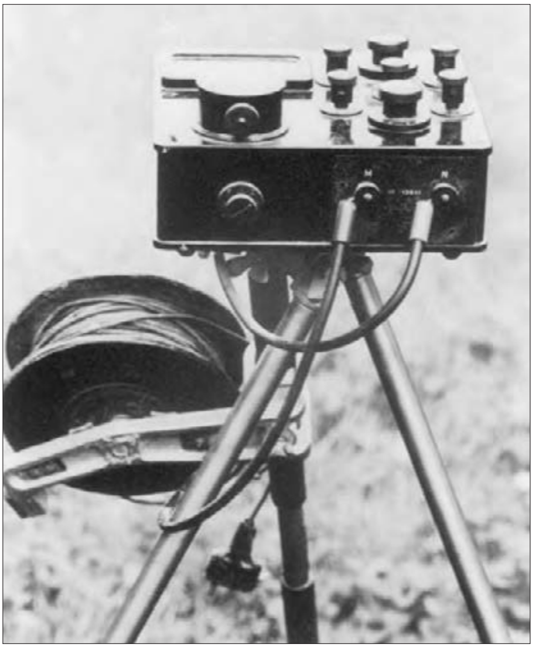
ABOVE–Conrad Schlumberger's first electrical resistivity truck (1912) (courtesy Fondation des Treilles).
BELOW–W.B. Robinson and Dr. John C. Karcher beside the Oklahoma City monument marking the location where the latter first recorded artificially induced seismic reflections (SEG file photo).



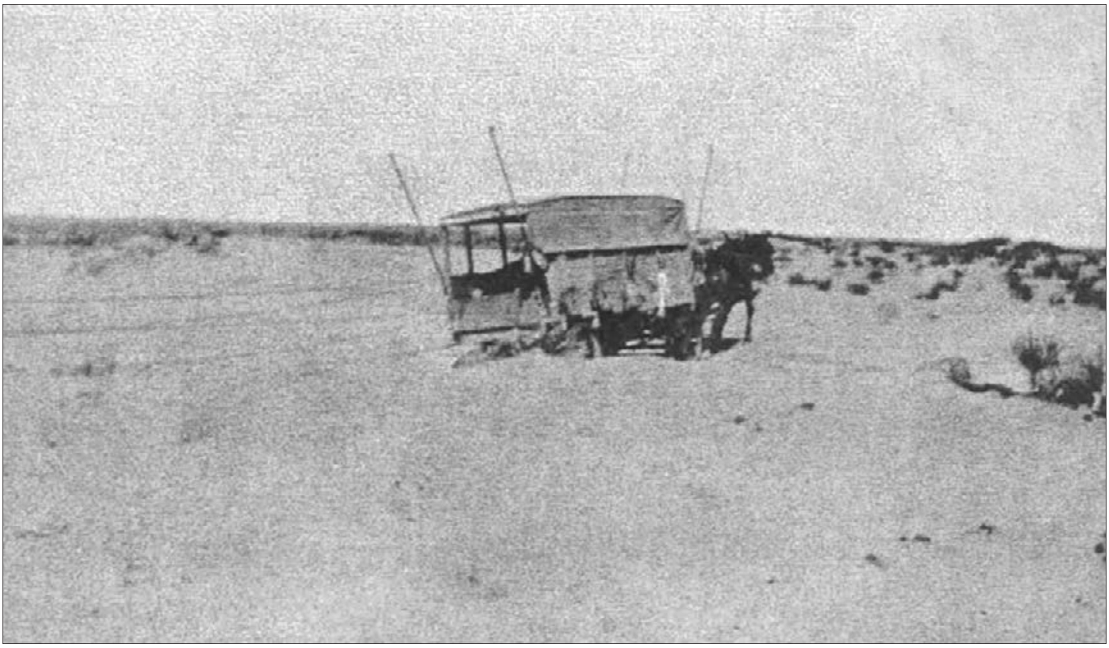



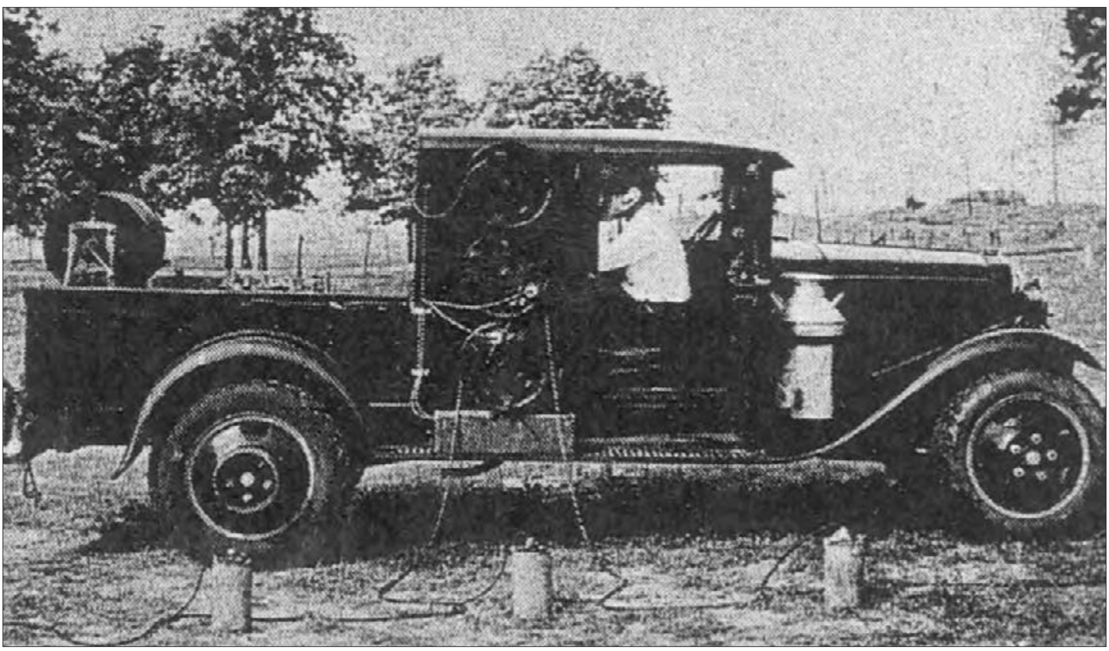
Above left–Dr. William P. Haseman, shooter for the world's first intentional reflection seismogram (courtesy J.E. Sweet).
Above right–Dr. E.A. Eckhardt, technical chief, Sound Section, U.S. Bureau of Standards (1917–18) and SEG President (1939–40) (SEG file photo).
Below left–Alongside a torsion balance, Dr. Burton McCollum, Eckhardt's wartime administrative assistant and subsequent founder of several geophysical firms (courtesy Bettye Athanasiou).
Below right–Dr. Everette De Golyer, founder of the pioneering Geophysical Research Corporation (1925) and its offshoot, Geophysical Service Inc. (1930) (courtesy J.E. Sweet).

ABOVE–O. Scott Petty, co-founder of Petty Geophysical Engineering Company, beside a tent for developing seismograph film in the Louisiana swamp, circa 1926.
BELOW–Elephants as prime movers for a Petty recording van in India, circa 1939 (courtesy Geosource Inc.).

