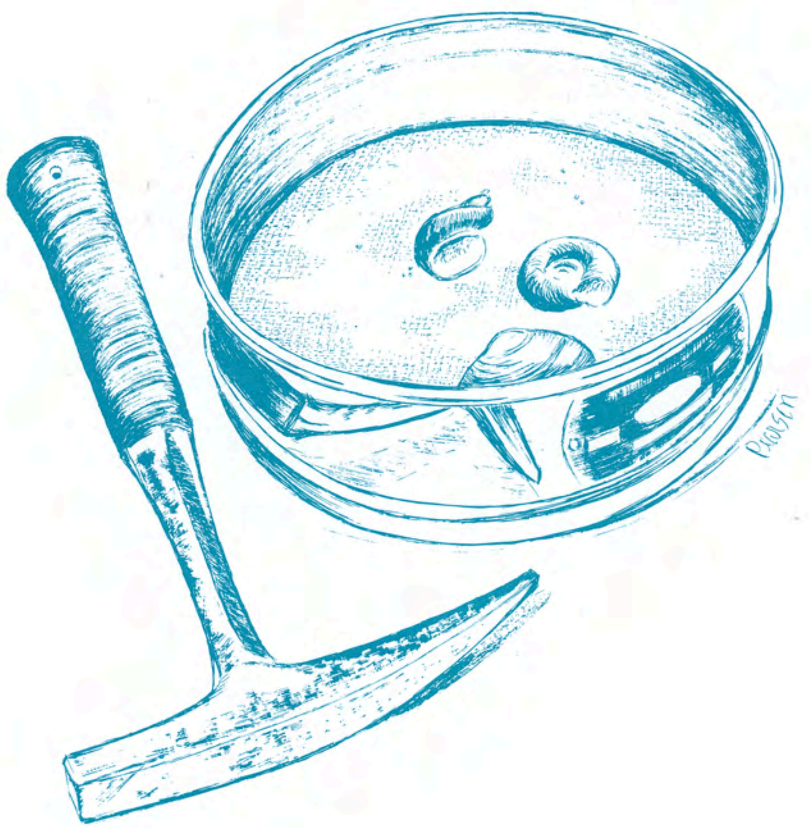
Pliocene and Pleistocene Deposits and Molluscan Faunas, East-central New Mexico

by A. BYRON LEONARD and JOHN C. FRYE



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Abstract

A reconnaissance of Pliocene and Pleistocene geology, and Pleistocene fossil mollusks was made for the region of east-central New Mexico, including the High Plains and Pecos valley areas, northward from northern Eddy County to the south side of Canadian River valley. The Ogallala Formation (Pliocene) was deposited by streams flowing east-southeast, resulting in a broad alluviated plain that masked the earlier erosional topography. Early Pleistocene time witnessed structural tilting and warping, increased precipitation, and development of a new drainage system that flowed eastward through the now abandoned Portales valley into Texas. An independent southward drainage system captured the drainage through Portales valley in the vicinity of Fort Sumner, and thus produced the present Pecos River.

Molluscan faunal assemblages from 45 localities produced a composite fauna of 47 species; 2 assemblages are from deposits judged to be Kansan, 7 assemblages are from Holocene terrace deposits dated at 6,000 to 5,000 radiocarbon years B.P.; the remaining assemblages are Woodfordian, 7 of them radiometrically dated at ages ranging from 18,000 to 13,000 B.P. Inferences drawn from the molluscan faunas include: 1) the 2 Kansas faunas lived in a xeric environment not unlike that produced by the present-day climate; 2) a long, perhaps intermittent pluvial period existed in the region from 18,000 to 13,000 B.P. and perhaps longer; and 3) by about 5,000 ***B.P.*** the present semiarid climate was well established. While the long pluvial period produced environments suitable for branchiate gastropods, many aquatic pulmonates, and a variety of terrestrial gastropods, evidence of forest cover or a climate significantly cooler than today is not clear.

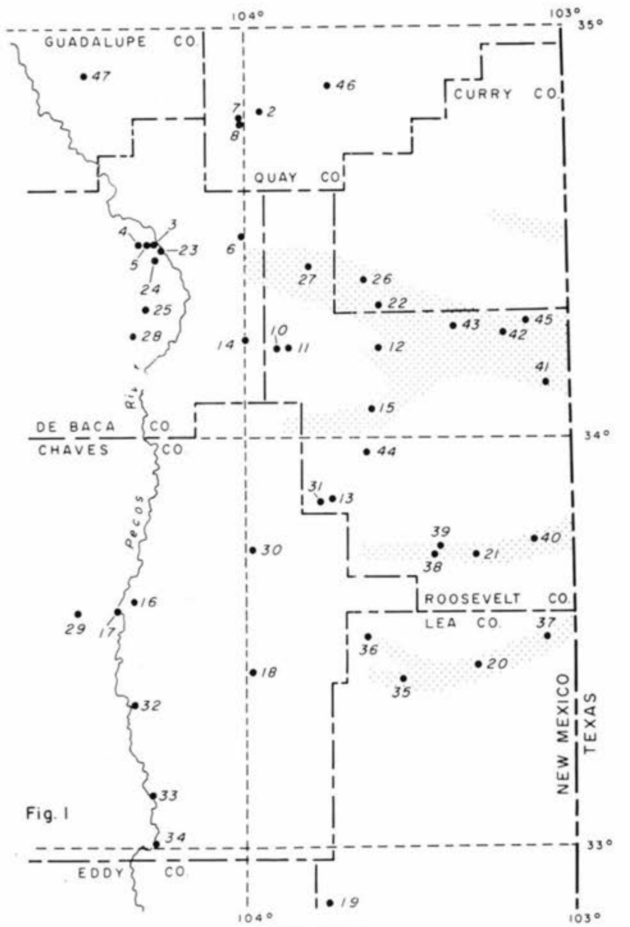


FIGURE 1

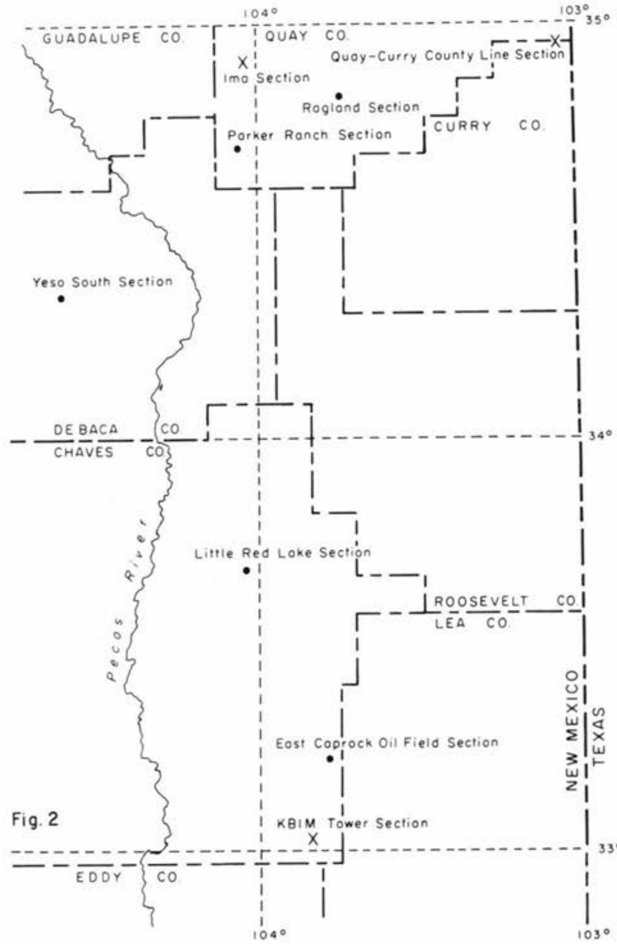
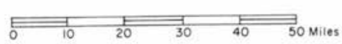


FIGURE 2



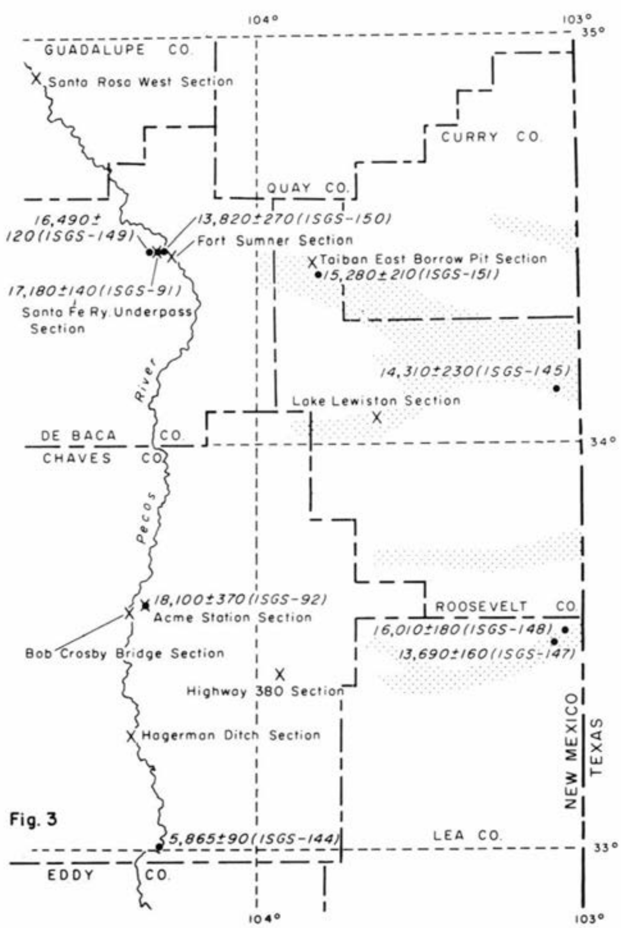


FIGURE 3

FIGURE 1-LOCALITIES FROM WHICH FOSSIL COLLECTIONS ARE DESCRIBED. LOCATION DATA FOR EACH COLLECTION ARE GIVEN IN APPENDIX A. THE LIGHTLY STIPPLED AREAS SHOW THE LOCATION OF THE ABANDONED PORTALES VALLEY, AND SEVERAL MINOR LINEAR TOPOGRAPHIC SAGS THAT MAY ALSO BE ABANDONED VALLEYS.

FIGURE 2-LOCATION OF MEASURED STRATIGRAPHIC SECTIONS OF OGALLALA FORMATION INCLUDED WITH THIS REPORT, SHOWN BY DOTS, AND THOSE PUBLISHED IN TARGET EXPLORATION REPORT E-6 (FRYE AND LEONARD, 1972), SHOWN BY AN "X." LOCATION DATA ARE GIVEN IN APPENDIX B.

FIGURE 3-LOCALITIES FROM WHICH RADIOCARBON DATES WERE DETERMINED (SOLID DOTS) AND THE DATES, AND LOCATION OF MEASURED STRATIGRAPHIC SECTIONS OF PLEISTOCENE DEPOSITS INCLUDED WITH THIS REPORT (SHOWN BY AN "X"). LOCATION DATA ARE GIVEN IN APPENDIX B.

Introduction

A reconnaissance study of the late Cenozoic geology and molluscan paleontology of the region of east-central New Mexico southward from the escarpment along the south side of the Canadian River valley to the northern edge of Eddy County and westward from the Texas state line to the west side of Pecos River valley, was made during several weeks in the summers of 1971 and 1972. The region, extending more than 200 miles north-south and approximately 125 miles east-west, is in the High Plains section and the Pecos valley section of the Great Plains Province. This segment of the High Plains, known also as Llano Estacado, is isolated on the north by a broad erosional belt, and is bounded on the east, north, and west by prominent escarpments. The Pecos River traverses the area west of the Llano Estacado, south and southeast across western Texas to the Rio Grande.

The area covered, and the locations of molluscan faunas collected, are shown in fig. 1. The location of described stratigraphic sections of the Ogallala Formation included with this report, and those published in 1972 (Frye and Leonard, 1972), are shown in fig. 2. The location of described stratigraphic sections of Pleistocene deposits included with this report, and the location of radiocarbon dates determined in the laboratories of the Illinois State Geological Survey, are shown in fig. 3. Samples collected for X-ray study of clay minerals have been reported by Glass, Frye, and Leonard (1973), and a preliminary discussion of the structure of the top of the Ogallala Formation has been published by Frye and Leonard (1972). Locations of all faunas described are given in Appendix A. Fifteen described stratigraphic sections of the Ogallala Formation and Quaternary deposits are included.

The pre-Cenozoic rocks exposed in this region are predominantly Triassic in the northern and central parts, and Permian extensively exposed in the south-western part of the area. A few small exposures of Cretaceous rocks have been mapped previously in the east-central part of the region. The High Plains constitutes a broad plateau capped by the resistant upper part of the Ogallala Formation (late Tertiary). The Pecos valley is a broad, lowland belt where bedrock is exposed, or thinly covered by Pleistocene deposits. The topography is the product of late Cenozoic geologic events.

The late Cenozoic geology of the southern High Plains was first extensively described by Johnson in 1901. In 1915 Baker described the late Cenozoic geology of western Texas and the High Plains of east-central New Mexico. In 1933 summaries of the Cenozoic geology of adjacent Texas were published by Sellards, Adkins and Plummer, and of the Pecos valley in the Roswell area by Fiedler and Nye.

Field work for this study was supported by the New Mexico Bureau of Mines & Mineral Resources. The Illinois State Geological Survey made the determination of radiocarbon dates used in the report, and the previously reported X-ray analyses of clay minerals from deposits of the region (Glass, Frye, and Leonard, 1973).

Ogallala Formation

The Ogallala Formation, one of the most extensively exposed rock-stratigraphic units in the United States, extends from South Dakota on the north, to south of the southern boundary of New Mexico in Texas. This widespread unit underlies the upland surface of much of the High Plains, and constitutes a major source of ground water throughout its extent. The formation was named by Darton in 1899, but his original spelling was "Ogalalla." His definition of the unit was, in part, as follows (Darton, 1899, p. 734-735):

> Extending from Kansas and Colorado far into Nebraska there is a calcareous formation of late Tertiary age to which I wish to apply the distinctive name *Ogalalla formation* . . . In its typical development the Ogalalla formation is a calcareous grit or soft limestone containing a greater or less amount of intermixed clay and sand, with pebbles of various kinds sprinkled through it locally, and a basal bed of conglomerate at many locatities . . . The pebbles it contains comprise many crystalline rocks, which appear to have come from the Rocky Mountains.

Although Darton failed to designate a type locality in either his original description or a subsequent report published in 1905, in 1920 (p. 6) he stated:

> The Ogalalla formation is believed to *be* a stratigraphic unit and to be continuous from the type locality near Ogalalla station in western Nebraska . . It is believed that the bones of Pleistocene age found in some places are in local deposits of later age that overlie the true Ogalalla, which appears more likely to have been laid down in Pliocene and late Miocene time.

Darton (1928) was also the first to use the term Ogalalla in New Mexico.

Later, Elias (1931) and Hesse (1935) re-examined the exposures in the vicinity of Ogallala, Nebraska, proposed a type section on Feldt Ranch approximately 2 miles east of the town, and described the vertebrate fossil fauna. In 1942, Elias described the fossil seed floras of the Ogallala Formation in Kansas and Nebraska, and established floral zones for the region.

Studies of the deposits now classed as Ogallala Formation in northwestern Texas, and their contained vertebrate fossils, were made during the past century (Cummins, 1891, 1892, 1893). Although several early reports described localities in east-central New Mexico, Baker in 1915 most adequately described these deposits, including origin and age, for the east-central part of the state.

The name Ogallala Formation was introduced into New Mexico in 1928 by Darton (p. 58); the formation was described in Curry and Roosevelt Counties in some detail by Theis in 1932. In the adjacent part of Texas to the east, the Ogallala Formation has been described more recently (Evans, 1949; 1956; Frye and Leonard, 1957a) and correlations northward across Kansas (Frye, Leonard, and Swineford, 1956) to the type localities in Nebraska have been made on the basis of fossil seed floras by Frye and Leonard (1959). A preliminary map of the structure of the Ogallala in east-central New Mexico has recently been published (Frye and Leonard, 1972), and the origin and character of these deposits in the New Mexico-Texas region have been reviewed by Reeves (1972).

In east-central New Mexico the Ogallala Formation regionally thins westward toward its source region in the upland and mountainous region lying between the present position of the Rio Grande on the west, and the Pecos River and headwaters of Canadian River on the east. With considerable local variation, the thickness of the formation decreases regionally westward from the east escarpment of Llano Estacado in Texas to the west-facing Mescalero Escarpment on the east side of Pecos valley in New Mexico. West of Pecos valley are a few thin outliers of Ogallala upland, notably the large upland flat on which Yeso is located, but most of the occurrences are small areas of thin deposits that may be continuous with caliche crusts developed on the subdued topography adjacent to the Ogallala alluvial plain. The suggestion by Bretz and Horberg (1949) that the Ogallala thickened to 1,300 ft as a fill of an "ancestral" Pecos valley is conclusively refuted by: 1) the stratigraphy and lithology of the Ogallala eastward from eastern New Mexico to the east scarp of Llano Estacado in Texas, 2) the stratigraphy and physiography of the lower Pecos in Texas, 3) the dated age of deposits in the Pecos valley of Chaves and De Baca Counties, and 4) the relations of the extensive pediment veneers. Apparently Bretz and Horberg failed to recognize those features.

The Ogallala Formation consists of alluvial deposits, some of probable eolian origin in the southern part of the area, and derived from the upland regions to the west and deposited on an earlier erosional topography (Frye, 1971). The streams had relatively low gradients and the lower parts of the valleys, with gently sloping valley sides, were filled first. As alluviation proceeded, the sediments overlapped the gentle valley slopes, slowly inundated the former topography, and produced a coalescent plain of alluviation. The conclusion that the formation did not develop as conventional alluvial fans is confirmed by the fact that the earliest deposits extend to the present eastern limit of the formation in areas where it is thickest (along the positions of pre-Ogallala valleys) whereas only the youngest deposits (uppermost units of the formation) occur on the bedrock of former divides throughout the east-west extent of the formation (Frye, Leonard, Swineford, 1956). In a north-south direction in eastern New Mexico, the formation is absent in some areas whereas it is more than 200 ft thick in others, depending on the configuration of the pre-Ogallala unconformity.

The culmination of Ogallala deposition resulted in an alluvial plain, marked with the typical topographic features of channel scars, natural levees, flood-plain topography, and associated local eolian deposits. Once the control of the pre-existing bedrock topography had been eliminated by the burial of that topography by alluvial deposits, the master stream channels were free to shift laterally, and, judging from the deposits, did so without regard to the earlier valley positions.

The fossil flora of the formation indicates that the climate of the region became progressively more arid from late Miocene through Pliocene time; this climatic change may have led to the slow termination of alluvial deposition. Pedocal soil profiles occur in the upper part of the Ogallala deposits indicating significant intervals of stability on the local surface, but none of these soils have been traceable as a stratigraphic marker bed. In any event, widespread alluviation ceased, and soil formed in the surficial sediments of the alluvial plain throughout the expanse of Ogallala deposits. This soil, marked in eastern New Mexico and western Texas by thick accumulation of soil caliche, has been called the "Ogallala Climax Soil" (fig. 4D). After initiation of the Ogallala Climax Soil, the plains region was tilted eastward, and locally warped, producing significantly greater slopes than existed during sediment deposition.

The Ogallala sediment sources, and the regimen of the depositing streams, were diffierent in the northern part of this region than in the southern part. In the area of northern Curry County, southern Quay and Guadalupe Counties, and northern De Baca County, channel deposits of gravel are common in the lower part of the formation, as illustrated by the exposures in the Yeso South, Santa Rosa Southeast, and particularly by the Ragland section where coarse, thick channel gravels are exposed in the basal part. The Quay-Curry County line section (fig. 4B) and the Parker Ranch section, where coarse gravels occur well above the base of the formation, illustrate the fact that coarse channel gravels were being carried at a later time. The Ima section demonstrates that, even in the northern part of the area (particularly where the formation is thin and rests on a relatively high part of the earlier topography), coarse channel gravels do not occur everywhere in the formation. In the southern part of this region, as illustrated by the Little Red Lake, East Caprock Oil field, and KBIM Tower sections, (fig. 4A), coarse channel gravels are exceedingly rare and the formation consists predominantly of sand with some silt. In all areas, calcium carbonate occurs in dense accumulations at the top of the formation, unless removed by erosion; caliche occurs commonly in zones throughout the thickness of the unit (fig. 4A, B, C, D, E). Throughout this region, sand, with minor amounts of silt and clay, is the predominant lithology of the Ogallala, as seen in the stratigraphic sections with this report, and those previously published (Frye and Leonard, 1972).

