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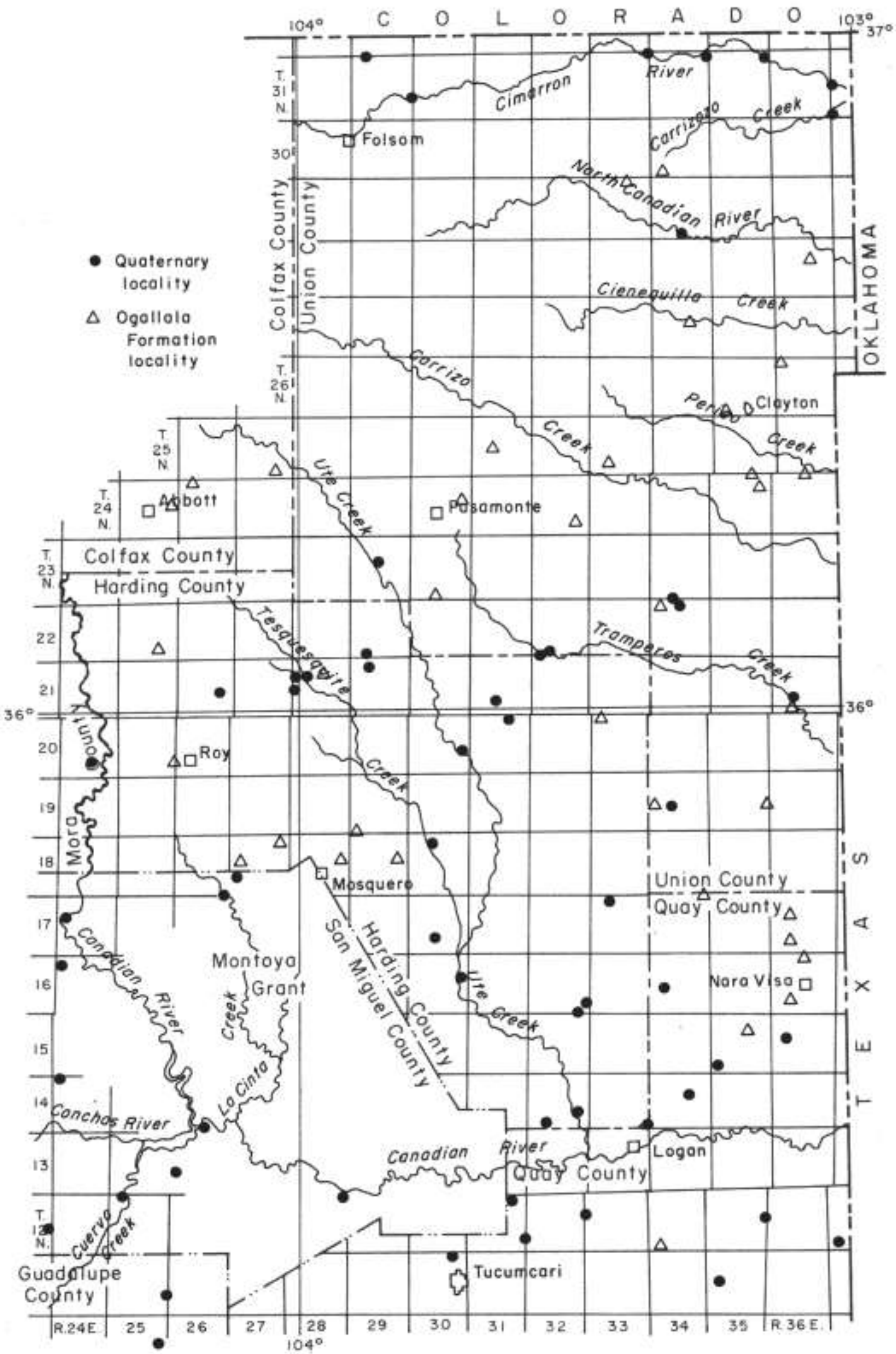

FIGURE 1—MAP OF NORTHEASTERN NEW MEXICO SHOWING THE GEOGRAPHIC DISTRIBUTION OF ALL LOCALITIES SAMPLED AND LISTED.

Abstract

A study of the Pliocene, Pleistocene, and Holocene stratigraphy, paleontology, and clay-mineral assemblages was made for the northeastern part of New Mexico. The stratigraphic zonation of the Ogallala Formation, using clay-mineral assemblages developed farther south in the state, is extended to the northern border and paleontologically correlated with the floral zones identified regionally throughout the Ogallala Formation. The stratigraphic relations of several basalt flows to the Ogallala as well as to Pleistocene deposits is included. Earliest Pleistocene deposits (Nebraskan) are sparse, but deposits of Kansas to mid-Pleistocene age are extensive in the area north and east of Canadian River. Wisconsinan to Holocene terrace deposits occur along virtually all of the valleys of the region; they have yielded 48 collections of fossil mollusks, and nine samples have been dated by radiocarbon analysis. The molluscan assemblages are compared through an age range from 27,000 to less than 1,000 B.P. with the living fauna and with fossil assemblages of similar age southward in New Mexico. Clay-mineral data for the Pleistocene and Holocene deposits are presented in the appendix, and the contrasting erosional histories of the several drainage systems are discussed.

Introduction

Northeastern New Mexico contains a variety of late Cenozoic strata that is observable at few places on the North American continent. The surficial rocks of this region range from late Tertiary to late Quaternary basaltic flows, interspersed with Pliocene, Pleistocene, and Holocene sediments, faunas, and floras; all are in a setting of a complex erosional topography in Triassic to Cretaceous bedrock. The topographic complexity has been caused not only by structural warping and by lava flows that periodically diverted drainage, but also by stream piracy and diversions that were initiated by the warping and changed gradients in the Plains region (to the east, southeast, and south), and by pulsating climatic changes.

In order to understand the present complex relations in this region, it is necessary to consider the stratigraphic relations of the late Tertiary and Quaternary sediments, their relation to the basalt flows and erosional history, and the climatic events interpreted from the clay-mineral suites and the molluscan fossil assemblages.

This study covers one area in a program of regional studies in the eastern third of New Mexico (Frye and Leonard, 1972; Leonard and Frye, 1975; Glass, Frye, and Leonard, 1973; Frye, Glass, Leonard, and Coleman, 1974; Leonard, Frye, and Glass, 1975). It is also an extension of a long-range series of studies in the southern Great Plains, including western Texas (Frye and Leonard, 1957a, 1957b, 1959, 1968; Leonard and Frye, 1962; Frye, 1971), and western Kansas and adjacent areas (Frye and Leonard, 1952; Frye, Leonard, and Swineford, 1956).

The field work upon which this report is based was conducted during several weeks in the summers of 1973, 1974, and 1975 under the auspices of the New Mexico Bureau of Mines and Mineral Resources. The x-ray diffraction analyses of clay minerals and radiocarbon age determinations were performed in the laboratories of the Illinois State Geological Survey.

The area described in this report is bounded on the north by Colorado, on the east by Oklahoma and Texas, on the south by I-40-US-66, on the northwest by the volcanic terrane north and south of Capulin, and on the west by the western edge of the Mosquero-Roy-Abbott Ogallala upland. The bedrock below the Cenozoic deposits of the region consists of Triassic, Jurassic, and Cretaceous rocks (Dane and Bachman, 1965). Except for a small area in the northwestern part of the region that is tributary to Purgatoire drainage, the region is drained by the east-flowing Cimarron River and by the Canadian River system.

The area studied and the general locations of the lithologic samples and fossil collections are shown in fig. 1. A schematic representation of the topographic relations of the Ogallala Formation and some of the Pleistocene units is shown in fig. 2. Views of some described localities are shown in fig. 3.

The late Cenozoic of the High Plains of eastern New Mexico was first extensively described by Baker (1915). Although there were many early papers describing the late Cenozoic geology of west-central Texas and the Texas panhandle (listed in Leonard and Frye, 1975; Darton, 1928), little direct work was done on the stratigraphy of these late Cenozoic sediments in northeastern New Mexico until the present decade. In contrast, studies of the igneous rocks of the region were extensive, as listed by Baldwin and Muehlberger (1959) and by more recent studies (Lipman and Mehnert, 1975; Stormer, 1972a and b).

The tables in the appendix include 210 x-ray analyses of Ogallala samples (table 1), 85 x-ray analyses of pre-Wisconsinan Pleistocene samples, and 89 x-ray analyses of Wisconsinan and Holocene samples (table 2). Four fossil floras from the Ogallala Formation and one fossil snail fauna from the Ogallala Formation (Leonard and Frye, 1978) are included. In the appendix (table 3) there are listed 48 fossil faunas from the Wisconsinan and Holocene deposits of the region, supported by 9

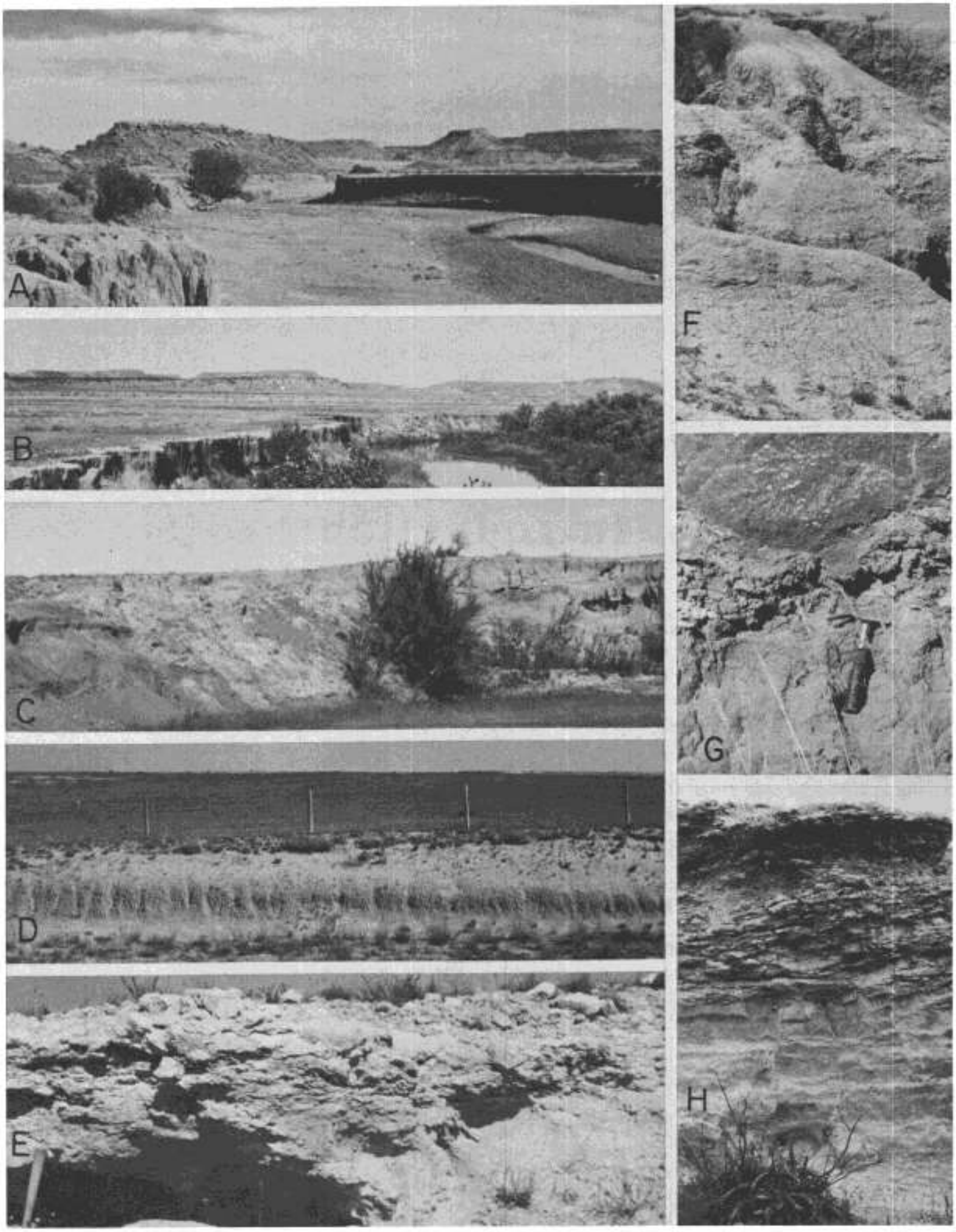

FIGURE 3—VIEWS OF SOME DESCRIBED LOCALITIES. **A)** Terrace of Cimarron River; Fauna No. 89. SE¼NE¼ sec. 36, T. 32 N., R. 33 E., Union County. Radiocarbon date 840 ± 75 (ISGS-370) B.P. Lithologic samples NMP-628-629. **B)** Terrace of Cimarrón River; Fauna No. 101. Center sec. 19, T. 31 N., R. 37 E., Union County. Lithologic samples NMP-761-763. **C)** Gallegos North section; Fauna No. 81. NW¼ sec. 13, T. 16 N., R. 30 E., Harding County. Basin fill along Ute Creek. Radiocarbon date 7,825 ± 90 (ISGS-343) B.P. Lithologic samples NMP-549-553. **D)** Mitchell West section; Pleistocene buried soils in silt and fine sand. NW¼SW¼ sec. 19, T. 21 N., R. 28 E., Harding County. Lithologic samples NMP-573-582, 730. **E)** Newkirk North section; Kansan caliche. SW¼ sec. 25, T. 11 N., R. 23 E., Guadalupe County. Lithologic samples NMP-768-769. **F)** Miera section; Wisconsinan terrace; Fauna No. 86. E½ sec. 32, T. 22 N., R. 32 E., Union County. Radiocarbon date 27,500 ± 1,300 (ISGS-344) B.P. Lithologic samples NMP-610-614. **G)** Clayton Northeast section; basalt on Ogallala Formation. SE¼NE¼ sec. 6, T. 26 N., R. 36 E., Union County. Lithologic samples NMP-617-625, 734-736. **H)** Clayton South section; fossiliferous zone (Fauna No. 52) in Ogallala Formation. SW¼SW¼ sec. 2, T. 24 N., R. 35 E., Union County. Lithologic samples NMP-600-607, 737-742.

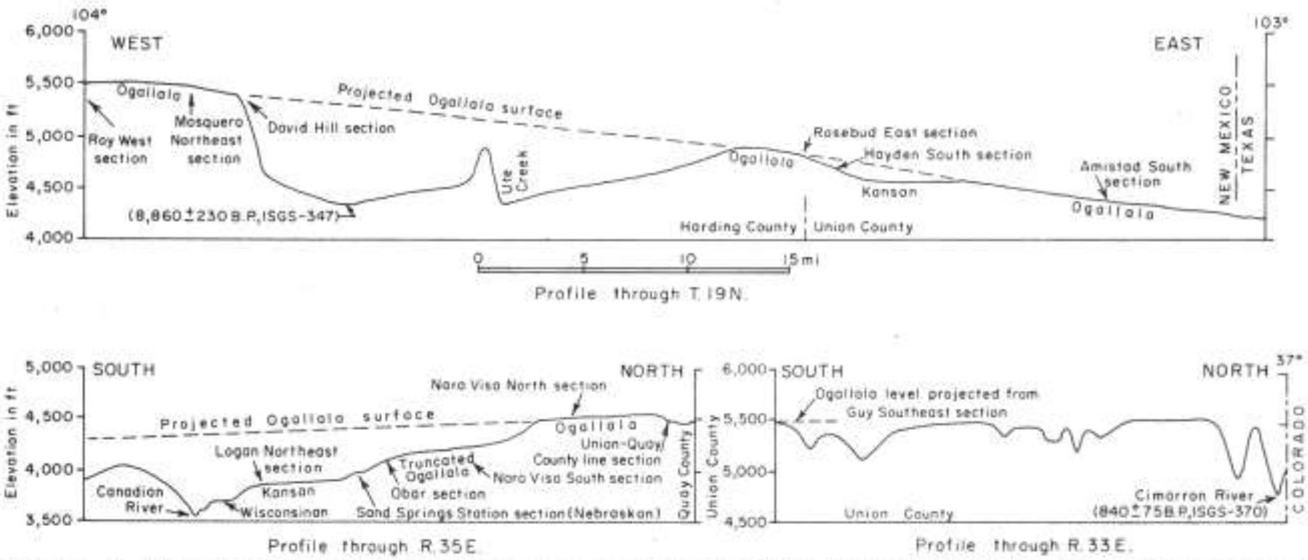

FIGURE 2—DESCRIBED SECTIONS HAVE BEEN PROJECTED ONTO THREE GENERALIZED PROFILES IN NORTHEASTERN NEW MEXICO TO SHOW PHYSIOGRAPHIC RELATIONS OF THE SEVERAL LATE CENOZOIC UNITS AND REGIONAL SLOPE OF THE TOP OF THE OGALLALA FORMATION; generalized from AMS 1:250,000 scale maps.

radiocarbon dates (table 4). Also in the appendix (table 5) are six described sections of deposits of Wisconsinan and Holocene age.

The results of a reconnaissance study of the late Cenozoic sediments, stratigraphy, fossils, and clay-mineral assemblages of the northeastern part of New Mexico are presented herein. The clay-mineral zones aid correlation of the units of the Ogallala Formation throughout all of eastern New Mexico, and the fossil floras and faunas from Ogallala deposits permit correlation of these zones with previously described zones in western Texas and northward to Nebraska. Pleistocene and Holocene deposits are correlated by stratigraphic and physiographic framing, fossil molluscan faunas, and radiocarbon dates. A unique aspect of the region is the intercalation of these sediments with previously described basalt flows. Another significant aspect is the striking contrast in erosional history of the several major stream systems draining the region.

Detailed information on all localities described herein is included in field notes on file at the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico.

ACKNOWLEDGMENTS—The field work for this study was supported by the New Mexico Bureau of Mines and Mineral Resources, Dr. Frank E. Kottlowski, Director, and for whose great personal interest in these investigations we herewith express our sincere thanks. We are also indebted to Dr. John Hawley, New Mexico Bureau of Mines and Mineral Resources, for having critically read the manuscript. Dr. Kottlowski and Dr. Hawley reviewed much of the pertinent geology in the field; we are grateful for their constructive comments made at that time.

Ogallala Formation

Stratigraphy and distribution

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 New Mexico's southern boundary with Texas. Darton (1928) was the first to use the term Ogallala in New Mexico, but his original spelling was "Ogalalla." The formation was named by Darton in 1899. 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 localities. . . . 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.

Elias (1931) and Hesse (1935) reexamined the exposures in the vicinity of Ogallala, Nebraska, proposed a type section of Feldt Ranch approximately 2 mi 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. The origin and character of these deposits in the New Mexico-Texas region have been reviewed by Reeves (1972) and by Leonard and Frye (1975).

The Ogallala Formation consists of alluvial deposits 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 sides, were filled first. As alluviation proceeded, the sediments overlapped the valley slopes, slowly inundated the former topography, producing 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 occur on the bedrock of former divides throughout the east-west extent of the formation (Frye, Leonard, and Swineford, 1956). In a north-south direction in eastern New Mexico the formation is absent in some areas and is more than 200 ft thick in others, depending on the configuration of the pre-Ogallala unconformity.

Several schemes of stratigraphic subdivision of the Ogallala Formation have been used in local areas (Evans, 1949 and 1956), and a system of three zones based on assemblages of fossil plant material has been used in western Texas (Frye and Leonard, 1957a and 1959). These zones were named (in descending order) Kimball, Ash Hollow, and Valentine, from the named members in western Kansas (Frye, Leonard, and Swineford, 1956) with which they were correlated by use of their contained fossils. The names of all three units are derived from type localities in western Nebraska with which paleontological correlations had been made previously. These three units have not been properly usable in east-central or southeastern New Mexico because they are floral zones rather than clearly defined rock-stratigraphic members. The terms have been used in a few sections on the basis of tenuous lithologic correlation with fossiliferous sections in western Texas. Only in the northeastern part of New Mexico have fossil floras and faunas been collected (Leonard and Frye, 1978) to permit reliable correlation. Unfortunately only the two upper units, the Kimball and Ash Hollow zones, can be identified in the thin Ogallala of the region.

The geographic distribution of the Ogallala Formation in northeastern New Mexico is discontinuous. The largest area of generally continuous Ogallala occurs west of the Texas State line and extends from southwest of Nara Visa (in northern Quay County) northward through the southern prong of Union County, interrupted by the valley of Tramperos Creek to the area south of Clayton. This relatively large area of Ogallala is topographically continuous with the Ogallala of northwestern Texas to the east. An upland prong extends westward to a position south of Pasamonte, New Mexico, and is terminated westward by the valley of Ute Creek. South of Cimarron Valley in northeastern Union County, thin Ogallala deposits cap a significant area of upland. Perhaps the most striking area of Ogallala-capped upland is in the area of relatively thin deposits that occur below the surface of the plateau extending in Harding County from east of Mosquero to Roy, and northward to northeast of Abbott in Colfax County. The prominent topographic escarpment at the eastern edge of this upland is shown by the profile in fig. 2. The western edge of this upland (for example, west of Roy), although displaying an even greater contrast in elevation down to the channel of the Canadian River along the Mora-Harding County line, is less spectacular because the descent is interrupted by several Pleistocene terrace levels. There appears to be some warping of the Ogallala surface in this region in addition to regional tilting, but the warping is not as sharply defined as it is farther south (Frye and Leonard, 1972).