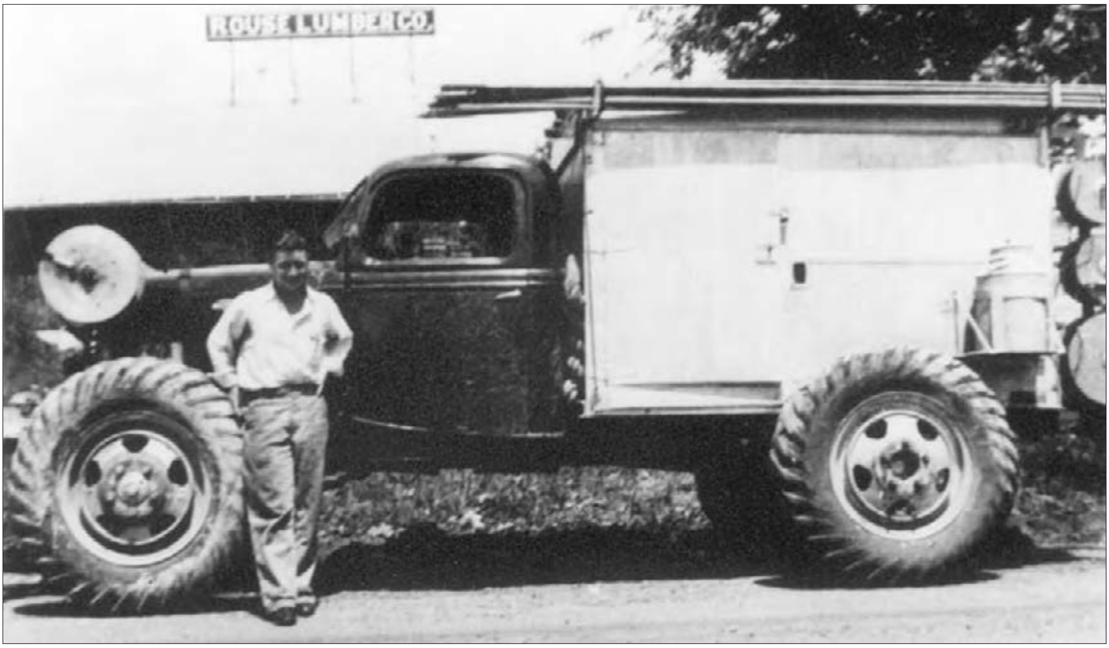


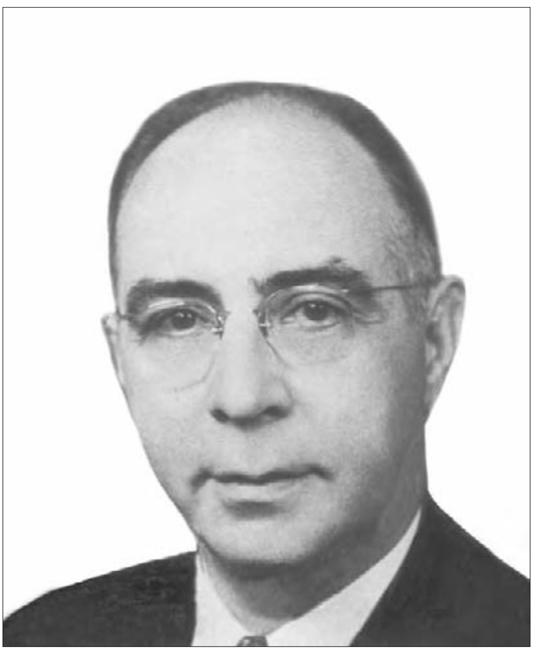
ABOVE LEFT–Société de Prospection Electrique's "black box" used for surface measurements of electrical resistivity; six such crews operated throughout North America during 1926 (courtesy Fondation de Treilles).
ABOVE RIGHT–GRC seismic refraction crew detonates a 225-kg dynamite charge in coastal Louisiana (1929) (courtesy J.E. Sweet).
BELOW–Continental Oil Company swamp buggy in Louisiana marsh (1931) (courtesy J.E. Sweet).





Above–GRC refraction crew led by T.I. Harkins prospecting for Gulf Oil Company in West Texas (1930).
Below–GSI recording truck with 16-kg seismometers "jugs" in the foreground (1931) (SEG file photos).

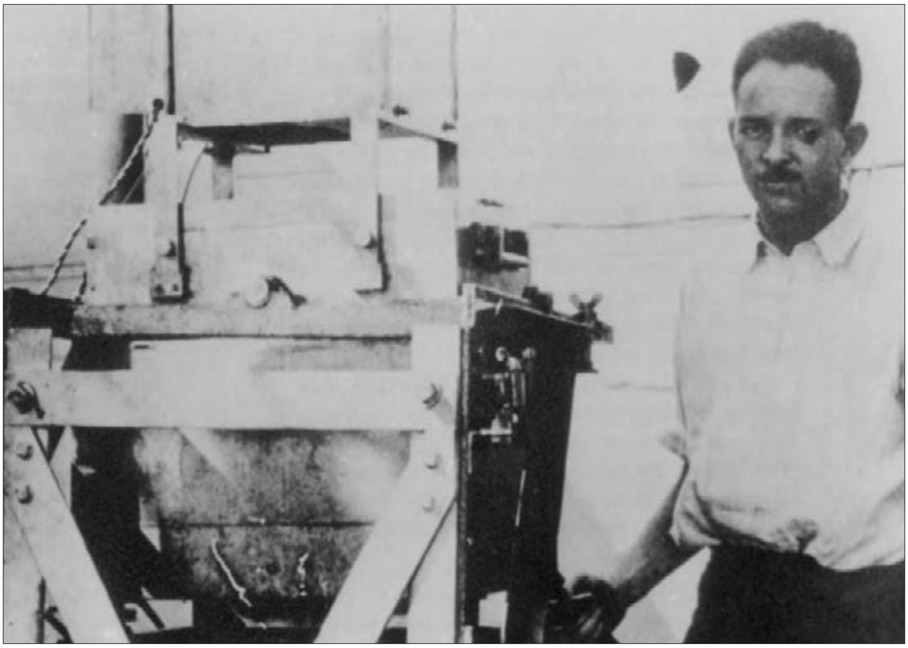


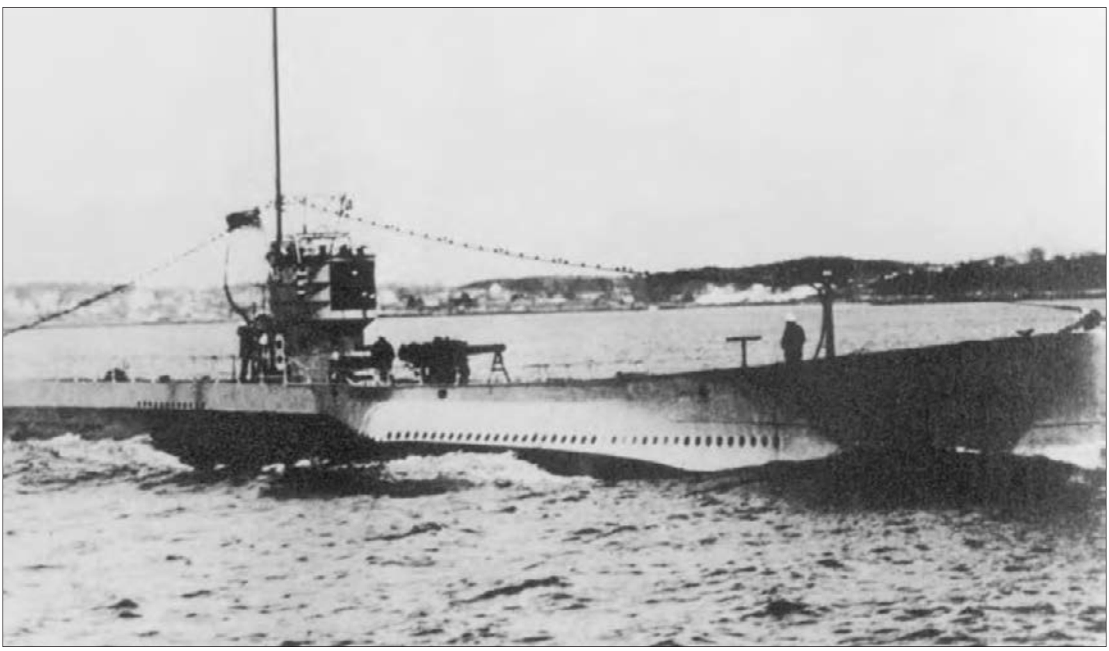


ABOVE–Observer Craig Ferris adjacent to an American Seismograph Company recording truck (1937). Six decades later, Ferris spearheaded creation of the SEG Foundation Museum (courtesy Craig Ferris).
BELOW LEFT–Andrew Gilmour, first to locate an American salt dome (Nash, in 1924) by utilizing a torsion balance; also SEG President (1949–50) (SEG file photo).
BELOW RIGHT–Dr. Norman H. Ricker of "Ricker wavelet" fame and Humble Oil's initial designer of geophysical instruments (courtesy J.E. Sweet).

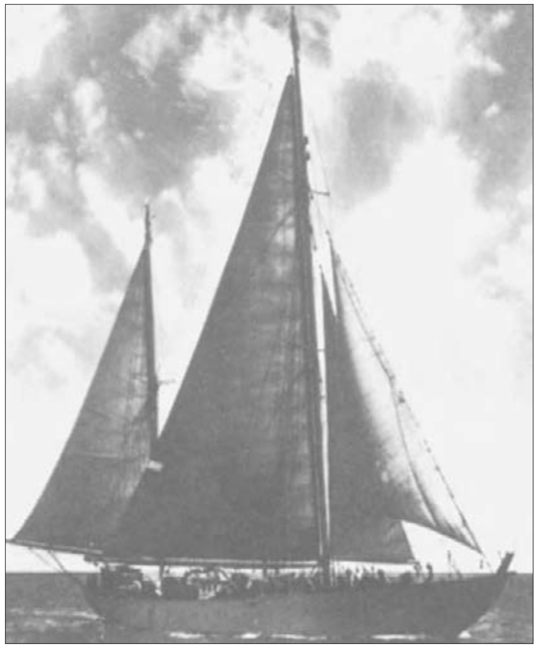



Above left–*Prof. Roland F. Beers, Sr., GSI's first party chief and later founder of the Geotechnical Corporation (1936) (courtesy Barbara Beers Trafford).*
Above right–*M. Elisabeth Stiles, SEG charter and "Life" member who served as associate editor, Geophysics (1936–37) and SEG business manager (1945–46) (SEG file photo).*
Below left–*Dr. Lucien LaCoste, prolific inventor of unique gravimetric systems (SEG file photo).*
Below right–*Dr. Ernest Hodgson, Canada's first recipient of a doctorate in seismology (1930); later, his replacement as director, Seismology Branch, Dominion Observatory, was son Dr. John H. Hodgson (courtesy J. Hodgson).*

