Clay Minerals in East-Central New Mexico

By H.D. Glass
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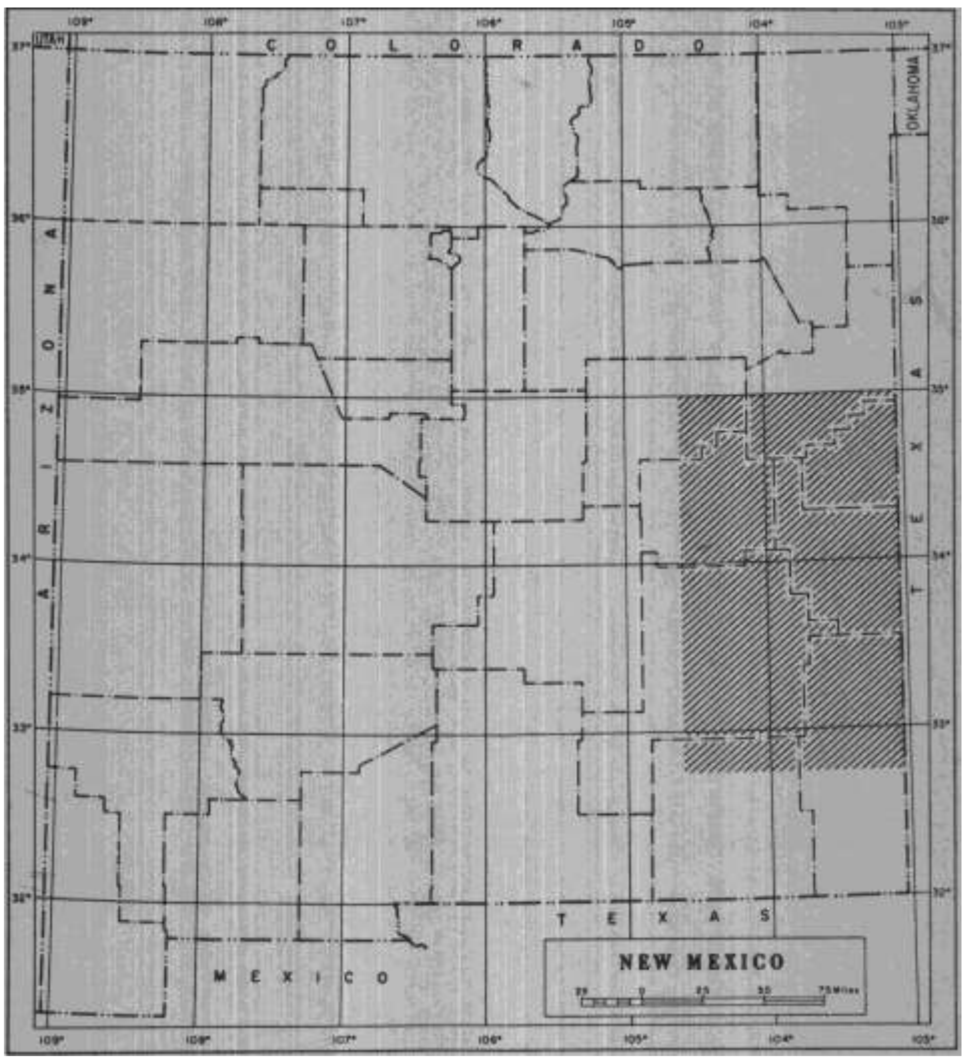

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CONTENTS

Figures

ABSTRACT

Samples of Pleistocene deposits from east-central New Mexico were analyzed for clay mineral composition, and representative samples of Tertiary, Triassic, and Permian rocks were analyzed for evaluation of sediment sources. Throughout the region mont morillonite, illite, and kaolinite were found to be most widespread and abundant, and are shown to be detrital minerals from identifiable sources. Sepiolite was present only in the pond and lake deposits of the High Plains area. Attapulgite occurs in the Ogallala Formation and in middle to early Pleistocene soil profiles on alluvial deposits. Corrensite was present in three localities: a Triassic sandstone, late Wisconsinan sediment fills in basins developed in Permian rocks, and Holocene terrace deposits of the Pecos River valley.

INTRODUCTION

During the summers of 1971 and 1972, Frye and Leonard spent several weeks in the field in east-central New Mexico, under auspices of the New Mexico State Bureau of Mines and Mineral Resources, investigating Pliocene and Pleistocene deposits. As part of this project, 129 samples were collected for clay mineral analysis. Geographic distribution of the sample localities is shown in fig. 1. Most of these samples were collected from late Pleistocene deposits, many of which were from the fillings of short-lived ponds and lakes of Woodfordian age (Wisconsinan), but other samples came from earlier Pleistocene deposits, from the widespread Ogallala Formation (Pliocene), and from the older bedrock of Triassic and Permian age. We present here the results of X-ray analyses of these samples as a reconnaissance of the clay mineral compositions of the region.

East-central New Mexico includes the western part of the High Plains. The High Plains extend from South Dakota southward across Nebraska, Kansas, Oklahoma, Texas, and New Mexico, to the Pecos valley of Texas. The part of the High Plains that includes west-central Texas and east-central New Mexico, stands as an Ogallala-capped plateau, generally called the Llano Estacado, above the erosional plains to the east, to the north along the broad valley of the Canadian River, and to the west along the Pecos River valley, bounded by prominent, sharp, high escarpments. On the south the High Plains merge with a portion of the Edwards Plateau.

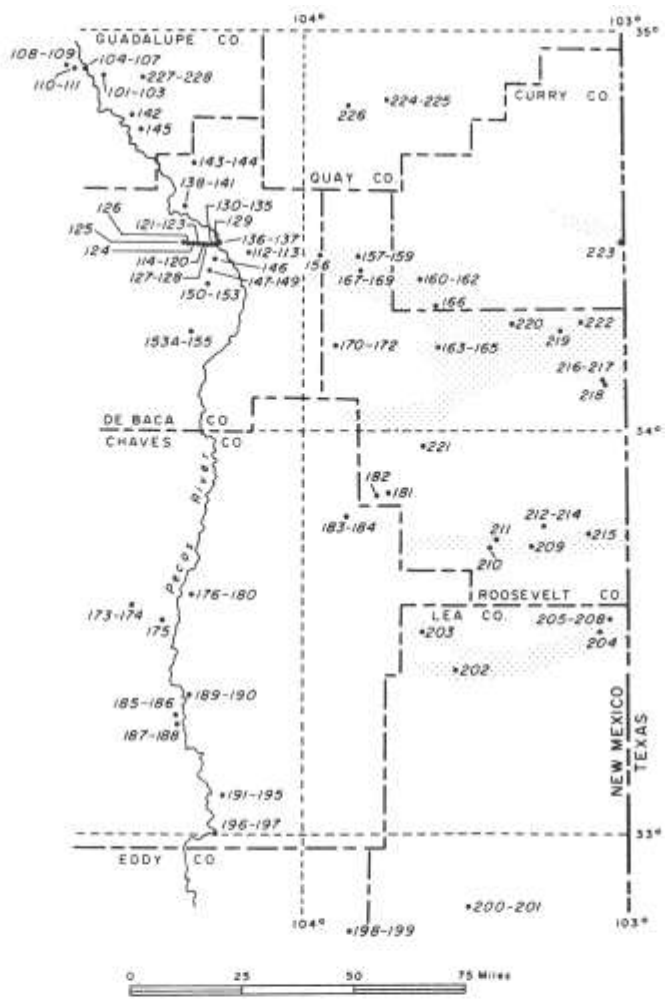

Figure 1 – Map of east-central New Mexico showing location of samples studied. Stippled areas show location of the abandoned early Pleistocene Portales valley, and comparable minor valleys.

The study area discussed here extends from central Lea County, and the northern part of Eddy County, northward to the north line of Curry County, and southern Guadalupe County, and westward from the Texas state line to the western side of Pecos River valley through De Baca and Chaves counties. The eastern part of this area is within the High Plains but the western part lies in the broad belt that comprises the valley of the Pecos River.

During late Tertiary time, the entire region was blanketed by alluvial deposits. These sediments were derived from the mountains to the west and, to a lesser degree, from the local bedrock. These deposits are classed as the Ogallala Formation of late Miocene and Pliocene age and have been described from the southern Great Plains region (Johnson, 1901; Darton, 1905; Baker, 1915; Frye and Leonard, 1957a, 1959, i972; Frye, 1971).