The southern limit of the Ogallala in northern Quay County is not as sharply reflected in the topography as it is in most other parts of the region. In fact, some geologic maps extend the Ogallala symbol southward across deposits of Nebraskan and Kansan (and even younger ages), virtually to the Canadian River. This southern boundary is marked by a series of topographic steps shown by the profile in northern Quay County in fig. 2. Unlike the terraced topography west of Roy, however, the first topographic level along this profile below the upland is developed in truncated Ogallala deposits. As one progresses southward toward the Canadian River, the topographic breaks between the several levels (including Nebraskan, Kansan, and Wisconsinan) are partly obscured by eolian sands and have a somewhat gradational appearance. In sharp contrast, along the Cimarron Valley in northern Union County (fig. 2), there are no definable terraces between the Ogallala upland and the late Wisconsinan or Holocene surfaces in the lowest part of the valley.

There are a few small outliers of Ogallala Formation outside these described areas. An example is the Porter West section (NMP-918) that occurs on an upland remnant south of Canadian River and north of the prominent north-facing Ogallala escarpment near the Quay-Curry County line. Such outliers are few, however, and contribute only to reconstruction of the Ogallala surface.

A unique aspect of the Ogallala Formation in this region is the widespread association with basalt flows (Baldwin and Muehlberger, 1959; Stormer, 1972a and b; Trauger, 1973; Lipman and Mehnert, 1975). The Martinez East section is the only section studied so far that includes a basalt flow in the upper part of the formation. At several localities, however, basalt flows cap a sequence of Ogallala deposits: Clayton Lake State Park section, Clayton Northeast section, Clayton Southwest section, and others. The basalt flows appear to have had a minimal effect on the clay minerals of the Ogallala sediments (or perhaps the effect has not been understood). Their relation to the formation provides an opportunity for stratigraphic correlation between the regionally correlated stratigraphy of the Ogallala Formation and the more localized stratigraphy of the basalt flows in northeastern New Mexico.

Although dates are not available for basalt at any of the stratigraphic sections described here, one date was obtained sufficiently nearby that reasonable stratigraphic extrapolation can be made. Stormer (1972b, p. 2445) lists a date of 2.5 ± 0.8 m.y. determined on plagioclase from west center sec. 22, T. 25 N., R. 35 E., Union County. The basalt analyzed overlies Ogallala Formation and occurs 2 1/2 mi north-northwest of the locality of samples NMP-598-599, and 3 1/2 mi north-northwest of the Clayton South stratigraphic section. The date is from a location 4 1/2 mi southeast of the Clayton West section. At these three localities the Ogallala is beyond the limit of the flow and hence is not overlain by basalt; however, the topographic relations indicate that the deposits are continuous with those below the dated basalt. None of the published dates (Trauger, 1973) are near enough to the Martinez East section to justify extrapolation of a date to the basalt that occurs within the upper part of the Ogallala Formation at that section.

Clay minerals and zonation

A general description of clay-mineral assemblages in the Ogallala Formation of eastern New Mexico was presented by Glass, Frye, and Leonard in 1973. For the region immediately south of the subject area of this report, a detailed discussion of the clay-mineral composition of the Ogallala was presented the following year (Frye, Glass, Leonard, and Coleman, 1974). Clay-mineral data based on x-ray analyses of 210 samples of Ogallala deposits from northeastern New Mexico are presented in the appendix of this report (table 1). The geographic distribution of these samples is shown on the map in fig. 10. Clay-mineral compositions were determined in the laboratories of the Illinois State Geological Survey by the same methods used in the previous studies. For the caliche samples carbonate was removed by slow dissolution in 5 percent acetic acid at room temperature, followed by repeated rinsing of the clay residue, then preparation for x-ray analyses.

The concept of a regionally usable clay-mineral strati-graphic zonation of the Ogallala Formation was developed for east-central New Mexico and published in 1974 (Frye, Glass, Leonard, and Coleman). A method of stratigraphic subdivision of the formation was urgently needed in this region; the paleontological system of subdivision (used in western Texas and northward across Kansas and into Nebraska) could not be used because of the lack of adequate floras and faunas. The scheme of clay-mineral zones was so successful that it was carried southward to the southern border of New Mexico (Leonard, Frye, and Glass, 1975). In this study we find that it can be traced northward to the Colorado State line with equal success. In this northeastern New Mexico area, it has been possible to correlate these clay-mineral zones, traceable north-south across New Mexico, with the floral zones described in western Texas and correlated northward to Nebraska (Leonard and Frye, 1978).

The description of the clay-mineral zones as originally presented for east-central New Mexico is as follows (Frye, Glass, Leonard, and Coleman, 1974, p. 7-8):

> At depths greater than about 50 ft below the top of the formation the clay mineral assemblage consists predominantly of montmorillonite, ranging from 76 to 98 percent, with very minor amounts of kaolinite and illite, and locally accompanied by identifiable amounts of heulandite. This lowest zone is low in carbonate minerals, and will be referred to as the montmorillonite zone, or Zone 1. At about 50 ft below the top, small amounts of attapulgite (palygorskite) appear, and increase upward to about 10 ft below the top, locally reaching a maximum of about 85 percent of the clay mineral assemblage. As illite and kaolinite remain essentially constant at very small percentages, and as attapulgite increases upward at the expense of montmorillonite, this zone (from about 50 to about 10 ft) will be called the attapulgite zone, or Zone 2. Calcium carbonate increases sharply in the upper part of this zone. Opal . . . commonly occurs in the middle and upper part of the attapulgite zone, as well as in the overlying sepiolite zone.
>
> Next above the attapulgite zone is an interval characterized by the presence of sepiolite in association with attapulgite (Zone 3). In this unit sepiolite generally exceeds attapulgite in amount, and the sum of the two may reach a maximum of about 85 percent of the clay mineral assemblage. Only in Zone 3 has the mineral sepiolite been detected. This zone is only 2 to 4 ft thick, contains small amounts of illite and kaolinite, and com-

monly the lowest percentage of montmorillonite found in the Ogallala Formation. This zone generally contains a high percentage of calcium carbonate, ranging up to more than 90 percent. In contrast to the sepiolite-rich Woodfordian pond deposits which may contain authigenic dolomite (Glass and others, 1973), the mineral has not been detected in Zones 2 and 3 of the Ogallala. Opal, which locally occurs in the middle and upper part of the attapulgite zone, terminates upward in the sepiolite zone. Zones 1, 2, and 3 present an upward sequence of progressive clay mineral change through Pliocene time.

Sepiolite and attapulgite terminate sharply at the top of the sepiolite zone (Zone 3), commonly 4 to 6 ft below the top of the formation. Above is a zone 2 to 4 ft thick, characterized by a sharp increase in well-crystallized montmorillonite to an average of about 75 percent of the clay mineral assemblage, accompanied by an increase in illite (15 percent), and in kaolinite (10 percent). This thin zone is referred to as the montmorillonite-illite zone, or Zone 4.

The uppermost clay mineral zone, Zone 5, generally coinciding with the pisolitic limestone, is rarely more than 2 1/2 ft thick. The clay mineral composition is characterized by a decrease in montmorillonite, and a corresponding increase in illite and kaolinite, and generally the presence of chlorite. In contrast with the well-crystallized montmorillonite of Zone 4, the montmorillonite of Zone 5 is always weathered, and is characterized by poorly defined X-ray diffraction peaks (Glass and others, 1973). This rock is predominantly calcium carbonate, having a unique and distinctive appearance because of its contained pisolites, many of which have been brecciated and recemented.

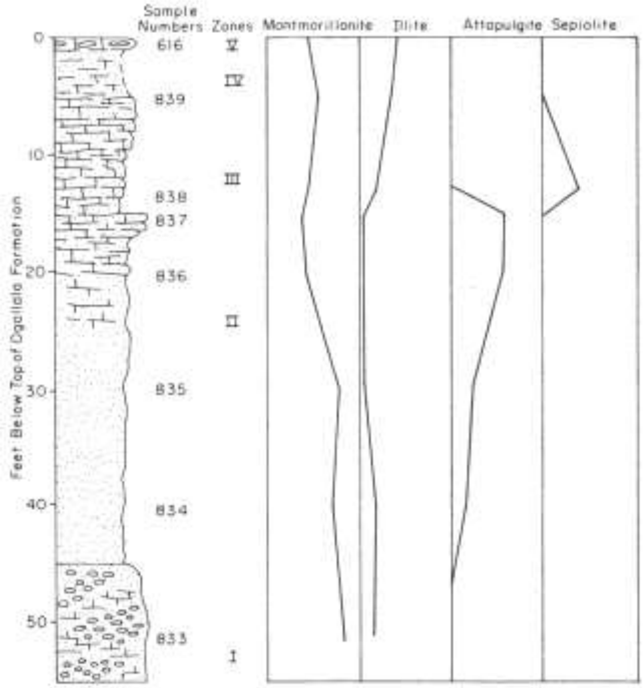

FIGURE 5—REA TOWER SECTION, OGALLALA FORMATION, MEASURED IN ROAD CUTS IN NW ¼ SEC. 5, T. 20 N., R. 33 E., HARDING COUNTY. The five clay-mineral zones are distinct in a section containing an exceptionally large percent of gravel and sand.

These clay-mineral zones were recently correlated into the southeastern corner of New Mexico (Leonard, Frye, and Glass, 1975), even though the Ogallala Formation in that area occurs only as discontinuous remnants.

North of Canadian River across Quay, Harding, Union, and eastern Colfax Counties, the clay-mineral zones display some geographic variations, as well as variations adjacent to basalt flows. The clay-mineral zonation of the Ogallala in this region is shown graphically from south to the northwest and north by a series of sections starting with Amistad South (fig. 4), progressing northwest (figs. 5, 6, and 7), then northeast (figs. 8 and 9) to the south side of Cimarron Valley in the northeast corner of the state. Additional sections, not displayed graphically but with identified zones in table 1 and located on fig. 14, are at the south of the Obar section progressing north by way of Nara Visa Southwest, Nara Visa North, Union-Quay County line, and Rosebud East; west by way of David Hill, Mosquero Northeast, and Mosquero West sections; north and northeast through Roy West, Abbott East and Northeast, Pasamonte South and Northeast, Davis T. S. South, Clayton South, Clayton West, Clayton Lake, and Seneca Northeast to the northeastern part of the state. Ogallala sections in this region that display distinctive clay-mineral zonation are illustrated by the six graphic sections and additionally by 18 sections for which numerical data are presented; 24 Ogallala sections in northeastern New Mexico are sufficiently thick and adequately sampled to demonstrate the continuity of clay-mineral zones.

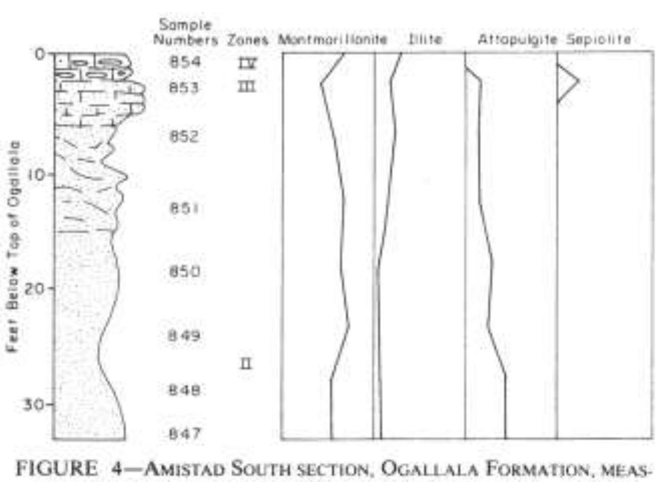

FIGURE 4—AMISTAD SOUTH SECTION, OGALLALA FORMATION, MEASURED IN CREEK BANK IN NW¼NW¼ SEC. 19, T. 19 N., R. 36 E., UNION COUNTY. Although sample NMP-854 is from pisolitic limestone, clay-mineral Zone V is not present.

Only one Ogallala section in the region exceeds 100 ft of sampled thickness (Martinez East, fig. 6), and only one additional section (REA Tower, fig. 5) exceeds 50 ft in thickness. Of the moderately thick sections Amistad South (fig. 4), Mills (fig. 7), and Snyder Ranch (table 1), exposed between 40 and 50 ft of section; Guy Southeast (fig. 9), Nara Visa North, Clayton South, Seneca Northeast, and Amistad South exposed between 30 and 40 ft of deposits. The relative thinness of the sampled sections reflects the fact that the Ogallala Formation was initially thin in much of this part of New Mexico; therefore, the data presented is largely from the upper part of the formation, above the thick Zone I which comprises the lower part of the formation farther to the south.

The clay-mineral zones in this region do not possess

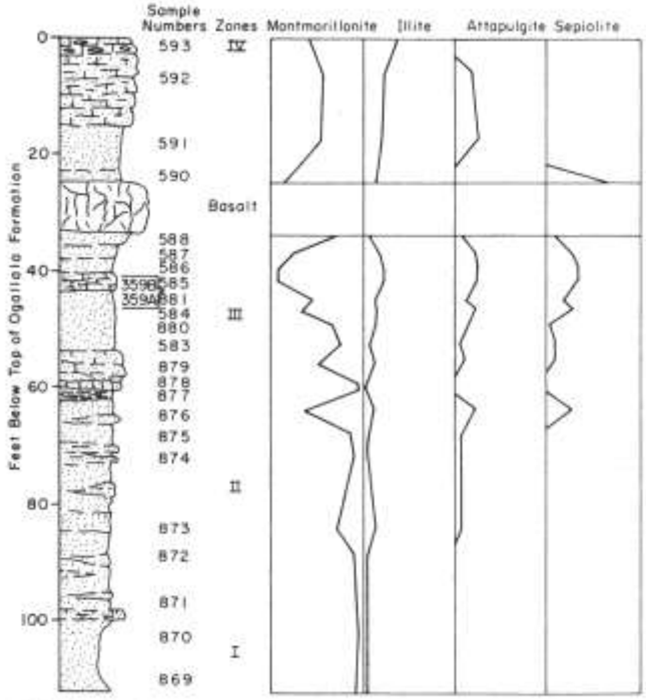

FIGURE 6—MARTINEZ EAST SECTION, OGALLALA FORMATION, MEASURED ALONG NM-120 IN CENTER, S½ SEC. 9, T. 21 N., R. 28 E., HARDING COUNTY. Note distortion of clay-mineral zones adjacent to basalt and interruption of zones by the bentonite bed (NMP-877-878).

the uniformity of thickness and character described for the formation farther south in the state (Frye, Glass, Leonard, and Coleman, 1974; Leonard, Frye, and Glass, 1975). The character of the formation is illustrated by the six graphic sections (figs. 4-9) and by the numerical data in table 1. In the southern part of this region (Amistad South, fig. 4; REA Tower section, fig. 5; Obar, Nara Visa Southwest, Nara Visa North, and Mosquero Northeast sections, and northwestward (Roy West; Mills sections, fig. 7, and north and northeast Abbott East, Abbot Northeast, Pasamonte, and

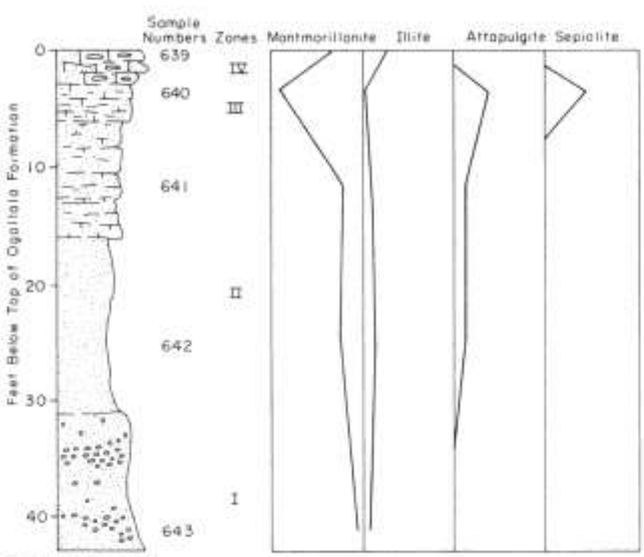

FIGURE 7—MILLS SECTION, OGALLALA FORMATION, MEASURED IN EXCAVATIONS EAST OF NM-39 IN NE¼NW¼ SEC. 35, T. 22 N., R. 25 E., HARDING COUNTY. Clay-mineral Zones I through IV distinctly developed.

David T. S. South sections), the clay-mineral zonation closely conforms to the zones extending southward to the southern limit of New Mexico. In some of these sections Zone IV or Zone V is absent, but as these zones may be no more than a foot thick, they may have been missed. Several of these sections are not thick enough to display Zone I (the lowest zone). In the extreme northeastern area (fig. 10), the Guy composite section and the Seneca Northeast section (fig. 9) also appear to conform to the statewide pattern.

The zones are distorted in the region of north-central Harding and central Union Counties (the region that is crossed by several basalt flows). In several sections (for example, Clayton South, Pasamonte South, Snyder Ranch, and Martinez East in Harding County, fig. 6) the zone of abundant sepiolite (Zone III) is abnormally thick, whereas the attapulgite zone (Zone II) is thinner than normal. In this area several sections display a compressed zonation (for example, Rosebud East and Clayton West), and a few sections (Quay-Union County line section and Clayton Southeast) display an erratic stratigraphic distribution of attapulgite and sepiolite. Barite occurs in the Snyder Ranch and Clayton Southeast sections.

It might be contended that in all of these sections the unusually thick zone of sepiolite results from the proximity of a source of magnesium in the adjacent basalts. Such an explanation is particularly attractive for the Martinez East section that not only contains a basalt in its upper parts but also contains two samples (NMP-359A and B) wherein the carbonate is entirely dolomite—a unique occurrence in the Ogallala Formation. At a lower stratigraphic position the Martinez East section also contains a distinctive bed of bentonite (NMP-731-732, 876-877). Although the abnormally thick sepiolite zones and the presence of dolomite may be attributable to the proximity of basalt, other data described below cast doubt on this interpretation.

In the east-central part of Union County, three exposures of Ogallala deposits have been studied below basalt that flowed over the surface of the formation (Clayton Southwest, Clayton Northeast, and Clayton Lake, fig. 8 and table 1). Clayton Northeast was sampled in detail. Although samples were taken immediately adjacent to the basalt contact, and in the case of Clayton Northeast from inclusions in the basalt, sepiolite and attapulgite were nonexistent; dolomite was not detected. The physical relations in all three localities

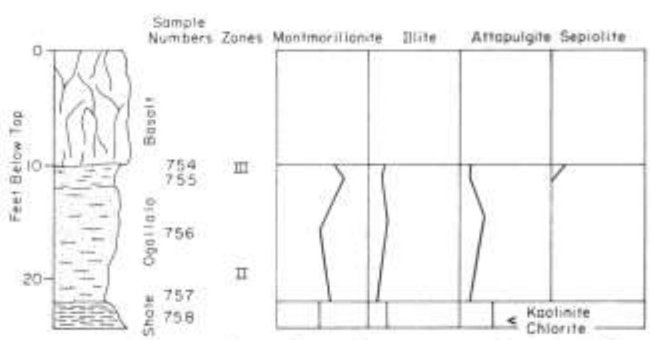

FIGURE 8—CLAYTON LAKE STATE PARK SECTION, OGALLALA FORMATION, IN SW¼ SEC. 15, T. 27 N., R. 34 E., UNION COUNTY. Basalt in contact with clay-mineral Zone III. Note clay-mineral contrast with Cretaceous shale below Ogallala Formation.

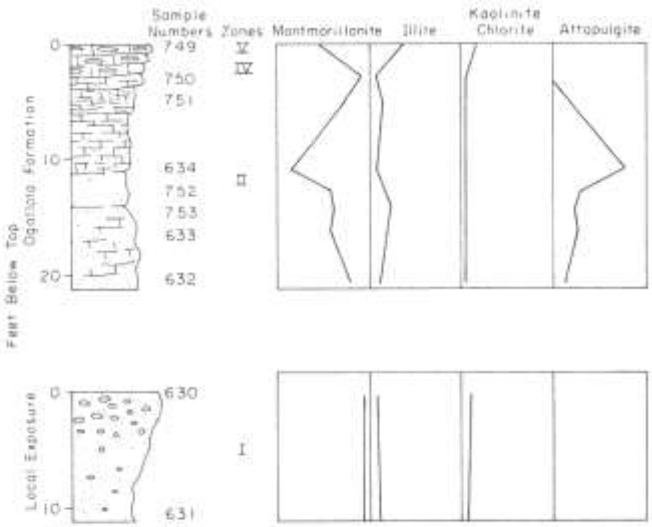

FIGURE 9—GUY SOUTHEAST COMPOSITE SECTION, OGALLALA FORMATION, MEASURED IN ROAD CUTS AND AN EROSIONAL SLOPE. Lower part in NE¼NE¼ sec. 3, T. 29 N., R. 33 E.; upper part in NW¼SW¼ sec. 32, T. 30 N., R. 34 E., Union County. Note the absence of sepiolite and clay-mineral Zone III.