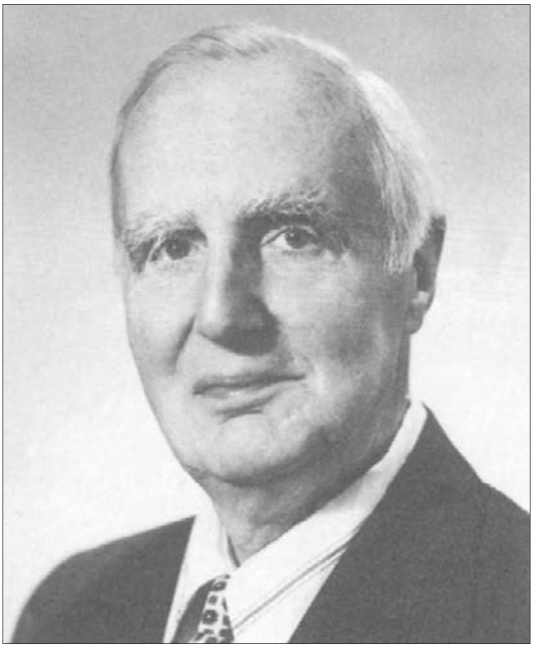




Above–Dr. Harry Hess and a Vening-Meinesz pendulum gravity sensor he operated aboard U.S. submarines (1932–36) (National Archives).
*Below–*USS S-48*, the gravity sensor platform used during the Navy-Princeton Expedition of 1932 to the area between Florida and Puerto Rico (National Archives).*



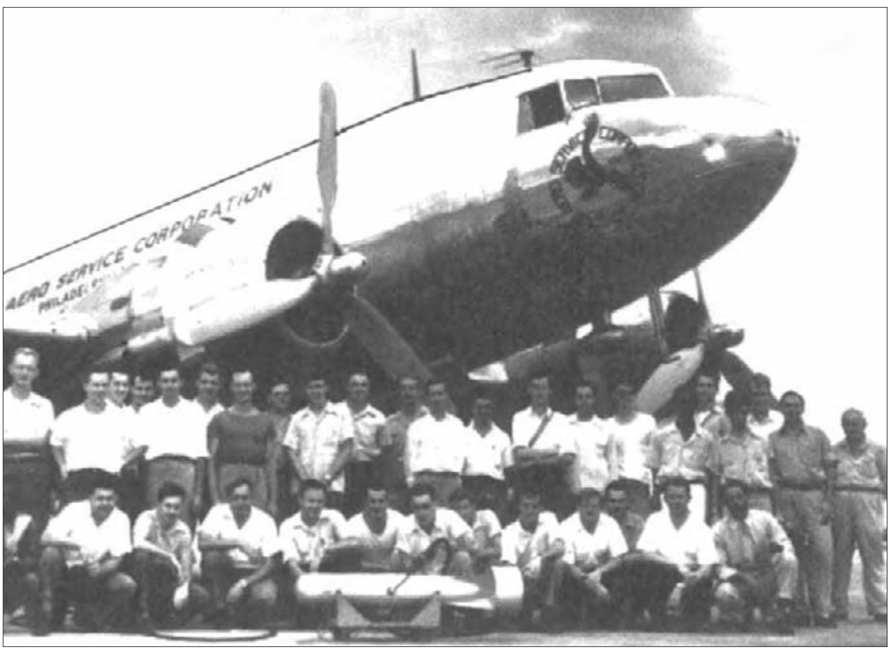
Above left–*Columbus Iselin and Rear Admiral Edward "Iceberg Eddy" Smith, USCG (Ret.), second and third directors of the Woods Hole Oceanographic Institution (1940–58) (courtesy WHOI).*
Above right–*Research vessel* Atlantis *(1932) (copyrighted by and reprinted by permission of National Geographic Society).*
Below–*Scripps Institution of Oceanography campus during the mid-1930s with La Jolla across the embayment (copyrighted by and reprinted through the courtesy of Eugene C. LaFond).*



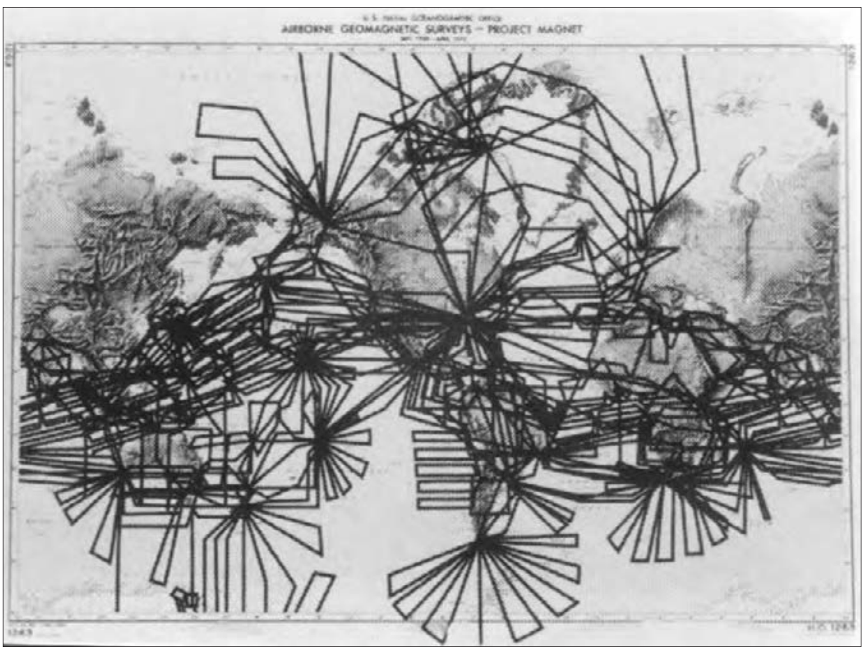
Above left–Sir Edward Bullard, eminent geophysicist in both peace and war (1930s–70s) (courtesy T. Bullard).
Below left–Dr. Thomas Gaskell, a Bullard student who became deputy science advisor, British Combined Operations (1944) (courtesy B. Athanasiou).
Right–Paul L. Lyons (SEG President, 1954–55) before "The Driller" in Robin Hood's Sherwood Forest (courtesy Abigail Lyons)

Above left–*Lt. George Elliott Sweet, USNR, cofounder American Seismograph Company and author,* The History of Geophysical Prospecting *(1978) (courtesy J.E. Sweet).*
Above right–*Operating sound recorder for a six-element microphone array, 2nd F.A. Observation Battalion, Fort Sill, Oklahoma (1941) (coauthor Bates photo).*
Below–*Picking time breaks caused by salvos of "enemy artillery" at Fort Sill (1941) (coauthor Bates photo).*

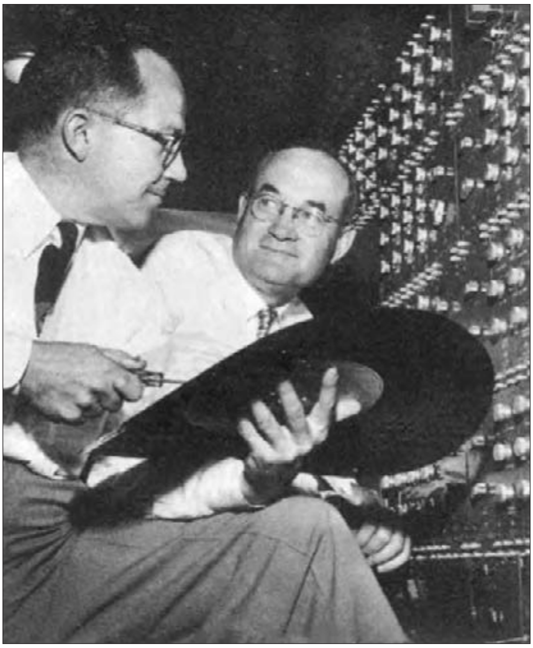
Above left–Lt. Mary Sears, USNR(W), chief, Oceanographic Unit, U.S. Navy Hydrographic Office (1943–46) (U.S. Navy photo).
Above right–Dr. Gordon G. Lill, chief, Geophysics Branch, Office of Naval Research (1950–61) (U.S. Navy photo).
Below–America's first class of military oceanographers (all Army Air Corps) at Scripps Institution of Oceanography (mid-1943). Left to right: H.G. Venn, J.C. Crowell, George Timpson, C.C. Bates, R.S. Klopper, Prof. Sir Harald Sverdrup, D.F. Leipper, and B.E. Olson. Later, Leipper initiated oceanographic departments at Texas A&M University and the U.S. Naval Postgraduate School (1951–79), Bates and Olson were successive Technical Directors, U.S. Naval Oceanographic Office (1964–79), and Crowell received the top award of the Geologocial Society of of America (1995) (courtesy Scripps Institution of Oceanography).