During Pliocene time the region became progressively more arid (Frye and Leonard, 1957b) and, after deposition of the Ogallala Formation, a deeply developed pedocal soil formed on the surface of the deposits. By the beginning of the Pleistocene the region had been structurally uplifted, tilted, and warped.

Early Pleistocene drainage was established across the region in a general east-southeast direction. Because the early Pleistocene drainage was, at least in part, consequent on the irregular depositional surface of the Ogallala alluvial plain, the drainage net developed independently of the late Tertiary channel positions. A major valley system across this region included the headwaters area of the present Pecos River, but, in the vicinity of Ft. Sumner the river flowed E-SE across northern Roosevelt County and the southwest corner of Curry County. This now abandoned valley, called Portales valley, has been described by Baker (1915), Theis (1932), Reeves (1972), Thomas (1972), and others. Minor valleys trending in the same direction, and perhaps tributary to this major stream, existed both north and south of the Portales valley in New Mexico.

After Kansan, but prior to late Wisconsinan time, the drainage that occupied the present Pecos valley in southern New Mexico captured the drainage of the Portales valley in the vicinity of Ft. Sumner, and diverted it southward, approximately along the position of the present Pecos River. Throughout the Pleistocene, major valleys were progressively, though intermittently, deepened by erosion to their present positions. During episodes of alluviation fills were deposited in these valleys; these fills now occur as dissected terraces along through-flowing valleys, and blanket the floors of abandoned valleys.

Solution-subsidence and solution-collapse features

(Lee, 1925) occurred widely during the Wisconsinan. Although some collapse and subsidence features may significantly pre-date the Wisconsinan, the widely distributed features containing the deposits sampled are mostly this age or younger. The association of the major areas of subsidence with the Pecos valley (Fiedler and Nye, 1933) and the abandoned early Pleistocene valleys, and the lack of evidence of Ogallala deposition in collapse features, suggest a relationship between the erosional incision of the Pleistocene streams and modification of deep ground-water circulation, and the resultant collapse and subsidence features. As has been pointed out (Frye, 1950; Judson, 1950), many of the small High Plains depressions were produced by factors other than solution-subsidence.

The paleontology and stratigraphy of the late Cenozoic of the region will be described in a subsequent paper by Leonard and Frye Age identifications used in this report are based on radiocarbon dates, paleontology, physical stratigraphy, and physiographic relationships, supplemented by data on mineral compositions presented here. Radiocarbon dates and clay mineral analyses were made in the laboratories of the Illinois State Geological Survey.

CLAY MINERALS

Clay mineral compositions of Pleistocene sediments have been used for some years as indicators of sediment source in the Midwest. Also, certain specialized Pleistocene environments have led to in situ development of some clay mineral species; clay minerals are altered by weathering processes in soil profiles. One purpose of the present study was to examine these three areas of application in east-central New Mexico.

Calcareous samples were treated with dilute acetic acid for removal of calcite, washed until dispersal occurred, and slides of oriented aggregates of clay fractions less than two microns were prepared for ethylene glycol treatment and X-ray examination. Where necessary, samples were heated to 250°C for one hour.

Montmorillonite

Montmorillonite is characterized by its strong reflection at about 17 A with ethylene glycol treatment, which collapses to about 10 A when heated. Lower order reflections are usually not observed. Montmorillonite is the dominant clay mineral of the area and occurs in all stages from well-crystallized varieties showing fairly sharp diffraction peaks, to the broad, diffuse peaks caused by weathering or the effects of diagenesis.

The weathering of montmorillonite causes unique changes to the principal diffraction peak (Frye, Glass, Willman, 1968, p. 15). The most apparent effect is the progressive broadening and rounding of the 17 A peak, which commences in the CL-zone of the soil profile, and is reduced and rounded in the B2- to A-horizons of the solum appearing only as a broad swell on the curve (fig. 2, sample 150). This change in diffraction effect may be considered as a change from homogeneous swelling material to heterogeneous swelling material. The material is referred to here as weathered montmorillonite.

The changes in the diffraction peak of montmorillonite caused by weathering necessitates caution in both sample preparation and quantitative calculation of the amount of montmorillonite present. Any attempt at cation saturation of weathered materials with Ca^{++} or Mg^{++} results in

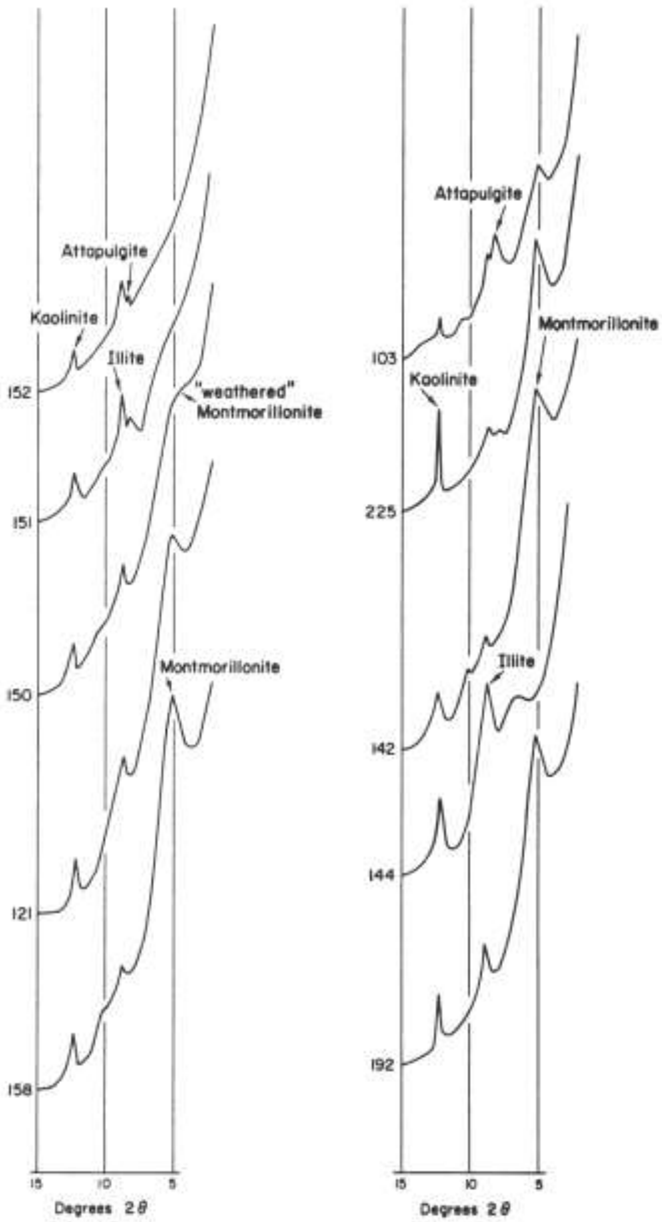

Figure 2 – Glycolated X-ray diffractometer traces illustrating clay minerals in bedrock units, and a soil profile on Kansan terrace deposits. Note progressive upward broadening of montmorillonite peak, and appearance of attapulgite in upper part of profile. *192, Permian from E of Hagerman; 144, Triassic shale, NW of Ft. Sumner; 142, clay pebble in Triassic shale, SE of Santa Rosa; 225, Ogallala Formation, at Ragland; 103, Ogallala Formation E of Santa Rosa, showing attapulgite. 158, Kansan deposits, northern Roosevelt Co.; 121, typical Kansan terrace deposit, W of Ft. Sumner; 150, base of B-horizon, 2" above top of caliche, soil profile in Kansan deposits, SW of Ft. Sumner; 151, top of B-horizon, 2½' above 150; 152, lower A-horizon, 3¼' above 150.*

enhancement of peak intensities, and masks the true diffraction effect of the material. Many treatments have resulted in the formation of clay minerals in the laboratory.

Calculation of the amount of montmorillonite present should be made only on the most unaltered material because any diminution of peak height or area results in an apparent decrease in montmorillonite and an apparent increase in other clay minerals — an artifact.

Examples of in situ weathering under well-drained oxidizing conditions are demonstrated in fig. 2 in material from the Kansan terraces of the Pecos valley (samples 121, 150, 151, 152) showing the changes in intensity and shape of the peak from essentially unaltered material upward through the B- and A-horizons.

Montmorillonite may also be altered when occurring in an environment which renders the montmorillonite unstable, as illustrated by the sepiolite-forming ponds of the High Plains area, as discussed below.

Sepiolite

Sepiolite is identified by its 12 A X-ray diffraction peak unaffected by ethylene glycol treatment or heating. Diffraction effects from sepiolite are shown in fig. 3 (samples 219, 218, 212, 217, 210). Its fibrous character, and the small size of the fibers are shown by the electron micrograph in fig. 4B.