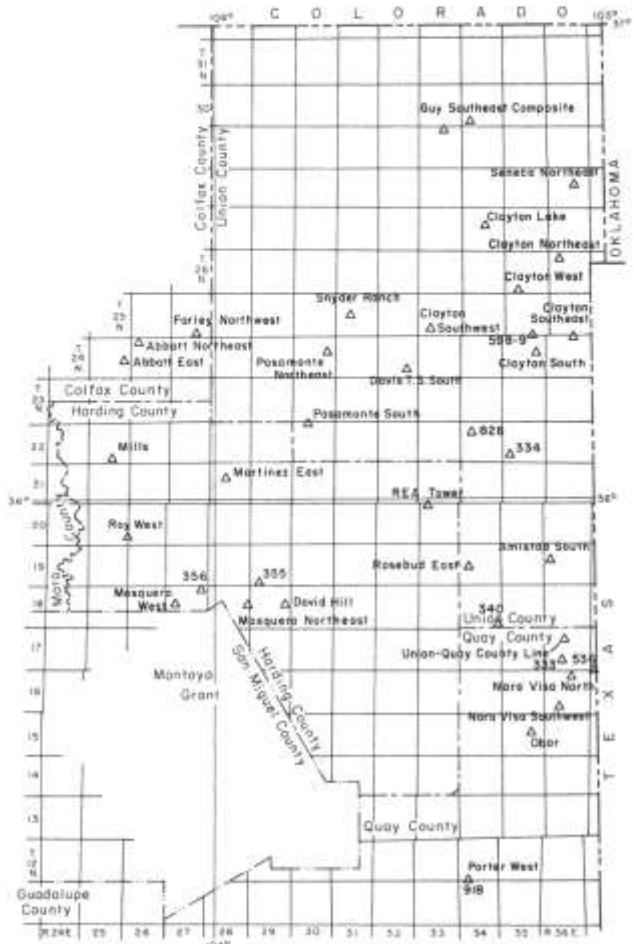

FIGURE 10—MAP SHOWING LOCATION OF OGALLALA FORMATION SAMPLES LISTED IN TABLE 1. Stratigraphic sections are shown by name where possible; for unnamed localities the NMP sample numbers are shown.

are similar to those at Martinez East immediately below the basalt. In all cases there is a foot or two of orange-red sand quite unlike other Ogallala deposits, immediately below the basalt. This orange-red sand at Martinez East and Clayton Lake sections contains minor amounts of attapulgite and sepiolite, whereas at Clayton Northeast and Southwest neither of these clay minerals was detected in several feet below the basalt (table 1). One might argue that as the orange-red sand appears possibly to be a thermally altered zone, the emplacement of the basalt flow destroyed (at Clayton Southwest and Northeast) any fragile fibrous clay minerals originally occurring in the Ogallala sediments.

There are no mineral changes observable in the orange-red zone, although the possible effects are elimination of fibrous minerals and rehydration of montmorillonite. At the Clayton Northeast section, samples NMP-621A and B are from a pocket within the basalt of relatively loose carbonate with chunks of harder carbonate, 2 ft above the base of the basalt; sample NMP-617 is of tan-brown silt, sand, and carbonate in a brecciated zone a foot above the base of the basalt; samples NMP-618 and 619 are of the orange-red sand at the basalt contact and a foot below the contact, respectively; sample NMP-625 (25 yd laterally along the exposure) is from a gray-tan sand and carbonate that forms a wedge between the basalt and the orange-red sand. All of these samples that are in intimate association with the basalt lack attapulgite and sepiolite, as do the samples in a sequence down to 20 ft below the basalt (table 1).

We do not have a fully adequate explanation of the abnormally thick stratigraphic placement of sepiolite and attapulgite (palygorskite) in the region surrounding Clayton in east-central Union County. Nevertheless, it is clear that the clay-mineral zones that are traceable from the southern border to the northern border of New Mexico (and surrounding this area) are distinctly recognizable in the Clayton South section.

The faunas and floras that occur in the Clayton South section can be placed in the sequence of clay-mineral zones widely recognized in the Ogallala Formation of eastern New Mexico. The foregoing indicates that the molluscan fauna and associated fossil flora (Leonard and Frye, 1978) at the Clayton South section (Fauna and Flora No. 52) should be placed stratigraphically near the base of the regional clay-mineral Zone III. These fauna and flora indicate a stratigraphic position in the basal part of the Kimball Floral Zone. Clay-mineral Zones III, IV, and V are included within the Kimball Floral Zone (southwest Texas to western Nebraska); clay-mineral Zone II (Flora No. 88) and the upper part of clay-mineral Zone I are in the Ash Hollow Floral Zone, and the middle to lower part of clay-mineral Zone I is is the Valentine Floral Zone.

Fauna and flora

During the several years we have been studying the Ogallala Formation in eastern New Mexico in the field, only one significant fauna of fossil mollusks, Fauna and Flora No. 52 from the Clayton South section, has been obtained from these deposits. Stratigraphically significant collections of fossil plant materials were obtained from this locality and from the Seneca Northeast section

(Flora No. 88); specimens of *Celtis willistoni* were collected from two additional localities in northeastern New Mexico (Flora Nos. 51 and 99). These fossil materials and their stratigraphic significance are described in a comparison paper (Leonard and Frye, 1978).

The fossil plant specimens from the Clayton South section (Fauna No. 52) include the following:

Panicum elegans Elias
Biorbia microendocarpica (Brooks) Leonard
Biorbia levis Segal
Biorbia papillosa Leonard
Celtis willistoni (Cockerell) Berry

The collection of fossil plant material from the Seneca Northeast section (Flora No. 88) includes the following:

Stipidium grande Elias
Berriochloa amphoralis Elias
Biorbia microendocarpica (Brooks) Leonard
Biorbia papillosa Leonard
Celtis hatcheri Chaney
Celtis willistoni (Cockerell) Berry
Celtis cf. *reticulata* Torrey

Flora No. 52 from the Clayton South section indicates a position in the lower part of the Kimball Floral Zone (Frye and Leonard, 1959). As this collection comes from the lower part of clay-mineral Zone III of eastern New Mexico, it indicates that clay-mineral Zones III, IV, and V can be correlated with the paleontologically defined Kimball Floral Zone of the Ogallala throughout the Great Plains. As Flora No. 88 is correlated with the middle of the Ash Hollow Floral Zone, and was collected from the lower part of clay-mineral Zone II, it also indicates the correlation of clay-mineral Zone II, and perhaps the uppermost part of clay-mineral Zone I, with the regionally recognized Ash Hollow Floral Zone. By implication, it may be assumed that all but the uppermost part of clay-mineral Zone I can be correlated to the Valentine Floral Zone of the Great Plains region.

Quaternary sediments

After the culmination of Ogallala deposition in middle to late Pliocene, northeastern 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 extreme eastern part of the region local relief was constructional (fig. 2), but westward the constructional plain was interspersed with areas of erosional topography. Still farther west the topography became predominantly erosional or dominated by basalt flows. The development of a widespread pedocal soil over the surface of the alluvial deposits indicates that the progressive trend toward desiccation continued for a significant interval of time, as demonstrated by the fauna and flora upward through the Ogallala (Frye and Leonard, 1957b). This soil was deeply developed before the next major episode of deposition (representing a hiatus in the sedimentary record), indicated by the presence of detrital cobbles of soil caliche in the basal deposits of the Blanco Formation to the east in Texas, as well as in the Nebraskan of this area.

During the hiatus, or perhaps genetically related to it, the mountainous region to the west was uplifted, and the alluvial plain tilted eastward. Then the greatly increased precipitation of the early Pleistocene developed a consequent drainage system upon this constructional and tectonically modified surface.

Nebraskan deposits

After the initial dissection of the Pliocene alluvial plain by the earliest Quaternary drainage, there was a pause in incision followed by valley alluviation. Although this episode is not datable by existing methods, it is classed as Nebraskan because it is clearly later than the initial Ogallala erosion and significantly older than the widespread cycle of alluviation we class as Kansan. The Nebraskan cycle, which has physiographic similarity to the Blancan of western Texas, is preserved in only a few remnant situations. In northeastern New Mexico only one extensive exposure of these deposits has been studied. This is the Sand Springs Station Northeast section (figs. 2, 11, and 15; table 2), which occurs in a small remnant area of deposits between and physiographically below an extensive upland area of dissected Ogallala Formation, and topographically above an extensive area of Kansan deposits. The Kansan deposits are partly covered by late Quaternary dune sands and locally are marked by basins containing Wisconsinan and younger basin-fill deposits.

This small remnant area of Nebraskan deposits, which probably marks the position of an "ancestral Canadian River," consists of coarse channel gravels, grading upward into alternating sand and gravel that contains cobbles and boulders of Ogallala calichecemented sand (fig. 11, table 2). This area also contains the remains of a deeply developed pedocal soil and has similar relations to presumably contemporaneous deposits near the Santa Rosa East section (Leonard and Frye, 1975, fig. 4c) that occurs to the southwest, which may be related to the "ancestral Pecos-Portales River" rather than to the Canadian. The drainage pattern during earliest Pleistocene time is not well known in the northeastern segment of New Mexico, and these two remnants may be related to the same drainage system.

The clay-mineral sequence in the one Nebraskan section studied (fig. 11, table 2) is generally a detrital assemblage, with predominant montmorillonite, but containing some illite and kaolinite through most of the thickness. The uppermost few feet of the sequence is

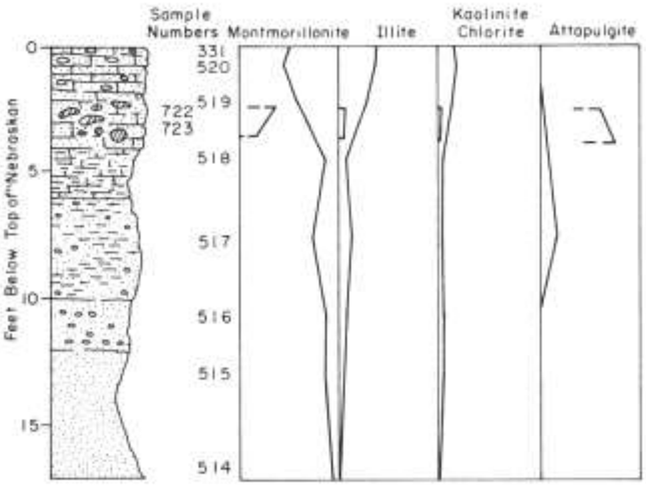

FIGURE 11—SAND SPRINGS STATION NORTHEAST SECTION, MEASURED IN ABANDONED GRAVEL AND CALICHE PIT IN SE¼SE¼ SEC. 20, T. 15 N., R. 35 E., QUAY COUNTY. Small remnant area of Nebraskan deposits. Dashed lines 2-3 ft below top show composition of boulders of Ogallala caliche cemented sand (NMP-722–723) in the Nebraskan sand and gravel.

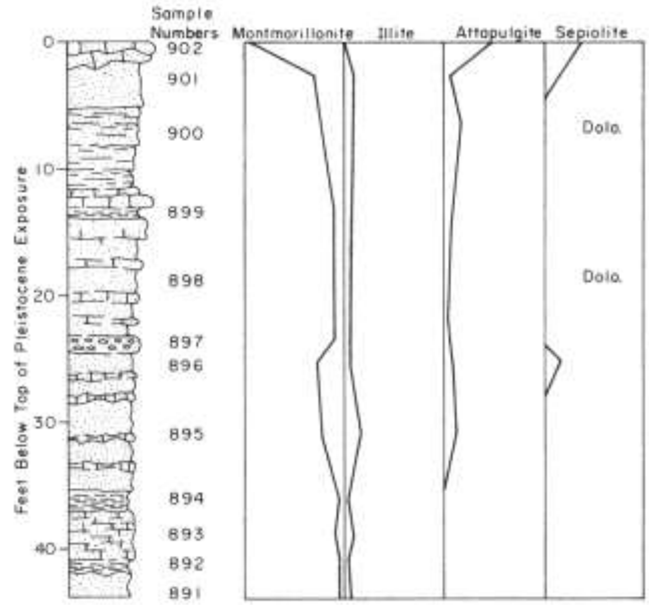

FIGURE 12—MARTINEZ WEST SECTION, MEASURED IN CUTS ALONG NM-120 IN NW¼SE¼ SEC. 18, T. 21 N., R. 28 E., HARDING COUNTY. Early to middle Pleistocene basin deposits. The clay-mineral composition contrasts strongly with the younger and topographically lower Martinez section deposits, which are predominantly montmorillonite (NMP-882–890) and contain no attapulgite, sepiolite, or dolomite.

marked by a decrease in montmorillonite and an increase in illite and kaolinite and contains some chlorite in the caliche zone at the top. The uppermost zone of this section mineralogically resembles the uppermost caliche of the Ogallala Formation but lacks well-developed pisolites. Only a small amount of attapulgite occurs in the section, and it is well below the top. No sepiolite was detected. The contrast of the upper part of the sequence with Zone II compositions of the Ogallala Formation is strikingly shown by the included Ogallala boulders, which contain abundant attapulgite and a relatively small amount of montmorillonite. The clay-mineral composition of the Nebraskan contrasts sharply with the upper zones of the older Ogallala deposits (although the basal samples are similar to Ogallala Zone I). It also contrasts with the younger Pleistocene deposits except for the uppermost samples. In general the composition indicates a detrital source from the west, resulting from a vigorous, post-Ogallala erosional cycle.

The Martinez West section (fig. 12, table 2) may be of Nebraskan age because it is the first depositional episode at its location below the general Ogallala upland level (note discussion of Martinez East section, fig. 6, table 1), and it is well above a lower and younger alluvial deposit. However, the physiographic setting clearly indicates deposition in a local basin, blocked at the south by basalt through which the present drainage flows in a narrow, steep-walled notch. The clay-mineral composition also suggests a basin environment of deposition, derived in part from adjacent Ogallala deposits (rather than a portion of an integrated drainage system) by the erratic stratigraphic distribution of sepiolite and dolomite, the predominance of detrital clay-minerals through most of its thickness, and the sharp increase of attapulgite and sepiolite in the top few feet. The basin area in which this and the Martinez section occur (table 2) warrants a more detailed investigation than was possible for us in this regional study. Although a Nebraskan age cannot be denied for the deposits at the Martinez West section, it seems probable that they are younger within the Pleistocene.

The Nebraskan cycle of erosion and deposition is sparsely preserved in northeastern New Mexico, as is also the case in east-central New Mexico (Leonard and Frye, 1975). Evidence of the shifting drainage pattern of this region from the Ogallala alluvial plain through the Nebraskan cycle is too poorly preserved to allow meaningful reconstruction, although it is clear that by Kansan and later Pleistocene time, the drainage patterns of the late Tertiary had been drastically modified. The Nebraskan deposits of northeastern New Mexico have yielded no identifiable fossils to date.

Mid-Pleistocene and Kansan deposits

In contrast to the scarcity of Nebraskan deposits in this northeastern New Mexico region, deposits of Kansan and/or mid-Pleistocene age were studied and sampled at more than a dozen localities across the central and southern parts of the region under investigation (fig. 15). Kansan deposits occur at an intermediate physiographic position, below the extensive Ogallala capped uplands (and below the remnants of Nebraskan) and well above the Wisconsinan and Holocene alluvial terraces (fig. 2). At many places pediments cut on bedrock are graded to the level of the Kansan alluvial deposits, and the Wisconsinan and younger valleys of the present streams are sharply incised below this level. The level of Kansan deposits occurs extensively along the valley of Canadian River in northern Quay County, to the vicinity of Tucumcari, and along tributaries from the north in southeastern Union County and adjacent Harding County. Westward into northeastern Guadalupe County (Newkirk North) the Kansan surface rises, perhaps reflecting the arching described farther south in the Ogallala (Frye and Leonard, 1972) and earlier suggested for this region (Baldwin and Muehlberger, 1959, p. 78). This inclined surface could be farther to the west-southwest at the level of the divide separating Canadian River drainage from Pecos River drainage in the region northeast of Santa Rosa in Guadalupe County. Although there is considerable doubt that the Kansan drainage that existed in the uppermost Canadian River system was integrated with the upper Pecos-Portales system drainage, the levels and orientation of the remnants of Nebraskan alluvial deposits show clearly that such an integration was possible during Nebraskan time.

Physiographic relations during Kansan and subsequent time in the Cimarron River drainage area, however, have a quite different implication. In the Cimarron Valley of extreme northeastern New Mexico there are no observable remnants of either Nebraskan or Kansan alluvial terraces (fig. 2). Furthermore, a Wisconsinan terrace fauna locality (Fauna No. 92, NMP-638) near the Colorado State line, and only about six miles north of Cimarron River (Oak Creek), is more than 300 ft higher than faunas of similar age in the Cimarron Valley directly south. This terrace and fauna are in the headwaters of Vachita Creek, a north-flowing tributary to Purgatoire River, which in turn flows northward to the Arkansas River. The available evidence indicates that Cimarron River incised its valley very rapidly during late Pleistocene and Holocene time and that it was not the location of either Nebraskan or Kansan major drainage. The implication of the available data is that in early Pleistocene time the southern headwaters of the Purgatoire-Arkansas River system extended south to at least the position of the present Cimarron River and met the headwaters of the southeast-flowing upper Canadian (upper Pecos-Portales) ancestral river systems. Perhaps by Kansan time, but certainly before Wisconsinan time, a complex series of stream piracies had produced the present regional drainage pattern, and the downstream gradient advantage had allowed the Cimarron River to extend its headwaters to about their present position. The young basalt flows originating in eastern Colfax County had dominated the local stream modifications since sometime during the Wisconsinan.

The composition and character of the Kansan deposits of the region are shown by the Hayden South section, Adberg Station, Logan Northeast, and Pinabetitos Creek sections (figs. 13 and 15, tables 2 and 5). Clay-mineral compositions are given for the Newkirk North section and nine miscellaneous Kansan samples in table 2. The Kansan deposits do not display a consistent clay-mineral zonation. Generally they are dominated by montmorillonite and illite, but a few samples contain unusually high percentages of kaolinite. Minor amounts of attapulgite occur at several localities, and in the Hayden South section there is a progressive increase downward. Such a downward increase of attapulgite was not apparent in the Kansan deposits of southeastern New Mexico (Frye, Glass, Leonard, and Coleman, 1974; Leonard, Frye, and Glass, 1975). The Martinez West section, which may be of Kansan age, shows a downward decrease in attapulgite, as do the Kansan sec

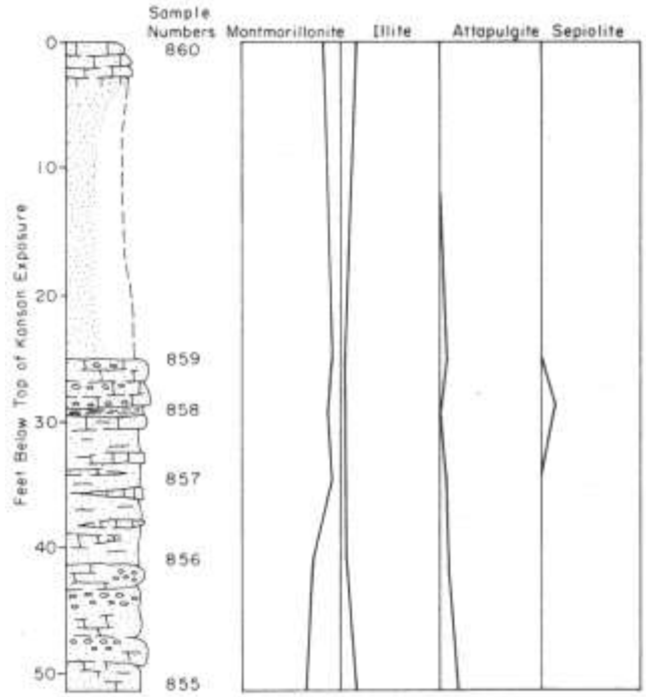

FIGURE 13—HAYDEN SOUTH SECTION, MEASURED IN GULLIES ADJACENT TO ROAD, IN NE¼NW¼ SEC. 22, T. 19 N., R. 34 E., UNION COUNTY. Typical of deposits of Kansan age. Sepiolite occurs only in a thin bed of cream to cream-tan clay (NMP-858), whereas attapulgite generally increases downward.

tions farther south. But unlike them, the Martinez West section contains a large amount of sepiolite in the uppermost samples. In this regard it has some similarity to the Newkirk North section (figs. 3E and 15, table 2), which has anomalously high percentages of sepiolite; however, the Newkirk North section contains no attapulgite. In summary, the Kansan deposits of this region are characterized by erratic distribution of attapulgite, sepiolite, and kaolinite. This serves to distinguish them from the older Ogallala and younger Wisconsinan deposits but does not aid in stratigraphic zonation.

Several localities in this region are classed as mid-Pleistocene because they appear to be younger than Kansan and older than Wisconsinan, at least in part. They are generally characterized by the presence of one or more buried soils in the sequence. These include the Mitchell West section (figs. 3D and 15, tables 2 and 5), and the Tucumcari North and Martinez sections (fig. 15, table 2). Several of the sections grouped with the Kansan might have been included here because of the presence of a buried soil in the upper part of the sequence (Logan Northeast, Pinabetitos Creek, Adberg Station) but were included with the Kansan because they were judged to be predominantly of that age. The three sections discussed here differ in their clay-mineral compositions. The Martinez section (which is probably the youngest of the three) is dominated by high percentages of montmorillonite throughout, minor percentages of illite and kaolinite, and no attapulgite or sepiolite. This composition holds through the buried soil profile that occurs 13 ft below the top of the sequence (NMP-886-887), and the soil profile is not indicated by the clay-mineral compositions.