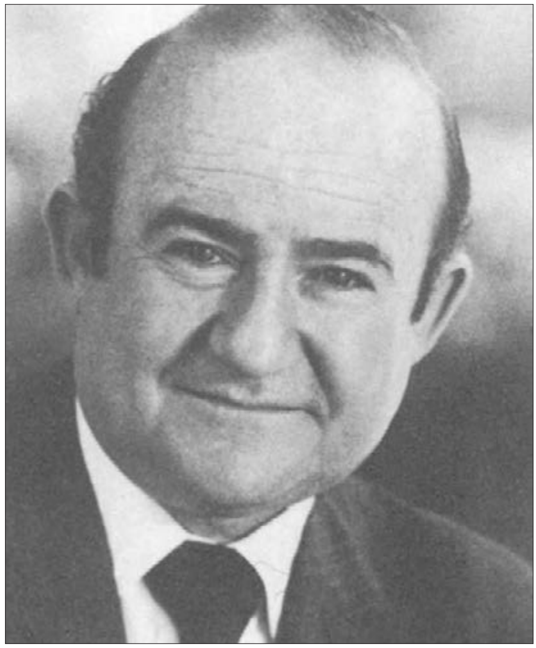


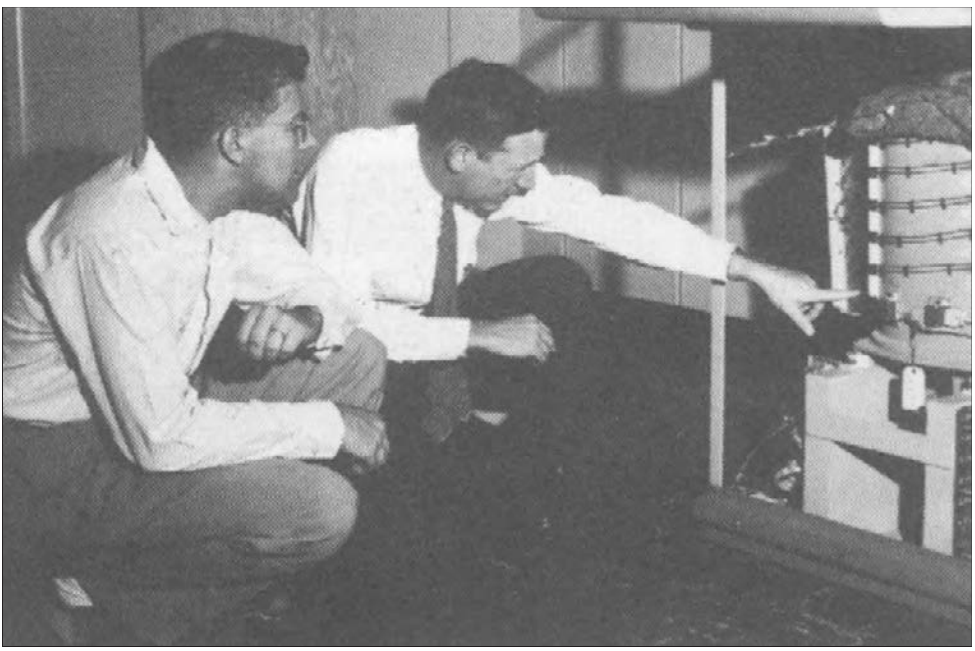
ABOVE LEFT–Prof. Maurice Ewing, first to perform seismographic measurements in the open ocean (1935). Eight years before he had been an observer on an early GRC land crew (courtesy J.E. Sweet).
ABOVE RIGHT–Prof. George P. Wollard, founder of the Hawaii Institute of Geophysics and initiator of the world gravity control net (1963) (courtesy University of Hawaii).
BELOW–Group photo of field crew used by Aeroservice, Inc., to survey the Bahamas archipelago aeromagnetically in 1947 (courtesy John M. Schmunk).



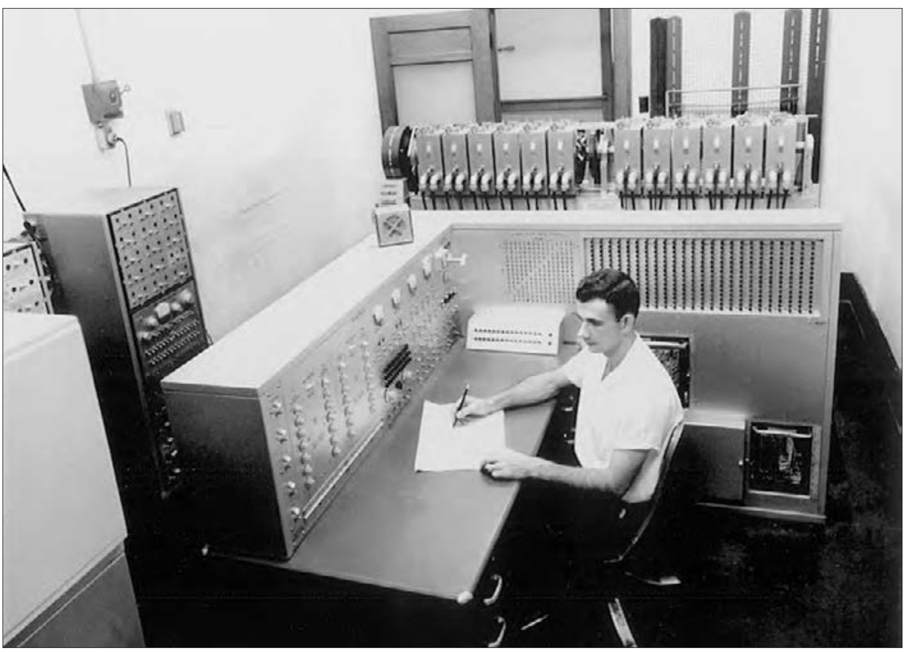
ABOVE–U.S. Navy Hydrographic Office, Suitland, Maryland in 1945 (U.S. Navy).
BELOW–Tracks of Project Magnet's aerial magnetic surveys (1959–70) (U.S. Navy).