Sepiolite has been reported from this region previously (Vanden Heuvel, 1966; Parry and Reeves, 1968a, 1968b; McLean, Allen, and Craig, 1972). The latter authors have shown that in western Texas sepiolite occurs only in outcropping Tahoka playa sediments of Wisconsinan age, or in eolian materials located on the lee side of the playa. No sepiolite was found in either soil caliche or the noncalcareous sola.

We have observed sepiolite only in the Wisconsinan ponds of the eastern Portales valley and High Plains, and in a lee dune associated with one of them — the identical conditions as reported from Texas. Sepiolite does not occur in the Wisconsinan ponds of the western Portales and Pecos valleys, nor in the Kansan or Woodfordian terraces of the Pecos valley region. In these areas the detrital assemblage of clay minerals generally occurs — montmorillonite-illitekaolinite.

Sepiolite has not been observed in the presence of well-crystalled montmorillonite. Where sepiolite occurs, the 17 A montmorillonite peak is either absent (samples 219, 218) or is, at best, a broad swell (samples 212, 217, and in fig. 3, 210). In these pond deposits, the least-altered montmorillonite (sample 220) occurs in samples that lack sepiolite. Although well-defined montmorillonite peaks are common in all detrital situations, they are exceedingly rare to absent in association with sepiolite, a mineral that forms diagenetically in magnesium-rich lake water. Montmorillonite is not stable in this environment (Hess, 1966), and the absence of well-defined diffraction peaks is associated with the loss of montmorillonite and the formation of sepiolite, as suggested by Parry and Reeves (1968a). Thus, the necessary silica is derived from the readily available montmorillonite; the presence of volcanic ash is not required.

The relationship between sepiolite and montmorillonite has been dramatically demonstrated by Parry and Reeves (1968b, fig. 17, p. 528) who show the X-ray dif-

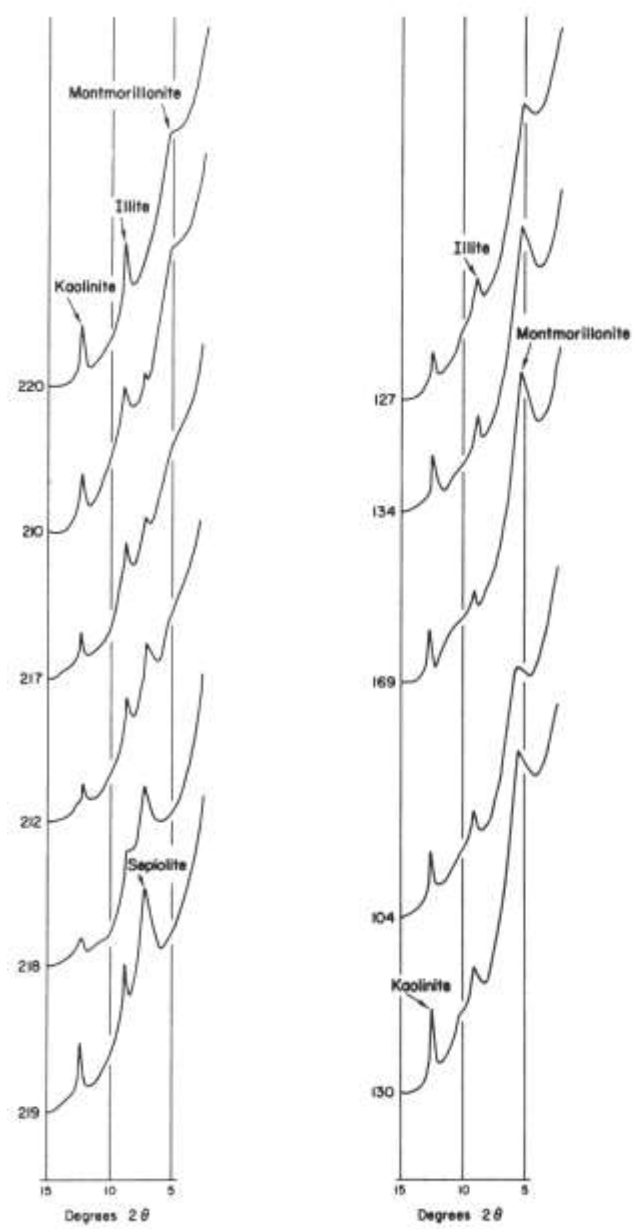

Figure 3 – Glycolated X-ray diffractometer traces from Wisconsinan terrace and pond deposits of Pecos valley region, and of Wisconsinan pond deposits in the High Plains region. Note the inverse relationship between sepiolite and altered montmorillonite. *130, Woodfordian terrace deposit, W of Ft. Sumner; 104, Woodfordian terrace deposit W of Santa Rosa; 169, pond deposit (dated 15,280 ± 210, ISGS-151), northern Roosevelt Co.; 134 (dated 17,180 ± 140, ISGS-91), 127 (dated 16,490 ± 120, ISGS-149), pond deposits, W of Ft. Sumner. 219, pond deposit NW of Portales; 218, lake deposit SE of Portales (dated 14,310 ± 230, ISGS-145); 212, pond deposit N-NE of Milnesand; 217, lake deposit SE of Portales; 210, pond deposit, SW Roosevelt Co.; 220, pond deposit, N Roosevelt Co.*

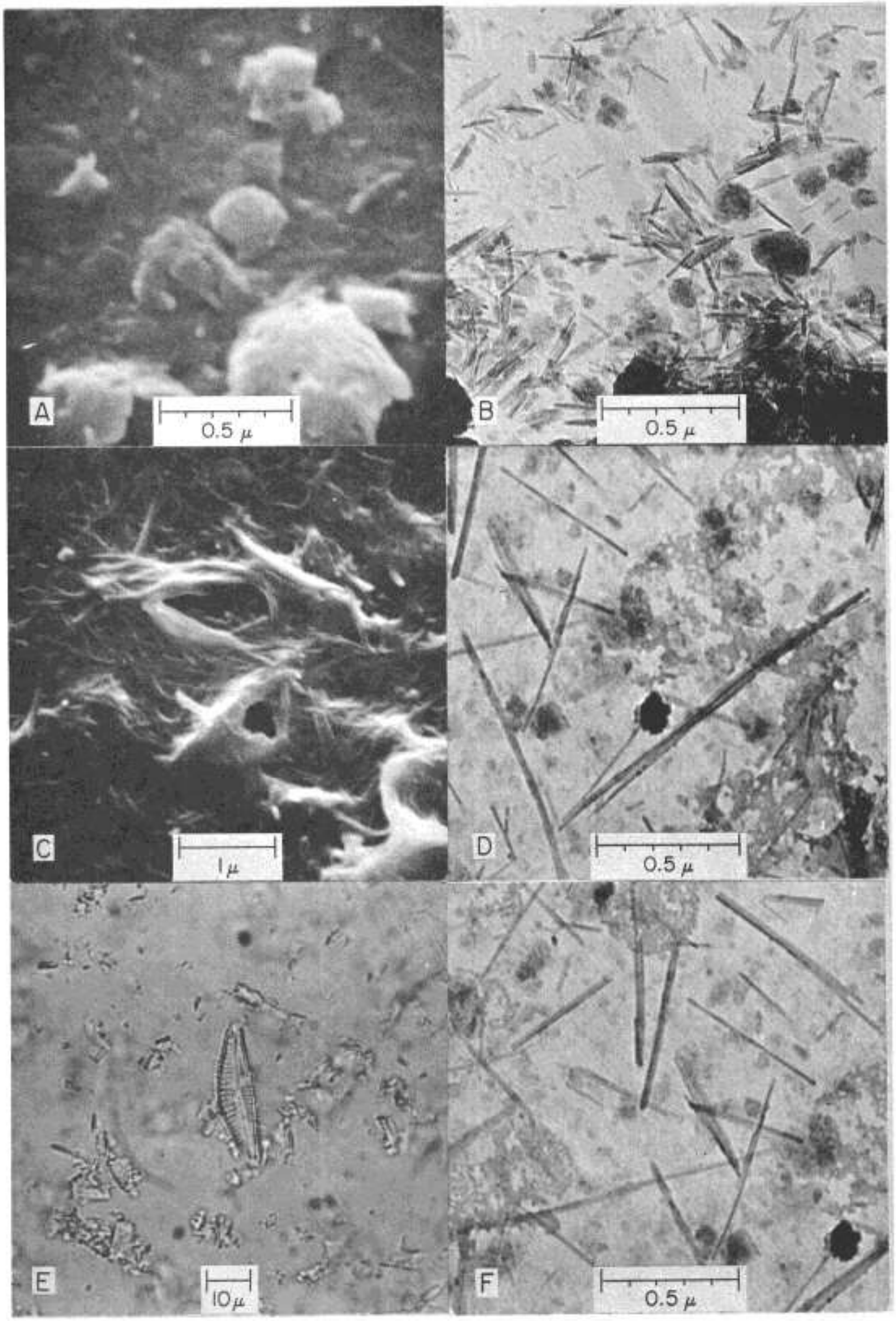

Figure 4 – Electron micrographs of sepiolite and attapulgite, and photomicrographs of diatoms and volcanic ash shards. *(Electron micrographs by Barbara Byrne in University of Illinois laboratory.)*

A) Sepiolite, with the scanning electron microscope, sample 218. Note poor resolution of fibrous structure.