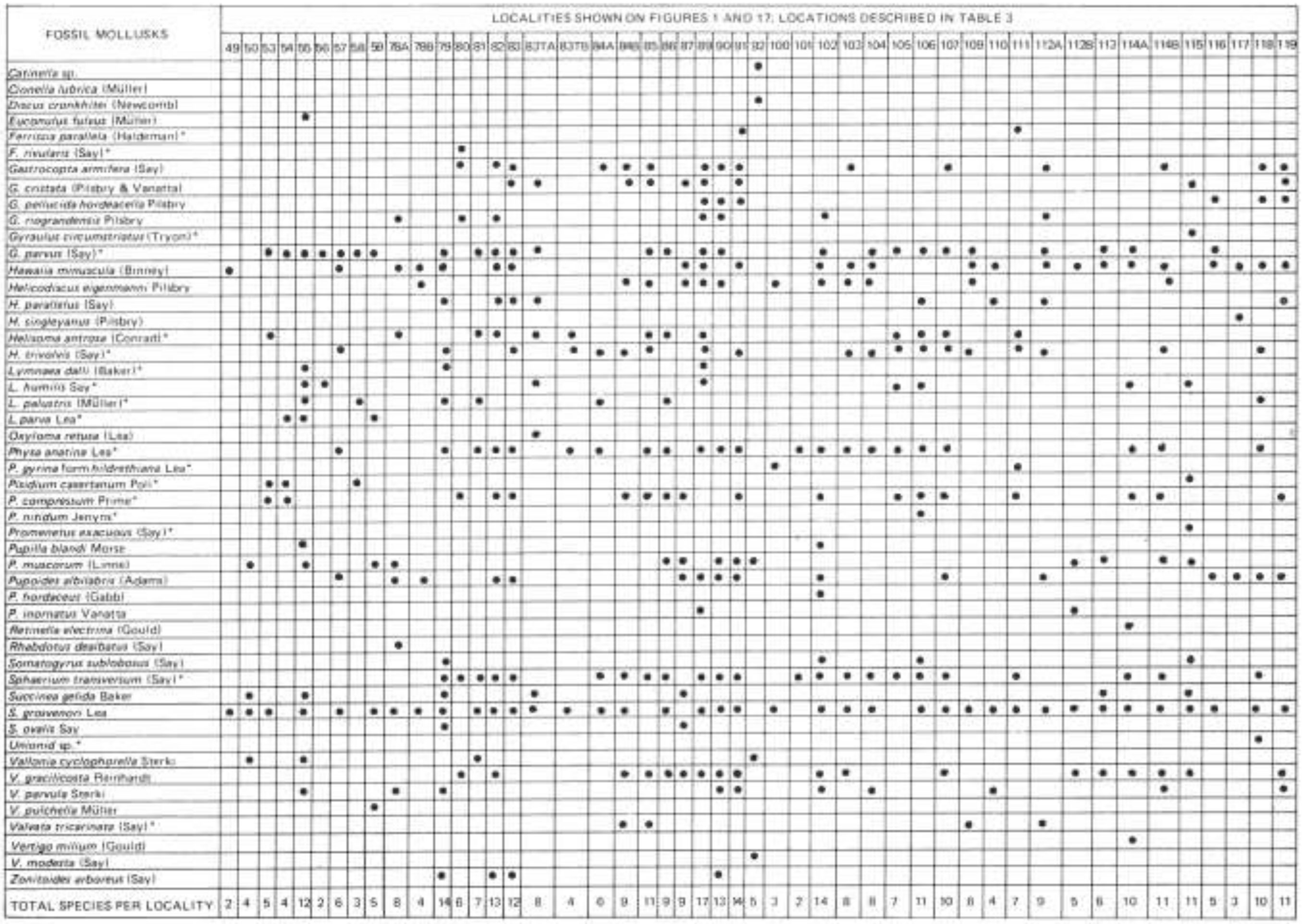

FIGURE 14—CHART SHOWING COMPOSITION OF FOSSIL MOLLUSCAN FAUNAS COLLECTED AT 43 LOCALITIES IN NORTHEASTERN NEW MEXICO. Location of fossil collections are shown on figs. 1 and 17 and are given in table 3 in the appendix. Radiocarbon dates on those faunas that have been dated are shown on fig. 18 and given in table 4 in the appendix. * indicates aquatic species, others are terrestrial.

In striking contrast, the Tucumcari North section contains illite percentages ranging from 13-45 percent and attapulgite up to 25 percent, although no sepiolite was detected. Furthermore, the compositions in the buried soils are not consistent, with Cca-horizons ranging from 0-25 percent attapulgite. In soil profiles the numerical value for each clay-mineral is the percent of the total, not a quantitative measure. The weathering processes operating in the development of the soil profile are more rapidly destructive to the x-ray intensity of montmorillonite than of illite, so the apparent increase in illite should be interpreted as an apparent decrease in montmorillonite with its alteration to heterogeneous swelling material (examples include NMP-505-507). Although not indicated by the calculated percentage, the characteristic alterations of montmorillonite by the weathering processes that produced the soil profile are distinctive in the x-ray diffraction curves (Willman, Glass, and Frye, 1966; Frye, Glass, and Willman, 1968, p. 15). The low percentage of montmorillonite in the caliche zone (NMP-508) is caused by the increase in attapulgite.

The Mitchell West section (figs. 3D and 15, tables 2 and 5) presents the best developed sequence of Pleistocene buried soils in northeastern New Mexico studied to date. The section contains illite ranging from 18-46 percent of the clay minerals, but no attapulgite or sepiolite. Montmorillonite ranges from 43-76 percent, with the lowest percentages of montmorillonite in the solum of the major buried soil profiles. Lithologic descriptions of the buried soil profiles are given in the stratigraphic section in table 5.

The general considerations of clay-mineral alteration described for the Tucumcari North section are particularly well illustrated by the Mitchell West section. A diagnostic method of identifying soil profiles from the analysis of clay-mineral assemblages is included. The "hsi" (heterogeneous swelling index) was described by Frye, Glass, and Willman (1968). The most apparent effect of weathering is the broadening and rounding of the 17A diffraction peak for montmorillonite on the x-ray diffraction curves; the greater the intensity of weathering, the greater the formation of heterogeneous swelling material. In examination of the several soils in the Mitchell West section, the surface soil (NMP-730) shows a distinct drop from the hsi of lower samples, as would be expected in a young soil. The maximum deviation from normal hsi (the maximum indication of soil formation) occurs in samples NMP-578 and 579, which are from the A and **B** horizons of the soil classed as Sangamon soil. The lowermost buried soil in the sequence (NMP-574-575) displays a degree of weathering that is less

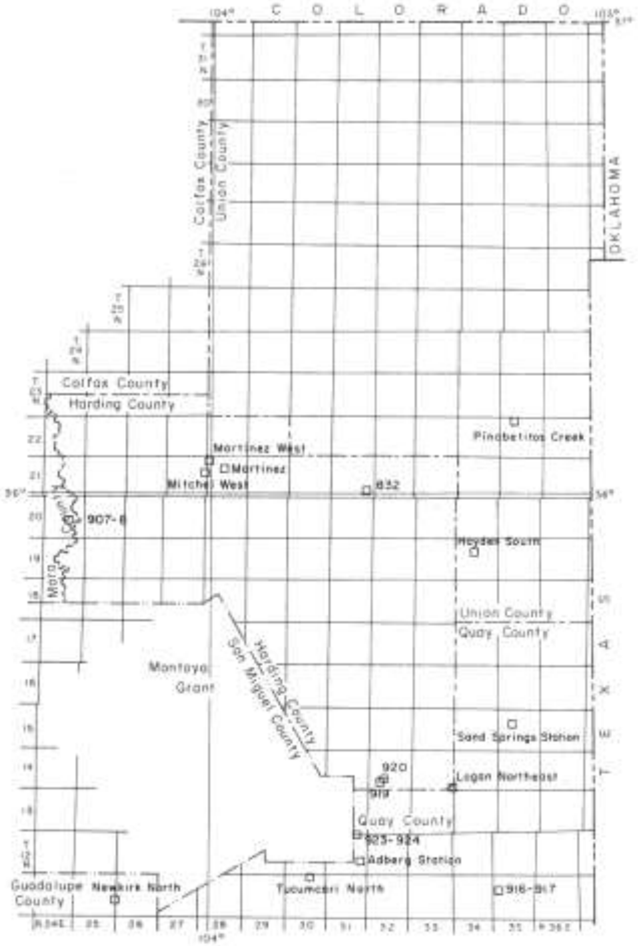

FIGURE 15—MAP SHOWING LOCATION OF NEBRASKAN, MID-PLEISTOCENE, AND KANSAN SAMPLES LISTED IN TABLE 2. Stratigraphic sections are shown by name where possible; for unnamed localities the NMP sample numbers are shown.

than the overlying (Sangamon) soil profile, although it is clearly well-developed.

It is precarious to correlate soil-stratigraphic units into an isolated region; nevertheless, there is sufficient similarity of the soil profiles and their stratigraphic positions described here to those described in western Kansas (Frye and Leonard, 1952) to justify the tentative correlation with the Sangamon soil. Although the high illite content of the fine textured sediments of the Mitchell West and Tucumcari North sections might be interpreted as indicating at least a partial sediment source in the nearby Triassic rocks, which contain abundant illite, the facts that the unweathered samples in these sections have a high montmorillonite content and that the texture is comparable to the average Ogallala suggest a prime source in Ogallala deposits. The high montmorillonite content and the much coarser sediments of the Martinez section reflect a source in the Ogallala sediments that underlie much of the drainage basin upstream from the exposure.

The minor A-C soil profile in the upper part of the Mitchell West section and the comparable young buried soil in several other sections described here can be categorized only as Wisconsinan in age without the aid of radiocarbon dates. The upper buried soil at Mitchell West might be correlated with the Brady Soil of western Kansas (Frye and Leonard, 1952), but there is no known technique to demonstrate such a correlation. The Yarmouth soil might be below the Sangamon soil at Mitchell West, but it is probably correlative with the Pike Soil (Willman and Frye, 1970) of mid-Illinoisan age. In order to confirm such correlations there must be dating techniques not now available, or regional field tracing that is not yet possible.

Identifiable fossils were not recovered from any of the Kansan or mid-Pleistocene deposits studied in this region.

Wisconsinan and Holocene deposits and faunas

Deposits and faunas of Wisconsinan and Holocene age are widespread throughout the region. Although earliest Wisconsinan (Altonian Substage) terraces have been recognized at only a few localities, terrace deposits of late Wisconsinan and Holocene age are extensively developed in the drainage basin tributary to the Canadian River and along the Cimarron River. Basin-fill deposits, widely distributed farther south in eastern New Mexico, are sparse on the remnant areas of Ogallala upland in northeastern New Mexico. Several extensive basin-fill deposits (for example, the McCarty Ranch section) occur in the broad area of Kansan deposits, and less extensive basin-fill deposits occupy subsidence areas in bedrock (for example, Gallegos North section).

Basin deposits

Only two major basins on the remnant upland areas of Ogallala Formation have been studied in northeastern New Mexico. One of these is the historic Lake Chicosa locality (figs. 1, 14, 16, and 17; tables 2 and 3) northeast of Roy in Harding County, and the other is the large and deep basin (Black Lake) northeast of Mosquero in Harding County (fig. 1). In Lake Chicosa very young sediments containing fossil mollusks were collected. The clay-mineral composition of the organic-rich lake mud shows a large percentage of illite and moderate content of montmorillonite and kaolinite. This sediment reflects modification caused by the organic content and the fluctuating water level. The lee dune derived from the basin (NMP-572) contains higher montmorillonite, although it still contains a high percentage of illite and kaolinite and is similar to many other weathered samples in the region derived from an Ogallala source. The historical use of this basin as a trail-herd watering place indicates its unusual situation and young age.

The Black Lake Basin northeast of Mosquero is probably quite young (even younger than the Chicosa Lake Basin); there are no exposures of post-Ogallala deposits along the sloping sides of this deep basin except surficial sands and silts. No fossils were observed in the post-Ogallala sediments.

In the areas of Kansan deposits, marked by a distinctive physiographic level, there are several areas of extensive basins with their contained deposits. The most prominent areas occur on the McCarty Ranch. The McCarty Ranch Southwest section (figs. 1, 14, 16, 17, and 18; tables 2, 3, and 4) occurs as the fill of a broad,

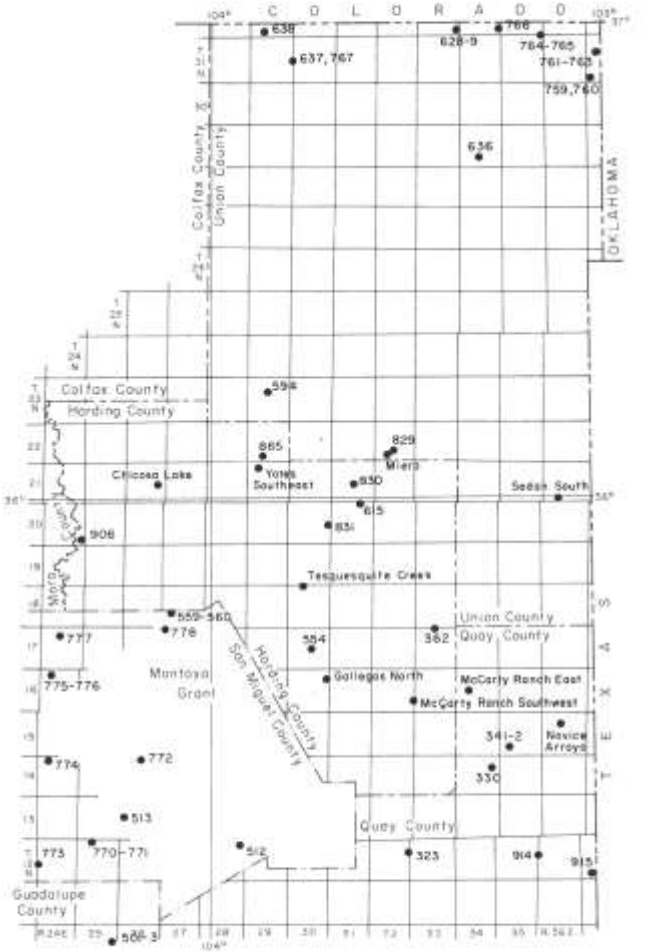

FIGURE 16—Map showing location of Wisconsinan and Holocene samples listed in table 2. Localities are shown by NMP number except for those sections named in the table.

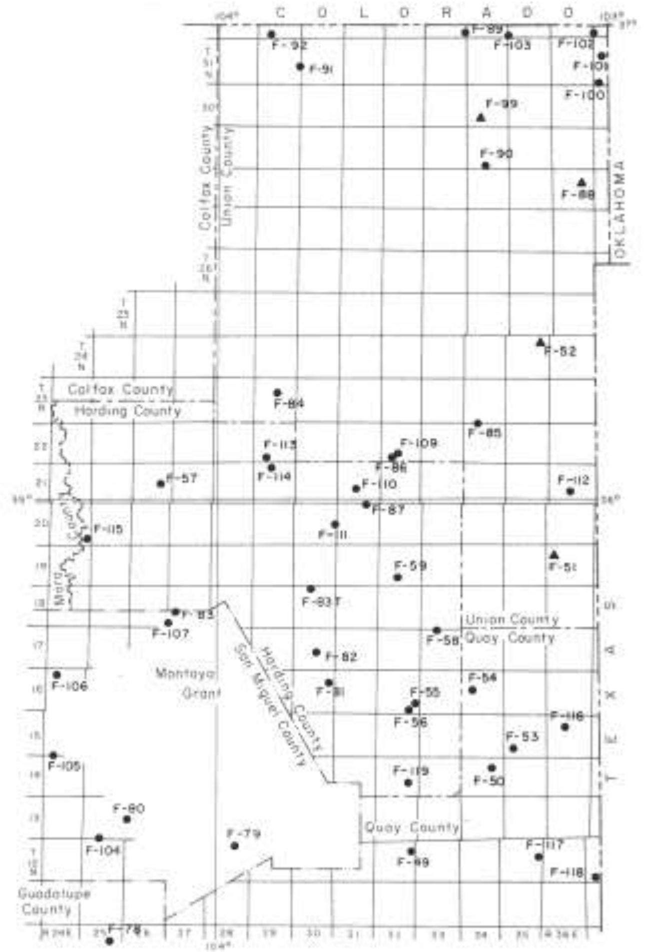

FIGURE 17—Map showing location of floras and faunas listed in text, in fig. 14, and in table 3. The circles denote faunas of Wisconsinan and Holocene age; the triangles denote floras or faunas from the Ogallala Formation.

shallow lake basin, dated at 21,180 ± 560 (ISGS-346) B.P. on the contained mollusk shells. This places the lake in Woodfordian time (midwestern glacial sequence). The clay-mineral assemblages (table 2) indicate a detrital source from the nearby Kansan, Ogallala, and bedrock sources and do not contain the fibrous clay minerals attapulgite and sepiolite.

The McCarty Ranch East section (figs. 16 and 17, table 2) is an example of a much smaller basin deposit in the same physiographic setting, and probably of about the same age. The basin deposits appear to be detrital; they contain more than 50 percent montmorillonite, abundant illite, and moderately high kaolinite with no attapulgite or sepiolite. The weathered Kansan deposits below the basin sediments are high in illite, as are the young sands above the basin deposits. The overlying young sands, although weathered, contain some chlorite. They overlie a weakly developed buried soil in the top of the basin deposits.

There are other basins and basin deposits in the Kansan region. Except for the McCarty Ranch localities, however, they have not yielded abundant fossil faunas or radiocarbon dates. One possible interpretation is that the deep incision of the drainage system in northeastern New Mexico that started in late Woodfordian time modified the topography and hydrology. These basin-type situations on the Kansan level, therefore, were not possible after mid-Woodfordian time. The radiocarbon dates (table 4) do not indicate the presence of basin deposits in the interval from mid-Woodfordian to Holocene time.

Of the younger basin deposits, the Gallegos North section was most thoroughly studied (figs. 1, 3C, 16, 17, and 18; tables 2, 3, 4, and 5). A collapse basin in Triassic rocks, filled with deposits dated 7,825 ± 99 (ISGS-343) B.P., has been truncated and beveled by Ute Creek so that the present eroded top of the basin deposits is concordant with an erosional terrace along the valley. An extensive fauna of fossil mollusks (Fauna No. 81) occurs in the deposits. The clay-mineral composition of the deposits, including the organic-rich silts, is high in montmorillonite, with normal to somewhat high percentages of illite and kaolinite. This is in contrast to the adjacent Triassic rocks that contain 88 percent illite and no kaolinite or chlorite (table 2). In northeastern New Mexico the Triassic rocks are characterized by high percentages of illite, Jurassic rocks by high montmorillonite, and Cretaceous rocks by high kaolinite.

Basin-fill deposits are far less common in northeastern New Mexico than they are in the east-central and

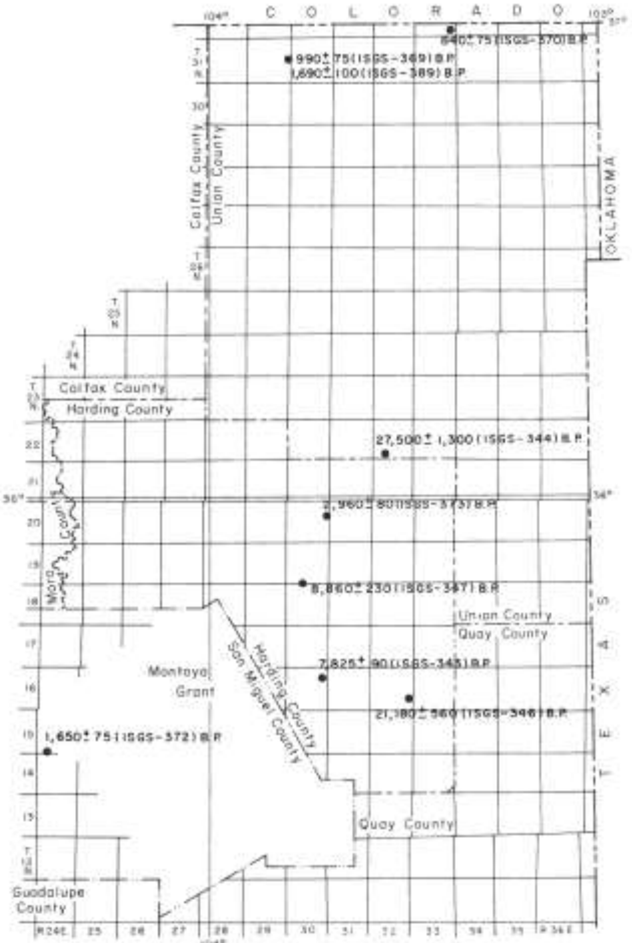

FIGURE 18—Map showing location of the nine radiocarbon dates determined in the Illinois State Geological Survey laboratories as part of this study. The dates are listed in table 4. Seven of the dates are determinations on mollusk shells and are indicated in table 3.

southeastern parts of the state (Leonard and Frye, 1975; Leonard, Frye, and Glass, 1975); however, molluscan faunas in basin and terrace deposits of similar age are likewise similar. For that reason, the molluscan faunas of these two depositional environments will be discussed together.

In striking contrast to the pond deposits described in east-central and southeastern New Mexico (Glass, Frye, and Leonard, 1973; Leonard and Frye, 1975; Frye, Glass, Leonard, and Coleman, 1974; Leonard, Frye, and Glass, 1975), none of the basin-fill deposits of northeastern New Mexico contains either attapulgite or sepiolite. This is interpreted as the result of environmental differences between the regions. In southeastern New Mexico the environment that produced sepiolite in pond deposits has been described as follows (Leonard, Frye, and Glass, 1975, p. 16):

> These relationships suggest that sepiolite forms in water-table ponds during times of increasing desiccation when such ponds become areas of ground-water discharge with increasing alkalinity; not in ponds above the water table where water leaves the pond by downward percolation, or in ponds fed only by surface runoff. We conclude that sepiolite is not now forming in the intermittently flooded playa flats common in the region.

The complete absence of sepiolite and attapulgite in pond deposits in northeastern New Mexico is consistent with this earlier interpretation. There is no indication that the pond deposits studied in this area served as areas of ground-water discharge; they were short-lived permanent lakes that supported aquatic fauna and flora until they became filled by sediments and thus were converted to swampy areas. Pond and basin deposits, widespread and prominent farther south in the eastern third of New Mexico, are of minor importance in the northeastern region.