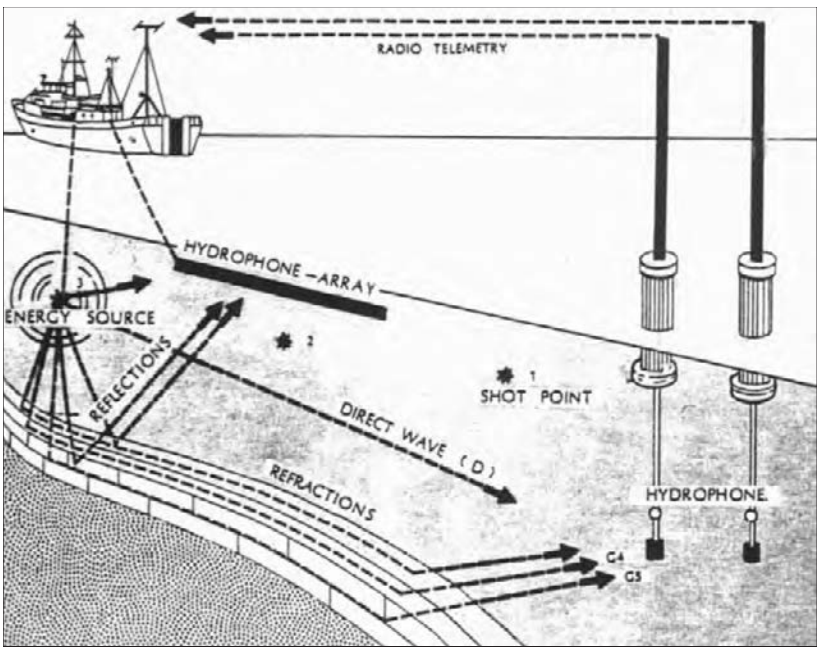




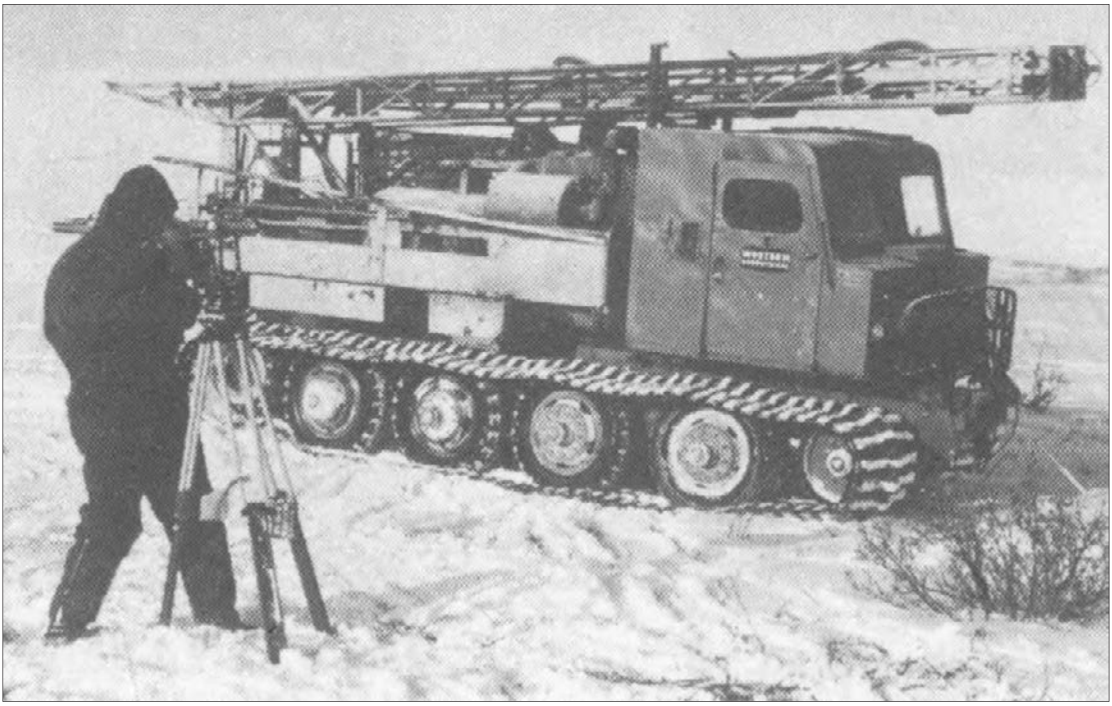
ABOVE LEFT–Fred Bucy and Cecil H. Green of GSI scrutinize a "magnedisc" in September, 1954 (courtesy Dallas Morning News*).*
ABOVE RIGHT–M. Turhan Taner, co-founder of Seiscom, Inc. (1964) and leading designer of seismic software (courtesy M.T. Taner).
BELOW–Dr. J. Edward White (right) and R.B. Rice inspect the 4000-word magnetic storage drum of an ElectroData Datatron computer in 1956 at Marathon Oil's Denver Research Center (coauthor Rice photo).



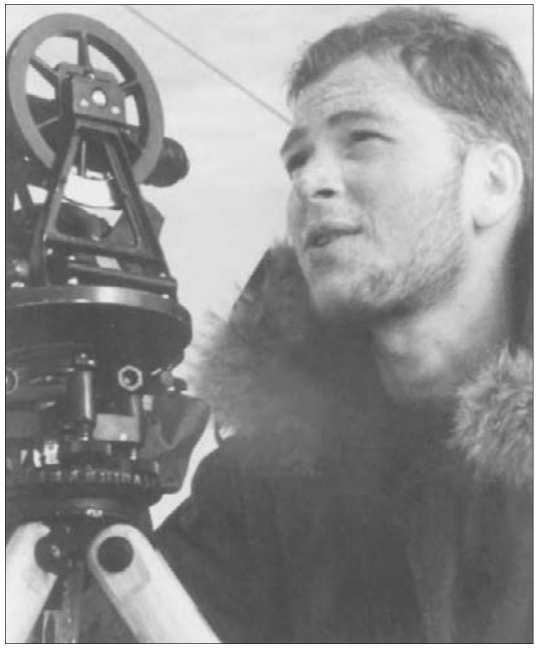
Above left–Hall-Sears miniature geophones used by the dozen in the 1960s to enhance signal-to-noise ratios (courtesy Bettye Athanasiou).
Above right–Hydrophone detector cables used in marine seismic work; by 1980, such a string could be up to 3.5 km in length (courtesy Western Geophysical Company).
Below–Operator and console of Phillips Petroleum Company magnetic tape playback center for seismic data enhancement (1957) (courtesy H.L. Mendenhall).

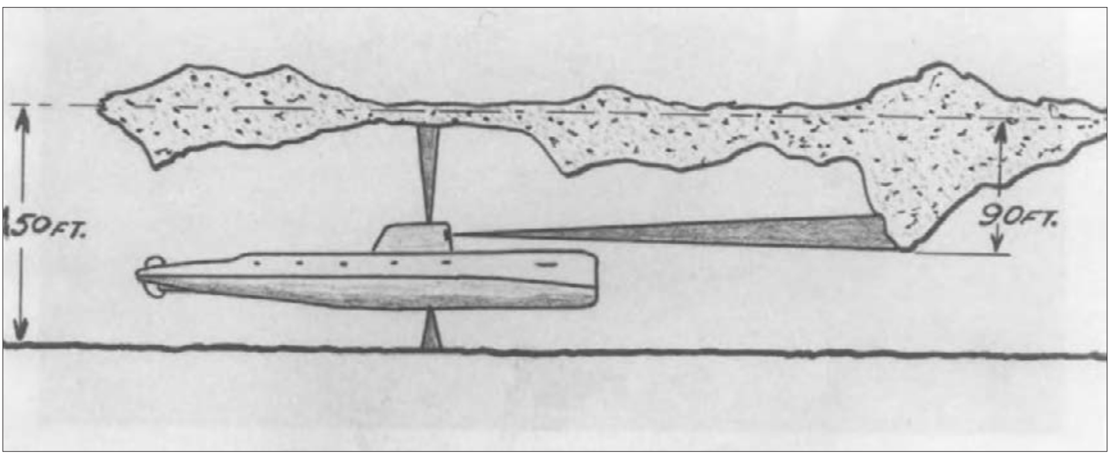


Above left–Prof. Enders A. Robinson, leader of MIT's embryonic Geophysical Analysis Group (1953–57) (SEG file photo).
Above right–Prof. Milo M. Backus, legendary developer of digital software for reverberation suppression; SEG President (1979–80) (SEG file photo).
Below–Schematic diagram illustrating method for performing seismic reflection and refraction measurements while underway (after Ludwig and Houtz, 1979).



ABOVE–Winterized surveyor and shothole drilling rig on Alaska's North Slope (1960s).
BELOW–Seismic vibrators working under the same winter conditions but a decade later.
(courtesy Western Geophysical Company).

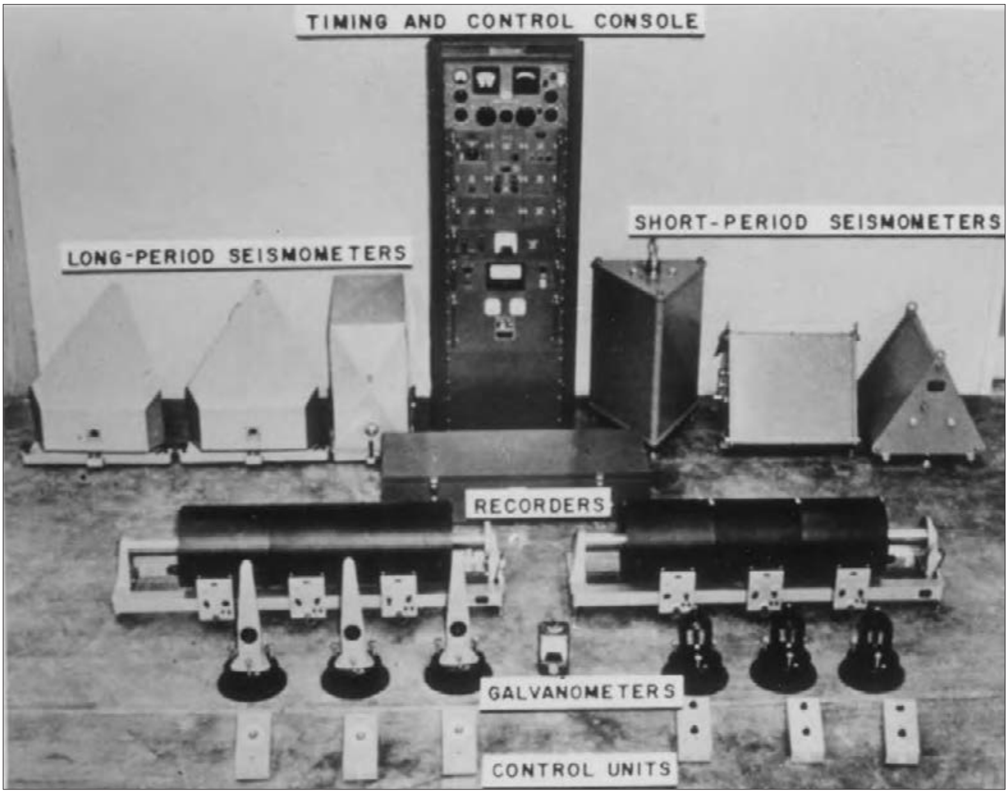




Above left–Dr. A.P. Crary, first to stand astride the North and South Poles (1952 and 1960, respectively), while operating a gravity meter on Ice Island T-3 (1951) (Military Airlift Command). *Above right*–Leonard Leshack while conducting a seismic survey of the Antarctic Ice Cap (1957). *Below*–Diagram illustrating USS Sargo's use of high-frequency sonar beams to transit the Bering Sea prior to arriving at an ice-covered North Pole (February 1960) (U.S. Naval Electronics Center).