B) Sepiolite, with transmission electron microscope, sample 218. Note fibrous structure and contrast with resolution in A.

C) Attapulgite, with the scanning electron microscope, sample 103.

D) Attapulgite, with transmission electron microscopé, sample 103. Note large size of fibers as compared with B.

E) Photomicrograph, sample 211, showing diatoms and volcanic ash shards.

F) Attapulgite, with transmission electron microscope, sample 103.

fraction traces for the Mound Lake section. The well-defined montmorillonite peak at -41 ft diminishes in intensity upwards, broadens and flattens at -25 ft, and by -20 ft only a broad smear results. At -15 ft sepiolite has appeared and increases in intensity upward. These observations demonstrate that as the lake became more alkaline, the montmorillonite was diagenetically altered to form sepiolite. The value of core samples showing a complete record of events, is apparent. As observed by McLean, Allen, and Craig (1972), dolomite seems to be associated with sepiolite (samples 212, 213, 214, 216, 217, and 218).

Attapulgite

Attapulgite is recognized by its characteristic 10.5 A reflection which does not expand with ethylene glycol treatment or collapse with heating (fig. 2, sample 103), and by its fibrous character (fig. 4C, D, F). The fibers of attapulgite are about 3 1/2 times larger than the fibers of sepiolite. Small amounts may be difficult to detect in the presence of illite (10 A peak); some attapulgite, therefore, may have been undetected.

Vanden Heuvel (1966) reported attapulgite in soil caliche near. Las Cruces, New Mexico, but not in the B- or A-horizons. However, more recently McLean, Allen, Craig (1972) state "We want to emphasize, however, that sepiolite and attapulgite occur in soil caliches, as well as in the sola (A- and B-horizons) of some calcareous soils of the region" (western Texas).

We have observed significant amounts of attapulgite in the Ogallala Formation from widely separated localities (samples 103, 200, 201). Presumably the mineral has widespread distribution within the Ogallala of the High Plains. Opal is often found associated with attapulgite (samples 200 and 201), both as a cement and as discrete irregular shaped masses within the sand.

On the other hand, small amounts of attapulgite have been identified in the soil profiles of Kansan terrace deposits of the Portales valley and the lower Pecos valley. It is present not only in the soil caliche, but in the B- or A-horizons as well (samples 151, 152, 163, 164, 165, 170, 171, 172, 188, and 194). Attapulgite has not been observed in any Wisconsinan deposits. Representative X-ray diffraction traces are shown in fig. 2 (samples 151 and 152).

The distribution of the two fibrous clay minerals sepiolite and attapulgite (fig. 4) is restricted to distinct environments; sepiolite having formed only in alkaline Woodfordian ponds of the eastern Portales valley and High Plains, and attapulgite occurring only in the Ogallala Formation and in soils of Kansan terrace deposits.

Corrensite

The clay mineral corrensite (Lippmann, 1954) has been reported from the area (Grim, Droste, and Bradley, 1960) in clay partings in the potash ore beds of the Salado Formation (Permian) at Carlsbad, New Mexico.

Corrensite can be readily recognized by its integral succession of diffraction peaks (fig. 5). Regular instratified clay minerals show diffraction peaks at spacings equal to the sum of the individual components. Corrensite may be considered as being formed by the segregation of abundant magnesium interlayers and represents the equilibrium relationship between montmorillonite and a mildly acid Mg^{++}- rich environment.

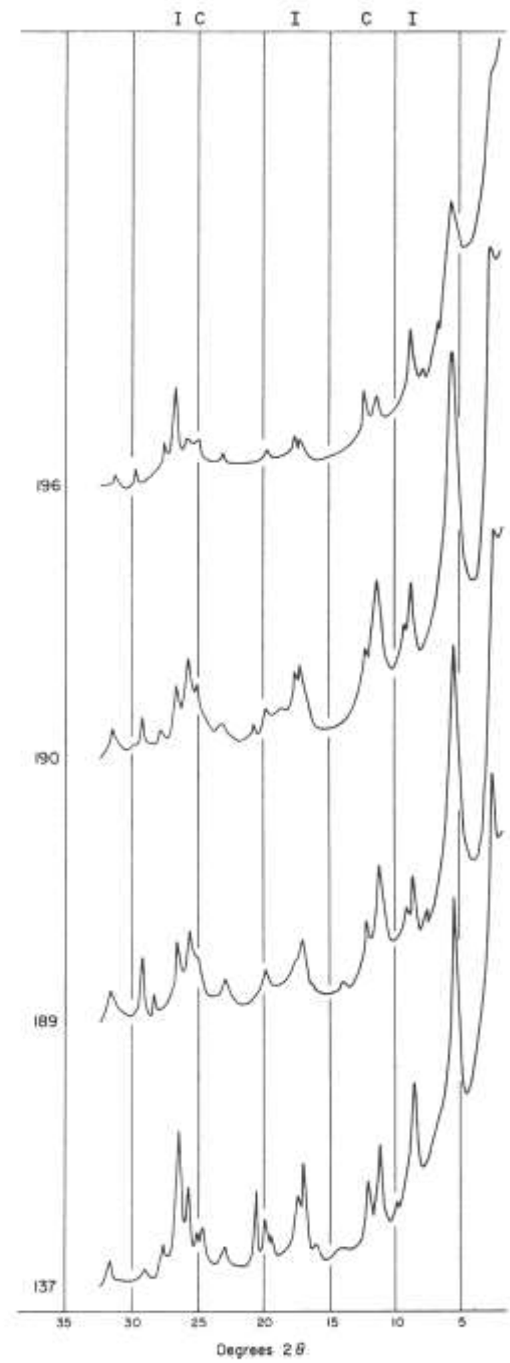

Figure 5 – Glycolated X-ray diffractometer traces of corrensite. The positions of accessory illite and chlorite diffraction features are marked, respectively, I and C. Note decreasing degree of crystallinity with decreasing geologic age. *137, Triassic sandstone at W edge of Ft. Sumner; 189 and 190, late Wisconsinan or Holocene pond deposit in Bottomless Lakes State Park, Chaves Co.; 196, Holocene terrace deposit (6" below shells dated 5,685 ± 90, ISGS-144), southern Chaves Co.*

The nature of the parent material has been well stated (Grim, Droste, and Bradley, 1960): "It seems highly unlikely that so nearly monomineralic detrital chlorite could ever have been introduced into the evaporite environment, to serve as parent for these specimens, but intermittent influxes of montmorillonite minerals... are easily conceived. Such sedimented solid would presumably then be constrained to come to heterogeneous equilibrium with the highly saline basin solution." As chlorite is rare or absent in the source materials and montmorillonite is common, the above statement seems reasonable.

Diffraction peaks for air-dried material show 29 A spacings (14 A "chlorite" plus 15 A montmorillonite). Treatment with ethylene glycol results in a 31 A spacing (14A "chlorite" plus 17 A montmorillonite). Heating to 250°C for one hour results in a 24 A spacing (14 A "chlorite" plus 10 A collapsed montmorillonite).

We have observed corrensite in strikingly different materials: a Triassic sandstone (sample 137), in the late Pleistocene, or younger, basin fill of a Permian solution-collapse area (samples 189 and 190), and in Holocene terrace deposits of the lower Pecos valley (sample 196).

The Holocene example of corrensite (sample 196, fig. 5) may be considered as poorly crystallized, and is characterized only by a prominent second order reflection at 15.5 A. The first order reflection at 31 A is not resolved, and all other orders are very weak or absent.