The physical continuity of the Ogallala Formation of east-central New Mexico with the Ogallala of the east scarp of Llano Estacado in western Texas is clearly demonstrated. However, the correlation of the floral zones described in Texas, and correlated northward with comparable units in Kansas and Nebraska, is less certain. Diagnostic fossil vertebrate faunas comparable to those described from northwestern Texas, Kansas, and Nebraska, have not been recovered in this part of New Mexico. Furthermore, the abundant and diversified floras of fossil seeds used for zonation and northward correlation in western Texas (Frye and Leonard, 1959) have not been found in east-central New Mexico. In our work in this area, only fossils of *Celtis willistoni* have been collected from the Ogallala Formation. The tentative correlations (paleontologically correlated with Kansas and Nebraska) of the Kimball and Ash Hollow zones of western Texas, indicated in the described stratigraphic sections in this report, are based on lithologic similarities, rather than on a firm paleontological basis. The pisolitic limestone, a multiple generation brecciated and recemented caliche, forms the top of the Kimble Zone, and generally is less than 2 ft thick. Below the pisolitic limestone, a massive caliche-cemented zone generally occurs, commonly platy at the top, consisting of sand and silt with calcium carbonate cement, locally with dispersed siliceous pebbles, from 5 to 10 ft thick. Below this caliche-cemented zone is sand and silt, 5 to 15 ft thick, irregularly cemented with caliche and resembling relatively unbedded flood-plain deposits. The Ash Hollow zone below is commonly of bedded sands, with some silt, and locally channel gravels, interspersed with intermittent caliche soils and irregular caliche-cemented sands.

Figure 4 follows

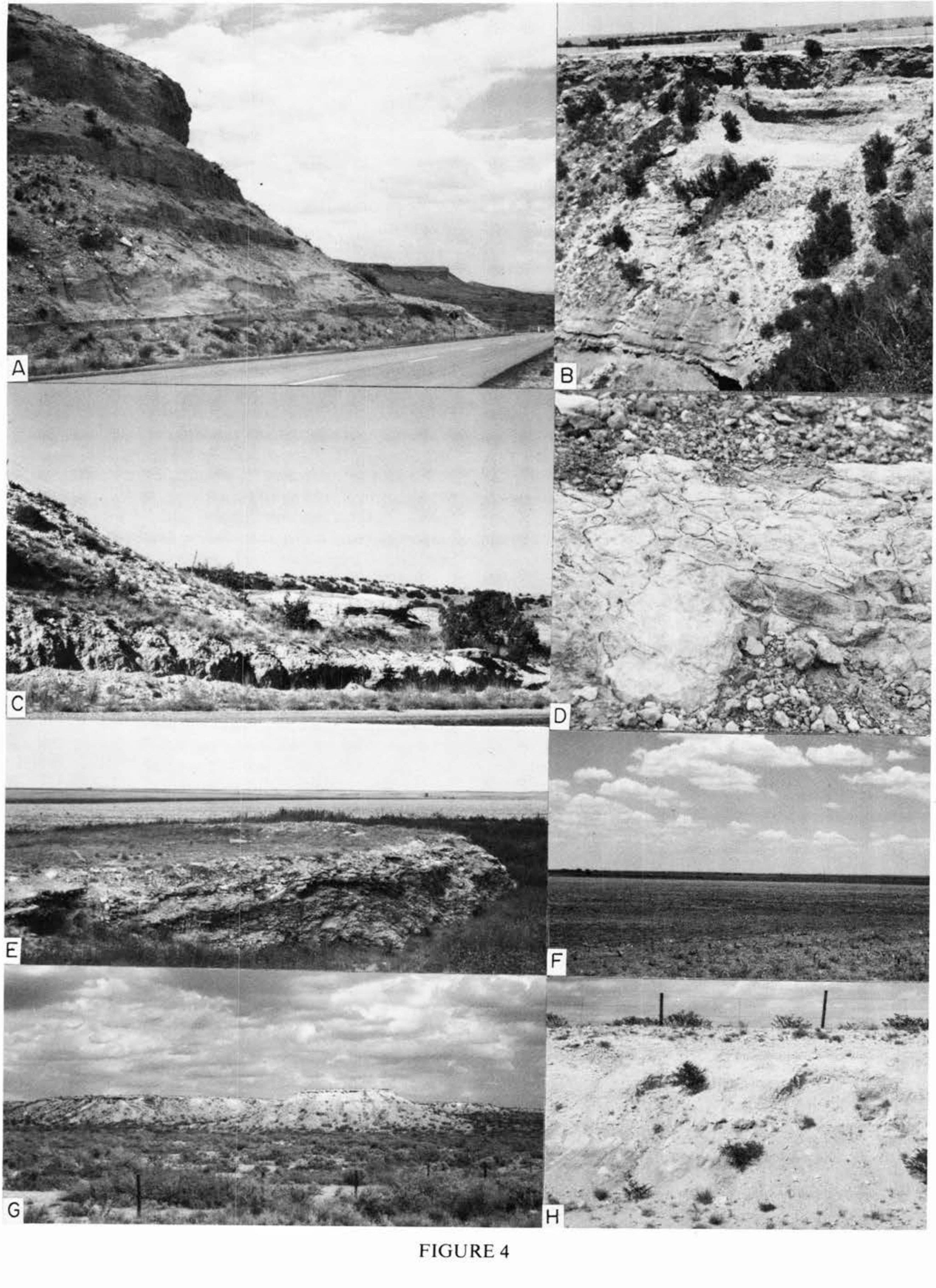


FIGURE 4

Pleistocene Geology

HISTORY

After the culmination of Ogallala deposition, in middle to late Pliocene, the region of east-central New Mexico was an alluvial plain, displaying minor local relief but regionally sloping toward the east or east-southeast at a gradient of a few feet per mile. In the eastern part of the region local relief was constructional (fig. 4F), but westward the constructional plain merged with areas of erosional topography. Still farther west the topography became predominantly erosional. The development of a widespread pedocal soil over the surface indicates that the progressive trend toward desiccation—as demonstrated by the fauna and flora upward through the Ogallala (Frye and Leonard, 1957b)—continued for a significant interval of time. The fact that this soil was deeply developed before the next major episode of deposition—therefore, representing a hiatus in the sedimentary record—is indicated by the presence of detrital cobbles of soil caliche in the basal deposits of the Blanco Formation to the east in Texas.

During this hiatus, or perhaps genetically related to it, the mountainous region to the west was uplifted, and the alluvial plain tilted eastward. Also, part of the surface of eastern New Mexico was warped (Frye and Leonard, 1972). Then, the greatly increased precipitation of early Pleistocene developed a new consequent drainage system upon this constructional and tectonically modified surface. The fact that the new master streams of the early Pleistocene did not generally coincide with the earlier major streams of the Ogallala is clearly demonstrated by the relation and character of the Ogallala deposits above Triassic rocks along the sides of the now abandoned Portales valley in eastern De Baca and northwestern Roosevelt Counties. Here, relatively thin Ogallala deposits cap the bluffs, both north and south, above valley walls in Triassic rocks. This relation is particularly clear at the south end of Taiban Mesa, in spite of some previous geologic maps showing Ogallala Formation continuous across the position of Portales valley.

The mechanism of capture of the "Portales River" by the lower Pecos in the vicinity of Fort Sumner was probably complex. As pointed out by Baker in 1915 the Triassic and Permian rocks underlying the Ogallala are less resistant to erosion than is the densely cemented upper part of the Ogallala Formation. Therefore, erosion may have proceeded more rapidly, after the initial uplift, in those places where the earlier Tertiary erosion surface was not protected by a cover of Ogallala deposits. An analogy may be the Colorado piedmont where tributary streams, roughly paralleling the Front Range, have excavated a belt of relative lowland bounded on the east by a west-facing Ogallala-capped escarpment. However, the structural history of the Ogallala appears to have been different in the two regions. Whereas in Colorado and western Kansas the Ogallala was tilted eastward (with, perhaps, a low east-west-trending arch in about the middle of those states), in this part of New Mexico a structural trough developed along the position of the present Pecos valley and a low north-south-trending arch crossed the Portales valley in northwestern Roosevelt County (Frye and Leonard, 1972). Possibly the diversion of the Portales valley drainage to the present position of Pecos River in Chaves County was caused by a combination of gradient advantage of the lower Pecos, more easily erodible rocks, and slow, progressive, gentle warping. That this warping was not culminated until after Kansan time is indicated by the fact that the floor of Portales valley is also arched in the same position, but to a lesser degree than the projected structure of the Ogallala. Solution-subsidence, or collapse, evidently was significant either in the capture of "Portales River", or in the localization of Pecos River in this part of the state. Although many subsidence basins contain deposits dated as Wisconsinan, nowhere has Ogallala been observed as basin fill. The same statement applies to the less extensive deposits of the region assigned a Kansan age.

Reconstruction of the positions of the early Pleistocene major drainage lines can be done with reasonable certainty in only part of the region. The Portales valley, of early Pleistocene age and subsequently abandoned, has been described by Theis (1932), Thomas (1972), and Reeves (1972), among others. The present headwaters of the Pecos River basin must have flowed eastward through this valley in early Pleistocene time. The level of the earlier Pleistocene stream is indicated by exposures east of Santa Rosa (fig. 4C) where Pleistocene stream gravels, containing abraded cobbles of Ogallala-type caliche, occur in a high terrace deposit, below the

FIGURE 4—OGALLALA FORMATION AND EARLY PLEISTOCENE DEPOSITS, EAST-CENTRAL NEW MEXICO

A) Ogallala Formation exposed along NM-31, the KBIM Tower Section, 3½ miles west of junction of NM-172, Chaves County. Looking southeast (NW SW sec. 18, T. 15 S., R. 31 E.)

B) Ogallala Formation at Quay-Curry County Line Section, 9 miles north of Bellview. Looking northeast (SW SE SE sec. 34, T. 9 N., R. 36 E.)

C) Ogallala Formation and earliest Pleistocene terrace gravels, 4 miles east of Santa Rosa, Guadalupe County. Looking southwest (NE NE sec. 4, T. 8 N., R. 22 E.)

D) Ogallala pisolitic limestone (indurated and brecciated caliche) at the Ima Section, at Ima, Quay County. Looking northeast (SW SW sec. 2, T. 7 N., R. 27 E.)

E) Caliche pit in upper part of Ogallala Formation, and the High Plains surface. Ogallala deposits contain Celtis willistoni. *Two miles north of Running Water Draw and west of NM-18, Curry County. Looking southwest (SE NE sec. 19, T. 4 N., R. 36 E.)*

F) High Plains surface, southwest from near Dora, Roosevelt County. Looking southwest (sec. 5, T. 4 S., R. 35 E.)

G) Escarpment capped by caliche in top of Kansan deposits, east side of Pecos River valley, east of Hagerman, Chaves County. Looking east (NW NW NW sec. 17, T. 14 S., R. 27 E.)

H) Caliche in top of Kansan deposits, east side of Pecos River valley, east of Hagerman, Chaves County. Looking north (SW SW NW sec. 17, T. 14 S., R. 27E.)

level of the adjacent Ogallala Formation. The fact that the upper Pecos did not flow southward from Fort Sumner along its present course is also indicated by the topographic constriction of the present valley, the presence of small remnants of Ogallala capping the west valley bluff in the former divide area, and the absence of any terraces in the present valley above the one of Woodfordian (late Wisconsinan) age in southern De Baca and northernmost Chaves Counties. Although we have not had an opportunity to examine the area of San Miguel County in the field, the existing drainage pattern supports the suggestion by Thomas (1972) that the headwaters region of the Canadian River, north of San Miguel County, was also integrated with the early Pleistocene drainage through Portales valley, and was subsequently pirated by the headward encroachment of Canadian River. The sharp elbow of capture (sharper than 90 degrees) in northernmost Roosevelt County indicates that Alamosa Creek was formerly a tributary to the eastward-flowing Portales River.

The headwaters of the early Pleistocene stream, now the lower Pecos, were located somewhere south of the De Baca-Chaves County line. In Pecos and Reeves Counties, Texas, a stream existed as early as Ogallala time in the approximate position of the present Pecos River because the highest pediment surface is graded northward from the mountains to deposits identified as equivalent to the Ogallala (Leonard and Frye, 1962). However, the valley of the lower Pecos in New Mexico has been significantly modified by solution subsidence during late Pleistocene time.

If the present headwaters of the Canadian River were indeed tributary to the early Pleistocene "Portales River," and later captured by the Canadian, the piracy occurred in the area of easily erodible Triassic rocks.

South of Portales valley, two east-west linear topographic sags may have been eroded by tributaries to "Portales River." They are much smaller and shallower, and their origin speculative.

Extensive veneered pediment surfaces were not observed in the Pecos or Portales valleys of Guadalupe, De Baca, Roosevelt, or Curry counties. South of the former divide however, in Chaves and northernmost Eddy Counties, are very broad, well-graded, and generally veneered pediments both east and west of Pecos River. These extensive high-level pediments, called the Diamond A Plain on the west and the Mescalero Plain on the east by Fiedler and Nye (1933), are graded to a higher position of the Pecos River and its tributaries. The topography of the pediment surfaces truncates the Ogallala Formation; in southern Chaves County the pediment toe merges with a high-level, caliche-capped terrace (fig. 4G). These surfaces show the same physiographic relationship to the Ogallala above, and to the younger terraces below, as the second pediment of the Pecos valley southeastward in Texas, described by Leonard and Frye (1962), and suggest a consistent history for the Pecos River valley from Chaves County, New Mexico, downstream.

The extent of these pedimented surfaces, (fig. 5G), the character of the veneers, the character of the caliche cementation in the upper part, and their physiographic relations, suggest that more than half of Pleistocene time was consumed in their development. Although a few small remnants projecting above the general surface suggest the possibility of an earlier Pleistocene cycle (possibly Nebraskan), these surfaces probably attained their present configuration by Yarmouthian (or perhaps Illinoian) time. The presence of Wisconsinan and younger terraces precludes a younger age. Clearly, these pediment and terrace deposits are not connected with the terraces of the upper Pecos valley, including the deposits underlying the floor of Portales valley, both of which are thought to be of Kansan, age.

Younger Pleistocene and Holocene terraces occur along the Pecos valley throughout the region. In Chaves County, two such terrace levels were named Orchard Park and Lakewood by Fiedler and Nye (1933). They also named a higher terrace the Blackdome. However, the term Blackdome terrace has been applied to veneered pediment surfaces as well as alluvial terrace surfaces. Clearly the Blackdome Terrace does not have continuity northward through northern Chaves and southern De Baca Counties, whereas the lower Wisconsinan and Holocene terraces are continuous through this area. Although the young terraces have continuity as a complex group, the individual terrace levels do not have continuity throughout the Pecos valley of this region. In some valley segments the terrace surfaces diverge and converge, and for that reason the terms Orchard Park and Lakewood are not used in this report except for their typical area in Chaves County.

In the area southward from Fort Sumner is an example of the changing relative positions of terrace surfaces having apparent continuity. West of Fort Sumner, the Ogallala upland is at an elevation of 4,500 ft; the dissected remnants of a high terrace exposing deposits correlated as Kansan range from 4,200 to 4,300 ft; a distinct terrace level, the upper part of which has yielded radiocarbon dates of 17,180 ± 140 (ISGS-91)

FIGURE 5—Pleistocene deposits and topography, east-central New Mexico

A) Irrigated surface of Woodfordian, or younger, terrace of Pecos River valley, 1 mile southeast of Fort Sumner, De Baca County. Looking north (NW SW sec. 33, T. 3 N., R. 26 E.)

B) South across floor of Portales valley, about 7 miles northwest of Portales, Roosevelt County. Looking south (sec. 11, T. 1 S., R. 33 E.)

C) Sink in Permian rocks, late Pleistocene deposits in foreground, Bottomless Lakes State Park, Chaves County. Looking east (NE SW sec. 27, T. 11 S., R. 26 E.)

D) Lake deposits, containing molluscan fauna (No. 41) dated 14,310 ± 230 (ISGS-145), in "Salt Lake" basin about 15 miles east-southeast of Portales, Roosevelt County. Looking northeast (SW SW sec. 1, T. 3 S., R. 36 E.)

E) Roadcut through late Wisconsinan or Holocene Lee Dune, 11 miles east-northeast of Milnesand, Roosevelt County. Looking northwest (sec. 4, T. 8 S., R. 37 E.)

F) Terrace deposits of Woodfordian age in roadcut west of Santa Fe Railway underpass on US-60, west of Fort Sumner, De Baca County. Fauna locality No. 5, dated 17,180 ± 140 (ISGS-91). Looking southwest (NW NW SW sec. 24, T. 3 N., R. 25 E.)

G) Pleistocene pediment surface looking northeast toward Kenna, Chaves County. Pediment pass through Ogallala escarpment (Mescalero Ridge) in middle skyline. Looking northeast (sec. 16, T. 6 S., R. 30 E.)

H) Caliche in top of Kansan age deposits swept clean of sand by wind. About 15 miles southeast of Loco Hills, Eddy County. Looking east (sec. 31, T. 19 S., R. 31 E.)

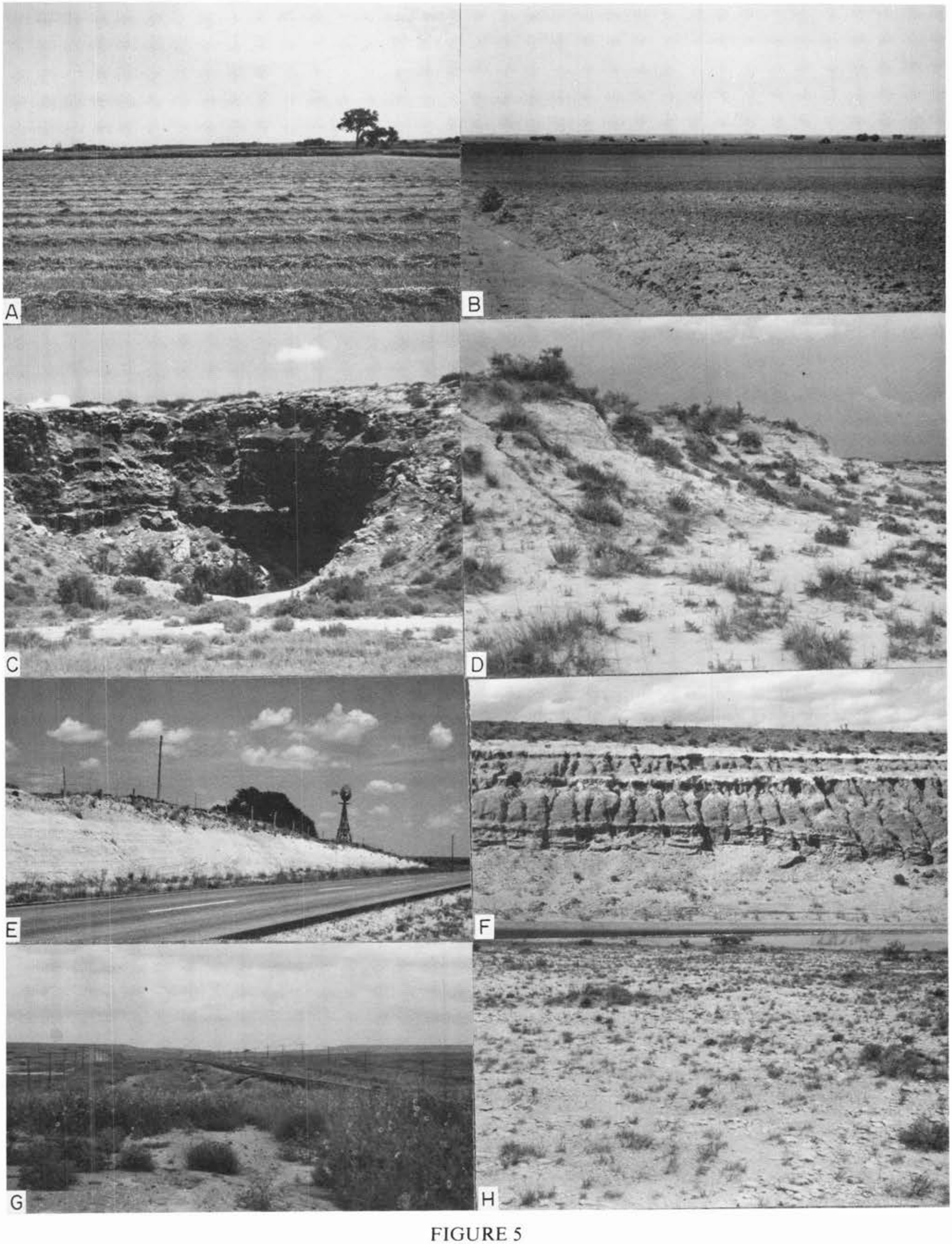


FIGURE 5

and 16,490 ± 120 (ISGS-149), ranges from 4,120 to 4,170 ft; below this, a terrace with a sharp topographic break extends from 4,090 to 4,060 ft, has provided a radiocarbon date of 13,820 ± 270 (ISGS-150) from the highest part, and supports commercial gravel pits in the lowest part; the flood-plain terrace levels here measure 4,020 to 4,030 ft, and the channel level is at 4,005 ft. Six miles south, the channel level has dropped to an elevation of 3,940 ft while the flood-plain terrace has dropped to 3,950 ft. A broad smooth surfaced terrace (fig. 5A) which is in apparent physical continuity with the terrace at 4,120 to 4,170 ft west of Fort Sumner, is at an elevation of 4,025 to 4,030 ft. Twelve miles south, the channel is at 3,890 ft, the flood-plain terrace is at 3,900 ft, and the continuation of the broad smooth terrace is at 3,975 ft. In other words, in the 12 miles southward, the interval between the channel level and the level of an apparently continuous and prominent terrace, has decreased by 40 to 50 ft. In addition, the two terrace surfaces near Fort Sumner have coalesced to become one.