Terraces and pediments

Alluvial terrace deposits containing molluscan faunas occur along all of the major streams and many of the tributary streams of this region (figs. 1, 16, and 17). At several places radiocarbon dates have been determined from the terraces (fig. 18), and clay-mineral analyses were made on samples from 38 localities (table 2).

An extensive terrace of early Wisconsinan age (Altonian Substage) was studied only in the valley of Tramperos Creek in southeastern Union County. The early Wisconsinan age of this terrace is confirmed by a radiocarbon date of 27,500 ± 1,300 (ISGS-344) B.P. from the Miera section (fig. 3; tables 2, 4, and 5).

Tramperos Creek (also called Major Long Creek and Punta de Agua Creek) roughly parallels Canadian River on the north and has a gradient from the Miera section toward the east-southeast to its junction with Canadian River in Oldham County, Texas, of approximately 12 ft per mi. In contrast, the Canadian River from due south of the Miera section to the same point in Oldham County has a gradient of more than 18 ft per mi. Furthermore, the Canadian River in the reach upstream from the point due south of Miera section and its major tributaries, such as Ute Creek, have excessively steep gradients. Although the details of the drainage history that caused such a discrepancy in gradients are not yet fully understood, the strong contrast of erosional competency explains why the extensive early Wisconsinan terrace is preserved only in the valley of Tramperos Creek and is not preserved along the valleys of Canadian River, Ute Creek, Tequesquite Creek, Conchas River, and Cuervo Creek.

The Miera section is described in the stratigraphic section in table 5. It is representative of the sediments under the broad terrace in this segment of Tramperos Creek valley and stands sharply above the low Holocene terrace (NMP-829, F-109, figs. 16 and 17) that extends along the channel. The clayey, organic-rich sediments at the top of the Miera sequence indicate that what is now the top of the terrace was for a significant time a relatively stable floodplain surface and that this surface may have persisted well into Woodfordian time. The fauna and the radiocarbon data are from the lower sand and silt deposits that reflect active alluvial deposition. The clay-mineral composition (table 2) in the lower part of the section contains moderate montmorillonite and illite, but the unusually high percentage of kaolinite indicates a significant sediment source in the nearby Cretaceous rocks.

Wisconsinan terrace deposits of Woodfordian age (called "classical Wisconsin" and late Wisconsin, by some) are lacking in northeastern New Mexico, whereas terraces of latest Wisconsinan and Holocene age occur extensively along all of the valleys (tables 4, 5). This relationship is in contrast to the situation in east-central (Leonard and Frye, 1975) and southeastern New Mexico (Leonard, Frye, and Glass, 1975) but is similar to the situation described by Hawley (1975) to the southwest in the Rio Grande valley. The relationship of the terraces in northeastern New Mexico is also in contrast with the situation in western Texas (Frye and Leonard, 1957a, 1968) and in western Kansas (Frye and Leonard, 1952). The absence of terraces in this region of Woodfordian age, which are widespread to the east and south, may be explained by the complex late Cenozoic drainage history of northeastern New Mexico. The Canadian River and its tributaries (with the exception of Tramperos Creek) were rapidly incising their valleys during latest Pleistocene time, and the Cimarron River appears to have been incising its valley even more rapidly.

Of the latest Wisconsinan terraces, one locality has been dated by radiocarbon analysis. This is from the Tequesquite Creek section (figs. 16, 17, and 18; tables 2, 4, and 5), where a date of 8,860 ± 230 (ISGS-347) **B.P.** was obtained on organic carbon from sample NMP-568. Molluscan faunas are described from this locality (Fauna No. 83TA, fig. 14, table 4) and from the adjacent but lower Holocene terrace (Fauna No. 83TB, fig. 14). The lithology of the deposits is described in the stratigraphic section in table 5. The clay-mineral composition is a typical detrital assemblage of high montmorillonite, moderate illite, and moderate kaolinite (table 2).

Along the middle reach of Ute Creek (above the junction with tributary Tequesquite Creek), the major terrace is Holocene. At the south Bueyeros section (F-111, fig. 14, table 3; and NMP-831, fig. 16, table 2) a radiocarbon date of 2,960 ± 80 (ISGS-373) B.P. from the lower part of an exposure of 15 ft of terrace sediments suggests correlation with the lower Holocene terrace at the Tequesquite section. The clay-mineral composition here, as elsewhere along Ute Creek, suggests a detrital source.

Three additional localities along Ute Creek confirm the Holocene age of its present valley: the Yates Northeast section (F-84A-84B, NMP-594); the Gallegos North section, where dated basin-fill deposits are truncated by the terrace level; and the Logan Northwest section (F-119; NMP-921-922), where Wisconsinan deposits occur 100 ft above the level of the channel and above two well-developed alluvial terraces cut into bedrock. The Logan Northwest locality is probably a Woodfordian basin-fill deposit, dissected by the Ute Creek during Holocene time.

West of Ute Creek, La Cinta Creek is another northern tributary to Canadian River. Two localities studied in San Miguel County (F-83 and NMP-559-560; F-107 and NMP-778) also indicate an extremely youthful age for the present valleys. The high percentages of illite among the clay minerals (table 2) indicate a predominant sediment source in the adjacent Triassic rocks.

A similar situation occurs along the Canadian River at the western edge of this region. The thin terrace deposits on bedrock along Lagartija Creek (F-106, NMP-775-776) and the minor terrace deposits along Canadian River (F-115, NMP-906) are examples of very young terraces. Clay-mineral compositions high in illite, and in one sample excessively high in kaolinite, indicate sediment sources in the local bedrock (table 2). This is strongly confirmed by a locality along Trementina Creek, which is a tributary to Conchas River a few miles above its junction with Canadian River. The narrow alluvial terrace (NMP-774) and its fauna (Fauna No. 105) along Trementina Creek have been radiocarbon dated at 1,650 ± 75 (ISGS-372) B.P. This terrace, which is notched into bedrock, has a clay-mineral composition (table 2) that is 70 percent illite, and more kaolinite than montmorillonite, suggesting a very local bedrock source for the sediments.

Cuervo Creek is a southwestern tributary to Conchas River above its junction with Canadian River. It too contains localities that are consistent with other Canadian River tributaries. A molluscan fauna (Fauna No. 104) was collected from a 12-ft exposure of terrace deposits above bedrock at channel level. Here again the clay minerals (NMP-770-771) are high in illite and indicate a bedrock source (table 2). The lowest terrace of the Canadian River just below Conchas Dam, although strikingly above the level of the river channel, is also quite high in illite and kaolinite (NMP-772).

Along the southern edge of this region are several terrace localities in the headwaters of southern tributaries to Canadian River. At the southwest corner is the Newkirk section (F-78, NMP-501-503) in drainage of Pajarito Creek. Seventeen feet of fossiliferous deposits are exposed below a narrow terrace surface flanked by Triassic bedrock. A very narrow lower terrace immediately borders the creek channel. This terrace yielded a meager very young fauna. The clay minerals are high in illite (table 2), reflecting the Triassic source, and also contain some chlorite.

In the southeastern corner of the region two terrace localities were studied, one along Rona Arroyo (F-117, NMP-914) and one along San Jon Creek (F-118, NMP-915). Rona Arroyo drains almost directly north by way of Rona Canyon into Canadian River. In contrast, San Jon Creek by way of Trujillo Creek joins Canadian River in Oldham County, Texas, about 10 mi east of the New Mexico State line. The divergent drainage has produced a strikingly steeper stream gradient in Rona Arroyo, with terrace deposits only four feet thick resting on bedrock, and a clay-mineral composition that is indistinguishable from the adjacent Triassic rocks (table 2). The locality along San Jon Creek exposes 20 ft of terrace deposits, including a narrow floodplain terrace that flanks the stream channel. The deposits are sand with gravel zones that do not appear to be entirely eroded from local bedrock and a clay-mineral composition that contains much more montmorillonite and less kaolinite than Rona Arroyo (table 2). Although the terrace deposits of Rona Arroyo are young within the Holocene, the terrace of San Jon Creek is probably late Wisconsinan.

In the Canadian River drainage area of this region, only one sample of pediment veneer was collected for x-ray analysis (NMP-773, table 2). The sample came from two feet below the surface of a smooth, sloping pediment from an artificial ditch. The deposits are poorly sorted sand, silt, and pebbles; they are red brown, and massive to indistinctly zoned. Triassic rocks are exposed at the head of the pediment slope, and the clay-mineral composition (64 percent illite, 26 percent montmorillonite, and 10 percent kaolinite and chlorite) is not distinguishable from the source Triassic rocks. A weakly developed A horizon occurs in the deposits below the pediment surface.

Along the Cimarron River valley at the northern edge of this region, the terraces (fig. 3A-B) are unrelated to those of the Canadian River drainage that dominate most of this region. Pre-Holocene terraces have not been studied in the Cimarron River valley, and three radiocarbon dates (table 4) ranging from 840 ± 75 (ISGS-370) B.P., to 1,690 ± 100 (ISGS-389) B.P. emphasize the young age of the terrace deposits. The lithology of the Cimarron River terraces is described in the Kenton West stratigraphic section (table 5).

Terrace deposits and faunas were studied at two localities along tributaries to Cimarron River. Along Carrizozo Creek (a tributary from the south that enters Cimarron River to the east of New Mexico in Cimarron County, Oklahoma), eight feet of terrace sediments occur above Triassic rocks into which the channel of the creek is incised (F-100, NMP-759-760). This creek drops from an elevation of 5,500 ft at Guy, near its headwaters, to 4,400 ft at its junction with Cimarron River, an air distance of about 28 mi. The creek's very young terrace has a clay-mineral composition predominantly of illite and kaolinite (table 2). The other tributary terrace is along Sloan Creek (F-102, NMP764-765), about 2 1/2 mi above its juncture with Cimarron River. Here 12 ft of gravel, with large cobbles, interbedded with sand, sand and gravel, and sand and silt, is exposed above Jurassic bedrock. Again, the clay-mineral composition is high in illite and kaolinite (table 2).

Three additional terrace exposures were sampled adjacent to the channel of Cimarron River. About two miles south of the Colorado State line 15 ft of terrace deposits are exposed above Triassic bedrock in the stream channel (F-103, NMP-766). Here, montmorillonite comprises 48 percent of the clay minerals, with illite 33 percent and kaolinite 19 percent. About six miles west, the Cimarron River section exposes nearly 20 ft of terrace deposits (F-89, NMP-628-629). A radiocarbon analysis on small clams in the middle of the terrace section yielded a date of 840 ± 75 (ISGS-370) B.P. Twenty miles farther west, the terrace deposits above a young basalt were studied in the Folsom Northeast section (F-91; NMP-637, 767). The top of the basalt below the terrace is quite irregular, as is the contact of the upper fossiliferous unit of the terrace deposit (F-91, NMP-637) on the lower discontinuous unit in the top of which an Indian fire pit was sampled (NMP-767). Radiocarbon analysis of mollusk shells from the upper unit yielded a date of 990 ± 75 (ISGS-369) B.P., and of charcoal from the fire pit at the top of the lower unit yielded a date of 1,690 ± 100 (ISGS-389) B.P.

South of Cimarron River drainage and roughly parallel to it, but 300 ft higher at the Texas State line and progressively rising to 600 ft higher farther west, are the headwaters of the North Canadian River. The valley of the North Canadian River in this region is largely erosional in the Ogallala Formation and bedrock and lacks prominent Pleistocene terraces. At one locality (F-90, NMP-636) a narrow but relatively thick alluvial terrace deposit was sampled. The sediments are gray-brown silt and sand with some pebbles, containing a black, clayey A horizon. The clay-mineral composition is 48 percent montmorillonite, 32 percent illite, and 20 percent kaolinite, which probably reflects a mixed sediment source. The available data are adequate only to conclude that this terrace of the North Canadian River is Wisconsinan or Holocene.

The distribution of chlorite in Canadian River valley is strongly suggestive of a bedrock source in Triassic rocks. A group of localities along Canadian River and from tributaries to Canadian River (NMP-501-503, 560, 770-771, 774-776, 778, and 914-915) all contain chlorite in association with moderate to low percentages of montmorillonite and high percentages of illite. These samples are all from young terrace deposits with a Triassic sediment source in the drainage basin, and they strongly reflect a detrital source in bedrock. Samples from along the Cimarron River valley contain no chlorite (Triassic rocks do not occur in the drainage basin) but are generally higher in montmorillonite. The one sample from a young terrace in Purgatoire River drainage, north of Cimarron River and with upper Cretaceous bedrock source rocks (NMP-638), is 81 percent montmorillonite. These contrasting groups of samples indicate that the very young terrace deposits are derived from a source in the bedrock of the local drainage basins.

Molluscan faunas

The composite molluscan faunal assemblage in northeastern New Mexico (figs. 14 and 17) consists of 48 separate collections, comprising 50 taxa of mollusks, including gastropods and pelecypods. Twenty of the taxa are aquatic, and 30 are terrestrial. Of the 20 aquatic mollusks, 6 are branchiates (including 4 kinds of pelecypods and 2 kinds of gastropods) and may be thought of as requiring permanent water as a habitat. This is not strictly true, since some pelecypods and some branchiate gastropods can survive periods of several months without access to open water as long as they can find a locally humid environment. The same is true of many pulmonate aquatic snails. The total molluscan assemblage is listed below.

Wisconsinan and Holocene Mollusca in northeastern New Mexico:

Class Pelecypoda
- Order Prionodesmacea
  - Family Unionidae
    - Unionid sp.
- Order Telodesmacea
  - Family Sphaeriidae
    - Genus *Sphaerium* Scopoli 1777
      - *Sphaerium transversum* (Say) 1818
    - Genus *Pisidium* Pfeiffer 1821
      - *Pisidium casertanum* Poli 1791
      - *P. compressum* Prime 1851
      - ***P.** nitidum* Jenyns 1832

Class Gastropoda
- Order Taenobranchiata
  - Suborder Basommatophora
    - Family Valvatidae
      - Genus *Valvata* Müller 1774
        - *Valvata tricarinata* (Say) 1817

Family Amnicolidae
Genus *Somatogyrus* Gill 1863
Somatogyrus subglobosus (Say) 1825
Order Pulmonata
Family Lymnaeidae
Genus *Lymnaea* Broderip 1839
Lymnaea (Stagnicola) palustris (Muller) 1774
L. (Fossaria) dalli F. C. Baker 1906
L. (Fossaria) humilis Say 1822
L. (Fossaria) parva Lea 1841
Family Planorbidae
Genus *Gyraulus* Agassiz 1837
Gyraulus parvus (Say) 1817
G. circumstriatus (Tryon) 1866 Genus *Helisoma* Swainson 1840 *Helisoma antrosa (anceps)* Conrad 1834
H. trivolvis (Say) 1817
Genus *Promenetus* F. C. Baker 1935
Promenetus exacuous (Say) 1821
Family Ancylidae
Genus *Ferrissia* Walker 1903
Ferrissia rivularis (Say) 1819
F. parallelus (Haldeman) 1841
Family Physidae
Genus *Physa* Draparnaud 1801
Physa anatina Lea 1864
P. gyrina form *hildrethiana* Lea 1841
Suborder Stylommatophora
Family Bulimulidae
Genus *Rhabdotus* Albers 1850
Rhabdotus dealbatus (Say) 1821
Family Zonitidae
Genus *Euconulus* Reinhardt 1883
Euconulus fulvus (Willer) 1774
Genus *Retinella* (Shuttleworth, ms.) Fischer 1877
Retinella electrina (Gould) 1841
Genus *Hawaiia* Gude 1911
Hawaiia minuscula (Binney) 1840
Genus *Zonitoides* Lehmann 1862
Zonitoides arboreus (Say) 1816
Genus *Discus* Fitzinger 1833
Discus cronkhitei (Newcomb) 1865
Genus *Helicodiscus* Morse 1864
Helicodiscus parallelus (Say) 1821
H. eigenmanni Pilsbry 1900
H. singleyanus (Pilsbry) 1890
Family Succineidae
Genus *Oxyloma* Westerlund 1885
Oxyloma retusa (Lea) 1864
Genus *Catinella*
Catinella sp.
Genus *Succinea* Draparnaud 1801
Succinea grosvenori Lea 1864
S. gelida F. C. Baker 1927
S. ovalis Say 1817
Family Pupillidae
Genus *Gastrocopta* Wollaston 1878
Gastrocopta armifera (Say) 1821
G. riograndensis (Pilsbry & Vanatta) 1900
G. cristata (Pilsbry & Vanatta) 1900
G. pellucida hordeacella (Pilsbry) 1890
Genus *Pupoides* Pfeiffer 1864
Pupoides albilabris (C. B. Adams) 1841
P. hordaceus (Gabb) 1866
P. inornatus Vanatta 1915
Genus *Pupilla* Leach 1831
Pupilla muscorum (Linne) 1758
P. blandi Morse 1865
Genus *Vertigo* Müller 1774
Vertigo milium (Gould) 1840
V. modesta (Say)
Family Vallonidae
Genus *Vallonia* Risso 1826
Vallonia pulchella (Muller) 1774
V. parvula Sterki 1893
V. gracilicosta Reinhardt 1883
V. cyclophorella Sterki 1892

The only published accounts of fossil molluscan assemblages in eastern New Mexico are found in the papers by Leonard and Frye (1975) and Leonard, Frye, and Glass (1975). We reported our own studies and reviewed those few studies previously made. In a report of fossil mollusks in east-central New Mexico, 47 taxa were listed, including 22 aquatic mollusks, seven of which were aquatic branchiates, and 25 kinds of terrestrial gastropods. The proportion of aquatic, terrestrial, and branchiate species is similar to that in northeastern New Mexico. In the southeastern part of New Mexico, we reported a total assemblage of 30 taxa, comprised of 13 kinds of aquatic mollusks, 4 of which were branchiates, and 17 taxa of terrestrial gastropods. Again, the proportion of aquatic mollusks to those of terrestrial habitat, and the proportion of branchiates among the total aquatics, is about the same in northeastern New Mexico. This similarity in the composition of the molluscan faunal assemblages in these three districts of eastern New Mexico (generally east of the Pecos River) is taken to mean that in Wisconsinan time the general environment in this part of New Mexico varied little from north to south. The total assemblage in southeastern New Mexico is smaller in numbers than in the other two areas reported, but this may reflect conditions for preservation of shells, rather than other environmental conditions.

Whenever conditions were favorable (when fossils were being collected from exposures near streams), collections of fine drift material were made and studied for their contained molluscan shells. Lest drifting fossil shells be collected, only those shells displaying original unbleached periostracum were taken. As far as practicable, drift samples were taken only from minor drainage, under conditions that seemed to limit the drainage area to the local surroundings. From several such drift collections, we obtained the following faunal assemblage:

Gastrocopta armifera (Say)
Gastrocopta cristata (Pilsbry & Vanatta)
Gastrocopta pellucida hordeacella Pilsbry
Gastrocopta pilsbryana (Sterki)
Gyraulus parvus (Say)
Hawaiia minuscula (Binney)
Helicodiscus parallelus (Say)
Physa anatina Lea
Pupilla blandi Morse
Pupilla muscorum (Linne)
Pupoides albilabris (Adams)
Pupoides hordaceus (Gabb)
Pupoides inornatus Vanatta
Succinea grosvenori Lea
Vallonia gracilicosta Reinhardt
Vallonia parvula Sterki

Of these 16 species, only two are aquatic in habit, *Gyraulus parvus* and *Physa anatina*, neither of which is a branchiate gastropod. With the exception of *Gastrocopta pilsbryana*, all these modern species occur in the molluscan faunal assemblages from the Wisconsinan and Holocene collections in northeastern New Mexico. All except two species, *Gastrocopta pellucida hordeacella* and *G. pilsbryana*, occur in the collections from east-central New Mexico. Four of the modern drift species are absent from the faunal assemblage reported from the southeastern part of New Mexico: *Gastrocopta pilsbryana, Helicodiscus parallelus, Pupoides hordaceus,* and *Vallonia parvula.* From these comparative views of the three faunal assemblages, it seems a rational conclusion that the persisting faunal assemblage is composed of those hardy species capable of survival in an environment with greatly reduced rainfall. Gone are all the branchiate mollusks, and the number of aquatic pulmonates has been decimated. Conversely, it is logical to assume that northeastern New Mexico was much better watered than it is now up to a time less than a thousand years ago. There is little evidence supporting any significant lowering of temperature during Wisconsinan and most of Holocene time in eastern New Mexico, although there may have been sufficient depression of average temperatures to reduce evaporation rates.