This type of corrensite is more common in sediments than hitherto reported, and may have been misidentified as a random interstratification type of mixed-layer clay mineral.

In these samples, montmorillonite is never associated with corrensite, but small amounts of detrital illite and kaolinite are present. The absence of montmorillonite, and the wide range of occurrence of corrensite imply that the mineral formed authigenically under those conditions necessary for its formation from montmorillonite. If the mineral were detrital, mixtures of corrensite and montmorillonite should be expected.

Corrensite has also been found in the insoluble residues of some Mississippian limestones in Illinois (Fraser, Harvey, and Baxter, 1973) and has been reported from the Mississippian carbonates of Colorado (Bradley and Weaver, 1956). Its geologic range of occurrence was reviewed by Flemal (1970), who does not list any occurrences in the Pleistocene or Holocene.

Illite

Illite is identified by its characteristic 10 A, 5 A, and 3.3 A reflections which are unaffected by ethylene glycol or heat treatments. It is the "mica" of some authors. Considered detrital in origin, it occurs in various amounts in all samples.

Kaolinite

Kaolinite is indicated by 7.2 A and 3.6 A reflections unaffected by ethylene glycol or mild heating. Kaolinite is a minor constituent in all samples, and is considered detrital.

However, well-crystallized kaolinite in some Wisconsinan and Kansan terrace deposits (samples 106, 130, and 187) is thought to be authigenic in origin (sample 130, fig. 3). Authigenic kaolinite has not been found in the pond deposits of this area.

DEPOSITS

Pre-Pleistocene

Although the majority of the samples analyzed are from Pleistocene sediments, 15 samples of Ogallala Formation (101, 102, 103, 108, 109, 125, 138, 139, 140, 145, 175, 200, 201, 224, and 225), 5 samples of Triassic rocks (136, 137, 142, 143, and 144) and 1 sample of Permian rocks (192) were also collected for reference. Their geographic distribution is shown in fig. 1.

The sample of typical Permian, red-brown silty shale, has a clay mineral content high in montmorillonite (72 percent), with 19 percent illite, and 9 percent kaolinite (fig. 2). Permian rocks appear to be a prime source of montmorillonite in the younger deposits, and a clay pebble (sample 142, fig. 2) in Triassic red siltstone, probably derived from the Permian, contains 82 percent montmorillonite and 13 percent illite.

In contrast to the Permian rocks, 3 samples of Triassic rocks (136, 143, 144) are exceptionally high in illite (70 percent to 77 percent), are moderately low in montmorillonite (14 percent to 22 percent), and quite low in kaolinite and chlorite (sample 144, fig. 2). Of particular interest is the occurrence of the regularly interstratified clay mineral corrensite in the interstices of a gray-green Triassic sandstone (sample 137, fig. 5). Corrensite was found in only 3 other samples (189, 190, and 196), all of which are late Wisconsinan or Holocene in age in the Pecos River valley of southern Chaves County. Triassic rocks appear to be an important source of illite for the younger sediments.

Of the 15 samples from the Ogallala Formation, 8 consisted of dense caliche of several types and were not used for clay mineral analysis. The only carbonate mineral detected by X-ray analyses of the dense caliche is calcite. Quartz was present in all caliche samples but feldspar was present in only part of the samples, and was not detected in the pisolitic limestone samples.

Seven samples of Ogallala were analyzed for clay minerals. Three of these samples (103, 200, and 201) contain significant amounts of attapulgite (sample 103, figs. 2, 4C, D, F) along with montmorillonite, illite, and kaolinite. Two of these samples (200 and 201) also contain opal, both as cement and as fragments in the sand. For Ogallala samples (138, 139, 224, and 225) lacking attapulgite and opal, percentage calculations show the high content of montmorillonite - more than 60 percent. In samples 224 and 225 (225 shown in fig. 2) well-crystallized montmorillonite is accompanied by well-crystallized authigenic kaolinite, and by some illite. These data indicate that the Ogallala Formation, as well as Permian rocks, are sources of montmorillonite for the younger deposits.

Early and Middle Pleistocene

From the Pecos River valley between Santa Rosa in Guadalupe County and the area of Ft. Sumner in De Baca County, and eastward through the Portales valley to the western edge of Curry County, 26 samples were collected from deposits assigned a Kansan age. In the Pecos valley these deposits occur on high terrace levels well above the terraces dated as Wisconsinan, but well below the adjacent Ogallala uplands. In every case Triassic rocks underlie the Pleistocene terrace deposits. Eastward from Ft. Sumner the deposits are on the erosionally dissected floor of the abandoned Portales valley. In this area the early Pleistocene Portales valley was cut well below the Ogallala Formation, that caps the uplands both to the north and south, into Triassic rocks. Here, these deposits are left in a terrace position above the present drainage because the formerly southeasterly flowing Alamosa Creek has been pirated by Taiban Creek, and the drainage now flows southwesterly and enters Pecos River south of Ft. Sumner. The major source area for these sediments was the drainage basin of Pecos River above Santa Rosa and Triassic and Ogallala rocks that formed the valley sides were a local source.

In this province the high terrace deposits are high in montmorillonite (about 70 percent), but contain about 25 percent illite and 5 percent kaolinite. This composition is present west of Santa Rosa (sample 110), west of Ft. Sumner (samples 114 and 121; sample 121 shown in fig. 2), and eastward into Portales valley (samples 113 and 157). This composition probably occurs in Kansan alluvial deposits eastward in Portales valley; these deposits were not sampled east of the Curry-Roosevelt county line.

Three samples (122, 148, 158; 158 shown in fig. 2) from this area contain 80 percent or more of exceptionally well-crystallized montmorillonite, probably the result of devitrification of volcanic ash. This explanation is supported by the presence of impure volcanic ash (samples 116, 117, 118, 156) within the adjacent deposits of this terrace level. The deposits containing volcanic ash are capped by dense caliche (samples 119, 120, 123), which contains K-feldspar and quartz in addition to calcite.

A soil profile developed in these terrace deposits was sampled at two localities southwest of Ft. Sumner (samples 147-149 and 150-153). At both places the soil profile is overlain only by young, calcareous, loose sand. The top of the dense caliche zone contains calcite, quartz, and some K-feldspar (sample 153). Sample 150, at the base of the B-horizon, shows broadening (weathering) of the montmorillonite diffraction peak, and samples 151 and 152, 2% and 3 1/2 ft above the top of the soil caliche zone and in the **A2 -** and B_1-horizons, show an almost total loss of montmorillonite, some illite, and small amounts of attapulgite (fig. 2). The parent material of the soil profiles (sample 149) one foot below the top of the dense, platy caliche, contains abundant soft, friable caliche and a clay mineral assemblage consisting of weathered montmorillonite, some illite, and kaolinite.

The Pecos valley of central and southern Chaves County, and southward, and the tributaries to this valley segment, had a distinctly different sediment source during early and middle Pleistocene time than did the Pecos valley above Ft. Sumner and the Portales valley. Prior to the piracy of Portales valley, this segment of the Pecos valley was separated from the portion above Ft: Sumner by the divide area north and south of the Chaves-De Baca county line. Therefore, the source for early and middle Pleistocene sediments in this region was in the Permian, Triassic, and Ogallala rocks of the vicinity, and in the region lying west of Pecos valley.

In this area, the Kansan deposits (samples 185, 187, 191, 193) are comparable to those in the northern province except that the percentage of montmorillonite is somewhat higher, ranging from about 75 to more than 80 percent; sample 194 contains a small amount of attapulgite. The soil caliche in this area (samples 186 and 195) resembles that farther north; sample 188 contains weathered montmorillonite and a small amount of attapulgite. A deposit judged to be of the same age occurs above Triassic rocks in the pediment pass east of Kenna (sample 181), above the terraces of Kenna Draw. Although the deposit is calcareous and contains a meager fauna of fossil snails, the clay minerals reflect extensive weathering and were probably derived from the adjacent Ogallala Formation.

In northern Eddy County, a sample of soil caliche (sample 198) resembles the caliche farther north; the B-horizon above (sample 199) shows intensely weathered montmorillonite, and resembles the samples from the B-horizons southwest of Ft. Sumner.

Wisconsinan and Holocene

The deposits of Wisconsinan and Holocene age in this region may be grouped into three generalized categories for purposes of discussion of clay mineral compositions. First are the alluvial deposits occurring as terraces along the Pecos River valley and along valleys tributary to Pecos River. Second are deposits that accumulated in basins within the valley of Pecos River, and valleys tributary to the Pecos River. This category includes basin deposits in the western part of Portales valley in western Roosevelt County and southwestern Curry County. In the third category are deposits that accumulated in basins and lakes related to the High Plains. This category includes basin areas in the floor of Portales valley in northeastern Roosevelt County and along smaller abandoned valley trends in southern Roosevelt and northern Lea counties (fig. 1).