In the segment of Pecos valley in southern Chaves County, only one radiocarbon date was obtained directly from terrace deposits. About 3 miles east-southeast of Lake Arthur, from the east side of Pecos River a date of 5,865 ± 90 (ISGS-144) was obtained from the terrace alluvium resting on Permian bedrock.The top of the terrace surface at this point is 12 ft above channel level; topographic setting and age confirm this terrace as a Holocene flood plain. A prominent Woodfordian terrace, about 30 ft higher, occurs along the west side of the valley; the eroded edge of the Kansan terrace (fig. 4G) is less than 100 ft above channel level. On the west side of the valley the Kansan terrace grades into a broad pediment surface rising to the west.

A summary of the alluvial history of the Pecos valley in Guadalupe, De Baca, and Chaves Counties follows. In the northern part of the area, a consequent drainage pattern developed on the surface of Ogallala deposits, with headwaters on the contiguous erosion surface to the west. The drainage area consisted of the present Pecos basin above Fort Sumner, and the headwaters of the Canadian River, with a master stream flowing east-southeast through Portales valley (fig. 5B). Contemporaneous streams that developed in both Chaves County and to the west, flowed southward into Texas. After Kansan and before Wisconsinan time, the Canadian 'River captured its present headwaters, and in the area of Fort Sumner the lower Pecos River diverted the stream formerly flowing through Portales valley to produce the present drainage pattern. Few remnants of early Pleistocene terrace deposits remained, although extensive areas of Kansan (and perhaps Illinoian) deposits existed as fill of Portales valley (fig. 5B), as small terrace remnants in the upper Pecos valley, and as extensive pediment veneers graded to marginal alluvial terraces in the lower Pecos valley. Valley incision occurred during the first half to two-thirds of Wisconsinan and Holocene time, followed by alluviation, interspersed with channel incision, along the entire Pecos valley.

Subsidence, or collapse due to salt solution at depth, so evident in the southern part of the region today, played a minor role in the drainage development prior to the Wisconsinan. Ogallala deposits, or Pleistocene deposits older than Wisconsinan as fillings of subsidence or collapse areas are not evident. These features were probably produced by the hydrologic system of circulation caused by the valley deepening until middle Pleistocene time, as well as the great amount of precipitation during Woodfordian time. The conspicuous collapse basins of Bottomless Lakes State Park (fig. 5C) are clearly related in time to the flood-plain terrace, and younger deposits of the Pecos valley.

In the eastern part of this region, on the High Plains, the early and middle Pleistocene history is obscure. Except in Portales valley, the only Pleistocene deposits on the High Plains in New Mexico possibly older than Wisconsinan are cover sands in Curry, northwestern Roosevelt, and Quay Counties. In this region, the upland surface is the flat (fig. 4E, F), thinly veneered, upper surface of the Ogallala Formation, pockmarked by shallow, small basins (Judson, 1950; Frye, 1950), partly filled with deposits of Wisconsinan age. A few large solution-collapse basins, typified by the basin of Salt Lake southeast of Portales, are filled with lacustrine deposits of late Wisconsinan (Woodfordian) age (fig. 5D; deposits dated 14,310 ± 230 (ISGS-145). In some of the shallow, small basins, eolian activity has blown the desiccated and pelletized clay-silt deposits from the basin floors into lee dunes, or clay dunes on the downwind side (fig. 5E). The environment of ponded deposits in these relatively shallow High Plains depressions was different from that of the Pecos valley terraces of approximately the same age and the ponds on their surfaces as demonstrated by the abundance of sepiolite in the pond deposits (Glass, Frye, and Leonard, 1973). The clayey lee dunes apparently are younger than the pond deposits on the High Plains surfaces because of the presence of aquatic mollusks indicate that the major pond deposits accumulated in permanent, or semipermanent water, whereas the lee dunes required intermittent episodes of desiccation of the deposits on the basin floors.

Radiocarbon dates from pond and lake deposits in the High Plains region range from 15,280 ± 210 (ISGS-151), and 14,310 ± 230 (ISGS-145), to 13,690 ± 160 (ISGS-147). Although no radiocarbon dates have been obtained directly from lee dunes, the implication is that they are younger than any of these dates from pond and lake deposits, and may be as young as Holocene. Previously determined radiocarbon dates from the Blackwater Locality No. 1 archaeological site in Roosevelt County, have been summarized by Hester (1972, p. 58). As the oldest dates listed (10,490 ± 900, A-386, and 10,600 ± 320, A-380) are reported from a diatomaceous bed containing Folsom artifacts, these dates suggest the probable age of diatomaceous deposits which contain some volcanic ash shards studied by us elsewhere in this part of the High Plains (Glass, Frye, and Leonard, 1973).

The present conditions on the High Plains and pediment surfaces in this part of New Mexico are characterized by minor stream erosion, some sheetwash, and locally significant eolian activity. Sand dunes are active in some places, and in a few small areas caliche surfaces have been swept clean of sand (fig. 5H).

DEPOSITS

Deposits of Pleistocene age in this part of New Mexico, although not volumetrically great, are both varied and widespread. The dating of pre-Wisconsinan Pleistocene deposits is somewhat problematical, but their stratigraphic and physiographic relations clearly place them in a time sequence. In the following discussion the time-stratigraphic terms Nebraskan, Kansan, and Illinoian will be used, but except for a few localities, these merely mean the first, second, and third major depositional episodes following the initial erosional dissection of the Ogallala Formation of late Tertiary age; subsequent correlations may not confirm their time-equivalence to the respective type localities in midwestern United States. In the case of the Wisconsinan Stage, we conclude that widely distributed radiocarbon dates and abundant molluscan faunas have firmly established the age of these deposits.

Deposits judged to be of Nebraskan age have been observed at only a few localities in this region, in spite of their relative abundance in adjacent Texas to the east (Evans and Meade, 1945). On the east side of Pecos River valley, east of Santa Rosa, the top of the Ogallala Formation is at an elevation about 500 ft above the channel of Pecos River to the west. A remnant of high terrace gravel (fig. 4C), cut through the Ogallala and resting on Triassic rocks, attains a level of only 25 to 10 ft below the top of the Ogallala, and 4 other distinct alluvial-veneered terraces occur at lower positions along the valley sides. The deposits of this high terrace consist of gravel, sand, and some silt, locally cross-bedded, and contain abraded pebbles of Triassic rocks and of caliche resembling that in the adjacent Ogallala Formation. West of Fort Sumner, remnants of alluvial deposits, capped by dense caliche, occur in a comparable topographic situation, although at a greater distance below the top of the Ogallala. In southeastern Chaves County, several knolls, projecting above the irregular surface of the regional Kansan pediment, are capped by alluvial deposits containing dense caliche. The caliche does not display multiple generations of brecciation, and the knolls are topographically below the projected level of the Ogallala; for these reasons they are considered to be Nebraskan remnants. In general, however, possible Nebraskan deposits are exceedingly scarce; we conclude that most deposits of this age were removed subsequently by the extensive episode of erosion.

Kansan deposits, in contrast to the Nebraskan, are relatively widespread in this region. In the Pecos valley near Santa Rosa, at a level about half way between the Ogallala upland surface and the series of young terraces above the Pecos River channel, are remnants of an alluvial terrace, capped with sand and gravel containing pebbles of crystalline rocks and abraded caliche. Similar remnants occur southeastward along the valley to the vicinity of Fort Sumner. Here on the west side of the valley, the deposits consist of sand and silt and, at one locality west of Fort Sumner, they contain a bed of volcanic ash. Inasmuch as several volcanic ash beds in the Great Plains region have been successfully dated (Izett, Wilcox, and Borchardt, 1972), the occurrence of this ash bed presents the potential for more precise dating.

The character of the upper part of the Kansan deposits in Portales valley is illustrated in the Taiban East Borrow Pit Section. Exposures of these deposits occur west of Fort Sumner and west of Santa Rosa, but eastward through the Portales valley there are few exposures. Theis (1932) has described the lower deposits of the Portales valley fill as consisting of gravel, locally cross-bedded, containing pebbles of crystalline rocks and abraded caliche pebbles, resting on the unevenly eroded surface of Triassic rocks. He suggested more than one episode of erosion and deposition, and that the uppermost deposits on the undissected valley floor (fig. 5B) may be younger than the water-bearing gravels, and have been derived by local erosion of the valley sides after abandonment of the valley by a major through-flowing stream.

The character of the Kansan deposits associated with the southern segment of the Pecos present a very different aspect than those related to Portales valley drainage. Fiedler and Nye (1933, p. 32) described the deposits of their Blackdome terrace as consisting "largely of lenticular beds of gravel, conglomerate, sand, sandstone, clay, and silt." An excellent exposure of these deposits was studied north of Arroyo del Macho, about 18 miles north of Roswell, where coarse gravels of diverse lithology, including abraded cobbles of caliche, are interbedded with red sands. The fine-textured phase of the deposits is shown by exposures in the terrace scarp east of the Pecos River opposite Hagerman. Westward from the valley, a broad pediment surface grades upward from the level of this terrace and is veneered with a rubble of cobbles, pebbles, and sand, poorly sorted, and is generally caliche-cemented in the upper part.

East of Hagerman, the Kansan terrace deposits are well exposed in a distinct escarpment and in roadcuts (fig. 4G, H). Here, the terrace deposits consist of brownish-red silt, sand, and clay, with some selenite crystals, some abraded pebbles of caliche, and few crystalline rocks. The color of the deposits ranges to pinkish tan and chalky gray, largely depending on the amount of caliche cement. The level of the Kansan terrace here is only 100 ft above the channel of Pecos River, whereas in the Fort Sumner area the Kansan level is more than 300 ft above channel level, suggesting the gradient advantage that led to piracy of the Portales valley. East of Hagerman, the terrace deposits are capped by a dense, platy caliche, grading downward into massive, softer caliche cement.

In contrast to the relatively smooth and generally eastward-sloping pediments on the west side of Pecos River in southern Chaves County, the pediments on the eastern side of the Pecos are irregular and present a general pattern of broad, south-southwest-trending troughs. However, from Long Arroyo eastward to the west-facing scarp of the Ogallala (Mescalero Ridge), the pediment surface has a relatively smooth slope to the west. The character of the deposits that veneer this part of the pediment is described in the NM-380 Section. Unlike the pediments west of the Pecos, much of this extensive surface, called the Mescalero Plain, is unevenly covered with sand dunes showing two or more, cycles of development.

In the pediment pass (fig. 5G) east of Kenna (fauna no. 13), a small exposure of presumed Kansan deposits occurs above Triassic rocks, topographically above the Wisconsinan terrace along Kenna Draw (fauna no. 31), and below the base of the Ogallala that caps the adjacent uplands. This deposit is at the head of the pediment and is presumed to be related to it. The deposit consists of tan sand with some silt, and dispersed pebbles that appear to have been largely derived from the adjacent and higher Ogallala. Another anomalous exposure that may represent the uppermost part of Portales valley fill of Kansan or Illinoian age (fauna no. 12) occurs west of Floyd where the deposit consists of gray sand and silt, with several buried soils.

In the High Plains part of this region, deposits assignable to a Kansan age have not been observed outside the Portales valley area.

Deposits assignable to an Illinoian age are not abundant in this region. In Curry, Quay, and Roosevelt Counties (fig. 4F) the surface of the High Plains is extensively but thinly veneered with a deposit of tan sand and silt, with some clay. This upland veneer is continuous eastward into Texas with deposits called cover sands (Frye and Leonard, 1957a) and assigned an Illinoian age. In much of the upland flat areas of Lea County this surficial deposit is lacking. Some of the surficial deposits on the floor of Portales valley may be the same age; the earliest cycle of dune sands, both on the pediment surface and along the abandoned valleys across the High Plains, may also be Illinoian in age. The extensive pediment veneers probably expanded and became more cemented, but extensive terraces of this age have not been recognized.

Deposits and faunas of Wisconsinan and Holocene age are widespread throughout the region. Although earliest Wisconsinan (Altonian Substage) terraces have not been recognized, terrace deposits of late Wisconsinan (Woodfordian Substage) and Holocene age are extensively developed in the Pecos valley. The character of these deposits in the northern segment of the Pecos valley is described in the Santa Rosa West Section, and in the Santa Fe Railway Underpass Section (fig. 5F) west of Fort Sumner. Throughout the Pecos valley of this region, the Woodfordian terrace deposits are characterized by gravel and sand in the basal part (west of Fort Sumner, and southward along the valley, the gravels are exposed in pits), grading upward into sands and silts, and locally pond deposits, with some soil caliche developed in the upper part. Radiocarbon dates, molluscan faunas, and physical continuity of the terrace deposits establish their Woodfordian age throughout the region. South of the early to middle Pleistocene divide near the De Baca-Chaves County line, in central and southern Chaves County, Fiedler and Nye (1933, p. 31) named this terrace the Orchard Park, and described its deposits as consisting "chiefly of gravel, sand, and clay derived from the limestone uplands, from the Sacramento Mountains and the Sierra Blanca, and from the deposits of the Blackdome terrace . . . these deposits differ from the deposits of the Blackdome terrace chiefly in that they are usually much less consolidated, the gravel consists of smaller pebbles, and the clay is somewhat darker in color." This terrace is the highest and oldest that persists through the divide area and gives continuity to the entire Pecos valley of the region.

In the area west of Fort Sumner this terrace was examined in detail. A pond deposit on its surface (fauna no. 4) was radiocarbon dated at 16,490 ± 120 (ISGS149). A pond deposit within the upper part of the deposits (fauna no. 5), and described in the Santa Fe Railway Underpass Section, was dated at 17,180 ± 140 (ISGS-91); the conformable silts, sands, and gravels below the position of the date are clearly still within the Woodfordian Substage. A sharp topographic break occurs east of this section and was apparently caused by erosional planation because the lower gravels persist toward the river channel. However, the fauna (no. 3) in the sands and silts that form a surficial veneer on the heel of this somewhat lower planated terrace surface was dated 13,820 ± 270 (ISGS-150), indicating the erosional planation of the terrace deposits occurred before that date. Coarse, unconsolidated gravels containing abundant crystalline rock types are exposed in gravel pits below this planate terrace surface near Pecos River.

East of Pecos valley, deposits of Woodfordian age occur as fills in basins of various sizes and types. One of the most unusual is described in the Acme Station Section (fauna no. 16), and was dated 18,100 ± 370 (ISGS-92). This deposit and fauna accumulated in a small basin, high above the contemporary valley level to the west, surrounded by Permian rocks and characterized by an abundance of gypsum or selenite.

The most extensive lake deposits (fig. 5D) of the region occur in the basin of Salt Lake, just west of the Texas line and southeast of Portales. Here a sequence of thin-bedded, light-gray to gray-tan silt and fine sand with some clay (fauna no. 41) is exposed; the upper part of the lake deposits was dated 14,310 ± 230 (ISGS-145). Somewhat comparable lakebeds that accumulated in a smaller basin are described in the Lake Lewiston East Section (fauna no. 15).

In contrast to the relatively large and deep basins such as contain Salt Lake and Lewiston Lake, are many shallow depressions that contain relatively thin pond deposits of silt, sand, and clay in northern Lea and Roosevelt Counties. A radiocarbon date from such a deposit in northeastern Lea County (13,690 ± 160, ISGS-147; fauna no. 37) indicates that the deposits in the shallow depressions accumulated at about the same time as those in the larger lake basins. Similar shallow depressions occur on the floor of abandoned Portales valley, and a radiocarbon date from one of these (15,280 ± 210, ISGS-151; fauna no. 27) places it in the same age range. These deposits may be equivalent, in part, to the Tahoka Formation (Evans and Meade, 1945; Reeves, 1972) or the Lake Lomax beds (Frye and Leonard, 1968) described from adjacent western Texas; a firm correlation is not possible at this time. The pond deposits are uniformly calcareous, except for local leaching in the top by soil formation, and are light to dark gray. In the High Plains section, these pond deposits commonly contain sepiolite among the clay minerals, locally authigenic dolomite, and at several places contain abundant diatoms and volcanic ash shards (Glass, Frye, and Leonard, 1973). In this region a diatomaceous bed that may be comparable was *described* from the Blackwater Draw archaeological locality (Hester, 1972) where the deposit was radiocarbon dated 10,600 ± 320 (A-380).

An unusual basin-fill deposit occurs in association with the closely spaced collapse features (fig. 5C) in Bottomless Lakes State Park in Chaves County. A 15-ft bed exposed above water level in the collapse area consists of clay and silt with organic matter and some gray, dark-gray, and locally brownish-gray fine sand, indistinctly bedded, and containing fossil snails (fauna no. 32) in one zone. Essentially continuous with the flood-plain terrace, the basin fill is Holocene in age. The presence of corrensite (Glass, Frye, and Leonard, 1973) gives the deposit a unique composition.

In the Pecos valley, the youngest terrace is referred to as the flood-plain terrace. In central and southern Chaves County, Fiedler and Nye (1933, p. 29) named this surface the Lakewood terrace, and described the deposits as consisting of "chiefly brown silt with inter-bedded lenses of gravel and sand." They stated the deposits were as much as 30 ft thick, probably attained a maximum thickness of 50 ft, locally rested directly on Permian rocks, and locally contained "alkali." In this study, only one radiocarbon date was obtained from the flood plain, or Lakewood terrace deposits, 5,865 ± 90 (ISGS-144) (fauna no. 34) from exposures along Pecos River southeast of Lake Arthur. Here 2 ft of loose, tan-brown sand underlies the surface, underlain by 4 to 5 ft of sand and silt with a few small dark-gray-brown pebbles, indistinctly bedded, and with more pebbles in the base. The radiocarbon date came from the base of this unit, which rests on 1 to 6 ft of compact, red, mottled with gray and yellow-tan sand, silt, and clay, with chunks of gypsum and recrystallized selenite. Locally, the lower unit extends down to channel level of the Pecos River, but nearby rests on Permian rocks a few ft above channel level. The character of the flood-plain deposits in central Chaves County is described in the Bob Crosby Bridge Section, and in central De Baca County in the Fort Sumner Section.

Dune sands are conspicuous in several parts of the region. The oldest cycle of dune sand may be as old as Illinoian; the sands are stabilized, generally red brown to reddish tan, contain clay in the interstices, and have a leached soil profile in the top. However, the cycle of dune sands that gives topographic expression to the dune form and are locally active, is quite young. The sands are generally loose, tan in color, and contain some carbonate. Locally, a weakly developed soil occurs in the top of the sand, but in other places, formation of soil is not evident. A prominent sand dune tract occurs along the north side of Portales valley in southwestern Curry and northeastern Roosevelt Counties. In this area the dunes occur on the northern edge of the Portales valley floor and mask the northern valley wall, locally overlying Ogallala Formation. Another extensive dune tract occurs on the broad, irregular pediment surface of the Mescalero Plain, and smaller areas of dunes are associated with the east-west linear sags on the High Plains surface in northeastern Lea County.

Molluscan Fauna

The fossil mollusks of the region covered by this report were studied at 45 localities (fig. 6) distributed from Guadalupe, Quay and Curry Counties on the north to Chaves and Lea Counties on the south (fig. 1). In addition, at localities 17 and 29 (Appendix A), collections were made from drift in an effort to identify the local modem molluscan fauna. The two modern local faunas are compared, and the occurrence of these species among the assemblages of fossil mollusks is noted (table 1).