ABOVE LEFT–Dr. Waldo Lyon, "Father of Under Ice Navigation," monitoring the ice canopy above USS Nautilus *prior to North Pole arrival on 3 August 1958 (U.S. Navy).*
ABOVE RIGHT–USCG icebreaker Storis *freeing barge of seismic equipment off Point Barrow, Alaska (July 1969).*
BELOW–Icebreaking tanker Manhattan *transiting the Northwest Passage in order to deliver a barrel of Prudhoe Bay oil to New York City (September, 1969) (courtesy Exxon USA).*

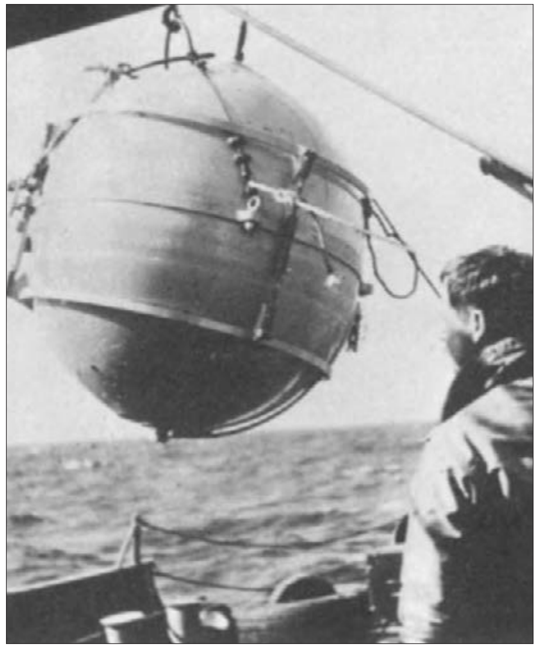
ABOVE LEFT–*Radioactive cloud of vapor and water generated by 20-kiloton Baker device in Bikini Lagoon (25 July 1946) (Joint Task Force One photo).*
ABOVE RIGHT–*Radioactive dust and vapor caused by balloon-born De Baca 2.5-kiloton event at Nevada Test Site (26 October 1958) (Las Vegas Office, Department of Energy).*
BELOW–*U.S. delegation in action at the Geneva Nuclear Test Ban negotiations (November 1969). Left to right, front row: W. Panofsky, James Fisk, and Carl Romney; second row: Frank Press, A. Turkeviche, Hans Bethe, and John Tukey (courtesy Carl Romney).*

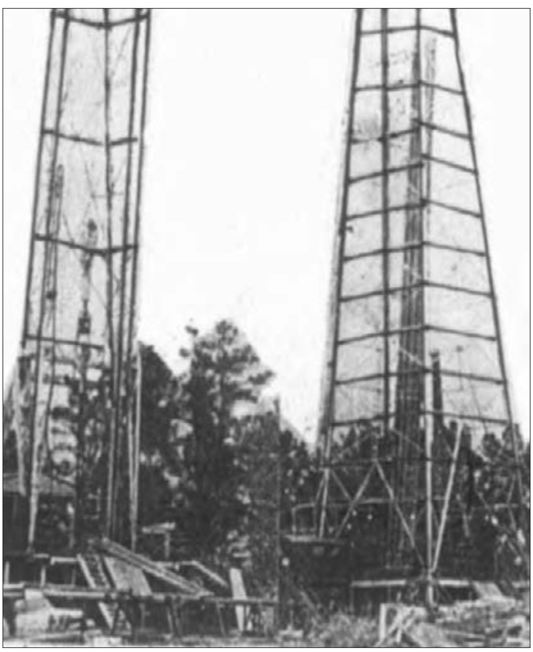


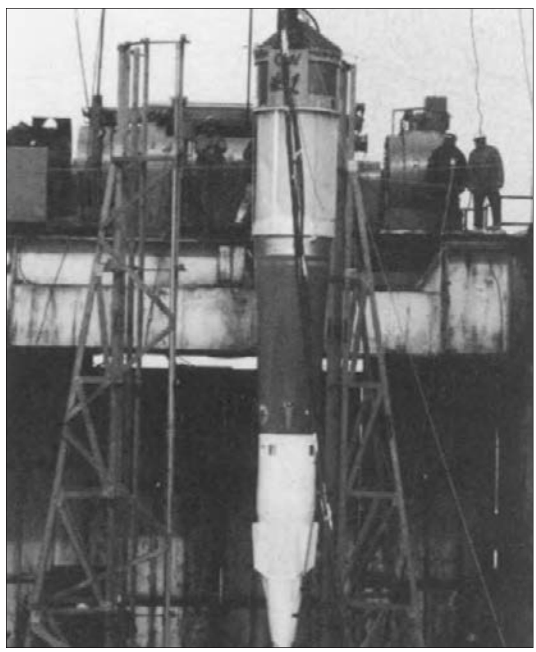
*A*BOVE*–Suite of instruments utilized in the Worldwide Standardized Seismograph Network (WWSSN) (1961) (courtesy USGS).*
*B*ELOW*–Jesuit Seismological Observatory, La Paz, Bolivia, a WWSSN site (courtesy USGS).*

Above–Lt. Seismic prospecing crew with volunteer recording of the unique Gnome event (10 December 1961) (coauthor Bates photo).
Below–One of 40 Long-Range Seismic Monitoring Units operated by Geotech (1961) (courtesy Teledyne Geotech).

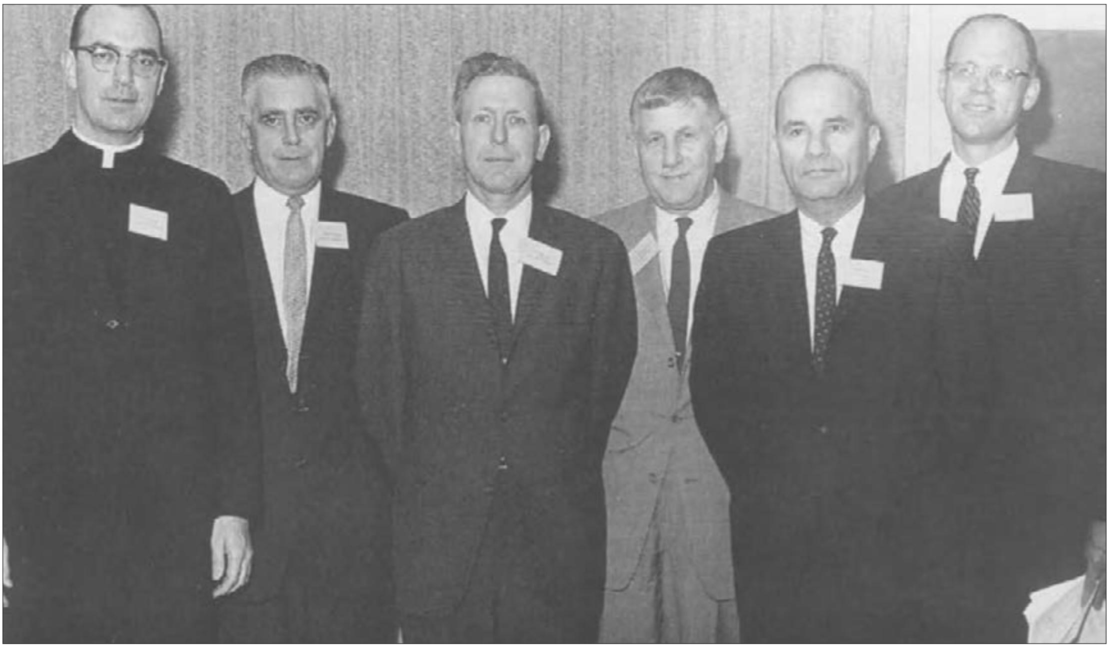
Above–Dedication Day at Berkner Seismic Array facility, Payson, Arizona (6 April 1963) (coauthor Bates photo).
Below–Artist's rendering of azimuthal array processor facility, Cumberland Plateau Seismological Observatory (1963) (courtesy Texas Instruments).





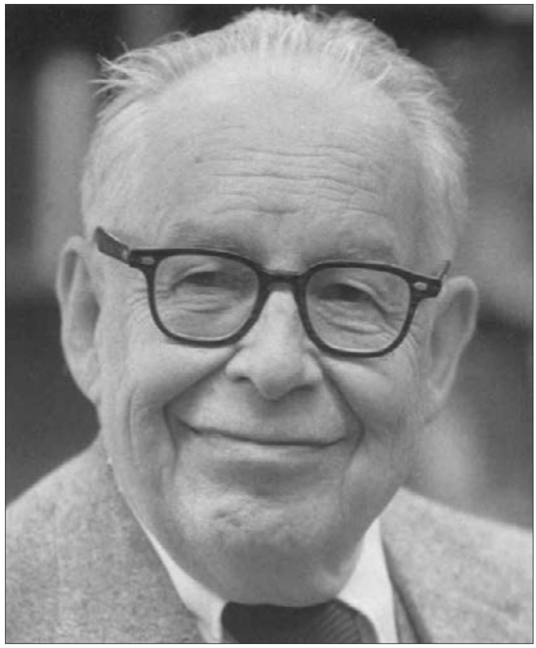


Above left–Gary Holcomb readying SRO sensor package for installation at Albuquerque Seismological Laboratory (1974) (courtesy USGS).
Above right–Deep-sea seismometer (Mark III) (1964) (courtesy Texas Instruments).
Below left–Drills readying instrumentation holes at Dribble nuclear explosion site near Baxterville, Mississippi (1964) (coauthor Bates photo)
Below right–Five megaton (approximate) Cannikin device being lowered into Amchitka Island for Vela Uniform's largest research explosion (6 November 1971) (courtesy Las Vegas Office, Department of Energy).