Radiocarbon age determinations and faunal assemblages from northeastern New Mexico ranged from more than 27,000 radiocarbon years B.P. (fig. 18, table 4) to as few as 840 radiocarbon years B.P. This wide range of radiocarbon determinations and the fact that most of the local faunal assemblages remain undated pose serious difficulties in attempts to correlate faunal assemblages and age of related deposits. Table 4 presents the available data on age of deposits and faunas in northeastern New Mexico based on 9 samples. The two oldest dated faunal assemblages (Fauna No. 86 and Fauna No. 55) are dated 27,500 ± 1,300 and 21,180 ± 560 radiocarbon years B.P., while the two youngest dated assemblages (Fauna No. 89 and Fauna No. 91) are dated 840 ± 75 B.P. and 990 ± 75 B.P. respectively. Of the 12 species in the faunal assemblage at locality 55 and the nine species recovered from locality 86, only 5 are common to both. In the case of the two youngest localities, the faunal assemblage from locality 89 comprises 17 species, that from locality 91, 14 species, and 10 species are common to both (fig. 11). Many of the terrestrial species are common to all four of these localities, but one significant difference is that *Lymnaea palustris* occurs in both of the older faunal assemblages and does not occur at all in the two youngest. This fact is important in the verification of ecological changes in this portion of New Mexico in the last 20,000 radiocarbon years. *Lymnaea palustris* is an aquatic pulmonate gastropod of circumpolar distribution; in North America it is at present distributed from Newfoundland across Canada to Alaska and mainly into the northern tier of states in the United States. There is a report of occurrence in the lakes in the Sand Hills of Nebraska. An area in southern Mexico at high elevations is inhabited by *Lymnaea attenuata* Say, which Hubendick (1951, p. 119) equates with *L. palustris.* The importance of the occurrence of *L. palustris* lies in the fact that it is a species of permanent standing water, rather than flowing water, which indicates that in early Wisconsinan time in northeastern New Mexico, this type of environment was available. *L. palustris* also occurs at Fauna Nos. 79, 84B, 115, and 118. While it would be less than rational to deduce the age of these faunal assemblages on the basis of a single species of gastropod, it is safe to conclude that these assemblages represent the same general type of environment—one with permanent standing water.

Branchiate gastropods in northeastern New Mexico—Only two species of branchiate aquatic mollusks were recovered from northeastern New Mexico: an amnicolid, *Somatogyrus subglobosus* (Say), and *Valvata tricarinata* (Say); these occur in only a few assemblages. F. C. Baker (1928, p. 154) placed this gastropod in a separate genus, *Birgella,* but malacologists have not followed this arrangement. Each of these two species of branchiate gastropods occurs in four assemblages (fig. 14) but, strangely, in no case do they occur together, although their ecological requirements are similar. *Somatogyrus subglobosus* is a pond or lake species, and this is also a preferred habitat of *Valvata tricarinata,* although the latter is known to occur in streams as well. The significant feature of these two gastropods is that they require permanent open water, from which it follows that such habitat was available at the localities in which they occurred. Unfortunately, none of the eight faunal assemblages in which these branchiates occur is dated. General physiographic and geologic considerations indicate, however, that a suitable habitat for aquatic gastropods linked to permanent, open water persisted long after the assemblages dated as early Wisconsinan flourished.

Of the 49 taxa represented in the total composite molluscan faunal assemblage, 16 taxa occur only once (fig. 14). Such unique occurrences have little value in interpreting the significance of faunal assemblages. The 10 taxa that occurred most frequently in faunal assemblages are: *Succinea grosvenori,* recovered in 38 assemblages; *Gyraulus parvus,* found in 26 assemblages; *Hawaiia minuscula* in 25 assemblages; *Sphaerium striatinum* in 24 assemblages; followed by *Physa anatina* in 22; *Helisoma trivolvis* in 19; *Vallonia gracilicosta* in 18; *Pisidium compressum* in 18; *Pupoides albilabris* in 16; and *Gastrocopta armifera* in 15 local faunal assemblages. For the most part, these are the rugged survivors of all climatic fluctuations that have occurred in late Pleistocene time in northeastern New Mexico, and most of them persisted into relatively recent time or even into the present.

Among terrestrial gastropods in northeastern New Mexico, the only taxon among the assemblages of fossil gastropods worthy of special note is *Helicodiscus eigenmanni* Pilsbry, which occurs in 12 of the 48 faunal assemblages. To our knowledge, this is the first report of *H. eigenmanni* in New Mexico; it is reported from many localities in southern Texas and from provinces in Mexico as far south as Puebla. Pilsbry (1948, p. 630) also notes records from Colorado and Utah. Little ecological data is mentioned by Pilsbry, except that living specimens were taken along the Guadalupe River north of New Braunfels, Texas, presumably in damp situations. The significance of *H. eigenmanni* in northeastern New Mexico is unknown; since it is a southern species it is difficult to explain its absence in collections farther south in eastern New Mexico. *H. eigenmanni* is superficially similar in appearance to *H. parallelus; H. eigenmanni* differs by being larger and more robust in all stages of growth. Unfortunately, none of the assemblages in which *H. eigenmanni* occurs has been dated.

Summary and conclusions

Northeastern New Mexico contains a diversity of Pliocene and Pleistocene strata not found elsewhere in the Great Plains region. The most unusual element is the presence of basalt flows, ranging in age from pre-Ogallala to Holocene, in association with the Ogallala Formation and deposits of Quaternary age.

Much of the region was blanketed by alluvial sediments of the Ogallala Formation during Pliocene time. Unlike the eastern edge of New Mexico and adjacent western Texas, however, the central and western parts of this region were discontinuously covered by these sediments; generally only the middle to upper stratigraphic units are present, and the average thickness decreases westward. In the western part of the region, the Ogallala Formation has been identified only in the western prong of Harding County and the southeast corner of Colfax County (Mosquero north to Abbott). The upper surface of the Ogallala is strongly sloping toward the east, and the pronounced warping of the Ogallala, so prominent farther south, is not evident in extreme northern New Mexico.

The clay-mineral zonation of the Ogallala Formation developed in east-central and southeastern New Mexico, where five stratigraphic units are recognized; the lowermost is Zone I (characterized by predominant montmorillonite), overlain by Zone II (characterized by the presence of attapulgite). Zone II is capped by relatively thin Zone III (distinguished by sepiolite) and the thin Zone IV (characterized by high percentages of montmorillonite and absence of fibrous clay minerals), overlain by the pisolitic limestone of thin Zone V (characterized by weathered montmorillonite, illite, kaolinite, and chlorite) and has been traced to the northeastern corner of the state. Stratigraphically significant is the fact that in this region distinctive fossil floras and faunas permit the correlation of these clay-mineral zones recognized throughout eastern New Mexico with the floral zones (based on fossil plant remains) used throughout the extent of the Ogallala Formation. The thin New Mexico clay-mineral Zones III, IV, and V correlate with the Kimball Floral Zone (or Kimball Member) to the east and north (Leonard and Frye, 1978). Clay-mineral Zone II, and probably the uppermost part of clay-mineral Zone I, correlates with the Ash Hollow Floral Zone (or Ash Hollow Member) of the regional Ogallala Formation subdivision. By inference from these facts, New Mexico clay-mineral Zone I (at least in the middle and lower parts) correlates with the Valentine Floral Zone (Valentine Member).

At one locality in northeast New Mexico (Martinez East section), a late Tertiary basalt flow occurs stratigraphically within the Ogallala Formation, and at many places basalt flows were emplaced on top of the Ogallala sediments. At one locality a basalt overlying Ogallala Formation has been dated 2.5 ± 0.8 m.y.

Deposits of Pleistocene and Holocene age are widely distributed throughout the region, primarily as terrace deposits but occasionally in filled basins. Only a few isolated areas have deposits of earliest Pleistocene (Nebraskan) age, and they are characterized by gravels, dense caliche in the upper part, and a detrital clay-mineral assemblage. Deposits of Kansan to mid-Pleistocene age are extensive in northern Quay County, northern Harding County, and southern Union County. At several localities well-developed soils occur in the sequence of sediments. Although the clay minerals are predominantly detrital, reflecting a source in the Ogallala Formation and older bedrock, locally the fibrous clay-minerals attapulgite and sepiolite are present. Distinctive fossils have not been collected from any of the early to mid-Pleistocene deposits.

Deposits of Wisconsinan and Holocene age occur as terraces along virtually all of the valleys of the region and at a few localities as extensive fills in basins. The clay-minerals of the terrace deposits and the basin-fill deposits are mainly detrital and reflect the range of sediment sources. This is in contrast to the extensive basin deposits farther south in New Mexico where abundant sepiolite characterizes many of the basin deposits. Radiocarbon dates from nine samples in the region range from 27,000 to less than 1,000 B.P. and serve to aid in time placement and correlation of the described faunas of fossil mollusks from 43 localities. The fossil mollusks correspond well with those described farther south but indicate a somewhat more equitable climate in this northern region. Comparison with the living fauna suggests some climatic deterioration during the past few thousand years.

The late Pleistocene and Holocene erosional history of the region is imperfectly understood. Incision of Canadian River and its tributaries has been rapid and extensive, but incision of the Cimarron River appears to have been even more rapid with the elimination of all terraces of an age older than Holocene. In contrast, the valley of Tramperos Creek contains an extensive and well-preserved terrace radiocarbon dated 27,000 B.P. A striking erosional feature is the east-facing escarpment of the Ogallala-capped upland north of Mosquero. The upland stands 1,000 ft above a lowland terrace dated 8,900 B.P. with no intervening terraces.

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Appendix

TABLE 1—CLAY-MINERAL ANALYSES OF 210 SAMPLES OF OGALLALA FORMATION SEDIMENTS FROM NORTHEASTERN NEW MEXICO. X-ray analyses by H. D. Glass in Illinois State Geological Survey laboratories. Arranged in approximate order of NMP sample number but by named section followed by isolated samples. Locations shown in fig. 14.

Sample No.	Feet below top of exposure	Clay mineral percent: Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks (Ogallala zone no. or fauna locality)
OBAR SECTION: NE¼ sec. 15, T. 15 N., R. 35 E., Quay Co.							
NMP-521	16	55	2	7	16	-	II
522	13	64	16	6	14	-	II
523	9	59	15	3	23	-	II
524	5	82	9	3	8	-	II
525	3	49	38	13	-	-	IV
526	1	no calculation					Pleistocene
NARA VISA SOUTHWEST SECTION: NE¼SE¼ sec. 29, T. 16 N., R. 36 E., Quay Co.							
NMP-527	25	93	4	3	-	-	I
528	23	92	5	3	-	-	I
529	19	90	5	5	-	-	I
530	17	94	4	2	-	-	I
531	9	95	3	2	-	-	I
532	4	97	2	1	-	-	I
532A	1	100	-	-	-	-	I
NARA VISA NORTHEAST SECTION: SE¼NE¼ sec. 6, T. 16 N., R. 37 E., Quay Co.							
NMP-533	20	48	19	3	30	-	II
534	15	47	22	4	27	-	II
535	5	56	18	3	23	-	II
NARA VISA NORTH SECTION: NW¼ sec. 3, T. 16 N., R. 36 E., Quay Co.							
NMP-542	35	40	19	3	38	-	II
541	20	44	16	2	38	-	II
540	10	64	15	2	19	-	II
539	4	4	18	2	43	33	III
538	1	10	8	2	-	80	III
UNION-QUAY CO. LINE SECTION: SW¼SW¼ sec. 9, T. 17 N., R. 36 E., Quay Co.							
NMP-548	24	53	20	7	20	-	II
725	22	71	12	3	14	-	II
547	20	8	10	2	39	41	
546	17	57	18	4	21	-	II
545	9	69	11	2	18	-	II
544	5	89	9	2	-	-	IV
724	1	88	9	3	-	-	IV
543	0	58	33	9	-	-	V
MOSQUERO NORTHEAST SECTION: NW¼SW¼ sec. 13, T. 18 N., R. 28 E., Harding Co.							
NMP-558	18	70	12	3	15	-	II
557	11	3	8	1	27	61	III
729	8	3	5	1	26	65	III
556	5	24	5	6	56	-	III
728	4	46	5	9	40	-	III
NMP-727	2	61	5	3	31	-	III
555	0	41	45	15	-	-	V
MOSQUERO WEST SECTION: SE¼NE¼ sec. 7, T. 18 N., R. 27 E., Harding Co.							
NMP-561	6	6	13	6	-	75	III
562A	1	9	11	3	-	77	III
562B	1	31	42	27	-	-	X
Cretaceous	7	5	10	5	19	61	Cretaceous
DAVID HILL SECTION: SW¼NE¼ sec. 14, T. 18 N., R. 29 E., Harding Co.							
NMP-563	10	10	14	12	19	43	III
564	6	25	5	2	68	-	II
565	1	58	5	6	31	-	II
CLAYTON NORTHEAST SECTION: SE¼NE¼ sec. 6, T. 26 N., R. 36 E., Union Co. (note: "b" indicates inclusion in basalt; basalt is top 10 ft)							
NMP-621A	8b	85	12	3	-	-	in basalt
621B	8b	94	4	2	-	-	in basalt
617	9b	76	17	7	-	-	in basalt
625	10	82	13	5	-	-	contact basalt
618	10	78	20	2	-	-	contact basalt
619	11	81	16	3	-	-	1 ft below basalt
733	11	86	13	1	-	-	1 ft below basalt
620	12	62	33	5	-	-	
734	12	71	23	6	-	-	
622	13	65	26	9	-	-	
735	14	61	32	7	-	-	
736	14	82	14	4	-	-	
623	15	59	32	9	-	-	
624	20	71	23	6	-	-	
CLAYTON SOUTH SECTION: SW¼SW¼ sec. 2, T. 24 N., R. 35 E., Union Co.							
NMP-737	29	70	25	4	-	-	I
600	25	69	27	4	-	-	I
601	21	75	21	4	-	-	I
602	20	52	25	4	19	-	II
603	18	17	20	1	30	32	III
738	16	18	19	3	-	60	III
604	15	30	23	3	-	44	III
739	14	30	31	7	-	32	Fauna 52
740	13	34	13	2	-	51	Fauna 52
605	11	17	16	3	-	64	III
606	9	26	24	6	-	42	III
741	8	26	25	5	-	44	III
742	2	67	26	7	-	-	IV
607	1	54	34	12	-	-	V
MILLS SECTION: NE¼NW¼ sec. 35, T. 22 N., R. 25 E., Harding Co.							
NMP-643	40	90	4	4	-	-	I
642	24	74	12	4	10	-	II
641	10	77	9	4	10	-	II
640	4	11	5	-	41	43	III
639	1	63	26	11	-	-	IV
SENECA NORTHEAST SECTION: SE¼NE¼ sec. 15, T. 28 N., R. 36 E., Union Co.							
NMP-743	29	78	16	6	-	-	I
628	24	79	9	5	7	-	II
744	21	78	9	5	8	-	Flora 88
745	19	70	13	4	13	-	Flora 88
746	9	72	12	2	14	-	II
747	5	53	20	2	25	-	II
748	1	73	12	4	11	-	II
GUY SOUTHEAST COMPOSITE SECTION: lower unit in NE¼NW¼ sec. 3, T. 29 N., R. 33 E.; upper unit NW¼SW¼ sec. 32, T. 30 N., R. 34 E., Union Co.							
NMP-631	11	90	6	4	-	-	I lower
630	1	90	4	6	-	-	I lower
632	20	77	10	3	10	-	II upper
633	16	58	17	3	22	-	II upper
753	15	57	20	4	19	-	II upper
752	13	58	15	2	25	-	II upper
634	12	15	5	2	78	-	II Flora 99
751	6	73	11	2	14	-	II Flora 99
750	4	90	7	3	-	-	IV upper
749	1	47	40	13	-	-	V upper
CLAYTON LAKE STATE PARK SECTION: SW¼ sec. 15, T. 27 N., R. 34 E., Union Co.							
NMP-758	23	45	17	38	-	-	Cretaceous
757	21	56	13	18	13	-	II
756	14	45	22	4	29	-	II
755	11	70	16	4	10	-	II
754	10	60	18	3	9	10	III base basal
SNYDER RANCH SECTION: NE¼SE¼ sec. 20, T. 25 N., R. 31 E., Union Co.							
NMP-779	41	58	8	2	14	18	
780	37	84	6	3	7	-	barite
781	15	33	8	2	-	57	
782	11	30	20	2	48	-	
595	10	19	11	2	-	68	
783	8	8	7	2	-	83	barite
596	6	36	14	5	-	45	
784	4	23	13	5	-	59	barite
597	3	23	13	5	-	59	
785	1	7	13	4	-	76	
FARLEY NORTHWEST SECTION: NW¼ sec. 34, T. 25 N., R. 27 E., Colfax Co.							
NMP-786	8	73	5	1	21	-	
787	3	37	46	17	-	-	chlorite
ABBOTT NORTHEAST SECTION: SW¼ sec. 4, T. 24 N., R. 26 E., Colfax Co.							
NMP-788	10	71	12	6	11	-	II
789	5	82	7	4	7	-	II
ABBOTT EAST SECTION: cent. S.I. sec. 13, T. 24 N., R. 25 E., Colfax Co.							
NMP-790	8	94	3	3	-	-	I
791	5	93	4	3	-	-	I
792	3	77	16	7	-	-	I
PASAMONTE SECTION: NW¼SW¼ sec. 10, T. 24 N., R. 30 E., Union Co.							
NMP-793	12	75	13	2	10	-	II
361B	8	72	5	4	19	-	II
794	7	66	16	3	15	-	II
795	4	44	5	2	49	-	II
796	2	76	16	8	-	-	IV
797	0	53	34	13	-	-	V chlorite
CLAYTON SOUTHWEST SECTION: SE¼ sec. 29, T. 25 N., R. 33 E., Union Co. (below basalt)							
NMP-800	14	82	7	3	8	-	
799	9	90	7	3	-	-	
798	4	92	5	3	-	-	
PASAMONTE SOUTH SECTION: SE¼ sec. 33, T. 23 N., R. 30 E., Union Co.							
NMP-806	24	94	5	1	-	-	I
805	22	42	44	14	-	-	soil
804	20	48	5	2	45	-	II
803	17	8	5	1	68	18	III
802	12	5	5	3	68	19	III
801	6	15	20	9	-	56	III
807	1	33	51	16	-	-	V chlorite
DAVIS T.S. SOUTH SECTION: SE¼ sec. 27, T. 24 N., R. 32 E., Union Co.							
NMP-808	13	80	8	3	9	-	II
809	8	57	16	2	25	-	II
810	4	48	14	3	13	22	III
811	0	30	46	24	-	-	V chlorite
CLAYTON WEST SECTION: NW¼ sec. 32, T. 26 N., R. 35 E., Union Co.							
NMP-812	20	69	26	5	-	-	I
813	12	58	19	6	17	-	II
814	7	33	15	4	19	29	III
815	3	73	23	4	-	-	IV
816	1	52	34	14	-	-	V chlorite
CLAYTON SOUTHEAST SECTION: SW¼SW¼ sec. 34, T. 25 N., R. 36 E., Union Co.							
NMP-817	25	66	15	3	16	-	
818	20	49	17	34	-	-	
819	18	80	13	7	-	-	
820	15	53	5	4	38	-	
821	5	67	22	11	-	-	barite
822	1	29	29	11	-	31	
REA TOWER SECTION: NW¼ sec. 5, T. 20 N., R. 33 E., Harding Co.							
NMP-833	55	81	12	7	-	-	I
834	45	69	16	3	12	-	II
835	30	74	5	3	19	-	II
836	25	40	5	2	53	-	II
837	15	36	5	2	57	-	II
838	10	40	16	4	-	40	III
839	5	55	34	11	-	-	IV
616	1	42	40	18	-	-	V
AMISTAD SOUTH SECTION: NW¼NW¼ sec. 19, T. 19 N., R. 36 E., Union Co.							
NMP-847	33	53	5	3	39	-	II
848	28	52	5	3	40	-	II
849	23	70	5	3	22	-	II
850	18	61	5	5	29	-	II
851	13	66	14	6	14	-	II Flora 51
852	8	55	23	7	15	-	II
853	3	44	16	3	16	21	III
854	1	65	27	8	-	-	IV

Sample No.	Feet below top of exposure	Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks (Ogallala zone no. or fauna locality)
NOGEBUD EAST SECTION: NE¼ sec. 20, T. 19 N., R. 34 E., Union Co.							
NMP-861	12	67	25	8	-	-	I
862	7	44	11	5	20	20	III
863	2	70	20	10	-	-	IV
864	1	23	46	31	-	-	V chlorite
MARTINEZ EAST SECTION: cent. S.I. sec. 9, T. 21 N., R. 28 E., Harding Co.							
NMP-869	114	93	4	3	-	-	I
870	104	94	3	3	-	-	I
871	101	93	4	3	-	-	I
872	96	90	6	4	-	-	I
873	89	71	14	5	10	-	II
874	78	90	4	6	tr.	-	II
875	72	87	5	3	5	-	II
876	66	39	11	1	21	28	III
877	64	98	1	1	-	-	bentonite (NMP-731)
878	61	95	3	2	-	-	bentonite (NMP-732)
879	58	53	14	4	11	11	III
583	50	74	7	3	6	10	III
NMP-880	48	69	14	3	14	tr.	III
584	44	34	16	2	21	27	III
881	43	50	13	4	13	20	III
359A	*	20	14	3	-	63	dolomite
359B	*	10	14	3	-	73	dolomite
585	41	13	24	3	26	36	III
586	39	13	24	2	28	33	III
587	36	26	19	3	23	29	III
588	34	72	9	2	7	10	basalt contact
589	32	not determined					basalt
590A	22	67	15	2	16	-	sand
590B	22	16	16	2	-	66	caliche
591	17	52	21	3	24	-	sand
592	5	53	22	5	20	-	caliche
593	1	42	38	19	-	-	IV

* Approximate position, sampled 100 yards north of section

Sample No.	Feet below top of exposure	Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks (Ogallala zone no. or fauna locality)
ROY WEST SECTION: NW¼ sec. 30, T. 20 N., R. 26 E., Harding Co.							
NMP-905	20	77	20	3	-	-	I
904	10	17	5	3	75	-	II
903	1	47	40	13	-	-	V chlorite
MISCELLANEOUS OGALLALA SAMPLES (location at end of table)							
NMP-333	-	83	8	9	-	-	
334	-	40	42	18	-	-	V chlorite
340	-	82	14	4	-	-	I
355	-	22	5	5	68	-	II caliche
356	-	12	5	2	81	-	II
361A	1	33	50	17	-	-	V pisolitic
361B	8	72	5	4	19	-	II
536	-	20	13	-	28	41	III
537A	-	91	3	6	-	-	
537B	-	90	3	7	-	-	
598	6	14	27	2	-	57	III
599	1	38	44	18	-	-	V pisolitic
828	-	32	35	33	-	-	V pisolitic
918	-	56	30	14	-	-	V chlorite

Location of miscellaneous Ogallala samples:
333 - SW¼ sec. 4, T. 16 N., R. 36 E., Quay Co.
334 - SW c. sec. 30, T. 22 N., R. 35 E., Union Co.
340 - NW¼SE¼ sec. 36, T. 18 N., R. 34 E., Union Co.
355 - NE¼SE¼ sec. 31, T. 19 N., R. 29 E., Harding Co.
356 - NW¼ sec. 1, T. 18 N., R. 27 E., Harding Co.
361 - NW¼NW¼ sec. 18, T. 24 N., R. 30 E., Harding Co.
536 - SE c. sec. 31, T. 17 N., R. 37 E., Quay Co.
537 - SE c. sec. 11, T. 16 N., R. 36 E., Quay Co.
598,599 - SW¼SW¼ sec. 35, T. 25 N., R. 35 E., Union Co.
828 - SW¼SE¼ sec. 5, T. 22 N., R. 34 E., Union Co.
918 - NW¼SW¼ sec. 32, T. 12 N., R. 34 E., Quay Co.