The collections of modern mollusks were made by the simple expedient of taking samples of fine drift stranded where recent high water reached the level where the drift was deposited. This drift, consisting of a wide range of detritus, largely of plant origin, contains many shells of mollusks. The coarser portions of the drift were removed, and the fine portion placed in containers and later searched for shells. The modem fauna obtained in this manner is discussed later.

Fossil shells were obtained by one of two methods, or by a combination of the two. Shells weathered from an outcrop may be handpicked, and preserved in rigid containers such as glass vials. At many exposures, the shells are so sparsely represented that handpicking is the only practical method. The disadvantage of this method is that it is time consuming. Also, small shells may be overlooked especially if their color is similar to that of the matrix.

The second—and generally more satisfactory method of collecting shells from unconsolidated deposits—is the sampling of the matrix in batches of fifty to several hundred pounds and washing over a screen fine enough to retain the smallest shells in the sample; the fossils are later recovered from the residue after drying. This method is quite effective in recovering a large proportion of the shells. The method requires somewhat bulky equipment as well as the opportunity to wash the matrix and dry the residue containing the shells. Wet screening of bulk samples is imperative to collect samples large enough for radiocarbon analysis, unless a great number of large shells can be handpicked from an exposure. At the Santa Fe Railway Underpass Section (Appendix A, no. 5), a sufficient number of the large shells of *Lymnaea palustris* permitted handpicking a sample large enough for radiocarbon assay. One other locality was collected in the same manner, but all other dated

FOSSIL MOLLUSKS		Localities shown on Figure 1 and described in Appendix A																																												
		2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Actinonais carinata (Barnes)	A																																●													
Armiger exigua Leonard	A			●																●			●																							
Deroceras aenigma Leonard	T		●	●																●																										
Discus cronkhitei (Newcomb)	T		●	●																	●																				●					
Euconulus fulvus (Müller)	T		●	●																																										
Ferrissia rivularis (Say)	A																																●													
Gastrocopta armifera (Say)	T						●	●								●					●												●													
Gastrocopta cristata (Pilsbry&Vanatta)	T		●	●			●	●		●		●				●	●	●				●	●	●	●		●			●			●			●										
Gastrocopta pentodon (Say)	T		●	●				●																				●																		
Gyraulus circumstriatus (Tryon)	A				●																					●											●									
Gyraulus parvus (Say)	A		●	●	●			●			●				●	●				●	●		●		●	●				●			●		●	●	●	●	●	●	●	●	●	●	●	●
Hawaiia minuscula (Binney)	T	●	●	●		●	●	●	●	●		●	●	●		●			●	●		●		●	●		●	●	●	●		●		●		●					●					
Helicodiscus parallelus (Say)	T							●															●																							
Helicodiscus singleyanus (Pilsbry)	T																						●					●																		
Helisoma trivolvis (Say)	A			●	●																●		●			●													●	●				●		
Lymnaea caperata (Say)	A																																			●		●				●				
Lymnaea dalli Baker	A		●	●	●			●				●								●	●				●	●	●			●					●	●	●		●					●		
Lymnaea exilis (Lea)	A			●																																										
Lymnaea humilis (Say)	A				●												●																													
Lymnaea obrussa Say	A		●	●	●			●							●						●																●									
Lymnaea palustris (Müller)	A			●	●										●					●						●														●				●		
Lymnaea parva (Lea)	A		●	●																●			●		●	●									●		●	●	●	●	●			●		
Physa anatina Lea	A							●								●					●						●				●	●								●		●		●		
Physa gyrina Say	A				●										●								●										●													
Pisidium compressum Prime	A			●	●																●					●														●						
Pisidium nitidum Jenyns	A		●																	●			●			●				●					●		●	●	●							
Promenetus umbilicatellus (Cockerell)	A				●																																									
Pupilla blandi Morse	T			●	●				●		●	●					●	●		●	●		●							●					●		●		●				●	●		
Pupilla muscorum (Linne)	T		●	●	●									●						●			●		●									●			●			●	●		●			
Pupilla syngenes (Pilsbry)	T							●												●																										
Pupoides albilabris (Adams)	T		●	●	●			●			●	●				●	●			●	●	●	●				●			●			●								●					
Pupoides hordaceus (Gabb)	T		●	●			●					●																																		
Pupoides inornatus (Vanatta)	T							●																																						
Retinella electrina (Gould)	T		●	●																	●																				●					
Sphaerium nitidum Clessin	A																			●																										
Sphaerium transversum (Say)	A																				●																			●						
Somatogyrus subglobosus (Say)	A		●		●															●	●																									
Succinea gelida Baker	T			●	●								●						●	●	●		●		●	●										●			●							
Succinea grosvenori Lea	T		●		●	●	●		●	●	●	●	●	●	●	●	●	●	●	●		●			●	●	●		●	●		●			●	●	●	●	●	●	●		●			
Succinea luteola Gould	T		●																														●	●		●					●		●	●		
Succinea ovalis Say	T																				●																									
Vallonia cyclophorella Sterki	T			●	●			●	●								●			●	●				●												●				●					
Vallonia gracilicosta Reinhardt	T		●	●				●			●	●		●			●	●		●			●		●	●				●				●			●						●			
Valvata lewisii Currier	A			●																																										
Vertigo diaboli Pilsbry	T		●		●			●												●					●											●										
Vertigo elatior Sterki	T																			●																										
Vertigo milium (Gould)	T		●	●				●				●									●																									
Total species per locality		1	21	25	18	2	5	16	4	3	5	9	3	4	5	7	7	4	3	20	17	4	14	2	11	11	6	3	2	9	1	3	8	4	6	9	11	5	8	9	10	3	6	8	1	1

FIGURE 6—CHART SHOWING COMPOSITION OF FOSSIL MOLLUSCAN FAUNAS COLLECTED AT 45 LOCALITIES IN EAST-CENTRAL NEW MEXICO. LOCATION OF FOSSIL COLLECTIONS ARE SHOWN ON FIG. 1 AND GIVEN IN APPENDIX A. RADIOCARBON DATES ON THOSE FAUNAS THAT HAVE BEEN DATED ARE SHOWN ON FIG. 3. THE DESIGNATION "A" AND "T" AFTER THE SPECIES NAME INDICATES A PREFERRED HABITAT OF AQUATIC OR TERRESTRIAL.

localities (table 2) required the wet screening of varying quantities of matrix to obtain a sample suitable for radiocarbon analysis.

Few previous studies of the modern mollusca of this region have been made, none in a systematic manner. Pilsbry (1939, 1940, 1946, 1948) in his monumental treatise of the terrestrial mollusks of North America, refers to New Mexico in discussions of the distribution of various species, but generally these references are vague. For example, in referring to *Succinea avara*, he states: "New Mexico and Arizona, mountains throughout the states" (1948, p. 838), while his reference to the distribution of *S. grosvenori* is somewhat more precise: "Las Vegas, Pleistocene and living" (1948, p. 821). Other authors, such as Baker (1928) and La Rocque (1966, 1967, 1968, 1970) refer to New Mexico in discussions of distribution, but without citing specific localities.

The earliest notice of fossil mollusks from the Pleistocene of east-central New Mexico known to us is the list supplied by Howard (1935, p. 89) from identifications by H. A. Pilsbry, then of the Philadelphia Academy of Natural Sciences. Howard reports the shells as coming from "lake bed southwest of Clovis, Roosevelt County, New Mexico," assumed by Hester (1972, p. 24) to be the gravel pit known as Blackwater Locality 1. This assumption is unwarranted because lakebed deposits abound in the area southwest of Clovis. At any rate, the fossil molluscan assemblage as identified by Pilsbry consists of:

Lymnaea palustris nutalliana Lea. "Large, well-developed . . ."
Helisoma trivolvis (Say). "Also large, up to 28 mm."
Helisoma anceps (Mke) [Menke]. "Up to 7 x 13 mm . . ."
Gyraulus parvus (Say). "Three young specimens . . ."
Physa "undetermined."
Sphaerium, "species probably new."
Pisidium "species not determined."

There is nothing unusual about this assemblage, except for the report of *Helisoma anceps (antrosa)* which we have not found in any of our large collections. In other respects, the fauna can be essentially duplicated in many basin-fill deposits in east-central New Mexico.

Hester (1972, p. 25) reports a collection of mollusks taken from the "diatomite bed" of his Blackwater Locality no. 1 (SE sec. 25, T. 1 N., R. 34 E., Roosevelt County, New Mexico) and identified by William T. Clarke, Jr. The fauna has been dated 10,490 ± 900 B.P. (Arizona-386). Clarke grouped the species according to his understanding of their habitat preferences as follows:

Species	Habitat
Gastrocopta armifera (Say) *Gastrocopta procera* (Gould) *Strobilops texasiana* Pilsbry & Ferris *Hawaiia minuscula* (Binney)	Under debris
Vallonia gracilicosta (Reinhardt) *Pupoides marginatus* (albilabris) (Say) *Retinella electrina* (Gould)	Flood plains
Gyraulus parvus (Say) *Lymnaea obrussa* (Say)	Inland lakes
Physa gyrina (Say)	Small streams

This faunal assemblage also fits our findings fairly well, except that *Strobilops*, essentially a woodland snail, is not in any of our collections. Pilsbry (1948, p. 857) does not list any records from New Mexico for *S. texasiana*. Neither have we identified *Gastrocopta procera* in our assemblages, perhaps due to a difference of opinion regarding identification.

McMullen and Zakrzewski (1972) list 20 kinds of mollusks from the Casados Ranch local fauna in the SE NW sec. 36, T. 16 N., R. 32 E., Harding County, New Mexico. According to their interpretation of the habitat preferences, the species may be grouped according to this scheme:

Species	Habitat
Vertigo ovata (Say) *Vertigo milium* (Gould) *Vertigo elatior* (Sterki) *Gastrocopta tappaniana* (Adams)	Hygrophilic: situated under debris, leaf mulch and sticks in shaded areas
Euconulus fulvus (Müller) *Nesovitrea (Retinella) electrina* (Gould)	Woodland, found under leaf mulch among tall grasses and fallen timber
Gastrocopta cristata (Pilsbry & Vanatta) *Pupilla blandi* Morse *Pupilla muscorum* (Linne) *Vallonia cyclophorella* Sterki *Vallonia gracilicosta* Reinhardt	Sheltered areas; confinement to woodlands is not mandatory because these species can withstand dry conditions
Fossaria (Lymnaea) dalli Baker *Fossaria (Lymnaea) obrussa* (Say)	Marginal: occurring near water's edge under drift; mud and shallow pools
Pisidium casertanum (Poli) *Stagnicola (Lymnaea) reflexa* (Say) *Physa gyrina* (Say) *Gyraulus circumstriatus* (Tryon)	Shallow, quiet waters: oxbows, marshes and sloughs that may be subject to seasonal drying
Gyraulus parvus (Say) *Promenetus exacuous* form *kansasensis* (Baker)	Shallow quiet waters: oxbows, marshes and sloughs that are not subjected to seasonal drying
Succinea sp.	Uncertain

McMullen and Zakrzewski also report bones of *Ambystoma*, a salamander, undetermined elements of some probiscidian, and remains of *Equus niobrarensis*, a late Pleistocene horse. The molluscan fauna reported seems typical of late Woodfordian assemblages, although differences in detail are evident (fig. 6).

The faunal assemblage of late Woodfordian age reported by Metcalf (1970) from Dry Cave, about 15 miles west of Carlsbad in the SE sec. 22, T. 22 S., R. 24 E., Eddy County (geographically beyond the province of this study), deserves mention here if for no other reason than this fauna has been dated radiometrically at 14,470 ± 250 years B.P. (1-3365). The source of carbon was the dung of *Neotoma*, or woodrat. The molluscan fauna, discussed by Metcalf at length, includes the following 15 species:

Stagnicola (Lymnaea) cockerelli (Pilsbry & Ferris)
Gastrocopta procera (Gould)
Gastrocopta pellucida hordeacella (Pilsbry)
Gastrocopta armifera (Say)
Pupoides hordaceus (Gabb)
Pupilla blandi Morse
Vallonia cyclophorella Sterki
Vallonia gracilicosta Reinhardt
Vallonia perspectiva Sterki
Succineids, indet.
Bulimulus dealbatus (Say)
Helicodiscus singleyanus (Pilsbry)
Retinella indentata (Say)
Hawaiia minuscula (Binney)
Thysanophora horni (Gabb)

Leonard and Frye (1962) reported on Pleistocene molluscan faunas in the Pecos valley in Texas. They report 44 kinds of fossil mollusks, including 2 genera of unionid mussels, *Actinonais* and *Ligumia;* only *Actinonais* has been discovered in our assemblages from east-central New Mexico. Of the 44 kinds of Pleistocene mollusks reported in the Pecos valley (and adjacent territory) in Texas, 23 kinds, approximately half, occur in the New Mexico portion of the Pecos valley, and adjacent terrain. Some species missing from Pleistocene assemblages in New Mexico might have been expected to occur in assemblages from the flood-plain terraces. Among them is *Bulimulus dealbatus,* a hardy gastropod adapted to xeric habitats; also, some species of the branchiate snail *Calipyrgula,* having abundant populations in Texas in Pecos River flood-plain terraces where at least 2 species, *Cochliopa riograndensis* and *Helisoma antrosa,* are found. Other genera might also have been expected. *Polygyra texasiana* is reported to have occurred "Near Roswell in a deposit probably Pleistocene" (Pilsbry, 1940, p. 620), but we have not rediscovered this species in our collections. The Pleistocene faunal assemblage in Texas, nearest our present area of study, is that reported as Locality no. 10 (Leonard and Frye, 1962, fig. 1, fig. 4) "15 mi. S Red Bluff Reeves Co.," and consists of the following species:

Deroceras cf. *aenigma*	*Physa anatina*
Gastrocopta cristata	*Pisidium casertanum*
Gyraulus parvus	*Sphaerium striatinum*
Hawaiia minuscula	*Succinea grosvenori*

All these species, or their ecological counterparts occur in the Pleistocene faunal assemblages included in this report.

Also pertinent in certain respects to our studies in east-central New Mexico is Taylor's (1965) publication concerning the study of nonmarine Pleistocene mollusks in North America, as well as Taylor's (1960) report of late Cenozoic molluscan faunas from the High Plains, The photographic illustrations of mollusks in the latter are especially useful to the student of Pleistocene molluscan assemblages.

Each of the species considered in this report is referred to by its currently accepted name. With few exceptions, each species is illustrated by a photograph of the shell; the original description of the species is cited for those who wish to pursue such matters. Also, reference is made to some readily accessible standard modern work using the current name combination, where additional information about the species may be obtained. In most instances, the systematic descriptions mention only salient points. For convenience of the reader, species are arranged alphabetically rather than systematically.

SYSTEMATIC DESCRIPTIONS

SYSTEMATIC INDEX TO MOLLUSCA IN THIS REPORT

*Known only from modern fauna in the area of this report

Modern Mollusca

A systematic attempt to collect modern mollusks from the region was not made, but at 2 places, one corresponding to locality 17 and the other to locality 29 (Appendix A), drift cast up by high waters in the Pecos River and in Ciénega del Macho, respectively, was collected and searched for modern shells. Only those kinds that presented at least some examples of unbleached shells were taken as unmistakably modern; others were discarded because of the difficulty of clearly distinguishing between bleached, weathered modern shells from fossils derived from eroding Pleistocene deposits. Therefore, no claim can be made for completeness in this brief study. An effort was made to observe modern mollusca in likely habitats, but with little success; the late summer season in which we worked undoubtedly contributed to this failure, because many species of snails are active only during a brief period in early spring.

A well-recognized hazard of drift collections is that the precise locality from which the shells have come is unknown. Many shells will float for miles then be cast up with fine floating vegetation, while others that do not float readily (for example, the valves of *Pisidium* and other pelecypods) do not appear often in drift collections. Nevertheless, such collections provide a general notion of the molluscan fauna of a region, and offer a basis for ecological and faunal comparisons with fossil molluscan assemblages in the same region.

TABLE 1—OCCURRENCE OF MODERN MOLLUSCA IN DRIFT COLLECTIONS FROM LOCALITIES 17 AND 29 (APPENDIX A), AND OCCURRENCE OF SAME SPECIES IN OUR COLLECTIONS OF FOSSIL MOLLUSKS (FIG. 6)

Modern molluscan species	Loc. 17	Loc. 29	Fossil
Gastrocopta cristata (Pilsbry & Vanatta)	x	x	x
Gastrocopta pellucida hordeacella (Pilsbry)	x	x	.
Gyraulus parvus (Say)	x	.	x
Hawaiia minuscula (Binney)	x	x	x
Lymnaea dalli Baker (?); 1 immature shell	x	.	x
Menetus cf. *portlandensis* Baker	.	x	.
Physa anatina Lea	x	x	x
Pisidium nitidum Jenyns (?); 1 immature valve	x	.	x
Planorbula armigera (Say)	.	x	.
Pupilla blandi Morse	x	.	x
Pupoides albilabris (Adams)	x	.	x
Pupoides inornatus (Vanatta)	.	x	x
Succinea avara Say	x	.	.
Succinea grosvenori Lea	.	x	x
Vallonia cyclophorella Sterki	.	x	x
Vallonia gracilicosta Reinhardt	x	x	x
Vallonia perspectiva Sterki	x	.	.
Total occurrences	12	10	12

*Known only from modern fauna in the area of this report

The total modern assemblage from these 2 localities comprises 17 species, 12 of which also occur as fossils in the regions. The 5 species not occurring as fossils in our collections are discussed below; the remainder will be considered under discussions of fossil assemblages.

Gastrocopta pellucida hordeacella (Pilsbry)

Pupa hordeacella Pilsbry, 1890, Acad. Nat. Sci. Proc., Philadelphia, p. 44, pl. 1, fig. g-k.

Gastrocopta pellucida hordeacella (Pilsbry), Land Mollusca, North America, v. 2, pt. 2, p. 913, figs. 494, a-d, fig. 495. Philadelphia.

This small gastropod, scarcely over 2 mm in length, seems to be basically a West Indian species, of which *hordeacella* is the continental form. It occurs from Florida to California, including New Mexico, and southward into northern Mexico. Its absence in our numerous collections of fossil mollusks suggests that its invasion of New Mexico is post-Woodfordian. The type and paratypes are drift specimens from New Braunfels, Texas.

Menetus cf. *portlandensis* Baker

Menetus portlandensis Baker, 1945, Mollusca Family Planorbidae, p. 233, pl. 121, figs. 12-18.

A good series of fresh shells is compared, doubtfully to *Menetus portlandensis.* Among the known species of the genus, this species compares most favorably; but is likely an undescribed kind. *Menetus* is a small planorbid snail that frequents aquatic habitats. It must be a relatively recent invader of eastern New Mexico, inasmuch as examples were not found among our extensive collections of Woodfordian fossils.

Planorbula armigera (Say)

Planorbis armigera Say, 1818, Jour. Phila. Acad., II, p. 164.

Planorbula armigera (Say) Baker, 1928, Freshwater Mollusca Wisconsin, pt. 1, Gastropoda, Bull. 70, Wisconsin Geol. Nat. Hist. Survey, p. 355, Plate VIII, figs. 27-30.

Planorbula armigera has a flattened, discoid shell about 7 mm in diameter. It lives in swamps and small stagnate bodies of water. Accounting for its apparent absence in the water-filled basins that provided a home for many other gastropods is difficult; examples were not seen among thousands of shells recovered from such Woodfordian habitats.

Succinea avara Say

Succinea avara Say, 1824, *in* Appendix to Keating's Narrative Expedition to Source St. Peter's River, etc., Major Long's Second Expedition, Northwest Terr., 2: 260, pl. 15, fig. 6.

Succinea avara Say, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 837, fig. 455 a-k. Philadelphia.

Identifying shells of Succineaidae is fraught with difficulties; the shells in question most nearly resemble those of *S. avara.* The shell is spiral, with a large aperture; total length ranges from 6 to 9 mm. The species, as recognized by Pilsbry (1948), ranges from Newfoundland across the United States to northern

Mexico. The animal lives under debris near bodies of water, or apparently may exist under logs and leaves in forest habitats.

Vallonia perspectiva Sterki

Vallonia perspectiva Sterki, 1893, Manual Conchology, 8:257, pl. 33, figs. 39-45.
Vallonia perspectiva Sterki, Pilsbry, 1948, Land Moll. North America, v. 2, pt. 2, p. 1033, fig. 533. Philadelphia.