Alluvial Terrace

Wisconsinan terrace deposits occur along many segments of the Pecos River valley, southward from Santa Rosa in Guadalupe County to the Chaves-Eddy county line. Above the floodplain and the flood-plain terrace, the most continuous terrace surface has been dated as within the

Woodfordian Substage of the Wisconsinan Stage by radiocarbon dates (17,180 ± 140, ISGS-91; and 16,490 ± 120, ISGS-149) in the area west of Ft. Sumner. In the same area an intermediate terrace, 20 ft below this one, but well above the flood-plain terrace, has been dated 13,820 ± 270, ISGS-150. In southern Chaves County, clam shells from the lower part of the flood-plain terrace have been dated 5,865 ± 90, ISGS-144. Along major tributaries to Pecos River, terraces in physiographic continuity with these surfaces extend many miles headward in their valleys and are, therefore, presumed to be of comparable ages. In the northern part of this valley segment the terrace deposits rest on Triassic rocks, whereas in the southern part (southern Chaves County) the terrace deposits rest on Permian rocks. The source of sediments for the terrace deposits along the major valley is the entire Pecos River basin above the sample point, but for the terraces of the tributary valleys the source may be quite local and consist only of the much smaller drainage basin above the point of sampling. Sixteen samples of Wisconsinan and Holocene terrace deposits were analyzed for clay mineral content.

Terrace deposits dated as Woodfordian in age were sampled west of Santa Rosa (samples 104-107) and west of Ft. Sumner (samples 129-135; samples 104, 127, 130, and 134 are shown in fig. 3). In these samples the montmorillonite averages about 60 percent, illite about 28 percent, and the remainder almost entirely kaolinite. This composition is similar to the Woodfordian pond deposits of the same region. The caliche on top of the terrace (107) consists only of calcite; its form suggests chemical precipitation around plant material.

Along Conejos Creek in southern De Baca County, which flows into the Pecos River from the west, the sparsely fossiliferous deposits in a low terrace (153 A) have a clay mineral composition 45 percent montmorillonite, 43 percent illite, and 12 percent kaolinite. A higher terrace at the same locality occurs above Permian gypsum and contains, in addition to abundant gypsum, dolomite with a similar clay mineral assemblage (samples 154 and 155).

Along Cienaga del Macho Arroyo, west of Pecos River in central Chaves County, deposits in the lowest terrace (samples 173 and 174), below a higher graveliferous terrace, contain a sparse fossil fauna and a thick buried soil. The clay minerals consist predominantly of weathered montmorillonite and illite, with a small amount of kaolinite. Far to the east, the deposits in a low terrace along Kenna Draw (sample 182), have a similar clay mineral assemblage, and also resemble the weathered Kansan deposits (sample 181) occurring on a higher terrace up the same valley. The weathered material in the terrace deposits (Woodfordian) appears to be related to weathered source materials, rather than to weathering in situ, because of the presence of unetched snail shells.

In southern Chaves County on the east bank of Pecos River, low terrace deposits (sample 197) with a molluscan fauna in the lower part (dated 5,865 ± 90, ISGS-144) contain weathered montmorillonite, illite, and some kaolinite. However, immediately below is a deposit of sand, silt, clay, gypsum, and recrystallized selenite, red to mottled red and gray, and lacking bedding. A sample from the upper part of this deposit (196) contains abundant corrensite (fig. 5) with some illite.

Pond and Lake Deposits

In the *Pecos River valley area,* pond deposits commonly containing fossil mollusks occur at many places on the surface of low terraces and in a few places on erosional benches on the bedrock. The molluscan faunas and radiocarbon dates indicated a Woodfordian age for many of these deposits (16,490 ± 120, ISGS-149, sample 127). Similar pond deposits have been found on the dissected floor of the western part of the abandoned Portales Valley and a radiocarbon date on fossil mollusks from one of these (15,280 ± 210, ISGS-151 from the position of sample 169) indicates that these deposits are only slightly younger than those on the terraces of the major valley. In central Chaves County, a fossiliferous pond deposit (samples 176-180) that occurs on an indistinct bedrock bench above Permian rocks at a level of 140 ft above the Pecos River channel less than 2 miles to the west, was dated 18,100 ± 370, ISGS-92. Two dates from pond deposits farther east in the High Plains are 2,000 to 3,000 years younger than the pond deposits along Pecos River valley.

At a few places in the valley, sharply defined solution-collapse areas have been partly filled with young sediments. In the area of Bottomless Lakes State Park, samples (189190) were taken from the sediments that accumulated in a complex of sinks that were subsequently integrated with Pecos River drainage, and below which younger collapse areas gave rise to the existing lakes. Twenty-five samples were collected from pond and lake deposits of the Pecos valley and the western part of Portales valley.

Pond deposits were sampled from the west side of Pecos valley, southwest of Ft. Sumner (127-128, 132-134, 146), and from the western part of Portales valley (161162, 166, 167-169; 169 shown in fig. 3). In these samples the montmorillonite ranges from 50 percent to 80 percent, illite from 15 percent to 40 percent, and small amounts of kaolinite are always present. Sepiolite or attapulgite were not detected in these samples. The montmorillonite is generally well crystallized and does not indicate extensive weathering. Samples (170-172) from a fossiliferous pond deposit on the extensive irregular pediment surface near the western edge of Roosevelt County have a similar composition, except for small amounts of attapulgite.

East of Santa Rosa (samples 227 and 228) a fossiliferous pond deposit, surrounded by Triassic rocks, reflects the local source by its high content of illite, as much as 50 percent, accompanied by weathered montmorillonite.

A fossiliferous pond deposit near Acme Station in central Chaves County (samples 176-180) occurs above Permian rocks, and is surrounded by Permian rocks. The deposit is predominately gypsum; clay mineral identification is difficult. However, well-crystallized montmorillonite and some illite were identified in sample 176.

An exceptional clay mineral assemblage occurs in the deposits associated with Bottomless Lakes, east of Pecos River in Chaves County. Here, lake silts occur as one rim of Figure Eight Lake, which is a young collapse lake with Permian rocks exposed in a nearly vertical wall around two-thirds of its perimeter. The lake sediments contain *Physa*, some gypsum and organic matter, and the clay minerals (samples 189 and 190) consist of abundant corrensite (fig. 5) with some illite.

A locality in which the deposits may be significantly older than the others discussed in this group is 3 miles west of Floyd in Roosevelt County. Here a dissected, fossiliferous pond deposit occurs at a higher topographic position than the other pond deposits and contains two A-horizons in the upper part (samples 164 and 165); a lower sample (163) is somewhat less weathered. These samples contain weathered montmorillonite, some illite and kaolinite; all contain small amounts of attapulgite.

In the *east-central High Plains area*, many depressions contain sediments. These depressions are of several types but generally are not integrated with throughflowing drainage. The most conspicuous are the large subsidence basins, typified by the basin that contains Salt Lake (fig. 6), southeast of Portales in Roosevelt County (samples 216-218). In this basin, fossiliferous lake deposits (dated14,310 230, ISGS-147, in the upper part) reach a level of about 60 ft below the level of the floor of Portales valley to the northwest; the present lake occupying an inner basin caused by a secondary subsidence, or blowout, or both, has a water level about 40 ft below the top of the lakebeds. The fact that the present basin is at least in part caused by blowout is indicated by the lee dune crossing the Texas state line, and rising more than 125 ft above lake level.

Lee dunes also occur adjacent to smaller basins not associated with observable abandoned valleys. One such feature (fig. 7) was sampled in southeastern Roosevelt County where the pond deposits in the floor had been excavated (samples 212-213) and the lee dune was exposed in a roadcut (sample 214).

Many shallow pond deposits, commonly fossiliferous, occur on the floors of minor abandoned valley trends in

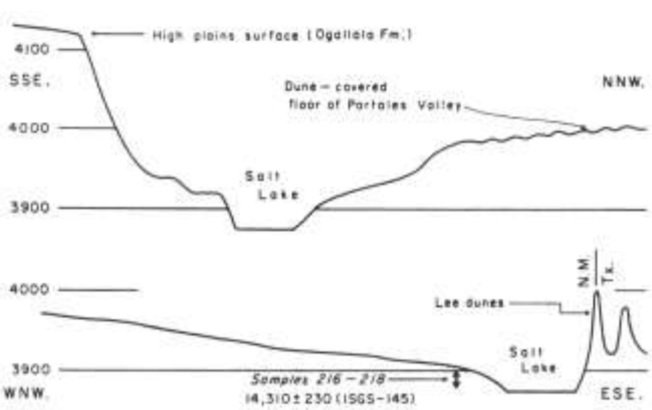

Figure 6 – Cross sections of the basin of Salt Lake, southeast of Portales, Roosevelt County. Locations of samples, and radiocarbon date on mollusks are shown.