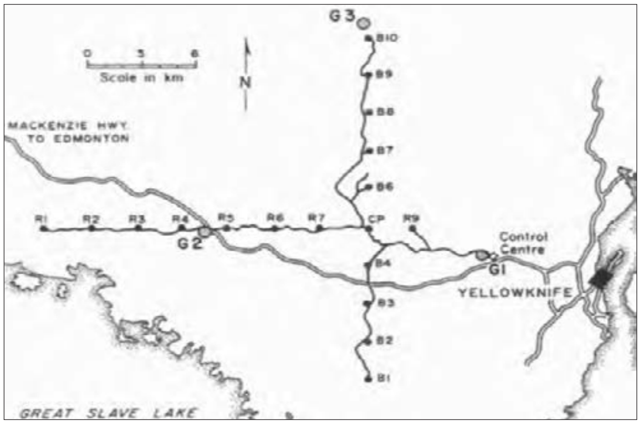


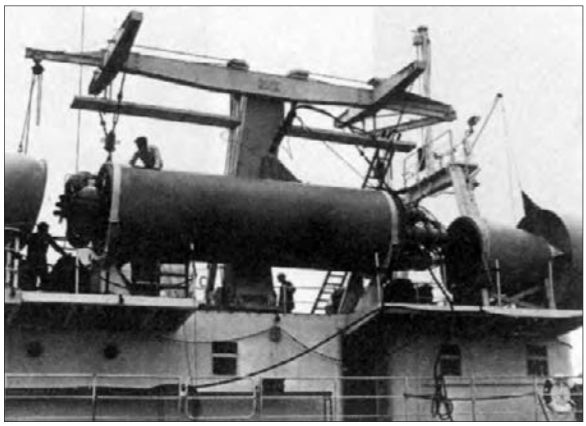
ABOVE–Air Force Office of Scientific Research's Seismological Advisory Committee (1964). Left to right: Dr. William Stauder, S.J.; Dr. Thomas O'Donnell, Gulf Research; Prof. James Wilson; Prof. Hugo Benioff; Dr. Sidney Kaufman, Shell Oil, and Prof. Jack Oliver (courtesy American Geophysical Union).

BELOW–"Relax, Bing! Sooner or later, one of them will come up with something!" *Concept of Major Robert Harris, USAF, converted into a sketch by Pricilla Robinson (1962).*



Above left–Louis Pakister, ex-Carter Oil company seismologist and instigator of the USGS's crustal studies program (courtesy L. Pakiser).
Above right–Prof. Charles Richter, inventor of the "Richter scale" of seismic magnitude (1935).
Below bottom left–Blacknext near Brimpton, Berkshire, home of the British Tabor Pluto program (courtesy H.I.S. Thirlaway).
Below top right–Spoof of British seismic array method (copyrighted by and used with permission of Daily Mirror, *London, 1962).*

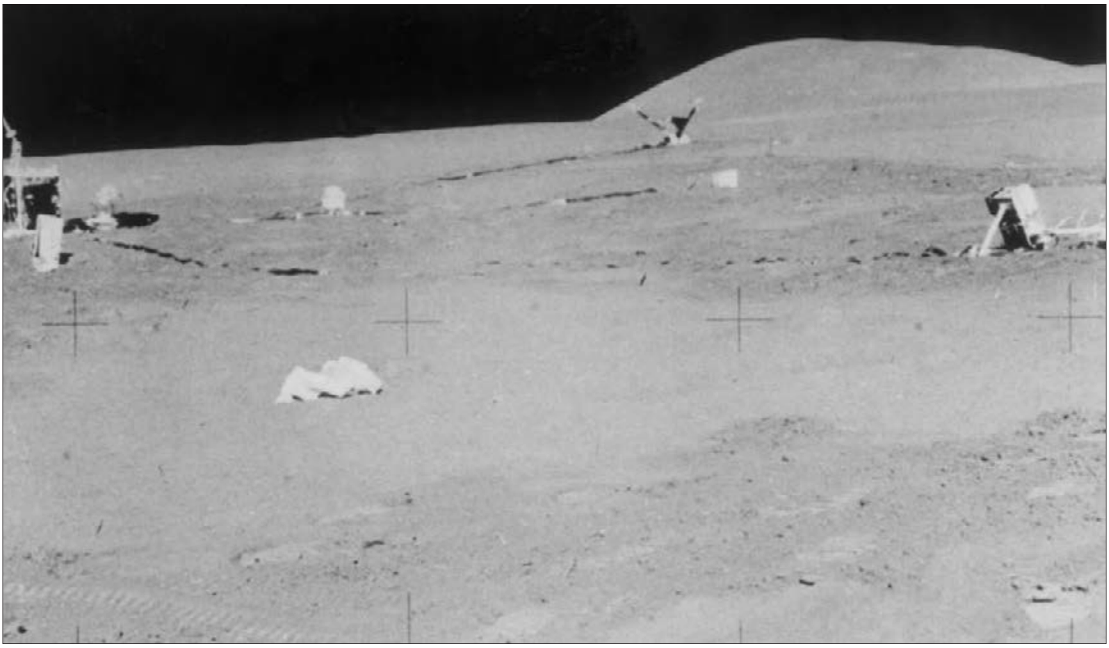


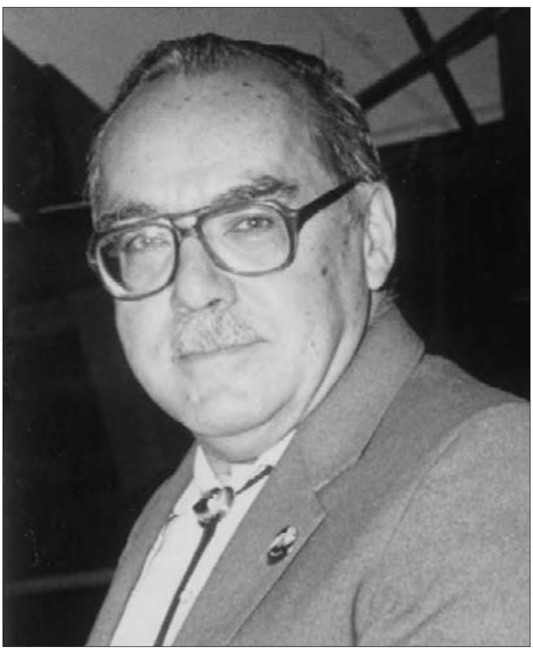


ABOVE–British-Canadian seismic array near Yellowkife, Northwest Territories (1974) (courtesy Energy, Mines and Resources Canada).
CENTER–Gloria (Mark I) side-looking sonar disassembled (courtesy A.S. Laughton).
BELOW–Wayward five-megaton bomb retrieved by U.S. Navy from waters off Palomares, Spain (1966) (U.S. Navy photo).

Above left–*Dr. H.I.S. Thirlaway (left) and Prof. L.P. Passechnik (right) at the Geneva session of the UN Disarmament Committee's ad hoc Group of Scientific Experts (1981) (courtesy H. Thirlaway).*
Above right–*Sir Anthony Laughton, developer of the Gloria side-looking sonar system and director, United Knigdom Institute of Oceanographic Sciences (1978–88) (courtesy A.S. Laughton).*
Below left–*Capt. J.E. Snyder, USN, (right) debates with RADM Harry "Plate Tectonics" Hess, USNR, prior to Snyder assuming command (1966) of the battleship, USS* New Jersey. *Later on, Snyder received the SEG Special Commendation Award (1980).*
Below right–*Dr. Robert A. Frosch experimenting with forked stick technology at Flers, Normandy (1963).*

ABOVE–Final meeting of U.S. Commission on Marine Science, Engineering and Resources (December 1968). Clockwise from center: David Adams (North Carolina), C.F. Baird (New York), Leon Jaworski (Texas), Taylor Pryor (Hawaii), Vice Chairman Richard A. Geyer (Texas), Chairman Julius Stratton (Massachusetts), Samuel Lawrence (staff), George H. Sullivan (Pennsylvania), Jacob Blaustein (Maryland) and John A. Knauss (Rhode Island) (U.S. Coast Guard).
BELOW–Retirement ceremony in Assistant Secretary of the Navy (R&D) Robert A. Frosch's office (January 1972). Left to right : Gordon Lill, Robert Abel, J. Lamar Worzel, Arthur Maxwell, Secretary Frosch*, Gordon Hamilton, John Ewing*, B.K. Couper (retiree), unknown, Alan Vine, E. La Fond, Maurice Ewing* and J. Brackett Hersey* (U.S. Navy). (Asterisk denotes SEG member).*