V. perspectiva is a terrestrial gastropod with a minute, helicoid shell, the diameter scarcely attaining 2.0 mm. The species is widely distributed over the United States and into northern Mexico; Pilsbry (1948, p. 1034) reports its occurrence in many places in New Mexico, largely in mountainous habitats. It occurs living among moist vegetational debris. East of the Rocky Mountain region it occurs erratically into North Dakota.

Species Accounts of Fossil Mollusks

Actinonais carinata (Barnes)
Pl. I, fig. 8

Unio caranatus Barnes, 1823, Amer. Jour. Sci., v. 6, p. 259, pl. 13, fig. 10.
Actinonais carinata (Barnes) Baker, 1928, Freshwater Mollusca Wisconsin, pt. II, Bull. 70, Wisconsin Geol. Nat. Hist. Survey, Madison.

A series of shells, comprising only the hinge-line and immediately adjacent areas of the shell, were found at only two localities (24 and 34), and were referred to *Actinonais* because of hinge-line characters and the shape of the shell. The genus has been reported from Pleistocene deposits in Reeves County, Texas (Leonard and Frye. 1962, fig. 4) but occurrence of *Actinonais* in New Mexico has not been reported. At locality 34, a single shell yielded sufficient carbon for a radiometric determination of 5,865 ± 90 (ISGS-144) (table 2), the sediments in question being a flood-plain terrace of the Pecos River.

Armiger exigua Leonard
Pl. III, fig. 29

Armiger exigua Leonard, 1970, Nautilus, v. 85, p. 78, fig. 2, 3.

Armigera exigua is a minute aquatic snail, previously known from deposits of Illinoian age, Henry County, Illinois. *A. exigua* differs mainly from *A. crista* (Linn) in being much smaller while having the same number of whorls and in having a granular rather than striate nuclear whorl (Leonard, 1970, p. 78). The small series of shells from localities 4, 21 and 24 seem to have the same characters as those from Illinois.

Deroceras aenigma Leonard
Pl. III, fig. 34

Deroceras aenigma Leonard, 1950, Kansas Univ. Paleont. Contr., Mollusca art. 3, p. 38, pl. 5, fig. E.

The small slugs of the genus *Deroceras,* of which *D. laeve* (Müller) is the most common living example in North America, possess an internal platelike shell bearing spiral markings. Whether or not the shells referred to as *D. aenigma* represent one or more species is moot. The shell plates are distinctly larger and heavier than those of *D. laeve,* therefore, not derived from that species. *Deroceras,* as known from the living species, frequents moist habitats, near water at times, but not necessarily so. Shells referred here to *D. aenigma* occur in small series at two localities, 4 and 22.

Discus cronkhitei (Newcomb)
Pl. II, fig. 24

Helix cronkhitei Newcomb, 1865, California Acad. Sci. Proc. v. 3. p. 180
Discus cronkhitei (Newcomb) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 600. Philadelphia.

Discus cronkhitei possesses a small depressed helicoid shell with conspicuous riblets; the greater diameter is 5 to 6 mm. Though widely distributed in the United States, this mollusk is a mountain species that invaded the plains during pluvial periods of the Pleistocene at least as far back as Kansan time. *D. cronkhitei* lives in leaf mold or even in dense grass; in the mountains tends to lose its riblets, but the specimens taken from 4 of our localities (3, 4, 22, 42, fig. 6) have well-developed riblets.

Euconulus fulvus (Muller)
Pl. II, fig. 16

Helix fulva Muller, 1774, Hist. Vermium, v. 2, p. 56.
Euconulus fulvus (Muller) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 1, p. 235. Philadelphia.

Euconulus fulvus is a small terrestrial gastropod; its shell is tightly wound, conical, and somewhat more than 2 mm in diameter. A widespread holarctic species that prefers flood-plain or other moist woodland habitats. In our collections, this species occurs only at two localities (3, 4, fig. 6) both in deposits related to terraces of the Pecos River.

Ferrissia rivularis (Say)
Pl. II, fig. 19

Ancylus rivularis Say, 1819, Jour. Philadelphia Acad. I, p. 125. *Ferrissia rivularis* (Say) Baker, 1928, Freshwater Mollusca Wisconsin, pt. 1, p. 398, pl. 24, figs. 16-18, Bull. Wisconsin Geol. Nat. Hist. Survey, Madison.

The single, somewhat damaged specimen taken at locality 34 seems best referred to *F. rivularis* on basis of size and form, although a series of shells might modify this preliminary judgment. The shell is limpetlike in form; the animal clings to smooth hard surfaces-preferring the dead shells of unionids-and feeds on algae and other microscopic food items. The species is strictly aquatic in habitat preference.

Gastrocopta armifera (Say)
Pl. III, fig. 41

Pupa armifera Say, 1821, Jour. Acad. Nat. Sci. Philadelphia, v. 2, p. 162.
Gastrocopta armifera (Say) Pilsbry, Land Mollusca North America, v. 2, pt. 2, p. 874, fig. 472. Philadelphia.

Gastrocopta armifera is a small pupillid snail about 4 mm long (large for the genus). The specific name is derived from a series of denticlelike excrescences on the aperture. This species adapts to a wide range of habitats from moist forests to open grasslands, sometimes common in dense growth of buffalo grass not too closely grazed. Specimens are not abundant in our collections, being known from localities 7, 8, 17, 22, and 34 (fig. 6), and not numerous in any of them. The species is widely distributed east of the continental divide, and from Kansan deposits in the Pleistocene.

Gastrocopta cristata (Pilsbry & Vanatta)
P1. III, fig. 42

Bifidaria procera cristata Pilsbry & Vanatta, 1900, Acad. Nat. Sci. Philadelphia Proc., p. 595, pl. 22, figs. 4, *5*.

Gastrocopta cristata (Pilsbry & Vanatta) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 911, fig. 493.

Gastrocopta cristata is a minute pupillid snail, the shell being less than 3 mm in length; it is often confused with *G. procera,* although differing in the character of the angulo-parietal lamella, and the stronger crest behind the aperture lip. This species occurs at 17 of our localities (fig. 6), usually in abundance. While not mentioned specifically in New Mexico by Pilsbry (1948), this mollusk occurs as a common living species (table 1) as well as a common Pleistocene fossil.

Gastrocopta pentodon (Say)
P1. III, fig. 43

Vertigo pentodon Say, 1821, Jour. Acad. Nat. Sci. Philadelphia, v. 2, p. 376.

Gastrocopta pentodon (Say) Pilsbry, Land Mollusca North America, v. 2, pt. 2, p. 886, fig. 477.

One of the smallest species of the genus, *G. pentodon* is less than 2 mm in length, and as the name suggests, has numerous denticles in the aperture, at times more than 7. The most widely distributed of all the gastrocoptids in North America, it tolerates a wide variety of microhabitats, including dry slopes, wooded flood plains, and deep stands of grass. As in the case of *G. armifera,* various attempts have been made to recognize geographical races or subspecies, but almost invariably specimens are local variations not related to race. *G. pentodon* is not common in our collections, being known only from 4 localities (fig. 6), and not numerously represented in any of them.

Gyraulus circumstriatus (Tryon)
P1. II, fig. 26

Planorbis (Gyraulus) circumstriatus Tryon 1866, Amer. Jour. Conchology, v. 2, p. 113.

Gyraulus circumstriatus (Tryon) La Rocque, Pleistocene Moll. Ohio, Bull. 62, pt. 3, Ohio Geol. Survey, p. 493, pl. 12, fig. 10-18.

Gyraulus circumstriatus is a small planorbid snail of aquatic habitat; the shell is disklike and about 5 mm in diameter. The species is often confused with *G. parvus,* which is much more numerous in our collection. *G. circumstriatus* was recognized only at localities 5 and 27, while *G. parvus* occurs at 26 of the 45 localities (fig. 6). *G. circumstriatus* lives in clear water in ponds and small streams.

Gyraulus parvus (Say)
P1. II, fig. 27

Planorbis parvus Say, 1817, Nicholson's Encyclopedia, 1st Ed., v. 2, pl. 1, fig. 5 (no pagination).

Gyraulus parvus (Say) La Rocque, Pleistocene Mollusca Ohio, Bull. 62, Ohio Geol. Survey, pt. 3, p. 491, pl. 12.

Gyraulus parvus is a small aquatic planorbid snail, the shell scarcely exceeding 4 mm in diameter. It is similar to *G. circumstriatus* but differs in that the last whorl enlarges in approaching the aperture, unlike *G. circum striatus. G. parvus* is widely distributed in North America, especially east of the Rocky Mountains; prefers shallow bodies of quiet water, and lives on vegetation; by far the most numerously represented aquatic gyraulid in the basin deposits of this report.

Hawaiia minuscula (Binney)
P1. II, fig. 17

Helix minuscula Binney, 1840, Boston Jour. Nat. Hist., v. 3, p. 435, pl. 22, fig. 4.

Hawaiia minuscula (Binney) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. I, p. 420, fig. 228. Philadelphia.

A minute snail, its shell little more than 2 mm in diameter, *Hawaiia minuscula* is one of the most ubiquitous mollusks in North America; also found in other parts of the world. Occurs in a majority of the localities of this report (fig. 6), often the only species found in a local exposure of Pleistocene sediments. Tolerates a wide range of ecological situations, as expected of a species so widely distributed. Found under leaves in moist woodlands, in grass, beneath stones or bark, on dry slopes with little cover.

Helicodiscus parallelus (Say)
P1. II, fig. 23

Planorbis arallelus (corrected to parallelus in index) Say, 1821, Jour. Acad. Nat. Sci. Philadelphia, v. 2, p. 164.

Helicodiscus parallelus (Say) Pilsbry, Land Mollusca North America, v. 2, pt. 2, p. 625, fig. 339. Philadelphia.

The shell of *Helicodiscus parallelus* is small and disk shaped, with parallel raised striations. Say first found the shells in a dried-up pond, and assumed that the animal was aquatic; however, the animal is terrestrial, primarily a species of moist woodlands, living under leaves and other forest debris. The diameter of the shell is about 3 1/2 mm. Neither Pilsbry (1948) nor La Rocque (1970) mention New Mexico in the area of general distribution. Species is rare in our collections, a few shells having been recovered from two localities, 8 and 24 (fig. 6). Not reported previously from New Mexico.

Helicodiscus singleyanus (Pilsbry)
P1. III, fig. 30

Zonites singleyanus Pilsbry, 1890, Acad. Nat. Sci. Proc. Philadelphia, p. 84 (for 1889).

Helicodiscus singelyanus (Pilsbry) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 636, fig. 346. Philadelphia.

Helicodiscus singleyanus is a minute terrestrial snail superficially resembling *Hawaiia minuscula.* The shell may be distinguished by the smooth glossy surface in *H. singleyanus,* and by subtle differences in form. Pilsbry (1948) mentions New Mexico in his discussion of distribution; widely distributed from Arizona eastward. Tolerates a variety of habitats, dry as well as moist, but generally is found under leaves or stones, or in grass. Rare in our collections, having been recognized at only two localities, 24 and 29.

Helisoma trivolvis (Say)
P1. I, fig. 9

Planorbis trivolvis Say, 1817, Nicholson's Encyclopedia, 2nd Ed., pl. 2, fig. 2 (no pagination).

Helisoma trivolvis (Say) Baker, 1928, Freshwater Mollusca Wisconsin

Bull. 70, pt. 1, Wisconsin Geol. Nat. Hist. Survey, p. 330, pl. 20, fig. 1-13, 22, 23, Madison.

Helisoma trivolvis is a large planorbid snail found in quiet bodies of water. Numerous races have been described, but the status of these remains confused. Shells recovered in our studies are referred to the typical form. Considering the evidence of ponded water at many of our localities, we expected to find *H. trivolvis* at more than 8 localities (fig. 6) *Helisoma antrosa (anceps)* reported by others was not recognized in any of our collections.

Lymnaea (Stagnicola) caperata (Say)
Pl. I, fig. 12

Lymnaeus caperatus Say, 1829, New Harmony Disseminator, p. 230.
Stagnicola caperata (Say) Baker, 1928, Freshwater Mollusca Wisconsin Bull. 70, Wisconsin Geol. Nat. Hist. Survey, pt. 1, p. 260, pl. 18, figs. 43-47, Madison.

Lymnaea caperata is an aquatic snail whose high spiral shells vary to 13 mm or more in length. The species is not common in our collections, where many local faunas contain large populations of lymnaeids; occurred only in localities 37, 39, and 43 where small numbers of shells were collected. Although living in quiet water, this animal can survive in intermittent ponds. Not reported previously from New Mexico.

Lymnaea dalli (Baker)
Pl. II, fig. 20

Lymnaea dalli Baker, 1906, Illinois State Lab. Bull. Nat. Hist., v. 7, p. 104.

Lymnaea dalli is one of the smallest of the lymnaeids, the elongate spiral shell is only 3 to 4 mm in length. Occurs from the Ohio valley and Michigan to Arizona. Common in our collections (fig. 6) and often locally abundant, this little lymnaeid often wanders from water but remains in damp situations. It frequently lives in ephemeral bodies of water, surviving dry periods with no apparent difficulty. *Lymnaea dalli* is frequently associated with *L. parva*, a somewhat larger snail. *L. dalli* is abundantly represented in our collections (fig. 6).

Lymnaea exilis Lea
Pl. I, fig. 14

Lymnaea exilis Lea, 1837, Trans. Amer. Philos. Soc., v. 5, p. 114, pl. 19, fig. 82.
Stagnicola exilis (Lea) Baker, Freshwater Mollusca Wisconsin, pt. I, p. 226, pl. 14, figs. 7-11, pl. 17, fig. 16.

At locality 4, a few broken shells of *L. exilis* were recovered, although the predominant species at this locality is *L. palustris. L. exilis is* a large aquatic snail, its elongated spiral shell often reaching nearly 40 mm in length. Lives in ponds, sloughs and sluggish streams subject to seasonal drying. Probably not an important element of the aquatic molluscan fauna in New Mexico in late Pleistocene times.

Lymnaea humilis Say
Pl. I, fig. 11

Lymnaeus humilis Say, 1822, Acad. Nat. Sci. Philadelphia Jour., v. 2, p. 378.
Fossaria humilis (Say) La Rocque. 1968, Pleistocene Mollusca Ohio, Ohio Geol. Survey Bull. 62, pt. 3, p. 469, fig. 323.

Lymnaea humilis is a relatively small lymnaeid, the length of the shell being about 8 mm. The species distributed mainly over the eastern United States, but records exist (La Rocque, 1968, p. 471) from Canada, California and New Mexico. Prefers mud flats and moist areas near small ponds, but occasionally lives in the water. This species is rare as recognized in our collections, occurring only at localities 5 and 18 (fig. 6).

Lymnaea obrussa Say
Pl. I, fig. 13

Lymnaeus obrussus Say, 1825, Jour. Philadelphia Acad., v. 5, p. 123.
Fossaria obrussa (Say) Baker, 1928, Bull. 70, Wisconsin Geol. Nat. Hist. Survey, pt. 1, p. 293, pl. 16, fig. 14; pl. 18, figs. 14-24, Madison.

Lymnaea obrussa is a snail of moderate size, the shells about 10 to 13 mm in length. Distributed widely over the United States from coast to coast. *L. obrussa* lives in small bodies of water, ponds, sloughs, marshes and small streams, and on sticks and other debris in the water. The species is most abundantly represented in our collections from localities west of Fort Sumner (localities 3, 4, 5) occurring with *L. palustris;* found in lesser abundance at other localities (8, 16, 22, 37, fig. 6).

Lymnaea palustris (Muller)
Pl. I, fig. 10

Buccinum palustre Müller, 1774, Verm. Terr. et Fluv. Hist., p. 131.
Stagnicola palustris (Müller) La Rocque, 1968, Pleistocene Mollusca Ohio, Bull. 62, pt. 3, Ohio Geol. Survey, p. 443, fig. 294.

Lymnaea palustris is a circumboreal species found in North America from the Canadian Border to south of New Mexico. A large aquatic snail (the shell measuring up to 40 mm in length) that lives in quiet waters-often small bodies of water that become reduced and stagnant in dry seasons-but unlike many other lymmaids apparently needs water to survive. Most numerous in our collections at localities 4 and 5; occurs in abundance at several other of our localities (fig. 6).

Lymnaea parva Lea
Pl. II, fig. 18

Lymnaea parva Lea, 1841, Am. Philos. Soc. Proc., v. 2, p. 33.
Fossaria parva (Lea) Baker, 1928, Freshwater Mollusca Wisconsin, Bull. 70, pt. 1, Wisconsin Geol. Nat. Hist. Survey, p. 285, pl. 16, fig. 7, pl. 18, figs. 1-5, Madison.

Lymnaea parva is larger than *L. dalli*, but still small; its shell measures about 5 mm in length. Distributed from James Bay and Montana south to New Mexico and Arizona. More likely to occur out of the water on mudflats, sticks, stones, and various debris. A hardy snail that survives year after year in or near ephemeral ponds and sloughs.

Physa anatina Lea
Pl. I, fig. 5

Physa anatina Lea, 1864, Acad. Nat. Sci. Philadelphia Proc., p. 115.
Physa anatina Lea, La Rocque, 1968, Pleistocene Mollusca Ohio, Ohio Geol. Survey Bull. 62, pt. 3, p. 535, pl. 13, figs. 2, 3, I 1, 12.

Physa anatina and *Physa gyrina are* so variable that, even within the same population, the identification of these species is fraught with many problems. However, typical forms of both species seem evident in our collections, although *P. skinneri* Taylor, perhaps to be expected here, was not found. In our area, *P. anatina is* more abundant than *P. gyrina,* both in the number of localities represented and in the abundance of individuals. *P. anatina* lives in quiet, even stagnant water, or the quiet edges of large streams; it often thrives in large numbers in ephemeral pools, roadside ditches and the like subject to seasonal drying. In Bottomless Lakes State Park, Chaves County, a series of relatively recent sinks occur at the periphery of a larger subsidence area. At one of these lakes, Mirror Lake, about 20 ft of lake deposits are exposed. These sediments contain large numbers of *Physa anatina,* although none were found in the lake itself, which seems to be rather deep, although not "bottomless". The present lake, though probably highly gypsiferous, supports abundant algae and small fish. Careful search, however, revealed no mollusks living in these waters.

Physa gyrina Say
Pl. I, fig. 7

Physa gyrina Say, 1821, Acad. Nat. Sci. Philadelphia Jour., v. 2, p. 171.
Physa gyrina Say, La Rocque, 1968, Pleistocene Mollusca Ohio, Ohio Geol. Survey Bull. 62, pt. 3, p. 541, fig. 396.

Physa gyrina prefers habitats similar to those occupied by *P. anatina,* and likewise thrives in ephemeral bodies of water. The shell is usually more streamlined and heavier than that of *P. anatina,* sometimes referred to as the tadpole snail because of its form. *P. gyrina* is widely distributed east of the Rockies, into arctic Canada, and south into Texas. Less common in our collections than *P. anatina;* represented at only 4 localities (fig. 6).

Pisidium compressum Prime
P1. II, fig. 22

Pisidium compressum Prime, 1851, Boston Soc. Nat. Hist. Proc., v. 4, p. 164.
Pisidium compressum Prime, La Rocque, 1967, Ohio Geol. Survey Bull. 62, pt. 2, p. 329, pl. 5, fig. 2, pl. 7, fig. 14.

The small pelecypod, *Pisidium compressum,* is widely distributed in North America, both living and as a fossil in Pleistocene sediments. Thrives in clear running 'streams or at outlets of springs, especially those with sandy bottoms. In our region, *P. compressum* is less common than *P. nitidum,* being found at only 5 out of 45 localities (fig. 6). The shell is larger and more rugged than *P. nitidum,* and has a characteristic, almost triangular, form.

Pisidium nitidum Jenyns
P1. III, fig. 33

Pisidium nitidum Jenyns, 1832, Cambridge Philos. Soc. Trans., v. 4, p. 304, pl. 20, figs. 7, 8.
Pisidium nitidum Jenyns, La Rocque, 1967, Pleistocene Mollusca Ohio, Ohio Geol. Survey Bull. 62, pt. 2, p. 333, pl. 5, fig. 6, pl. 7, fig. 17.

Pisidium nitidum is smaller than *P. compressum;* the shell tends toward being round in lateral view and more inflated. In our collections, *P. nitidum is* more widely distributed than is *P. compressum* but both have about the same wide distribution in the United States. Although *P. nitidum* occurs in 9 of our localities, nowhere is it numerous.

Promenetus umbilicatellus (Cockerell)

Planorbis umbilicatellus Cockerell, 1905, Conchologist's Exchange, v. 2, p. 68.
Gyraulus umbilicatellus (Cockerell) Baker, 1928, Freshwater Mollusca Wisconsin, Bull. 70 Wisconsin Geol. Nat. Hist. Survey, pt. 1, p. 383, pl. 22, figs. 18-21.