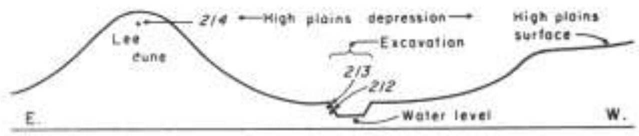

Figure 7 – Schematic diagram of High Plains basin with lee dune, southeastern Roosevelt County. Location of excavation in bottom of basin, and samples are shown.

northern Lea County (samples 202-207), and in southern Roosevelt County (samples 209-11, 215), as well as on the floor of Portales valley in northern Roosevelt County. One radiocarbon date (13,690 ± 160, ISGS-149, determined on fossil mollusks associated with sample 204) indicates that these shallow pond deposits, lacking sharply defined basin sides and lee dunes, are of the same approximate age as the fills of the larger lake.

Samples of fossiliferous pond deposits (220 and 222) were collected at two localities where prominent sand dune tracts prevented observation of their topographic setting. However, the topographic map indicates that they are less than 25 ft higher than the floor of Portales valley to the south; presumably they are related to that abandoned valley floor rather than to the Ogallala upland.

The primary source of clay minerals in these pond and lake deposits is from the nearby Ogallala Formation, with eolian sediment as a possible secondary source. In those basins associated with the floor of the Portales valley, the earlier Pleistocene deposits may be an important secondary source, and, in many places, diagenetic development of clay minerals in response to the local environment has been a significant factor.

These samples of pond and lake deposits not containing sepiolite show a dominant composition of illite and altered montmorillonite, with a minor amount of kaolinite (samples 202, 215, 220, 221). However, 7 samples (203, 212-213, 216-218, 219) contain significant amounts of sepiolite, and 3 others (204, 210, 214) contain a small amount. (See sample 218 in fig. 4B and sample 210 in fig. 3.) Dolomite occurs in 6 samples (212, 213, 214, 216218). The occurrence of sepiolite and dolomite in pluvial lakes in eastern New Mexico and western Texas has been reported by McLean, Allen, and Craig (1972). Although the altered montmorillonite and the illite are clearly derived from the nearby Ogallala Formation of the High Plains, the sepiolite and dolomite were formed diagenetically in the high magnesium environment of the ponds and lakes of Woodfordian age. The pond environment of this region during Woodfordian.time differed subtly, but significantly, from the environment in ponds of the same age in the Pecos valley (and the western part of Portales valley) where sepiolite has not been found, but where unaltered montmorillonite does occur.

A special morphologic type of pond deposit occurs in southeastern Roosevelt County where a High Plains depression contains a fill with a composition (samples 212, and 213) similar to other High Plains ponds, and with a high content of sepiolite and dolomite; the lee dune (sample 214), presumably derived by blowout from the basin, contains less sepiolite, illite, and dolomite, but better crystallized montmorillonite than the pond deposits.

A soil profile developed in pond deposits was sampled in the northeast corner of Lea County. Here calcareous and fossiliferous pond deposits form the parent material. Nodules of soil caliche from this zone were radiocarbon dated at 16,010 ± 180 (ISGS-148), but, as the nodules undoubtedly incorporated some older carbonate from the sediment, the date is probably older than the actual age of the soil profile. From similar deposits to the southwest, the fossil shells were dated 13,690 ± 160 (ISGS147). The clay mineral composition (sample 205) is typical of the region, consisting primarily of weathered montmorillonite and illite, with minor amounts of kaolinite, but with no sepiolite. The overlying leached B-horizon (206) has a similar composition. Overlying this profile is a red, clayey, leached sand (sample 207) appearing to be a younger generation B-horizon; its composition is the same as the material below. This in turn is overlain by calcareous, loose, eolian sand (sample 208) which again displays the same composition although the montmorillonite may be slightly more weathered. This young profile presents a distinct contrast with the strongly developed profiles described from the Kansan terrace deposits.

Two samples from ponds in this area (211 and 222), although calcareous and fossiliferous, gave unusually low intensities for clay minerals, and consist largely of very fine grained volcanic ash and diatoms (see sample 211 in fig. 4E).

In the northern part of the High Plains region, "cover sands" veneering the Ogallala Formation (sample 226) have a clay mineral composition similar to the Ogallala.

CONCLUSIONS

In east-central New Mexico the clay mineral compositions of the Pleistocene sediments are controlled by 1) the available sediment sources, and 2) diagenetic development of clay minerals in response to particular environments. The dominant clay mineral in the region is montmorillonite, which in nearly all cases appears to be a detrital mineral from older source rocks, but in some environments has been strongly modified by weathering or by diagenesis. Locally, devitrification of volcanic ash may have given rise to some of the well-crystallized montmorillonite. Illite is an important detrital mineral, and kaolinite, although locally occurring as an authigenic mineral, appears mostly to be detrital from older sources.

Within the region, the Permian rocks appear to be a major source of montmorillonite, the Triassic rocks a major source of illite, and Ogallala deposits a major source of both montmorillonite and illite, and possibly a source of detrital attapulgite.

The deposits of different environments, and different ages, contain strikingly different clay mineral assemblages. Montmorillonite in the deeply developed soil profiles on early Pleistocene deposits is degraded to a weathered, heterogeneous swelling material, and is not recognizable in the A-horizon and upper part of the B-horizon. However, attapulgite appears in small quantities in the upper part of the soil profile. Montmorillonite appears to be modified also by the magnesium-rich, alkaline environment of the lakes and ponds of Woodfordian age on the High Plains. Although not the result of weathering and formation of soil, a degradation of montmorillonite also occurs and is in part the parent material for sepiolite. In all samples with abundant sepiolite, well-crystallized montmorillonite does not occur.

Attapulgite and sepiolite were not found to occur together in any sample from this region. Attapulgite occurs widely, in association with montmorillonite, in Ogallala deposits, in soil profiles, and locally in soil caliche. But sepiolite is known only from deposits in ponds and lakes of Wisconsinan age on the High Plains, and at one locality in sediment blown from an adjacent pond deposit. Pond and lake deposits along the Pecos River valley and the dissected western part of Portales valley contain detrital clay mineral assemblages from readily identifiable sources.

Corrensite occurs in 4 samples from the Pecos Valley region. One occurrence is in a Triassic sandstone. The others are in very young deposits closely associated with Permian rocks. As corrensite does not occur in association with montmorillonite, corrensite formed from montmorillonite in response to the local environment.