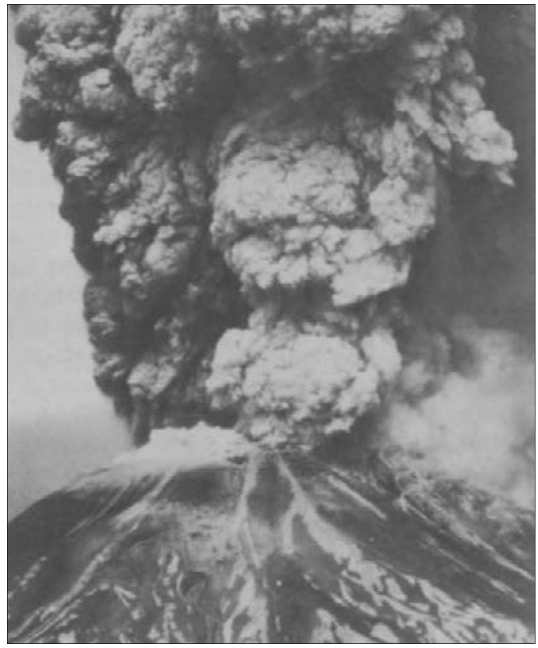




Above–Apollo Lunar Surface Experiment Package (ALSEP) deployed near the moon's Cone crater on 6 February 1971 by astronauts Alan Shepard and Edgar Mitchell (Apollo 14).
Left side: Press-Ewing designed seismometer subsystem adjacent to larger plutonium-powered central recording/transmitting station; center: magnetometer subsystem; right side: mortar for creating man-made seismic events (NASA).
Below left–Dr. Paul W. Lowman, Jr., initial Director, Geophysics Branch, Goddard Space Flight Center (courtesy P.W. Lowman, Jr.).
Below right–Willard Bascom, the first ocean engineer to utilize dynamic positioning for deep sea drilling (courtesy W. Bascom).

Above–Exploration seismologists Milton Dobrin, Sidney Kaufman, and Harry Mayne inspect a COCORP deep reflection record in 1975 (courtesy S. Kaufman).
Below–President Jimmy Carter (right) inspects the book, Earth, *coauthored by his Science Adviser, Dr. Frank Press (1977) (White House photograph).*

Above–USNS Stalwart *(T-AGOS-1), the Navy's first ocean surveillance ship (1982) (U.S. Navy photo).*
Below–Soviet Victor III attack submarine capable of 33 knots submerged wallows at the surface after becoming entangled in towed array cable off the Carolina coast (1983) (U.S. Navy photo).



Above left–Mount St. Helens, a quiescent volcano until 1980 (USGS).
Above right–Mount St. Helens during the seismologically indicated eruption of 18 May 1980 (USGS).
Below–IRIS's PASSCAL Instrumentation Facility, Socorro (courtesy New Mexico Institute of Mining and Technology).

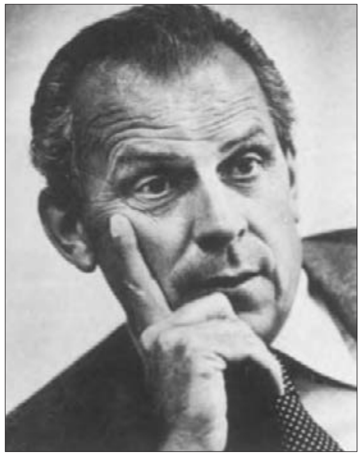
Above–President William Clinton signs a directive of 12 June 1998 extending the offshore leasing moratorium out to year 2012. Left to right: Leon Panetta (former White House chief of staff), Congresswoman Anna Eshoo, Vice President Albert Gore, Congresswoman Lynn Woolsey, President Clinton, Congressman George Miller, Congresswoman Lois Capps, Congressman Sam Farr, Senator Barbara A. Boxer, and aquanaut Sylvia Earle (U.S. Navy photo credited to Javier Chagoya, U.S. Naval Postgraduate School).

Below left–Waverly Person, director, National Earthquake Information Center (USGS), Golden, Colorado (USGS).

Below right–U.S. Secretary of the Interior Bruce Babbitt (1992–2001) holder of a master's degree in earth physics (courtesy B. Babbitt).

Major technological advances in exploration geophysics during the 1990s.
Above–Twin Otter aircraft capable of simultaneously performing quality airborne gravity and magnetic surveys (courtesy Carson Servcies).
Center–Airborne time-domain pulsed electromagnetic system (Megatem™) mounted on Dash 7 aircraft (courtesy Geoterrex-Dighem, a CGG subsidiary).
Below–Ramform design seismic survey vessel underway with ten full-length streamers for making rapid 3-D surveys (courtesy Petroleum Geo-Services, 1998).

Early explorationists of note:
Above left–Dr. Donald C. Barton, founding SEG President (1930–32).
Above Center–Dr. Paul Weaver, second SEG President (1932–33).
Above Right–Dr. Louis L. Nettleton, gravity specialist and SEG President (1948–49).
Below Left–Dr. Sigmund Hammer, gravity survey proponent and SEG President (1951–52);
Below Center–Dr. M. King Hubbert, creator of "Hubbert's Pimple" relative to oil production versus time.
Below right–Dr. J. Tuzo Wilson, Canada's leading geophysicist of the 1960s and 1970s. (SEG photo files).



Contemporary exploration geophysicists of note:
Above left–Dr. Ned Ostenso, Director, Sea Grant Programs, National Science Foundation (courtesy N. Ostenso).
Above center–Dr. Anthony Barringer, holder of 40 patents in serial and geochemical prospecting (courtesy A. Barringer).
Above right–Prof. Randolph Bromery, first geophysicist to serve on a "Seven Sisters" board of directors (Exxon, 1977–) (courtesy University of Massachusetts).
Below left–Dr. Roland G. Henderson, first USGS staff member to be named SEG Honorary Member (1976).
Below center–Bettye Athanasiou, SEG Life Member (1978) (SEG file photo).
Below right–Dr. Gregory E. van der Vink, multifaceted planner, IRIS Consortium (1989–) (courtesy G.E. van der Vink).

Above left–Norman J. Christie, first Canadian to become SEG president (1963–64) (SEG file photo).
Above right–R.O. Lindseth, pioneer in seismic stratigraphy and founder of several Canadian digital processing firms; also SEG president (1976–77) (SEG file photo).
Below–Reception at the Sixth Anniversary Meeting of the European Association of Exploration Geophysicists at The Hague, Netherlands (June 1976) (courtesy EAGE).

Doodlebugging is never easy.
Above–Preparing shotholes in the Tunisian desert.
Below–Pakistani bullock cart transporting geophone cables. (Note: Photos are from the late 1970s and are provided courtesy of Western Geophysical Company).

"Westerners" in action.
Above–Founder Henry Salvatori and his senior research specialist, Carl Savit (41 patents to his credit), exchanging viewpoints.
Center–Western Geophysical Comapny's world headquarters in Houston, Texas.
Below–Magnetic tape reels of seismic recordings by the thousands awaiting processing in Houston data center (1978).
(photos courstesy Western Geophysical Company.)

ABOVE–Geophysical Service Incorporated's new owners of 6 December 1941—J. Erik Jonsson, Henry Bates Peacock, Eugene McDermott, and Cecil H. Green.
BELOW–Cutting GSI's 40th Anniversary cake (1970) by the firm's sundry presidents.
Left to right: John C. Karcher, Eugene McDermott, Fred Agnich, Robert C. Dunlap, Jr., Mark K. Smith, Cecil H. Green, Edward O. Vetter, and H. Bates Peacock
(photos courtesy Texas Instruments.)

ABOVE LEFT–Cecil and Ida Green in front of Green Earth Sciences Building on MIT campus circa 1970 (courtesy MIT Historical Collections).
ABOVE RIGHT–Charles F. Darden, long-time president of International Association of Geophysical Contractors (1998) (courtesy C. Darden).
BELOW LEFT–Sally Griffiths Zinke, SEG President (2000-01).
BELOW RIGHT–Main entrance to five-story AGU Headquarters, Washington, D.C. (courtesy American Geophysical Union).

Cecil and Ida Green Tower at the SEG Geophysical Resource Center located at 8801 South Yale, Tulsa, Oklahoma (1985).

ABOVE–Modern Geophysical workstation (courtesy Landmark Graphics).
BELOW–Group photo of past SEG Presidents. Top row (left to right): Milo M. Backus, W. T. Born, L. Decker Dawson, Douglas D. Barman, Kevin M. Barry, Thomas R. LaFehr, J. Dan Skelton; middle row: Kenneth L. Larner, Sigmund I. Hammer, Norman J. Christie, E. John Northwood, L. C. (Lee) Lawyer, Roy O. Lindseth, J. E. White, A. M. Olander, T. Norman Crook; bottom row; Carl H. Savit, E. R. Brumbaugh, Marvin R. Hewitt, Cecil H. Green, Robert J. Graebner, Paul L. Lyons, and W. Harry Mayne.