A single shell of this small aquatic planorbid, having the characters of *P. umbilicatellus* rather than those of *P. exacuous* was recovered from locality 5 (Appendix A). The shell is imperfect, therefore, the identification is not completely certain. The shell measures 5 to 6 mm in greater diameter. Ecological requirements are not well known.

Pupilla blandi Morse
P1. III, fig. 39

Pupilla blandi Morse, 1865, Ann. Lyc. Nat. Hist. New York, v. 8, fig. 8.
Pupilla blandi Morse, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 929, fig. 502.

Pupilla blandi is widely distributed in the Rocky Mountain region. During various phases of the Pleistocene epoch, at least as far back in time as the Kansan, this species moved out onto the High Plains. This small pupillid snail of terrestrial habit lives on flood plains among plant debris, but can withstand considerable dessication. Like *P. muscorum,* however, *P. blandi* seems unable to withstand the extremes of climatic fluctuation today on the Great Plains. The shell is about 3 mm long and bears 0 to 3 denticles on the aperture, sometimes difficult to distinguish from *P. muscorum.*

Pupilla muscorum (Linne)
P1. III, fig. 37

Turbo muscorum Linne, 1758, Syst. Nat., 10th Ed., p. 767.
Pupilla muscorum (Linnaeus) Pilsbry, 1949, Land Mollusca North America, v. 2, pt. 2, p. 933, fig. 503. Philadelphia.

Pupilla muscorum is about the same size as *P. blandi,* the shell attaining a length of about 3 mm or more, but typically lacking denticles in the aperture, although one or more may occur at times. *P. muscorum* differs from *P. blandi* in having the lip thickened within, with a heavy crest behind the aperture, characters not found in *blandi. P. muscorum* lives on dry flood plains, and in grass and other vegetation in the Rocky Mountain region. The eastern populations apparently require more *water. P. muscorum is* widely distributed in North America and in northern Europe. Like *P. blandi,* or to an even greater extent, *P. muscorum* invaded the Great Plains Province during Pleistocene times, beginning with the Kansan.

Pupilla syngenes (Pilsbry)
P1. III, fig. 38

Pupa syngenes Pilsbry, 1890, Nautilus, v. 4, p. 39, pl. 1, fig. 7.
Pupilla syngenes (Pilsbry) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 939, fig. 503. Philadelphia.

In many ways, *P. syngenes is similar* to *P. blandi* and *P. muscorum,* but the whorls of the cylindrical shell are sinistrally wound. There may be 1, sometimes 2, snail denticles in the aperture. The species occurs in Arizona, Utah, New Mexico, and Montana as living colonies. *P. syngenes* did not invade the Great Plains as did *P.*

muscorum and *P. blandi,* although a few records exist. Ecologically, *P. syngenes* seems to be a species of xeric habitats.

Pupoides albilabris(Adams)
Pl. III, fig. 46

P(upa) albrilabris "Ward's Letter" C. B. Adams, 1841, Am. Jour. Sci., v. 40, p. 271 (new description for *Cyclostoma marginata* Say).
Pupoides albilabris (C. B. Adams) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 921, fig. 499. Philadelphia.

Pupoides albilabris is large for a pupillid, the shell being about 5 mm in length, tall, and conic in shape, with a thickened lip (from which it gets its name), and without apertural denticles. Distributed from Maine to Florida and west to the plains states and Arizona, this species lives under stones, bark, and other plant detritus, but does not require a constantly moist environment. According to Pilsbry (1948, p. 923) *P. albilabris* never occurs at high altitudes. The species occurs at many localities in our region (fig. 6), but never in large numbers at any one locality.

Pupoides hordaceus (Gabb)
Pl. III, fig. 45

Pupa hordacea Gabb, 1866, Am. Jour. Conchology, v. 2, p. 331, pl. 21, fig. 7.
Pupoides hordaceus (Gabb) Pilsbry, Land Mollusca North America, v. 2, pt. 2, p. 924, fig. 499. Philadelphia.

Pupoides hordaceus is similar in form to *P. albilabris* but bears distinctive spiral riblets and is also smaller. *P. hordaceus* is a montane species, occurring in New Mexico, Colorado, Utah, and Arizona; during the climatic oscillations of the Pleistocene, there was a meager migration onto the plains. This species prefers the arid plateaus and foothills to the higher reaches of the mountains. In our collections, *P. hordaceus* occurs at only 4 localities, and then not abundantly (fig. 6).

Pupoides inornatus Vanatta
Pl. III, fig. 44

Pupoides inornatus Vanatta, 1915, Nautilus, v. 29, p. 95.
Pupoides inornatus Vanatta, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 926, fig. 499. Philadelphia.

Pupoides inornatus is similar to *P. hordaceus* but lacks the conspicuous riblets of the latter. According to Pilsbry (op. cit., p. 926), *P. inornatus* is a species of the Rocky Mountains spreading eastward, but never seems to be abundant in any locality. Represented in our collections by a single shell at a single locality, 8.

Retinella electrina (Gould)
Pl. II, fig. 15

Helix electrina Gould, 1841, Invertebrates Mass., p. 183. fig. 111.
Retinella electrina (Gould) Pilsbry, Land Mollusca North America, v. 2, pt. 2, p. 256, fig. 126. Philadelphia.

Retinella electrina has recently been assigned to the genus *Nesovitrea*, a genus proposed by C. M. Cooke for another species. To make this change for fossil shells seems unwarranted. *R. electrina* is a small snail with a glossy shell with indented spiral impressions. Distributed over eastern North America, and in favorable environments, extends as far west as Arizona. The species is basically a woodland snail, but will invade gallery woodlands along streams, and to a certain extent, chaparral. The shell is a depressed helicoid spiral, about 5 mm in diameter. A related species, *R. indentata,* frequently sympatric with *R. electrina,* was not found in our collections. *R. electrina* is not common in our region, occurring at only 4 localities (fig. 6).

Sphaerium nitidum Clessin
P1. II, fig. 25

Sphaerium nitidum Clessin, 1876, *in* Westerlund, Neue Binnenmoll. Sibir., p. 102.
Sphaerium nitidum Clessin, La Rocque, 1967, Pleistocene Mollusca Ohio, Ohio Geol. Survey Bull. 62, pt. 2, p. 293, pl. 1, fig. 6.

A small series of valves that seems best assigned to *Sphaerium nitidum* was recovered from locality 21 (fig. 6). This small sphaeriid, of circumboreal distribution, occurs widely in North America, but has not been reported previously from New Mexico. According to Herrington, 1962, p. 21, it requires cold, deep water in temperate climates. The sediments from which the shells came at locality 21 reflect a permanent body of water, but we lack data on the depth of the basin.

Sphaerium transversum (Say)
Pl. I, fig. 6

Cyclas transversa Say, 1829, New Harmony Disseminator, v. 2, p. 356.
Sphaerium transversum (Say) La Rocque, 1967, Pleistocene Mollusca Ohio, Ohio Geol. Survey Bull. 62, pt. 2, p. 293.

Sphaerium transversum is one of the large species of the genus, much larger than *S. nitidum. S. transversum* is widely distributed east of the Rockies, from northern Canada to Florida. It has been recorded from large and small streams, and from lakes, ponds and sloughs. This species is not common in our collections, occurring at only two localities, 22 and 41. However, at these localities shells were common, and at locality 41, shells were extremely abundant in the upper few feet of exposed lakebeds, but entirely absent in the older and deeper deposits.

Somatogyrus subglobosus (Say)
Pl. II, fig. 28

Paludina subglobosa Say, 1825, Acad. Nat. Sci. Philadelphia Jour., v. 5, p. 125.
Somatogyrus subglobosus (Say) La Rocque, 1968, Pleistocene Mollusca Ohio, Ohio Geol. Survey Bull. 62, pt. 3, p. 404, pl. 11, fig. 1, 3.

Somatogyrus subglobosus is the only branchiate snail, except *Valvata lewisii,* discovered in our studies of the fossil mollusks of east-central New Mexico. The occurrences in localities 4, 6, 21, and 22 constitute a new record for New Mexico and apparently a record for western distribution as well, previous records being largely limited to east of the Mississippi River. The shell is, as the name suggests, nearly globose; shells are about 9 mm high, but 7 to 8 mm wide. The shell is operculate, but no opercula have been recovered in our collections.

Succinea gelida Baker
Pl. I, fig. 4

Succinea grosvenori gelida Baker, 1927, Nautilus, v. 40, p. 118. *Succinea grosvenori gelida* Baker, Pilsbry, 1948, Land Mollusca North America, v. 2, p. 2, p. 823, fig. 444. Philadelphia.

This species, a loess fossil described by Baker as a subspecies of *Succinea grosvenori,* does not intergrade with *grosvenori-although* many hundreds of both kinds have been taken both together and separately. If one may judge from shell characters, *S. gelida is* probably *a Catinella,* but this relationship cannot be substantiated because of the lack of the soft anatomy and the somewhat confused state of the genus *Catinella* at the present time. However, the shells assigned to *Succinea gelida* occur at many localities (fig. 6) and are usually represented by sizable populations where present. The shell is small, and quite distinct from *S. grosvenori,* which frequently occurs in the same assemblage (fig. 6).

Succinea grosvenori Lea
Pl. I, fig. 3

Succinea grosvenori Lea, l864, Acad. Nat. Sci. Proc. Philadelphia, p. 19.

Succinea grosvenori Lea, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 819, figs. 44, 452. Philadelphia.

Succinea grosvenori is the most common succineid in our collections, occurs at a majority of the localities (fig. 6), and is abundantly represented at most of these. The shells compare favorably with those in the Gallinas River valley below Las Vegas, New Mexico. The living species has a wide range of climatic tolerance, including the ability to endure long periods of drought. Individuals have been found aestivating on rocky outcrops in open sunlight where summer temperatures are extremely high; on one occasion, one of us found such individuals living after 6 months of continued dormancy in the laboratory.

Succinea luteola Gould
Pl. I, fig. 2

Succinea luteola Gould, 1848, Boston Soc. Nat. Hist. Proc., v. 3, p. 337.

Succinea luteola Gould, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 828, fig. 450. Philadelphia.

Succinea luteola is about the same size although generally somewhat smaller than *S. grosvenori. S. luteola* is much larger in the southern part of its range, where shells measure up to about 20 mm in length. The shells of the two species are sometimes difficult to distinguish, but in *S. luteola,* the aperture is relatively more narrow and the body whorl is less swollen. The diameter of the body whorl of *S. luteola* is generally about half the height, while the diameter of this whorl in *S. grosvenori* is approximately two-thirds the height. *S. luteola* is the most common in Texas, but living colonies have been reported from New Mexico.

Succinea ovalis Say
P1. I, fig. 1

Succinea ovalis Say, 1917, Jour. Acad. Nat. Sci. Philadelphia, v. I, p. 15.

Succinea ovalis Say, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 801, fig. 430-433. Philadelphia.

Succinea ovalis is one of the larger species of the genus, shells measuring up to nearly 20 mm in length; the aperture is large and oval. In our collections a small series of immature individuals was recovered from the deposits at locality 22 (fig. 6; Appendix A). The species seems not to have been previously recorded from New Mexico. Living colonies that we have observed elsewhere were in wet situations associated with brushy slopes where contact spring water emerged, or in swales among reeds and sedges. The rarity of the species in our collections allows room for little speculation about local habitats.

Vallonia cyclophorella Sterki
P1. III, fig. 31

Vallonia cyclophorella Sterki, 1892, Nautilus, v. 5, p. 101.

Vallonia cyclophorella Sterki, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 1035, fig. 554. Philadelphia.

The genus *Vallonia* is composed of small terrestrial snails with low helicoid shells, most often with conspicuous riblets. They live in flood plains and other moist habitats among plant debris and other litter. *Vallonia cyclophorella* is widely distributed in the mountain states, sometimes associated with *V alba* or *V. gracilicosta. V. cyclophorella* is generally more northern in distribution than *V. perspectiva,* but their ranges overlap. *V. cyclophorella* is always larger than *V. perspectiva. V. cyclophorella* occurs at several of our collecting localities (fig. 6).

Vallonia gracilicosta Reinhardt
Pl. III, fig. 32

Vallonia gracilicosta Reinhardt, 1883, Stizungs-Ber. Ges. Naturforsch Freunde Berlin, p. 42.

Vallonia gracilicosta Reinhardt, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 1028, fig. 549a. Philadelphia.

This species is the most common fossil vallonid in our collections, and in Pleistocene faunas across the Great Plains. Living colonies occur in Arizona and New Mexico, and northward to Minnesota. *V. gracilicosta* has, like *V. cyclophorella,* riblets but differs by having a conspicuous reflected and thickened lip at the rim of the aperture. *V. gracilicosta* lives in the mountains under leaves in aspen groves, but is equally at home in grassy, forest border situations or flood plains where grass and plant debris conserve moisture. In our experience, this species occurs most frequently in colonies of great numbers of individuals.

Valvata lewisii Currier
Pl. II, fig. 21

Valvata lewisii Currier, 1868, Kent Sci. Inst. Misc. Pubis. no. 1, p. 9 (new name for *Valvata striata* Lewis).

Valvata lewisii Currier, Baker, 1928, Freshwater Mollusca Wisconsin, Wisconsin Geol. Nat. Hist. Survey, Bull. 70, pt. 2, p. 26, pl. 1, figs, 28-30, Madison.

Valvata lewisii Currier is, like *Somatogyrus subglobosus,* a gill-bearing, operculate gastropod that requires permanent, clear water, and, apparently, prefers sand bottoms. *V. lewisii* lives on vegetation, floating sticks and logs, and the like. It is distributed mostly in the northern half of the United States; our collections record a southwestern distribution for the species. Shells are small, usually less than 5 mm in length, and turbinate in form. Locality 4 (Appendix A) consists of a large ponded area on a terrace surface, exposed by erosional degradation of the original terrace surface. The faunal assemblage, which is relatively extensive, contains many aquatic snails; *Somatogyrus,* the other branchiate snail in our collections seems not to occur with *V. lewisii.*

Vertigo diaboli Pilsbry
Pl. III, fig. *35*

Vertigo ovata diaboli Pilsbry, 1919, Manual Conchology, v. 25, p. 88, figs. 11, 12.
Vertigo ovata diaboli Pilsbry, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 953, fig. 513. Philadelphia.

The lower palatal folds and other characteristics of *V. diaboli* seem not to intergrade with those of typical *V. ovata*, thus *V. diaboli is treated* as a distinct species. The shell is small, pupoid, less than 2.5 mm in length; external features are very similar to typical *V. ovata*. Previous records of *V. diaboli* in New Mexico are not known to us; the specimens known to Pilsbry came from Val Verde County, Texas, not far from the Rio Grande. Typical *V. ovata* ranges widely across North America into Canada and eastern United States, southwest to Utah and Arizona, where this species seems to prefer rather moist habitats in leaf litter and other plant debris. The ecological requirements of *V. diaboli* are unknown.

Vertigo elatior Sterki
Pl. III, fig. 36

Vertigo ventricosa var. *elatior* Sterki, 1894, The Land and Freshwater Mollusca in the vicinity of New Philadelphia, a contribution to the Natural History of Tuscarawas County, Ohio, p. *5*.
Vertigo elatior Sterki, Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 956, fig. 514, 515. Philadelphia.

Vertigo elatior is a small pupillid gastropod of terrestrial habits, in form somewhat similar to *diaboli*, but smaller and more cylindrical; distinguishing features of *V. elatior are* its apertural denticles. *V. elatior*, more widely distributed than *V. diaboli*, has been previously reported from New Mexico, *V. elatior* is able to survive in severe climatic zones, including the montane regions of New Mexico. In our collections *V. elatior* is less common than *V. diaboli* and occurs only at locality 21 (fig. 6).

Vertigo milium (Gould)
Pl. III, fig. 37

Pupa milium Gould, 1840, Boston Jour. Nat. Hist., v. 3, p. 402, v. 4, p. 359.
Vertigo milium (Gould) Pilsbry, 1948, Land Mollusca North America, v. 2, pt. 2, p. 944, fig. 509. Philadelphia.

Vertigo milium, whose shell measures less than 2 mm long, is one of the smallest species of the genus. The shell is ovate, and its apertural denticles quite distinctive. *V. milium* is distributed from Quebec and Maine to North Dakota and southwestward to Arizona; also in some of the Caribbean islands. This species prefers a wet habitat; because of habitat selection, small size, and capillarity of water, *V. milium* often lives submerged, although not in open water itself. Colonies are, therefore, most often situated near ponds, springs, and sloughs. In our collections, *V. milium* is not common, but does occur at 5 localities (fig. 6).

DISCUSSION OF MOLLUSCAN ASSEMBLAGES

At each of 8 localities, a sufficient quantity of molluscan shells were collected to permit radiometric dating of the shells and, thereby, the sediments containing them. These localities and dates are listed in table 2. Locality numbers are same as in fig. 1 and 6, and in Appendix A.

Dated Assemblages

There are difficulties in comparing the dated assemblages among themselves, because all were not collected in the same manner or thoroughness. Comparing the 5 oldest Woodfordian faunal assemblages (nos. 16, 5, 4, 27 and 41, ranging from 18,000 to 14,310 radiocarbon years B.P.), the oldest was a handpicked fauna from a site where we recovered only 5 species, all of which occur among the other localities, and all are aquatic except for *Succinea grosvenori*. Large bulk samples were taken from localities 4, 5, and 27; locality 41 was handpicked. Locality 4, where 25 species were recovered, consisted of lake deposits extensively exposed in recent gullies and in road-ditch excavations. Various facies of the ancient lake deposits, such as shoreline, bar, and offshore, are exposed, and the site was studied intensively.

Evidently the meager collection of species from locality 16 (18,100 B.P.) cannot be compared with that from locality 4 (16,490 B.P.), even though the time lapse is less than 2,000 years. Obviously, at locality 16, only an open-water facies was exposed *(Succinea grosvenori* floats readily), hence, the lack of the shoreline and

TABLE 2—LOCATION AND RADIOCARBON DATES OF 8 MOLLUSCAN FAUNAS IN EAST-CENTRAL NEW MEXICO. *(In all cases, molluscan shells served as a source of carbon for radiometric analysis)*

LOCALITY 16 3.6 mi northeast Pecos River crossing of US-70 northeast of Roswell, Chaves Co., SE SW SW sec. 20, T. 8 S., R. 26 E.	18,100 ± 370 (ISGS-92) B.P.
LOCALITY 5 1.4 mi west Pecos River bridge at Fort Sumner, De Baca Co., NW NW SW sec. 24, T. 3 N., R. 25 E.	17,180 ± 140 (ISGS-91) B.P.
LOCALITY 4 1.9 mi west Pecos River bridge at Fort Sumner, De Baca Co., S½SW NE sec. 23, T. 3 N., R. 25 E.	16,490 ± 120 (ISGS-149) B.P.
LOCALITY 27 1 mi south of Krider (US-60), Roosevelt Co., SW cor. sec. 6, T. 2 N., R. 30 E.	15,280 ± 210 (ISGS-151) B.P.
LOCALITY 41 15 mi east-southeast center Portales, Roosevelt Co., NE cor. sec. 11, T. 3 S., R. 36 E.	14,310 ± 230 (ISGS-145) B.P.
LOCALITY 3 1.1 mi west Pecos River bridge at Fort Sumner, De Baca Co., NE SW sec. 24, T. 3 N., R. 25 E.	13,820 ± 270 (ISGS-150) B.P.
LOCALITY 37 10.8 mi southwest of Texas-New Mexico line on NM-125, Lea Co., W½ sec. 16, T. 10 S., R. 37 E.	13,690 ± 160 (ISGS-147) B.P.
LOCALITY 34 3.3 mi east-southeast Lake Arthur, Chaves Co., SW NE sec. 27, T. 15 S., R. 25 E.	5,865 ± 90 (ISGS-144) B.P.

terrestrial aspects of the fauna. These observations are in part conjecture, but the fact remains that faunas represented by such localities as 16, on the one hand, and localities 4 and 5 on the other, are difficult to compare, apart from age similarity. Locality 27 was worked intensively to obtain material for dating; it is a pond deposit exposed in a road ditch and only an offshore facies was observed. At locality 41, shells were handpicked from the final phases of deposition when Salt Lake was much higher than now; the shells represent the youngest deposits in the basin. Only offshore sediments are exposed, and the limited assemblage reflects this, as well as the method of collecting.