TABLE 2—CLAY-MINERAL ANALYSES OF 85 SAMPLES OF PRE-WISCONSINAN PLEISTOCENE SAMPLES AND OF 89 SAMPLES OF WISCONSINAN AND HOLOCENE DEPOSITS FROM NORTHEASTERN NEW MEXICO. X-ray analyses by H. D. Glass in Illinois State Geological Survey laboratories. Locations shown in fig. 15 and 16.

QUATERNARY DEPOSITS - Nebraskan

Sample No.	Feet below top of exposure	Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks
SAND SPRINGS STATION NORTHEAST SECTION: SE¼SE¼ sec. 20, T. 15 N., R. 35 E., Quay Co.							
NMP-514	17	98	1	1	-	-	sand
515	13	89	7	4	-	-	sand
516	11	86	7	5	-	-	sand
517	7	72	11	2	15	-	sand + silt
518	4	85	6	3	6	-	sand + caliche
723	4	19	5	1	75	-	Ogallala boulder
722	3	33	5	2	60	-	Ogallala boulder
519	3	59	29	12	-	-	chlorite
520	1	48	35	17	-	-	chlorite
331	0	51	34	15	-	-	chlorite

QUATERNARY - Middle Pleistocene - Kansan

Sample No.	Feet below top of exposure	Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks
LOGAN NORTHEAST SECTION: NE¼SE¼ sec. 36, T. 14 N., R. 33 E., Quay Co.							
NMP-329	12	72	10	4	14	-	
328	9	77	18	5	tr.	-	Cca horizon
327	8	75	19	6	tr.	-	B horizon
326	6	46	45	9	-	-	B horizon
325	5	27	61	12	-	-	B horizon
324	4	23	61	16	-	-	A horizon
TUCUMCARI NORTH SECTION: NW¼SW¼ sec. 2, T. 11 N., R. 30 E., Quay Co.							
NMP-511	75	69	13	5	13	-	sand
510	26	52	17	13	18	-	sand
509	19	65	13	5	17	-	Cca horizon
508	14	49	21	5	25	-	Cca horizon
507	11	50	42	8	-	-	
506	7	47	45	8	-	-	Cca horizon
505	4	56	36	8	-	-	B horizon
504	2	50	21	4	25	-	B horizon

QUATERNARY DEPOSITS - Nebraskan

Sample No.	Feet below top of exposure	Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks
MITCHEL WEST SECTION: NW¼SW¼ sec. 19, T. 21 N., R. 28 E., Harding Co.							
NMP-573	25	No determination					Cca horizon
574	21	55	34	11	-	-	B horizon
575	19	62	28	10	-	-	B horizon
576	17	71	23	6	-	-	Silt & fine sand
577	15	72	22	6	-	-	Cca horizon
578	13	48	38	14	-	-	B horizon
579	11	43	46	11	-	-	A horizon
580	8	56	31	12	-	-	C horizon
NMP-581	5	76	18	6	-	-	A horizon
582	2	75	19	6	-	-	B horizon
730	0	70	22	8	-	-	A horizon
NEWKIRK NORTH SECTION: SW¼ sec. 25, T. 11 N., R. 25 E., Guadalupe Co.							
NMP-769	3	15	14	15	-	56	pink sand
768B	1	16	19	18	-	47	caliche
768A	0	63	20	17	-	-	pisolites
PINABETITOS CREEK SECTION: SE¼NE¼ sec. 4, T. 22 N., R. 34 E., Union Co.							
NMP-823	11	58	22	20	-	-	sand & gravel
825	7	66	17	17	-	-	
824	6	43	19	19	19	-	Cca horizon
826	4	66	16	18	-	-	B horizon
827	2	66	14	20	-	-	Cca horizon
609 low ter		40	32	28	-	-	Holocene; Fauna 85
HAYDEN SOUTH SECTION: NE¼SW¼ sec. 22, T. 19 N., R. 34 E., Union Co.							
NMP-855	51	67	14	3	16	-	
856	41	75	7	9	9	-	
857	34	92	3	2	3	-	
858	29	84	3	1	tr.	12	platy clay
859	26	92	3	2	3	-	
860	1	80	14	6	-	-	
MARTINEZ SECTION: NE¼SE¼ sec. 17, T. 21 N., R. 28 E., Harding Co.							
NMP-882	42	83	11	6	-	-	
883	27	88	6	6	-	-	silt, clay, sand
884	22	96	2	2	-	-	
885	17	94	3	3	-	-	
886	14	92	5	3	-	-	Cca horizon
887	13	84	10	6	-	-	B horizon
888	7	93	3	4	-	-	
889	2	94	3	2	-	-	caliche, sand
890	0	86	9	5	-	-	cemented
MARTINEZ WEST SECTION: NW¼SE¼ sec. 18, T. 21 N., R. 28 E., Harding Co.							
NMP-891	44	93	4	3	-	-	sand
892	41	93	4	3	-	-	silt & clay
893	38	89	7	4	-	-	dense cement
894	35	95	3	2	-	-	clay & silt
895	30	76	11	2	11	-	soft cement
896	28	70	7	3	9	11	sand
897	24	86	5	3	6	-	sand & gravel
898	19	87	4	3	6	-	dolomite
899	14	89	4	3	4	-	clay-silt
NMP-900	9	74	8	3	15	-	dolomite
901	5	68	8	2	7	15	sand
902	2	6	5	1	48	39	dense cement
ADRERG STATION SECTION: SW¼ sec. 35, T. 12 N., R. 31 E., Quay Co.							
NMP-925	8	53	5	2	40	-	
926	4	75	18	7	20	-	Cca horizon
927	3	no determination					B horizon
928	1	28	58	14	-	-	sand
MISCELLANEOUS KANSAS SAMPLES (locations at end of section)							
NMP-832	-	62	26	12	-	-	
907	-	34	44	22	-	-	caliche
908	-	73	16	11	-	-	
916	-	61	31	8	-	-	caliche
917	-	62	31	7	-	-	
919	-	63	31	6	-	-	
920	-	55	22	6	17	-	barite
923	6	54	23	4	19	-	
924	2	61	29	10	-	-	chlorite

Locations of miscellaneous Kansan samples:
832 - NW¼ sec. 2, T. 20 N., R. 31 E., Harding Co.
907,908 - NW¼ sec. 27, T. 20 N., R. 24 E., Mora Co.
916,917 - SW¼SW¼ sec. 16, T. 11 N., R. 35 E., Quay Co.
919 - NW¼ sec. 32, T. 14 N., R. 32 E., Harding Co.
920 - SE¼ sec. 33, T. 14 N., R. 32 E., Harding Co.
923,924 - NE¼NE¼ sec. 2, T. 12 N., R. 31 E., Quay Co.

QUATERNARY - Wisconsinan - Holocene

Sample No.	Feet below top of exposure	Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks
McCARTY RANCH EAST SECTION: NW¼SE¼ sec. 20, T. 16 N., R. 34 E., Quay Co.							
NMP-343	14	39	51	10	-	-	pre-Wisconsinan
344	12	62	29	9	-	-	
345	10	62	29	9	-	-	Fauna 54
346	8	55	35	10	-	-	
347	3	28	58	13	-	-	loose sand
McCARTY RANCH SOUTHWEST SECTION: NE¼NW¼ sec. 36, T. 16 N., R. 32 E., Harding Co.							
NMP-348	-	71	24	5	-	-	lateral
349	-	51	37	12	-	-	facies samples
350	-	46	46	7	-	-	
351	-	49	31	10	-	-	Fauna 55(R)
352	-	50	38	17	-	-	
353	-	77	16	6	-	-	
354	-	69	24	7	-	-	
CHICOSA LAKE SAMPLES: cen. sec. 11, T. 21 N., R. 26 E., Harding Co.							
NMP-357	-	25	63	12	-	-	organic muck
358	-	26	64	10	-	-	Fauna 57
572	-	47	39	14	-	-	lee dune
GALLEGOS NORTH SECTION: NW¼ sec. 13, T. 16 N., R. 30 E., Harding Co.							
NMP-549	20	77	14	9	-	-	
550	15	83	9	8	-	-	Fauna 81(R)
551	10	66	20	14	-	-	
552	5	65	21	14	-	-	
553	8	12	88	-	-	-	Triassic
TEQUESQUITE CREEK SECTION: SE¼SW¼ sec. 4, T. 18 N., R. 30 E., Harding Co.							
NMP-566	14	65	20	15	-	-	1 ft above Triassic
567	13	70	17	13	-	-	Fauna 83TA(R)
568	11	71	16	13	-	-	

Sample No.	Feet below top of exposure	Montmorillonite	Illite	Kaolinite plus chlorite	Attapulgite	Sepiolite	Remarks
QUATERNARY DEPOSITS - Nebraskan							
569	8	86	7	7	-	-	
570	4	58	27	15	-	-	
571	6	60	26	14	-	-	Fauna 83TB
MIERA SECTION: SW¼ sec. 32, T. 22 N., R. 32 E., Union Co.							
NMP-610	25	40	25	34	-	-	sand & silt
611	20	62	17	21	-	-	Fauna 86(R)
612	15	73	12	15	-	-	
613	10	74	12	14	-	-	
614	5	35	38	27	-	-	
SEDAN SOUTH SECTION: SW¼SE¼ sec. 28, T. 21 N., R. 36 E., Union Co.							
NMP-841	10	77	11	12	-	-	Fauna 112B
842	7	56	32	12	-	-	black silt,
843	4	57	32	11	-	-	main terrace
840	-	51	28	21	-	-	Fauna 112A
YATES SOUTHEAST TERRACES: SE¼ sec. 8, T. 21 N., R. 29 E., Harding Co.							
NMP-866	low	50	39	11	-	-	Fauna 114A
867	main	77	18	5	-	-	Fauna 114B
868	high	40	48	12	-	-	pre-Wisconsinan
NOVICE ARROYO TERRACES: SW¼NE¼ sec. 10, T. 15 N., R. 36 E., Quay Co.							
NMP-909	low	35	51	14	-	-	Fauna 116
910	main	63	30	7	-	-	
911	-	72	14	3	11	-	
912	upper	82	7	2	9	-	
913	-	66	26	8	-	-	
MISCELLANEOUS WISCONSINAN AND HOLOCENE SAMPLES (locations below)							
NMP-323	-	38	53	9	-	-	Fauna 49
330	-	52	38	10	-	-	Fauna 50
341	4	47	40	13	-	-	Fauna 53
342	1	54	33	13	-	-	pond deposit
362	2	48	43	9	-	-	Fauna 58
501	15	51	41	8	-	-	chlorite
502	8	43	49	8	-	-	Fauna 78
503	4	32	58	10	-	-	chlorite
512	-	45	34	21	-	-	Fauna 79
513	-	53	40	7	-	-	Fauna 80
554	10	75	16	9	-	-	Fauna 82
559	4	28	45	27	-	-	Fauna 83
560	8	28	58	14	-	-	chlorite
594	10	53	25	22	-	-	Fauna 84A,B
615	15	73	21	6	-	-	Fauna 87
628	10	46	26	28	-	-	Fauna 89
629	2	40	28	32	-	-	
636	15	48	32	20	-	-	Fauna 90
637	4	63	26	11	-	-	Fauna 91
767	6	48	34	18	-	-	charcoal
638	5	81	11	8	-	-	Fauna 92
759	4	10	64	26	-	-	Fauna 100
760	8	12	72	16	-	-	
761	3	25	40	35	-	-	
762	5	29	42	29	-	-	Fauna 101
763	10	48	33	19	-	-	
764	6	27	52	21	-	-	Fauna 102
765	10	26	53	21	-	-	
766	8	48	33	19	-	-	Fauna 103
770	4	26	64	10	-	-	chlorite
771	8	29	63	8	-	-	Fauna 104
772	2	25	46	29	-	-	conglom. matrix
773	2	26	64	10	-	-	pediment veneer
774	3	14	70	16	-	-	Fauna 105
775	2	6	85	9	-	-	chlorite
776	5	27	65	8	-	-	Fauna 106
777	1	22	38	40	-	-	point bar
778	3	28	54	18	-	-	Fauna 107
829	3	19	33	48	-	-	Fauna 109
830	5	83	8	9	-	-	Fauna 110
831	10	64	28	9	-	-	Fauna 111
865	1	74	19	7	-	-	Fauna 113
906	-	24	53	23	-	-	Fauna 115
914	4	16	66	18	-	-	Fauna 117
915	7	38	51	11	-	-	Fauna 118
921	10	30	55	15	-	-	Fauna 119
922	4	51	39	10	-	-	

Locations of miscellaneous Wisconsinan and Holocene samples:
323 - SW¼ sec. 12, T. 12 N., R. 32 E., Quay Co.
330 - NE¼ sec. 15, T. 14 N., R. 34 E., Quay Co.
341,342 - NE¼NW¼ sec. 31, T. 15 N., R. 35 E., Quay Co.
362 - NW¼NW¼ sec. 4, T. 17 N., R. 33 E., Harding Co.
501,502,503 - NW¼SW¼ sec. 23, T. 10 N., R. 25 E., Guadalupe Co.
512 - SE¼NW¼ sec. 2, T. 12 N., R. 28 E., San Miguel Co.
513 - SE¼SW¼ sec. 19, T. 13 N., R. 26 E., San Miguel Co.
554 - NE cor. sec. 28, T. 17 N., R. 30 E., Harding Co.
559,560 - W½SE¼ sec. 19, T. 18 N., R. 27 E., San Miguel Co.
594 - SE¼SW¼ sec. 16, T. 23 N., R. 29 E., Union Co.
615 - SE¼NE¼ sec. 3, T. 20 N., R. 31 E., Harding Co.
628,629 - SE¼NE¼ sec. 36, T. 32 N., R. 33 E., Union Co.
636 - W½SE¼ sec. 4, T. 29 N., R. 34 E., Union Co.
637,767 - NW¼SE¼ sec. 24, T. 31 N., R. 29 E., Union Co.
638 - SW¼SW¼ sec. 32, T. 32 N., R. 29 E., Union Co.
759,760 - NE¼ sec. 31, T. 31 N., R. 37 E., Union Co.
761,762,763 - cent. sec. 19, T. 31 N., R. 37 E., Union Co.
764,765 - SE¼NW¼ sec. 2, T. 31 N., R. 35 E., Union Co.
766 - NW¼ sec. 36, T. 32 N., R. 34 E., Union Co.
770,771 - NW¼ sec. 5, T. 12 N., R. 25 E., San Miguel Co.
772 - East of Conchas Dam, San Miguel Co.
773 - SW¼ sec. 24, T. 12 N., R. 23 E., San Miguel Co.
774 - SW¼ sec. 5, T. 14 N., R. 24 E., San Miguel Co.
775,776 - NW¼ sec. 8, T. 16 N., R. 24 E., San Miguel Co.
777 - SW¼ sec. 34, T. 17 N., R. 24 E., San Miguel Co.
778 - SE¼ sec. 36, T. 18 N., R. 26 E., San Miguel Co.
829 - E½ sec. 32, T. 22 N., R. 32 E., Union Co. (see Miera Section)
830 - SW¼SE¼ sec. 22, T. 21 N., R. 31 E., Harding Co.
831 - SE¼NE¼ sec. 24, T. 20 N., R. 30 E., Harding Co.
865 - NW¼SE¼ sec. 32, T. 22 N., R. 29 E., Harding Co.
906 - NW¼SE¼ sec. 35, T. 20 N., R. 24 E., Harding Co.
914 - NW¼SE¼ sec. 13, T. 12 N., R. 35 E., Quay Co.
915 - SW¼SW¼ sec. 32, T. 12 N., R. 37 E., Quay Co.

TABLE 3—LOCATION OF FAUNAS AND FLORAS DESCRIBED FROM NORTHEASTERN NEW MEXICO. There are four floras from the Ogallala Formation (F-51, F-52, F-88, and F-99), one snail fauna from the Ogallala Formation (F-52), and 48 faunas from Wisconsinan and Holocene deposits.

Fauna or Flora	Section or related NMP no.	Location
F-49(73)	NMP-323	SE¼ sec. 12, T. 12 N., R. 32 E., Quay Co.
F-50(73)	NMP-330	NE¼ sec. 15, T. 14 N., R. 34 E., Quay Co.
F-51(73)	Amistad South Sec.	NW¼SW¼ sec. 19, T. 19 N., R. 36 E., Union Co.
F-52(73-5)	Clayton S	SW¼SW¼ sec. 2, T. 24 N., R. 35 E., Union Co.
F-53(73)	NMP-341-2	NE¼NW¼ sec. 31, T. 15 N., R. 35 E., Quay Co.
F-54(73)	McCarty R.E	NW¼SE¼ sec. 20, T. 16 N., R. 34 E., Quay Co.
F-55(73-4)	McCarty R.SW	NE¼NW¼ sec. 36, T. 16 N., R. 32 E., Harding Co.
F-56(73)	-	NE¼SE¼ sec. 35, T. 16 N., R. 32 E., Harding Co.
F-57(73)	NMP-358	cent. sec. 11, T. 21 N., R. 26 E., Harding Co.
F-58(73)	NMP-362	NW¼NW¼ sec. 4, T. 17 N., R. 33 E., Harding Co.
F-59(73)	-	SE¼ sec. 33, T. 19 N., R. 32 E., Harding Co.
F-78A(74)	Newkirk	
F-78B(74)	Interchange	NW¼SW¼ sec. 23, T. 10 N., R. 25 E., Guadalupe Co.
F-79(74)	NMP-512	SE¼NW¼ sec. 2, T. 12 N., R. 28 E., San Miguel Co.
F-80(74)	NMP-513	SE¼SW¼ sec. 19, T. 13 N., R. 26 E., San Miguel Co.
F-81(74)	Gallegos N	NW¼ sec. 13, T. 16 N., R. 30 E., Harding Co. (R)
F-82(74)	NMP-554	NE cor. sec. 28, T. 17 N., R. 30 E., Harding Co.
F-83(74)	NMP-559	W½SE¼ sec. 19, T. 18 N., R. 27 E., San Miguel Co.
F-83TA(74)	Tesquesquite	
F-83TB(74)	Creek Sec.	SE¼NW¼ sec. 4, T. 16 N., R. 30 E., Harding Co. (R)
F-84A(74)	NMP-594	
F-84B(74)	-	SE¼SW¼ sec. 16, T. 23 N., R. 29 E., Union Co.
F-85(74)	Pinabetitos Creek	NW¼NW¼ sec. 3, T. 22 N., R. 34 E., Union Co.
F-86(74)	Miera	SW¼ sec. 32, T. 22 N., R. 32 E., Union Co.
F-87(74)	NMP-615	SE¼NE¼ sec. 3, T. 20 N., R. 31 E., Harding Co.
F-88(74)	Seneca NE	SE¼NE¼ sec. 15, T. 28 N., R. 36 E., Union Co.
F-89(74)	NMP-629	SE¼NE¼ sec. 36, T. 32 N., R. 33 E., Union Co. (R)
F-90(74)	NMP-636	W½SE¼ sec. 33, T. 29 N., R. 34 E., Union Co.
F-91(74)	NMP-637	NW¼SE¼ sec. 24, T. 31 N., R. 29 E., Union Co. (R)
F-92(74)	NMP-638	SW¼SW¼ sec. 32, T. 32 N., R. 29 E., Union Co.
F-99(74-5)	Guy SE	NW cor. S½ sec. 32, T. 30 N., R. 34 E., Union Co.
F-100(75)	NMP-759	NE¼ sec. 31, T. 31 N., R. 37 E., Union Co.
F-101(75)	Kenton W	cent. sec. 19, T. 31 N., R. 37 E., Union Co.
F-102(75)	Sloan Creek	SE¼NW¼ sec. 2, T. 31 N., R. 35 E., Union Co.
F-103(75)	NMP-766	NW¼ sec. 36, T. 32 N., R. 34 E., Union Co.
F-104(75)	Cuervo Creek	NW¼ sec. 5, T. 12 N., R. 25 E., San Miguel Co.
F-105(75)	Trementina Creek	SW¼ sec. 5, T. 14 N., R. 24 E., San Miguel Co. (R)
F-106(75)	Lagartija Creek	NW¼ sec. 8, T. 16 N., R. 24 E., San Miguel Co.
F-107(75)	La Cinta Creek	SE¼ sec. 36, T. 18 N., R. 26 E., San Miguel Co.
F-109(75)	Miera East	E½ sec. 32, T. 22 N., R. 32 E., Union Co.
F-110(75)	NMP-830	SW¼SE¼ sec. 22, T. 21 N., R. 31 E., Harding Co.
F-111(75)	S Bueyeros	SE¼NE¼ sec. 24, T. 20 N., R. 30 E., Harding Co. (R)
F-112A(75)	Sedan S	SW¼SE¼ sec. 28, T. 21 N., R. 36 E., Union Co.
F-112B(75)	NMP-841	as above
F-113(75)	Yates S	NW¼SE¼ sec. 32, T. 22 N., R. 29 E., Harding Co.
F-114A(75)	Yates SE	SE¼ sec. 8, T. 21 N., R. 29 E., Harding Co.
F-114B(75)	NMP-867	as above
F-115(75)	NMP-906	NW¼SE¼ sec. 35, T. 20 N., R. 24 E., Harding Co.
F-116(75)	Novice Arroyo	SW¼NE¼ sec. 10, T. 15 N., R. 36 E., Quay Co.
F-117(75)	Mona Arroyo	NW¼SE¼ sec. 13, T. 12 N., R. 35 E., Quay Co.
F-118(75)	San Jon Creek	SW¼SW¼ sec. 32, T. 12 N., R. 37 E., Quay Co.
F-119(75)	Logan NW	SE¼SE¼ sec. 26, T. 14 N., R. 32 E., Harding Co.