Assemblages 4 and 5 have nine species in common (50 percent of the 18 species in no. 5, and 36 percent of the 25 species in no. 4). There seems to be little difference between the two assemblages. Each contains a branchiate snail that demands clear, permanent water; each bears a large assortment of aquatic pulmonates; each has abundant small pelecypods that demand permanent water; each has a series of terrestrial shells washed in from the surrounding slopes. Comparing the 5 oldest faunas among themselves, indicates that aquatic pulmonates form the common denominator, with varying numbers of terrestrial snails according to facies exposed. The localities where branchiates occur are limited, permanent bodies of water, whereas the other bodies of water may have been intermittent.

From the standpoint of ecological interpretation, evidently little change was produced in the local molluscan faunas during pluvial conditions that continued, at least intermittently, for more than 4,000 years. Although the list of shells in Hester (1972, p. 25) included *Strobilops texasiana* Pilsbry and Ferris, in the Blackwater Draw fauna, we have not recovered this woodland species in our collections. We have no evidence of permanent woodlands near the vicinity of any of these 5 faunal assemblages, although indications of a minimal gallery woodland and shrubby undergrowth are indicated by such terrestrial species as *Retinella electrina* and *Euconulus fulvus.* Truly woodland genera are absent from these deposits, however. Doubtless the local climate was much wetter than now. Few aquatic pulmonates are in the region now, and certainly no branchiate snails. In fact, the local terrestrial fauna is depauperate, as noted in table 1. Whether the climate was much cooler than at present is less certain, but probably the climate was cooler as a result of being much wetter. However, little evidence in the fauna suggests north temperate conditions. Many of the species no longer live as far south as east-central New Mexico, probably mostly a response to lack of suitable aquatic habitats rather than appreciably cooler climate. For example, *Lymnaea palustris,* a species of more northern distribution, still exists in New Mexico at higher altitudes where suitable aquatic habitats persist.

Terrace vs. Pond Assemblages

Among our collections, two assemblages, one from locality 3, the other from locality 37, are almost exactly of the same age as determined by radiocarbon analysis. Locality 3 is in terrace deposits of the Pecos River, dated at this place at 13,820 **B.P.,** while locality 37 is an ancient pond deposit situated on the high plains upland, and is dated at 13,690 B.P. (table 2). Again, comparisons are complicated by differing collecting methods. Locality 3 was very intensively worked, and large quantities of matrix were washed over a screen in a successful attempt to obtain sufficient shells (most of them small) for a radiocarbon date. Locality 37 was along a road ditch, and was handpicked. The abundance of *Succinea grosvenori* exposed on the surface at Locality 37 provided sufficient carbon for a radiometric analysis; the fauna seemed too sparse for bulk sampling. Yet all except one of the 9 species recovered at locality 37 occur in the much larger assemblage recovered at locality 3; that one species, *Lymnaea caperata* is basically the ecological equivalent of *L. obrussa,* apparently its counterpart in assemblage no. 3. Presumably pond faunas of the High Plains along with contemporary faunas associated with terraces were not significantly different, except that possibly the latter were more varied.

Comparison of Two Large Assemblages

Assemblages 3 and 21 are compared because of similar numbers in the assemblage, as well as because one is a terrace fauna, the other an upland pond deposit. Locality 21 has not been dated. Locality 3 contains 21 species, locality 21 has an assemblage of 20 known species. Only one genus, *Promenetus,* is not shared by both assemblages, and only 5 species, other than *P. umbilicatellus,* occur only in assemblage no. 21 and not in assemblage no. 3. Inasmuch as the shells at locality 21 have not been dated, the age correspondence between the two faunas is not firmly established, but the assemblage at locality 21 is probably slightly older than that at locality 3. At any rate, these two assemblages, one on a Pecos River terrace, the other from a pond fill on the High Plains, are remarkably similar in faunal composition.

Assemblages from Kansan Deposits

Only two small assemblages were recovered from deposits classified as Kansan in age, no. 12 near the town of Floyd adjacent to the ancient Portales valley, and one (no. 13) near the village of Kenna in a pediment pass veneered with Kansan sediments (fig. 6, Appendix A). Assemblage no. 12 contains only 5 species, *Gyraulus parvus, Pupilla blandi, Pupoides albilabris, Succinea grosvenori,* and *Vallonia gracilicosta.* Among these 5 species, only *G. parvus* is absent from assemblage 13 which is somewhat larger and contains 9 species. Fig. 6, however, reveals that none of the additional species are unusual or unique in any way; they occur commonly in terrace and pond faunas widely distributed over our study area. Therefore, the Kansan assemblages do not possess distinctive elements. Rather, they reflect species adaptable to basic ecological conditions in east-central New Mexico, that have either persisted over the latter half of the Pleistocene here, or have migrated in and out of the region as conditions changed. The former conjecture is most likely.

Assemblages from Flood-plain Terrace Deposits

Seven collections (localities 17, 23, 28, 29, 31, 33, and 34, Appendix A) consist of mollusks in flood-plain terrace deposits, from a variety of local sources. Four came from the flood-plain terrace of the Pecos River, distributed from Fort Sumner to near Lake Arthur, one (locality 28) from Conejos Creek southeast of Yeso, one (locality 29) from Ciénega del Macho near the crossing of US-285 north of Roswell, and one (locality 31) from Kenna Draw, near the village of Kenna. One of these collections, 34 southeast of Lake Arthur, contained unionid shells, making possible a radiometric age determination of the shells and the deposits containing them as 5,865 ± 90 radiocarbon years B.P. (ISGS-144). The composite fauna of the 7 flood-plain terrace deposits consist of 17 species; local assemblages vary from 3 to 9 species. Ten of the 17 species occur in the modern faunal assemblage. These facts are summarized in table 3.

Inasmuch as a majority of the mollusks occurring in flood-plain terrace deposits also occur in the modern molluscan assemblage as now known, the local climatic conditions 5,000 to 6,000 years ago were probably similar to those of the present in the region. The flood-plain fauna is also composed of generalized and hardy species that seem to have been persistent in east-central New Mexico. For example, 8 of the 10 species comprising the composite Kansan fauna (nos. 12, 13; fig. 6) are also found in the flood-plain terrace assemblages; furthermore, all the species in the flood-plain terrace assemblages also occur in older terrace and basin-fill molluscan fauna assemblages. However, the flood-plain terrace assemblages do not contain branchiate gastropods which are also absent in the modern faunal assemblage. Following the pluvial period that strongly affected east-central New Mexico about 17,000 to 18,000 years ago, and for a few thousand years after that, the climate shifted toward the present semiarid conditions attained at least 5,000 years ago (table 2). Also, if one may speculate on the basis of the meager faunal assemblages now available, the veneer on the great Kansan pediment slopes that form so conspicuous a feature of the terrain west of the Ogallala escarpment, probably developed under a climate similar to the present.

Fossil molluscan faunas, by their composition and abundant populations of aquatic species (now locally exterminated), indicate a pluvial period from 18,000 to 13,000 B.P. The great majority of these bodies of water have subsequently disappeared completely, leaving bottom and shoreline sediments and contained fossils as evidence of their former presence. Such existing lakes as Salt Lake, southeast of Portales, are now a small fraction of their former volume and area. The volume of these persisting lakes fluctuates somewhat with minor oscillations in local seasonal precipitation, temperature, and air movement, but the lakes seem to be basically in equilibrium with these elements upon which they depend for existence. In other words, their relatively stable volume today reflects the mean balance between water gained by runoff from surrounding slopes and water lost by evaporation from the exposed surface.

TABLE 3—Distribution of 17 species of fossil mollusca in flood-plain terraces at 7 localities (figs. 1 and 6, Appendix A) and occurrence of these species in the modern molluscan assemblage (MMA) of east-central New Mexico

Species	Locality							MMA
	17	23	28	29	31	33	34	
Actinonais carinata	.	.	.	.	.	.	x	.
Ferrissia rivularis	.	.	.	.	.	.	x	.
Gastrocopta armifera	.	.	.	.	x	.	x	.
Gastrocopta cristata	x	x	x	.	.	.	x	x
Gastrocopta pentodon	x	.	.	x	.	.	.	.
Gyraulus parvus	x	.	.	.	x	.	x	x
Hawaiia minuscula	x	x	x	x	x	x	.	x
Helicodiscus singleyanus	.	.	.	x	.	.	.	.
Lymnaea dalli	.	.	x	.	x	.	.	.
Physa anatina	x	.	x	.	.	x	.	x
Physa gyrina	.	.	.	.	.	.	x	x
Pisidium nitidum	.	.	.	.	x	x	.	x
Pupilla blandi	.	.	.	.	x	.	.	x
Pupoides albilabris	x	x	x	.	x	.	x	x
Succinea grosvenori	x	x	x	.	x	x	.	x
Succinea luteola	.	.	.	.	.	.	x	.
Vallonia gracilicosta	.	.	.	.	x	.	.	x

This delicate balance can be disturbed by decreased or increased precipitation, by fluctuations in the rate of evaporative loss, or a combination of the two. The rate of evaporation, in turn, is influenced by a combination of air temperature and air movement. Loss of water from a lake surface is, therefore, not closely related to *mean* annual temperature, but responds to extremes; more than half the annual evaporation from a body of water may occur in a few summer months, especially when accompanied by high winds.

The numerous ponds and lakes in east-central New Mexico during the 18,000 to 13,000 B.P. pluvial period, therefore, were maintained by increased precipitation and/or decreased evaporative loss resulting from lowered annual mean temperatures, or, more likely, by supression of the summer extreme high temperatures relative to those prevailing today. Although the molluscan faunas do not clearly indicate a substantial lowering of mean annual temperatures, several species are known to be sensitive to extreme highs. For example, we have observed thriving colonies of *Papilla muscorum* on the flood plain of a small, spring-fed creek in the Red Desert of southern Wyoming, where the mean annual rainfall was even less than it is today in east-central New Mexico, but where summer extremes of temperature seldom exceeded the low 80's F.

During this long pluvial period the water budget was positive, and maintained the ponds and lakes at high levels over long periods of time—lakes contained impressive volumes of water. Inasmuch as the fossil mollusks found did not clearly require any considerable lowering of mean annual temperatures in the region, we may suppose that the lakes in question were maintained at permanent high levels by decreased evaporation during lowered summer extreme temperatures, as well as by increased precipitation. The contemporaneous deposition of impressive terraces in Woodfordian times by the Pecos River supports this conclusion.

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Appendix B—Described Stratigraphic Sections

This appendix includes 15 stratigraphic sections, measured and described during 1971 and 1972. These sections are grouped by principal stratigraphic unit. First are 6 sections of Ogallala Formation, arranged alphabetically by section name, followed by 9 sections of Pleistocene deposits, also arranged alphabetically. Numbers preceded by NMP- refer to samples for which clay minerals were described by Glass, Frye, and Leonard (1973). Location of Ogallala sections are shown on fig. 2; location of sections of Pleistocene deposits are shown on fig. 3.

OGALLALA FORMATION

East Caprock Oil Field Section—measured in west-facing escarpment, 2½ miles west of Lea-Chaves Co. line and 14½ miles north of lat. 33°00′ (sec. 10, T. 13 S., R. 31 E.), Chaves Co., New Mexico (1971)

Unit		Thickness (ft)
	Pliocene Series	
	Ogallala Formation (total thickness)	124
	Kimball zone	
13	Limestone (indurated caliche), platy with pisolitic structures, gray; exposed in slope from crest of scarp up slope to the High Plains surface	5.0
12	Sandstone, densely cemented with $CaCO_3$, massive becoming platy in upper part, gray, some travertine banding in upper part	15.0
	Ash Hollow zone	
11	Sand, medium to fine, gray, irregularly cemented with caliche; some pockets of relatively loose sand	5.0
10	Sand, medium to fine, pinkish-tan, cemented throughout but weathers to knobby surface and vertical face	8.0
9	Sand, fine to medium, relatively loose except for a few irregular areas of soft caliche, tan	5.0
8	Sand, pink-tan, massive, loosely cemented throughout	12.0
7	Sand, pinkish-tan, massive with nodular caliche throughout, relatively loose	10.0
6	Sand, pinkish-tan, uniformly cemented throughout, massive, distinct vertical jointing	5.0
5	Sand, gray-tan, massive, caliche in nodules dispersed throughout and some pipy caliche	7.0
4	Sand, massive, tan, caliche in vertical pipes and joint plane fillings	4.0
3	Sand, massive, tan; lacks both nodular and pipy caliche	10.0
2	Sand, fine to medium, massive, tan, loose, contains some streaks of nodular caliche and a few dispersed caliche nodules throughout	28.0
1	Mostly covered by slope colluvium but at least in part loose sand; resting on Triassic sandstone	10.0

Little Red Lake Section—measured in eroded scarp west of Little Red Lake in a small outlier of Ogallala Formation, on O'Brian Ranch, 3 miles east of Elkins Station on Santa Fe Railway (SE SW sec. 25, T. 7 S., R. 28 E.), Chaves Co., New Mexico; elevation of top is 4,100 ft (1971)

Unit		Thickness (ft)
	Pliocene Series	
	Ogallala Formation (total thickness)	34
	Kimball zone	

Unit		Thickness (ft)
5	Limestone (indurated caliche), dense, sandy, strongly developed pisolitic structures, gray	3.0
4	Sandstone cemented with caliche, dense, massive but somewhat platy in upper part, gray	11.0
	Ash Hollow zone	
3	Sand, medium to fine, pinkish-tan, compact but cemented only locally; some thin zones of caliche	12.0
2	Sand, massive, gray and pinkish-tan, unevenly cemented with caliche; uneven contacts top and bottom	6.0
1	Sand, tan-brown, bedded, compact but not cemented; on Triassic purple shale	2.0

Parker Ranch Section—measured in valley sides, 2 miles west of Hassel Church (near NW cor. sec. 35, T. 6 N., R. 27 E.), Quay Co., New Mexico (1971)

Unit		Thickness (ft)
	Pleistocene Series	
	Kansan Stage, or younger	
11	Sand, pinkish-tan, massive, caliche nodules throughout; top one foot is platy caliche, moderately dense, with some travertine banding	10.0
	Pliocene Series	
	Ogallala Formation (total thickness)	90.0
	Kimball zone	
10	Limestone (indurated caliche), dense, sandy, platy, with some pisolitic structures in top 1 ft	8.0
9	Sand, irregularly cemented, light gray-tan, some nodular caliche and some pockets of loose sand	7.0
8	Caliche, dense, sandy with dispersed small pebbles, indistinct platy structure	2.0
7	Sand with dispersed gravel, massive, pipy cementation with pebbles capping the caliche pipes	3.0
	Ash Hollow zone	
6	Gravel and sand, well-cemented, some cobbles 1 ft in diameter, gravel predominantly crystalline rocks	4.0
5	Sand, loose, with a few thin beds of red-brown silt and clay; partly covered in mid-part	30.0
4	Sand, fine to medium, yellow-tan, loosely cemented, bedded, jointed	2.0
3	Silt and clay, massive and blocky, maroon-brown in lower part to lavender-tan at top	4.0
2	Sand and silt, pinkish-tan, massive, compact, weak caliche cementation at top	5.0
1	Sand, loose, gray-tan, with some gravel of crystalline rocks and Triassic rocks in lower part; poorly exposed in middle and upper part; base on Triassic sandstone	25.0

Ragland Section—measured in roadcuts along New Mexico NM-18 and adjacent gravel pits and erosional valleys immediately northwest of Ragland (sec. 15, T. 7 N., R. 30 E.), Quay Co., New Mexico (1971)

Unit		Thickness (ft)
	Pleistocene Series	
	Illinoian Stage	
	"Cover Sands"	
8	Sand and silt, red-brown and somewhat clayey in top 1½ ft, lower part tan and loosely cemented with caliche	5.0

Unit		Thickness (ft)
	Pliocene Series	
	Ogallala Formation (total thickness)	79.0
	Kimball zone	
7	Limestone (indurated caliche), dense, gray, pisolitic structures throughout but strongly developed in top half, platy	3.0
6	Sandstone, dense and uniformly cemented, gray, massive	3.0
5	Sand, silty, massive, a few dispersed crystalline pebbles, irregularly and unevenly cemented, pink-tan where poorly cemented (NMP-224) and gray-tan where cemented; contains small lenses of sand and gravel; 5 ft above base a local lens of opal cemented rock; lower 3 ft prominent caliche pipes with irregular horizontal zones; relatively massive caliche at top	34.0
	Ash Hollow zone	
4	Sand, tan, massive, loose, dispersed caliche nodules; contact sharp at top and transitional at base	6.0
3	Sand with a boxwork of caliche cement with loose sand where not cemented; tan where not cemented, gray where cemented	8.0
2	Sand, contains pebbles, more abundant in lower part, pink-tan where not cemented, (NMP-225) irregular cementation but cemented zone at top, platy and blocky	3.0
1	Conglomerate resting on Triassic red shale; pebbles and cobbles of crystalline rocks except near the base where boulders of Triassic occur up to 2 ft in diameter; interbedded with well-bedded sand; locally cemented	22.0

Santa Rosa Southeast Section—measured in eroded slope ¼ mile east of NM-84, 5 miles south of junction US-84 and I-40 at east end of Santa Rosa (SE sec. 22, T. 8 N., R. 22 E.), Guadalupe Co., New Mexico (1972, 1973)

Unit		Thickness (ft)
	Pliocene Series	
	Ogallala Formation (total thickness)	30
6	Limestone (indurated caliche), gray, dense, tough; well-developed pisolites (NMP-145, 307)	2.0
5	Caliche, platy, dense, gray	2.0
4	Caliche, sandy, massive, well-indurated but less dense than above, gray (NMP-308, 1 ft below top of bed)	4.0
3	Sand, loosely but generally cemented with caliche, pink-tan (NMP-309, base of bed)	2.0
2	Covered interval, appears to be similar to bed above	8.0
1	Sand and gravel, well-cemented, cross-bedded, makes distinct bench on the slope; partly covered in lower part; rests on Triassic rocks (NMP-310, 10 ft below top of bed)	12.0

Yeso South Section—measured in valley sides about 200 yards northeast of graded road, 1 mile east and 10 miles south of Yeso (NE sec. 23, T. 1 N., R. 22 E.), De Baca Co., New Mexico; elevation of top of section, 4,720 ft (1971)

Unit		Thickness (ft)
	Pliocene Series	
	Ogallala Formation (total thickness)	43
	Kimball zone	
7	Limestone (indurated caliche), dense, platy, banded in lower part and pisolitic structure in upper part	3.0
6	Sandstone, densely cemented in upper part and unevenly cemented in lower part, contains a few dispersed pebbles in lower part, gray	6.0
5	Sand with some silt, pink-tan, locally cemented, a few dispersed pebbles, massive	9.0
	Ash Hollow zone	
4	Gravel, coarse, cobbles up to 1 ft diameter, pebbles and cobbles mostly crystalline rocks, loosely cemented, matrix of pink-tan sand	10.0
3	Sand, pink-tan, massive some silt and a few dispersed pebbles, caliche nodules throughout	7.0
2	Gravel, coarse, cemented, cobbles up to 6 in. in diameter of both crystalline rocks and Triassic rocks; many pebbles and cobbles coated with laminated caliche and in some zones cemented together by laminated caliche	3.0
1	Sand, silt, and clay, red-brown, massive, contains irregular streaks of shale pebbles, and few crystalline pebbles; on Triassic gray sandstone	5.0

PLEISTOCENE DEPOSITS

Acme Station Section—measured in eroded ditches along northwest side of US-70, 3.6 miles northeast of Pecos River bridge (SE SE SW sec. 20, T. 8 S., R. 26 E.), Chaves Co., New Mexico; elevation of top of section 3,670 ft (1971, 1972)

Unit		Thickness (ft)
	Pleistocene Series	
	Wisconsinan Stage (total thickness)	11
3	Sand and silt, strongly gypsiferous with conspicuous selenite crystals, gray (NMP-179 middle; NMP-180 upper)	7.0
2	Sand and silt, gray, calcareous, massive, contains abundant *Lymnaea* and other fossil shells; radiocarbon date on snail shells, 18,100 ± 370 (ISGS-92); fauna locality No. NM-16. (NMP-178 base)	2.0
1	Sand and silt, dark-gray, nonfossiliferous, noncalcareous, massive, to bottom of exposure (NMP-176 base; NMP-177 top). Although Permian rocks are not exposed at the immediate locality, Permian red beds are extensively exposed nearby	2.0

Bob Crosby Bridge Section—measured in cut bank of Pecos River in flood-plain terrace, west side, 100 yards west of bridge on US-70 (SW sec. 35, T. 8 S., R. 35 E.), Chaves Co., New Mexico; elevation of top of section 3,525 ft (1971)