TABLE 4—RADIOCARBON DATES DETERMINED FROM NINE COLLECTIONS OF MOLLUSK SHELLS, ONE SAMPLE OF ORGANIC-RICH SILT, AND ONE SAMPLE OF CHARCOAL FROM NORTHEASTERN NEW MEXICO. Age determinations by Dennis D. Coleman in Illinois State Geological Survey laboratories. Locations shown in fig. 18.

Laboratory number	Date million years before present	Fauna no. or Sample no.	Material dated	Location
ISGS-343	7,825±90	F-81	mollusk shells	NW¼ sec. 13, T. 16 N., R. 30 E., Harding Co.
ISGS-344	27,500±1,300	F-86	unionid shell	SW¼ sec. 32, T. 22 N., R. 32 E., Union Co.
ISGS-346	21,180±560	F-55	mollusk shells	NE¼NW¼ sec. 36, T. 16 N., R. 32 E., Harding Co.
ISGS-347	8,860±230	NMP-568	organic silt	SE¼NW¼ sec. 4, T. 18 N., R. 30 E., Harding Co.
ISGS-369	990±75	F-91	clam shells	NW¼SE¼ sec. 24, T. 31 N., R. 29 E., Union Co.
ISGS-370	840±75	F-89	clam shells	SE¼NE¼ sec. 36, T. 32 N., R. 33 E., Union Co.
ISGS-372	1,650±75	F-105	clam shells	SW¼ sec. 5, T. 14 N., R. 24 E., San Miguel Co.
ISGS-373	2,960±80	F-111	mollusk shells	SE¼NE¼ sec. 24, T. 20 N., R. 30 E., Harding Co.
ISGS-389	1,690±100	NMP-767	charcoal	NW¼SE¼ sec. 24, T. 31 N., R. 29 E., Union Co.

TABLE 5—DESCRIBED STRATIGRAPHIC SECTIONS FROM NORTHEASTERN NEW MEXICO. Included are six sections of Ogallala Formation and eight sections of Pleistocene and Holocene deposits.

Ogallala Formation

Clayton Northeast section—roadcuts of NM-18, SE¼NE¼ sec. 6, T. 26 N., R. 36 E., Union County, New Mexico (1974, 1975)

Unit	Thickness (ft)
Pliocene or Pleistocene Series (total thickness)	21.0
4 Basalt, contains pockets of tan-brown silt and sand (NMP-617, 1 ft above base) and pockets of relatively loose carbonate (NMP-621, 2 ft above base); top of basalt forms level of local upland	10.0
Pliocene Series	
Ogallala Formation	
3 Sand and caliche, gray-tan, immediately below basalt (NMP-625); this unit pinches out to the north, and the underlying orange-red sand is in contact with base of basalt	1.0
2 Sand and silt, orange-red, grading downward to a reddish-brown; locally below unit 3 above, but to the north the exposure is in contact with base of basalt (NMP-618, 2 inches below basalt; NMP-619, 1 ft below basalt; NMP-733, 1 ft below basalt where unit 3 is present; NMP-620, 2 ft below basalt; NMP-734, 2½ ft below base of basalt and top of red-orange sand; NMP-622, 3 ft below basalt and top of red-orange sand; NMP-735; 4 ft below basalt and top of red-orange sand)	4.0
1 Sand with some silt, calcareous, light-brown; massive to indistinct columnar structure in upper part; some areas of caliche cement and some soft caliche nodules (NMP-736, top; NMP-623, 1 ft below top; NMP-624, base of exposure)	6.0

Clayton South section—in creek banks east of NM-18 (section is progressively offset 350 yds along arroyo sides); SW¼SW¼ sec. 2, T. 24 N., R. 35 E., Union County, New Mexico (1973, 1974, 1975)

Unit	Thickness (ft)
Pliocene Series (total thickness)	30.0
Ogallala Formation	
7 Pisolitic limestone, dense, hard caliche with travertine banding, at top (NMP-607); overlying dense, platy caliche (NMP-742, 2 ft below top); top at upland surface	3.0
6 Sand, medium to coarse, well-cemented, platy; grades downward to massive, caliche-cemented sand with nodular caliche (NMP-606, lower part; NMP-741, 100 yds to the west)	7.0
5 Sand, medium to coarse, well-cemented, indistinct bedding (NMP-605); forms ledge along valley side; laterally becomes caliche with sand	3.0
4 Sand, moderately to loosely cemented, gray to locally greenish-gray (NMP-740); locally contains areas of reddish-tan, calcareous, loosely cemented sand (NMP-739); gray predominates and is abundantly fossiliferous (NMP-604, 50 yds to east); fossil mollusks throughout (F-NM-52-73, 74, 75)	2.5
3 Sand, gray, massive to indistinct platy structure (NMP-603); laterally grades white to light gray, chalky, massive caliche (NMP-738, 100 yds west of NMP-603)	2.5
2 Sand, light-gray-tan to pinkish-tan, moderately cemented, massive, nodular (NMP-601); grades laterally to silt and fine sand, with some clay, greenish-gray, massive but with a "box-work" of caliche veinlets, some nodular caliche (NMP-602, 200 yds west of NMP-601)	4.0
1 Sand, calcareous, pinkish-tan, relatively loose; contains caliche nodules; massive (NMP-600, middle; NMP-737, base, 100 yds east of NMP-600)	8.0

Martinez East section—roadcuts of NM-120, center south line sec. 9, T. 21 N., R. 28 E., Harding County, New Mexico (1973, 1974, 1975)

Unit	Thickness (ft)
Pliocene Series (total thickness)	112.0
Ogallala Formation	
16 Pisolitic limestone (dense caliche), hard, sand grains (NMP-593)	3.0
15 Caliche, dense, brittle; some platy structure and travertine banding; contains sand grains (NMP-592)	12.0
14 Sand, calcareous, reddish-tan, loosely cemented, massive; caliche nodules (NMP-591); lateral to upper part of basalt	8.0
13 Sand, calcareous, gray-tan (NMP-590); contains lenses of caliche cemented sand	2.0
12 Basalt, black, jointed (NMP-589, base)	8.0

Unit		Thickness (ft)
11	Sand, orange-red, loose, massive (NMP-588)	1.5
10	Sand, reddish-tan, loose, massive (NMP-587)	2.5
9	Sand, fine to medium, reddish-tan, loosely cemented (NMP-586)	2.0
8	Sand, soft caliche cement, tan to light-gray, massive with caliche nodules, locally platy (NMP-585)	2.0
7	Sand and silt, cream-tan to pinkish-tan, streaks and nodules of caliche (NMP-881, NMP-584, upper; NMP-880, middle; NMP-583, lower)	12.0
6	Sand, cemented, gray, tough, hard; pockets of pink-tan sand (NMP-879)	5.0
5	Sand, reddish-tan; contains lens of dense, gray caliche, brittle and lacking sand, 1 ft thick (NMP-878)	3.0
4	Clay, as a lens in sand, cream-gray, massive to platy, non-calcareous, soft (NMP-879)	2.0
3	Sand, alternating with sand and silt, and zones of densely cemented sand (NMP-876, top; NMP-875, upper; NMP-874, middle)	22.0
2	Sand, rusty tan in upper part (NMP-873), grading downward to yellow-tan, bedded sand with lenses of cemented sand (NMP-872), and downward to tan-gray to yellow-tan, well-cemented and bedded sand (NMP-871)	15.0
1	Sand, fine to medium, rusty tan to tan mottled with gray, massive; local streaks of light-brown silt and clay; generally loose and partly covered (NMP-870, upper; NMP-869, base)	12.0

Nara Visa North section—arroyo and roadcut exposures west of NM-18, in NW¼ sec. 3, T. 16 N., R. 36 E., Quay County, New Mexico (1974)

Unit		Thickness (ft)
	Pliocene Series (total thickness)	37.0
	Ogallala Formation	
3	Caliche, densely cemented, gray, grading downward to densely cemented sand, travertine banding but no pisolitic structure (NMP-538, top; NMP-539, 4 ft below top)	6.0
2	Caliche, moderately dense, gray, few small pebbles, mostly cemented sand (NMP-540, 2 ft below top)	6.0
1	Sand with a few small pebbles, pink-tan, moderately well cemented with $CaCO_3$ in upper part, grading downward into less cemented sand (NMP-541, 8 ft below top; NMP-542, 23 ft below top)	25.0

Pasamonte South section—SE¼ sec. 33, T. 23 N., R. 30 E., Union County, New Mexico (1975)

Unit		Thickness (ft)
	Pliocene Series (total thickness)	29.0
	Ogallala Formation	
5	Pisolitic limestone; dense caliche with travertine banding (NMP-807); section offset 0.4 mi to the south, 5 ft below pisolitic limestone not exposed	6.0
4	Caliche, sandy, dense, tough, banded; caps local spur, 5 ft below is mostly covered (NMP-801, top)	6.0
3	Sand and caliche, well-cemented, irregularly platy, cream-tan (NMP-802, top; NMP-803, lower)	9.0
2	Sand, pinkish-tan to reddish-tan, silt and clay with a few pebbles (NMP-804); downward to reddish-brown sand, silt, and clay, indistinctly blocky to massive (resembles B-horizon material), poorly exposed (NMP-805)	5.0
1	Sand, cream-tan; loosely cemented, poorly exposed (NMP-806); covered down slope	3.0

Snyder Ranch section—in roadcuts, SE¼SE¼ sec. 20, T. 25 N., R. 31 E., Union County, New Mexico (1974-1975)

Unit		Thickness (ft)
	Pliocene Series (total thickness)	41.0
	Ogallala Formation	
5	Dense caliche, travertine-banded, position of the pisolitic limestone but does not contain pisolites (NMP-597; NMP-785)	3.0
4	Sand, densely cemented, gray-tan, crenulate platy structure, some travertine banding (NMP-784, top; NMP-596, middle; NMP-783, lower)	5.0
3	Sand, gray-tan, well-cemented, nodular to massive, indistinct travertine banding (NMP-595, lower; NMP-782, base)	3.0
2	Sand, caliche cemented at top, gray-tan at top, pink-tan lower, covered in lower part (NMP-781, 4 ft below top)	26.0
1	Sand, poorly cemented to uncemented, gray to pink-tan; locally small area of opal cement; massive to indistinctly platy (a covered interval occurs between this unit and the overlapping exposure), (NMP-780, 4 ft above base; NMP-779, base)	4.0

Pleistocene and Holocene

Adberg Station section—in cuts of Chicago, Rock Island, and Pacific Railroad, SW¼ sec. 35, T. 12 N., R. 31 E., Quay County, New Mexico (1975)

Unit		Thickness (ft)
	Pleistocene Series (total thickness)	9.0
	Kansan Stage	
4	Sand, brown, leached, friable, granular (NMP-928); presently, spoil from the cut rests on this material that was the A horizon of the surface soil, and related to the thick B horizon below	1.5
3	Sand, silt, and clay, red-tan, leached, massive, sharp contact at base; B horizon of soil (NMP-927)	2.5
2	Caliche, platy, locally dense at the top, some banding in upper part, a few pebbles, upper surface irregular but sharp contact with unit above; thickness ranges from ⅓ ft to 1 ft, Cca horizon of soil (NMP-926)	1.0
1	Sand, pink-tan, massive, a few pebbles throughout; soft caliche cement in upper part (NMP-925, lower)	4.0

Gallegos North section—cut bank on west side of Ute Creek, north of NM-39, NW¼ sec. 13, T. 16 N., R. 30 E., Harding County, New Mexico (1974)

Unit		Thickness (ft)
	Pleistocene Series (total thickness)	26.2
	Wisconsinan Stage	
7	Sand, tan, loose; surface sand of terrace that extends across Pleistocene deposits of the section and overlies adjacent truncated Triassic rocks	3.0
6	Sand, fine to medium, and silt, blocky, bedded, gray-tan; irregularly unconformable below bed above, and upper unit of basin fill below terrace surface and below level of beveled Triassic rocks (NMP-552, 2 ft below top of unit)	6.0
5	Clay, silt, and sand, organic rich, dark-gray to black, lens sloping up and pinching out to north; contains some streaks of tan sand; some fossil mollusks (NMP-551)	2.0
4	Sand, and some silt with a small amount of clay, loose, bedded, gray; contains fossil mollusks (F-74-81) (NMP-550); radiocarbon date on shells: 7,825 ± 99 (ISGS-343) B.P.	5.0
3	Silt, clay, and sand, organic-rich, dark-gray to black; a lens pinching out to south	0.2
2	Silt, clay, and sand interbedded, tan-brown; clayey beds with blocky structure, bedded (NMP-549); extends down to level of creek channel in lower part of basin fill	10.0
1	Triassic rocks below and marginal to the basin-fill deposits (NMP-553 adjacent to upper part of Pleistocene basin fill)	—

Kenton West section—cut bank of Cimarron River, center sec. 19, T. 31 N., R. 37 E., Union County, New Mexico (1975)

Unit		Thickness (ft)
	Holocene Series (total thickness)	12.0
5	Sand and silt, with few small pebbles, bedded, tan, friable (NMP-761, base)	2.5
4	Silt with some sand and a few small pebbles, black to dark-gray-brown, columnar jointing, checked surface; fossil mollusks in lower part (NMP-762, base)	2.0
3	Sandy silt, gray-tan, indistinctly bedded	1.0
2	Silt with some sand and clay, a few small pebbles, columnar jointing, black to dark-gray-brown, checked surface; fossil mollusks throughout (F-101-75)	2.0
1	Sand and gravel, coarse gravels in lenticular masses; cobbles of Triassic, Cretaceous, and Jurassic rocks as well as crystalline rocks (NMP-763, middle)	4.5

Logan Northeast section—cuts of Chicago, Rock Island, and Pacific Railroad, NE¼SE¼ sec. 36, T. 14 N., R. 33 E., Quay County, New Mexico (1973)

Unit		Thickness (ft)
	Pleistocene Series (total thickness)	17.2
	Wisconsinan Stage	
6	Sand with a few pebbles, loose, tan	4.0
	Illinoisan and/or Kansan Stage	
5	Sand with some clay and silt, and a few pebbles, leached, brown, compact; A horizon of Sangamon and/or Yarmouth soil (NMP-324); overlying B_t horizon in sand, pinkish-tan, containing a few pebbles, massive, not as compact as upper part (NMP-325)	3.0
4	Silt, sand, and clay, brick-red to red-brown, leached, compact, massive; sharp truncation contact at top; B_t horizon of Yarmouth soil, overlain by subsequent soil above; grades downward to pinkish-tan sand and silt; sharp crenulate contact at base with caliche zone below (NMP-326, top; NMP-327, base)	2.2
3	Caliche, massive, soft; pink-tan to red-tan sand, cemented, with platelets of caliche and caliche veins; Cca horizon of solum above (NMP-328, top; NMP-329, lower)	3.0
2	Gravel and sand, pebbles and cobbles of crystalline rocks and of Ogallala-type caliche; base on Triassic sandstone	5.0
1	Triassic sandstone, brick-red mottled with gray-green	—

Miera section—in cut bank of Tramperos Creek, SW¼ sec. 32, T. 22 N., R. 32 E., Union County, New Mexico (1974)

Unit		Thickness (ft)
	Pleistocene Series (total thickness)	29.0
	Wisconsinan Stage	
6	Sand, tan to light-brown, bedded, moderately loose, to top of terrace surface	4.0
5	Silt, clay, and sand, dark-gray-brown to dark-reddish-brown, massive to blocky (NMP-614)	4.0
4	Silt, clay, and fine sand, massive to small blocky structure, gray-brown to tan-brown (NMP-613)	5.0
3	Sand (fine) and silt, bedded, dark-gray (NMP-612); abundant fauna of fossil mollusks in this unit, continuing downward to base of section (F-86-74); radiocarbon date, 27,500 ± 1,300 (ISGS-344) B.P.	6.0
2	Silt and fine sand, bedded, gray	1.0
1	Sand and silt, gray, compact, massive to platy (NMP-611, upper; NMP-610, 3 ft above base); most abundant fossils upper part; base at level of channel Tramperos Creek (8 ft of loose sand in floodplain terrace of Tramperos Creek unconformably adjacent to this unit)	9.0

Mitchell West section—roadcuts of NM-120, NW¼SW¼ sec. 19, T. 21 N., R. 28 E., Harding County, New Mexico (1973, 1974, 1975)

Unit		Thickness (ft)
	Pleistocene Series (total thickness)	25.0
	Wisconsinan Stage	
9	Sand (fine) and silt, massive, friable, calcareous, gray-tan, (NMP-582, middle); at top, surface solum (NMP-730, ½ ft below top of A horizon)	4.5
8	A horizon; fine sand and silt, light-gray-brown, some filaments of $CaCO_3$, indistinct columnar structure (NMP-581)	1.0
7	Sand (fine) and silt, massive, calcareous, tan (NMP-580)	4.0
	Illinoisan Stage	
6	A horizon (Sangamon soil); sand with some silt, granular to indistinct blocky, friable, brown, leached matrix with some secondary carbonate (NMP-579)	2.0
5	B horizon; sand, silt and clay, reddish-brown, massive, leached but interlaced with "box-work" of caliche (NMP-578)	1.5
4	Sand (fine), silt and clay; upper part (Cca horizon) contains abundant caliche nodules up to 3 inches in diameter, light-reddish-brown (NMP-577); grades downward to light-tan sand and silt, calcareous, massive, friable (NMP-576)	5.0
	Kansan Stage and/or Illinoisan Stage	
3	A or B_1 horizon of soil; silt and fine sand, light-brown, granular to indistinct platy structure, some vesicles with indistinct clay skins; mottled with secondary $CaCO_3$ (NMP-575)	1.5
2	B_2 horizon of soil; sand and silt, reddish-tan, massive, leached but mottled with secondary $CaCO_3$ (NMP-574)	1.5
1	Sand, gray, calcareous; caliche nodules in upper part (Cca horizon) (NMP-573)	4.0

Pinabetitos Creek section—roadcut and creek bank, SE¼NE¼ sec. 4, T. 22 N., R. 34 E., Union County, New Mexico (1974, 1975)

Unit		Thickness (ft)
	Pleistocene Series (total thickness)	11.0
	Wisconsinan Stage—lowest terrace	
6	Sand, loose, brownish-gray, with a few pebbles; A horizon of surface soil	1.0
5	Sand with some pebbles, loosely cemented; contains a few cobbles of Ogallala-type caliche, tan to cream-gray; Cca horizon of surface soil (NMP-827)	2.0
	Kansan (?) Stage—higher terrace	
4	Sand, clayey, with a few pebbles, red-brown, blocky; caliche along joints and in a few nodules but leached elsewhere; B horizon of soil (NMP-826)	2.0
3	Sand, loosely cemented, gray to gray-tan, with a few pebbles and scattered cobbles (NMP-824); 50 yds to south, densely cemented, gray (NMP-825); Cca horizon with the B horizon above	2.0
2	Sand and gravel, tan; cobbles up to 4 inches in diameter (NMP-823)	4.0
1	Cretaceous bedrock	—

Tequesquite Creek section—cut bank of creek, SE¼NW¼ sec. 4, T. 18 N., R. 30 E., Harding County, New Mexico (1974)

Unit		Thickness (ft)
	Holocene Series—lowest terrace (total thickness)	9.0
6	Sand, silt and some clay, with a few zones of gravel; sand in lower part, silt and sand in upper part (NMP-571; F-83B-74, 5 ft above base); this is the floodplain terrace unconformable against the truncated higher terrace; from level of creek channel	9.0
	Pleistocene Series—a higher terrace (total thickness)	16.0
	Wisconsinan Stage	
5	Silt and sand; grading downward to sand and silt with some clay; tan, compact, bedded; surface soil in top (NMP-570, 3 ft below top)	6.0
4	Sand, silt, and clay, tan-brown, bedded, compact (NMP-569); laterally thickens and replaces the 2 underlying beds	4.0
3	Clay, silt, sand, and organic matter, black to dark-gray, blocky to massive (NMP-568); radiocarbon date on organic content, 8,860 ± 230 (ISGS-347) B.P.	1.5
2	Silt, clay, and sand, compact, blocky, bedded, tan (NMP-567); fossil mollusks in upper part and in overlying bed (F-83A-74)	2.0
1	Sand, clayey, massive, gray-green (NMP-566), contains cobbles; on Triassic rocks at level of creek channel	2.5

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