Unit		Thickness (ft)
	Holocene Series (total thickness)	9
6	Sand, loose, tan, indistinctly bedded; this unit is continuous with the thick dune sands that mantle this surface nearby	0.5
5	Clayey silt bands interbedded with sand, reddish-brown and tan	1.0
4	Sand, tan, bedded, loose	1.5
3	Silt, clay, and sand, with a few thin streaks of fine gravel, irregular, some small stringers of caliche, red-dish-light-brown; contains fossil snail shells sparsely throughout, fauna locality No. NM-17 from this unit and the unit below	1.5
2	Sand, tan, loose, massive; contains sparse fossil snail shells in upper part	1.5
1	Sand, silt, and clay, with a thin bed of loose sand in middle, compact, massive, reddish-brown; to low water level in Pecos River	3.0

Fort Sumner Section—measured in cut bank of Pecos River in flood-plain terrace (active flood plain of the river is 6 ft lower), 100 yards downstream from Pecos River bridge of US-60 at Fort Sumner (SE NW sec. 19, T. 3 N., R. 26 E.), De Baca Co., New Mexico; elevation of top is 4,020 ft (1971)

Unit	Thickness (ft)
Holocene Series (total thickness)	12
6 Silt and sand, tan, indistinctly bedded, locally pebbles are at top surface of terrace	1.5
5 Silt and sand with some clay, dark-gray-brown, partly leached; A-horizon of soil with weakly developed columnar structure, but no recognizable B-horizon; a few snail shells in lower part	1.0
4 Sand and silt, massive, reddish-brown; snail shells sparsely throughout (fossil locality, No. NM-23)	2.0
3 Clay and silt with some sand, red-brown	0.5
2 Silt and sand, massive, reddish-brown	2.0
1 Silt and sand, massive, reddish-brown; a bed of loose, tan, sand, 1½ inches thick at top; covered in lower part to low water level in Pecos River	5.0

Hagerman Ditch Section—measured in valley side and road ditch just west of Hagerman ditch, 2.8 miles north of Santa Fe Railway tracks in Dexter (NE cor., sec. 31, T. 12 S., R. 26 E.), Chaves Co., New Mexico; elevation of top 3,470 ft, 60 ft above level of Pecos River channel to the east (1972)

Unit	Thickness (ft)
Pleistocene Series	
Kansan Stage, or younger (total thickness)	17
6 Sand and silt, brick-red to reddish-tan, highly gypsiferous and gypsum crust forms on exposure; to top of terrace surface	2.0
5 Sand and caliche, gray to light-cream-tan, irregularly densely cemented in plates and rounded masses, blocky caliche between dense masses	2.0
4 Sand and silt, with some streaks and patches that are slightly clayey, reddish-brown; contains some dispersed caliche nodules	5.0
3 Silt, fine sand and some clay, calcareous, massive, red-brown; contains large masses of light-cream-gray caliche (NMP-188 upper part)	4.0
2 Silt, clay and $CaCO_3$ massive, cream-tan to pale-greenish-tan	1.0
1 Silt and clay, with some very fine sand, calcareous, massive, green-gray; contains a few gypsum crystals (NMP-187 lower part)	3.0

Highway 380 Section—measured in excavated pit, north of US-380, and 3 miles east of long. 104°00′ (NE sec. 25, T. 10 S., R. 29 E.), Chaves Co., New Mexico (1971)

Unit	Thickness (ft)
Pleistocene Series	
Wisconsinan Stage (total thickness)	1
5 Sand, tan, loose; a thin veneer but apparently related to the extensive dune sands that mantle this surface to the south	1.0
Kansan Stage (total thickness)	15
4 Sand, massive, tan, some dispersed pebbles and some uneven caliche cement	4.0
3 Sand, massive, with dispersed pebbles; irregular platy caliche at top with an uneven upper surface	5.0
2 Sand and gravel, coarse, partly cemented, contains pebbles of crystalline rocks and of Ogallala limestone and cemented sandstone	3.0
1 Silt, clay and sand, red-brown; contains some pebbles of Triassic rocks; Triassic sandstone exposed in bottom of pit	3.0

Lake Lewiston East Section—measured in eroded ditch west of NM-330, 2 miles north of Boone Draw and 1 mile east of Lake Lewiston (SE sec. 2, T. 3 S., R. 31 E.), Roosevelt Co., New Mexico (1971)

Unit	Thickness (ft)
Pleistocene Series	
Wisconsinan Stage (total thickness)	12
7 Sand, loose, tan to reddish-tan	2.0
6 Sand, gray with some caliche; truncates beds below and overlain by cover sands	1.0
5 Silt, clay, and sand, light-gray, massive, calcareous	2.0
4 Sand with some silt, calcareous, gray becoming gray-tan at top, massive, moderately compact; contains fossil snails throughout, fauna locality No. NM-15	2.0
3 Sand, pink-tan, loosely and irregularly cemented with $CaCO_3$, massive	3.0
2 Sand, gray, loosely cemented throughout	1.0
1 Sand, with a few abraded caliche pebbles, pink-tan, massive; to bottom of exposure	1.0

Santa Fe Railway Underpass Section—measured in roadcuts along US-60, west of Santa Fe Railway underpass, 1.4 miles west of Pecos River at Fort Sumner (NW NW SW sec. 24, T. 3 N., R. 25 E.), De Baca Co., New Mexico; elevation of top of section 4,120 ft (1971, 1972)

Unit	Thickness (ft)
Pleistocene Series	
Wisconsinan Stage (total thickness)	30
5 Sand, contains some dispersed pebbles, red-brown, massive, moderately compact; contains some caliche nodules; contains discontinuous lens of red-brown clayey silt 4 ft below top (NMP-135)	12.0
4 Sand and silt, gray with thin beds of tan in lower part, loosely but generally cemented with $CaCO_3$; contains fossil snail shells throughout, abundant in lower ⅓ (fossil locality NM-5; radiocarbon dated 17,180 ± 140 (ISGS-91) B.P.; (NMP-132 at base; NMP-133 middle; NMP-134 top)	5.0
3 Sand, reddish-brown, moderately compact, massive, calcareous; contains some dispersed pebbles and caliche nodules; jointed with caliche along joints (NMP-131)	6.0
2 Silt and clay with some sand, red-brown with areas of gray caliche, moderately compact, massive (NMP-130)	1.0
1 Gravel and sand, bedded, loose with a few weakly cemented zones; pebbles are about 60 percent crystalline rocks and 40 percent limestone and detrital Ogallala caliche pebbles. To highway grade	6.0

Santa Rosa West Section—measured in roadcut and valley side, 0.7 mile west Pecos River crossing in Santa Rosa (S½, sec. 3, T. 8 N., R. 21 E.), Guadalupe Co., New Mexico (1972)

Unit	Thickness (ft)
Pleistocene Series	
Wisconsinan Stage, or older (total thickness)	27.5
6 Caliche, tan, vesicular; vesicles appear to be molds of plant stems, in some cases the openings are filled with sand (NMP-107)	1.5
5 Sand, fine to medium, gray, massive, calcareous, contains abundant gypsum (NMP-106)	6.5
4 Gravel, coarse, gray, with gray sand; contains crystalline rocks; irregular contacts at top and bottom. Average thickness	1.5
3 Sand, fine to medium, massive, yellow-tan, calcareous, contains gypsum throughout (NMP-105)	3.0

Unit		Thickness (ft)
2	Sand, medium to fine, contains a few small pebbles, reddish-tan, massive, calcareous, locally contains gypsum crystals (NMP-104)	3.0
1	Gravel, coarse, contains boulders more than 1 ft in diameter; contains crystalline rocks, some sand, some cobbles of Triassic rocks, thickness ranges from 1 to 15 ft. Rests on Triassic rocks	12.0

Taiban East Borrow Pit Section—9.2 miles east of junction NM-252 and NM-60 at Taiban, north of Krider Siding (SE SE sec. 36, T. 3 N., R. 29 E.), Roosevelt Co., New Mexico (1972)

Unit		Thickness (ft)
	Pleistocene Series	
	Kansan Stage (total thickness)	17
3	Caliche, gray, dense, platy, tough at top (NMP-159), grading downward to massive but relatively soft caliche, grading downward to red sand and silt with abundant caliche nodules	8.0
2	Sand, silt, and caliche, gray, massive (NMP-158)	2.0
1	Sand and silt, red-brown, calcareous, massive; contains some dispersed caliche nodules and a few pebbles (NMP-157 base), to bottom of borrow pit	7.0

Plates

PLATE 1

Pleistocene mollusks from east-central New Mexico. All figures enlarged approximately X4, except figure 8, X 1. Locality numbers refer to localities shown on fig. 1 and described in Appendix A.

*Nomenclature of various species of Lymnaea follows the revision of the family Lymnaeidae by Hubendick (1951).

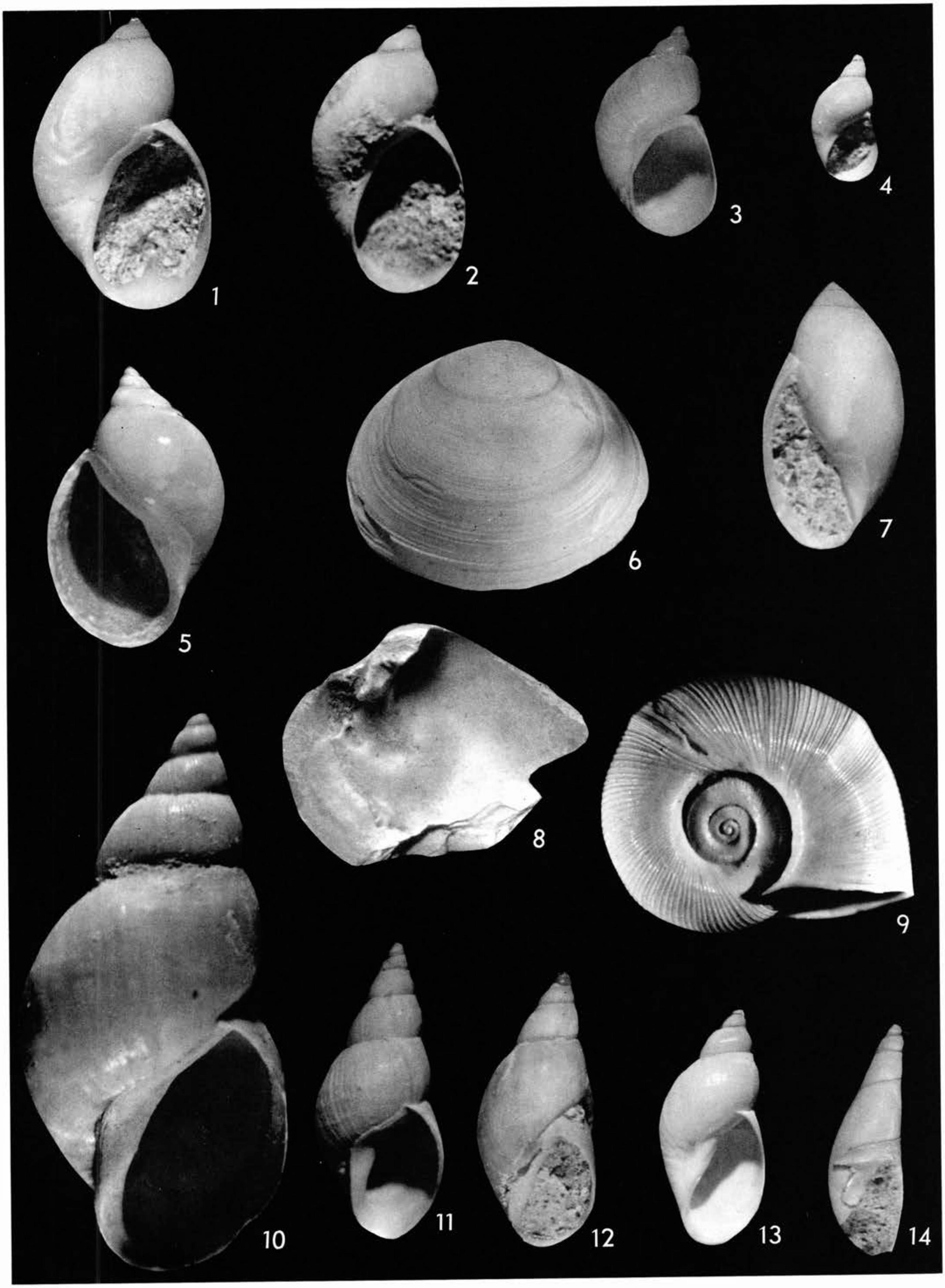
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PLATE 2

Pleistocene mollusks from east-central New Mexico. Figures 24 to 28 inclusive, enlarged approximately X8, figures 15 to 23 inclusive, X 12. Locality numbers refer to localities shown on fig. 1 and described in Appendix A.

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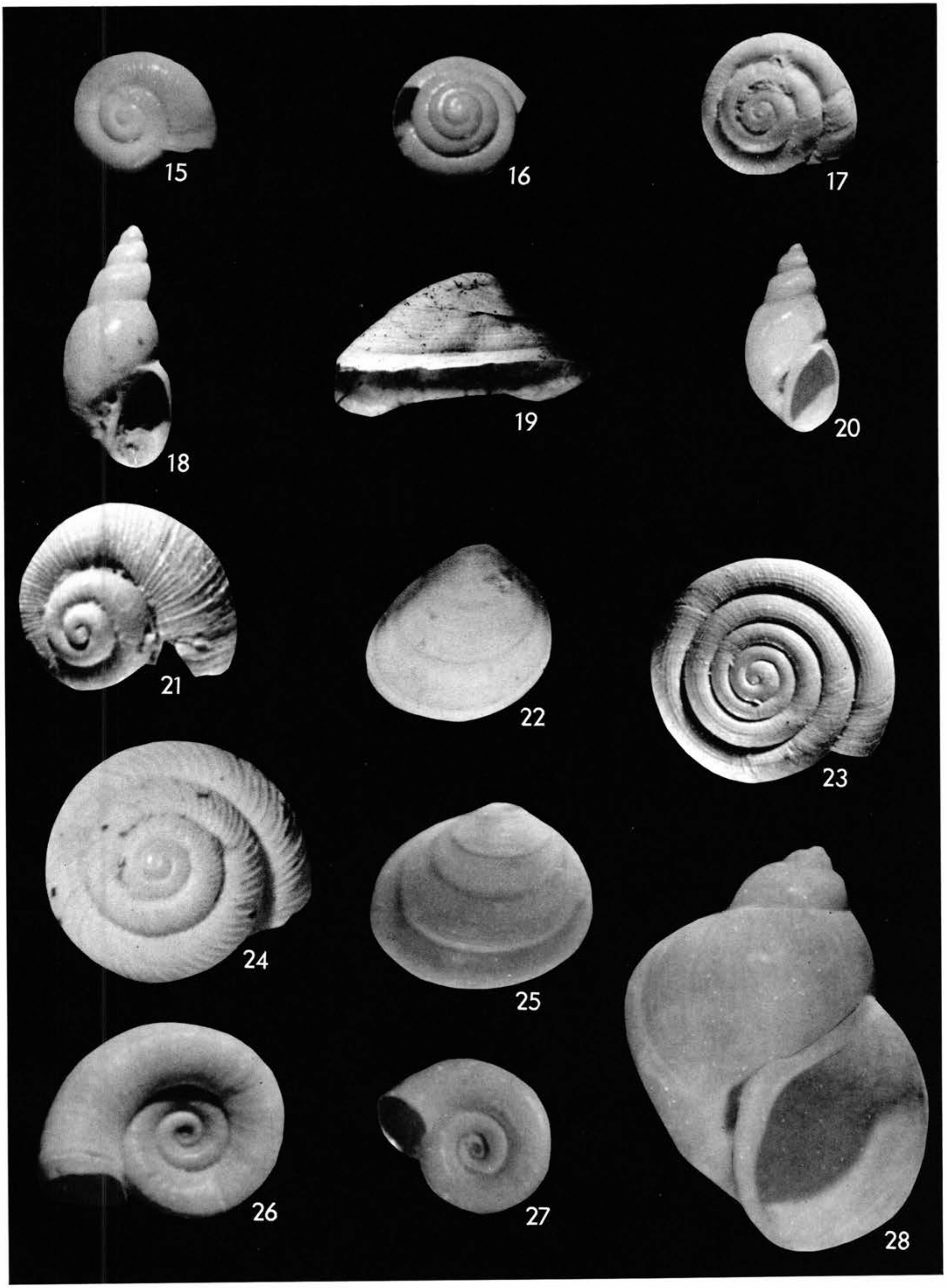
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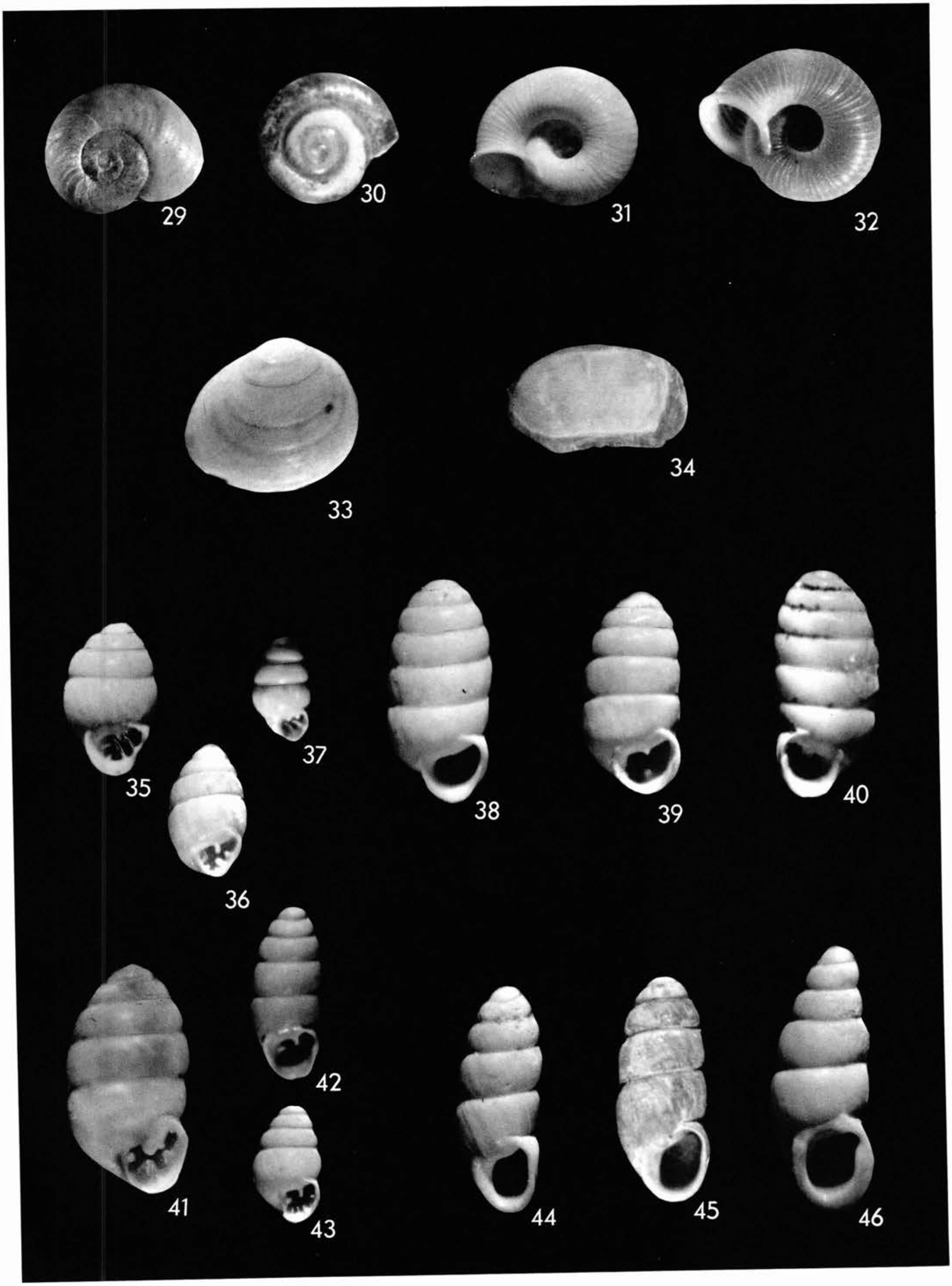
PLATE 3

Pleistocene mollusks from east-central New Mexico. All figures enlarged approximately X12. Locality numbers refer to localities shown on fig. 1 and described in Appendix A.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Display heads in 24 pt. Times Roman, letterspaced

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