# # #

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Appendix follows

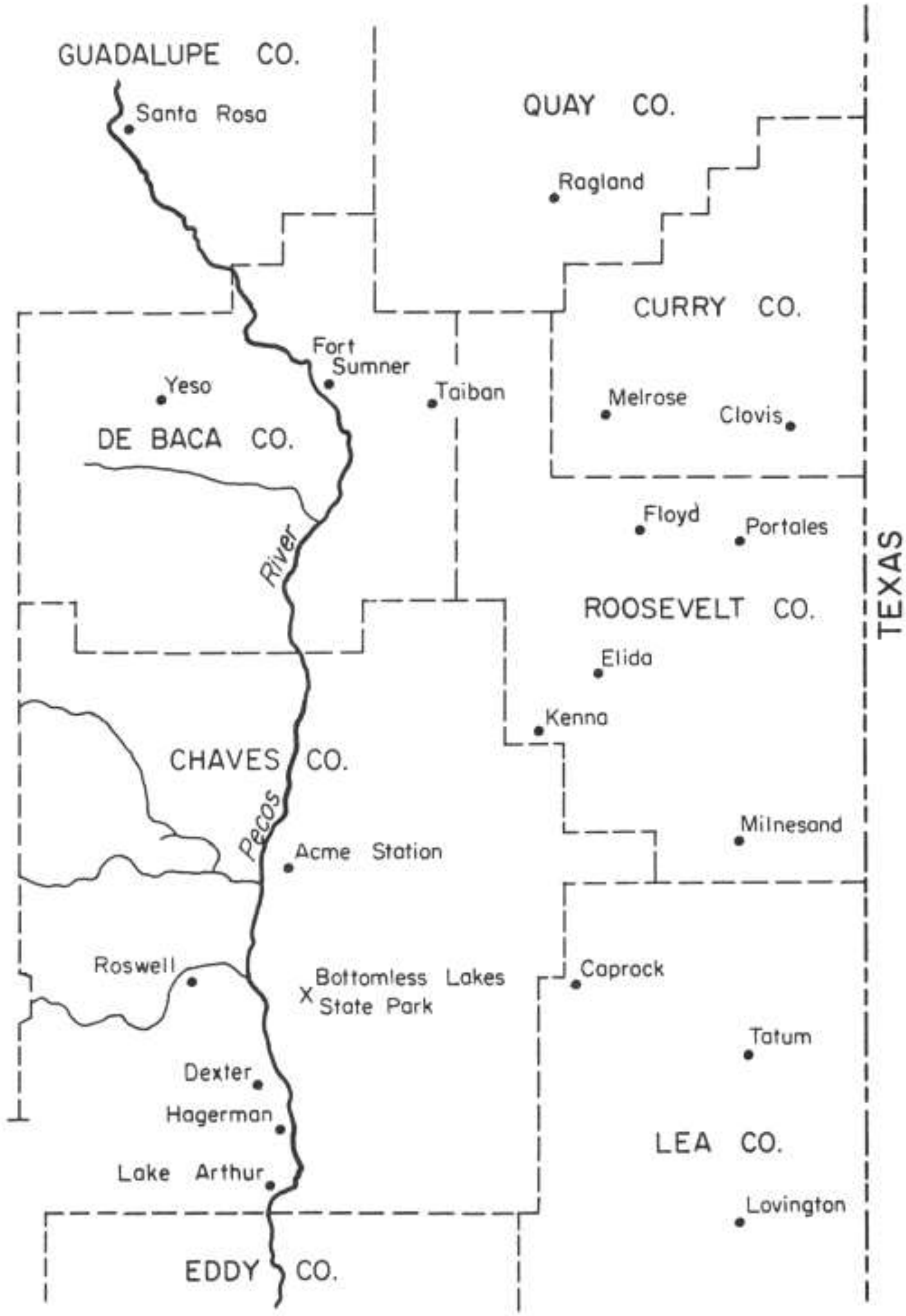

Figure 8 – City and county location map.

APPENDIX — Sample Sites

Sample numbers are those used in the field notes, prefixed by NMP-. Field note descriptions are on file at the New Mexico State Bureau of Mines and Mineral Resources.

Sample No.	Location
101-103	2.1 miles E. jct. N.M. 156 and U.S. 84, Guadalupe Co.
104-107	0.7 mile W. Pecos R. crossing of business loop at Santa Rosa, Guadalupe Co. (Santa Rosa W. section)
108-109	5.5 miles WNW Pecos R. crossing of business loop at Santa Rosa, Guadalupe Co., on flanking road
110-111	3.6 miles WNW Pecos R. crossing of business loop at Santa Rosa, Guadalupe Co., on 1-40
112-113	3 miles E. jct. N.M. 212 and U.S. 60, east of Ft. Sumner, on U.S. 60, De Baca Co.
114-120	2.55 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co.
121-123	3.05 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co.
124	4.05 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co.
125	6.15 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co.
126	5.1 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co.
127-128	1.75 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co.
129	1.15 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co., 200 yards E. of RR overpass
130-137	1.35 miles W. Pecos R. at Ft. Sumner by way of U.S. 60, De Baca Co., 150 yards W. of RR overpass (Santa Fe overpass section)
138-141	3.5 miles W. and 0.3 mile N. jct. N.M. 203 and U.S. 84, De Baca Co.
142-144	15 miles SE of Santa Rosa, on U.S. 84, Guadalupe Co.
145	19 miles SE of Santa Rosa, on U.S. 84, Guadalupe Co.
146	2.8 miles S. jct. N.M. 20 and U.S. 60 (SW of Ft. Sumner), along N.M. 20, De Baca Co.
147-149	3.2 miles S. jct. N.M. 20 and U.S. 60 (SW of Ft. Sumner), along N.M. 20, De Baca Co.
150-153	4.8 miles S. jct. N.M. 20 and U.S. 60 (SW of Ft. Sumner), and 0.7 mile N. of "Ricardo road", along N.M. 20, De Baca Co.
153A-155	Along Conejos Creek W. of N.M. 20, 19.5 miles SE of Yeso, De Baca Co.
156	4.4 miles E. jct. N.M. 252 and U.S. 60 at Taiban, just E. of De Baca-Roosevelt Co. line
157-159	10.1 miles E. jct. N.M. 252 and U.S. 60 at Taiban, borrow pit N. of U.S. 60, Roosevelt Co.
160-162	3.6 miles S. of U.S. 60 in Melrose, Curry Co.
163-165	3 miles W. of Floyd, at jct. N.M. 88 and 330, Roosevelt Co.
166	1 mile N. of Curry-Roosevelt Co. line, W. side N.M. 88, Curry Co.
167-169	1 mile S. of U.S. 60 on Kreider road (5 miles W. of Curry-Roosevelt Co. line), Roosevelt Co.
170-172	2.2 miles E. of De Baca-Roosevelt Co. line, in Roosevelt Co., and 19 miles W. of Floyd
173-174	W. of U.S. 285 along Arroyo del Macho, 18 miles N. of U.S. 380 at Roswell, Chaves Co.
175	8 miles NE jct. U.S. 70 and 285, near U.S. 70 (NE of Roswell), Chaves Co.
176-180	3.6 miles NE of Pecos R. bridge along U.S. 70 (Acme Station section), Chaves Co.
181	0.7 mile NE of Kenna, N. of U.S. 70, Roosevelt Co.
182	2.2 miles SW of Kenna, along Kenna Draw, N. of U.S. 70, Roosevelt Co.
183-184	12.1 miles SW of Kenna, along U.S. 70, Chaves Co.
185-186	5.3 miles N. of Dexter, E. of Hagerman Ditch, Chaves Co.
187-188	2.8 miles N. of Santa Fe RR tracks in Dexter, W. of Hagerman Ditch (Hagerman Ditch Section), Chaves Co.
189-190	Bottomless Lakes State Park, west side of Figure Eight Lake, SW cor, NE'% SW 1/4, sec. 27, T. 11 S., R. 26 E., Chaves Co.
191-192	1.3 miles SE of Pecos R. bridge, E. of Hagerman, on N.M. 31, Chaves Co.
193-195	1.7 miles SE of Pecos R. bridge, E. of Hagerman, on N.M. 31, Chaves Co.
196-197	E. of the S. end of Pecos R. bridge, 3.3 miles ESE of hwy. crossing of Santa Fe RR tracks N. of Lake Arthur, Chaves Co.
198-199	5 miles S. of U.S. 82 on N.M. 31, 4 miles W. of Lea Co. line in Eddy Co.
200-201	21 miles SW of Lovington, N. side of N.M. 429, Lea Co.
202	6 miles NNE of jct. N.M. 457 and U.S. 280, and ENE of Caprock, Lea Co.
203	3.9 miles E. of Lea-Chaves Co. line, and 9.7 miles N. of Caprock, in Lea Co.
204	10.8 miles SW of intersection of Lea-Roosevelt Co. line with Texas state line, on N.M. 125, Lea Co.
205-208	5.8 miles SW of intersection of Lea-Roosevelt Co. line with Texas state line, on N.M. 125, Lea Co.

209 5.2 miles N. of Milnesand, E. side N.M. 18, Roosevelt Co.
210 9.5 miles W., and 5.5 miles N. of Milnesand, Roosevelt Co.
211 8.7 miles W., and 7.2 miles N. of Milnesand, Roosevelt Co.
212-214 3 miles E. of N.M. 18 and 9 miles N. of Milnesand, Roosevelt Co.
215 3.8 miles W. of Texas state line (13 miles E. of N.M. 18), and 7.5 miles N. of Milnesand, Roosevelt Co.
216 3.2 miles S. of N.M. 88, and 4.7 miles W. of Texas state line, SW of Salt Lake and ESE of Portales, Roosevelt Co.
217-218 2.9 miles S. of N.M. 88, and 4.7 miles W. of Texas state line, N. side of tributary to Salt Lake, Roosevelt Co.
219 4.5 miles S. of Curry Co. line, and 13 miles W. of Texas state line, along U.S. 70, Roosevelt Co.
220 6.7 miles N., and 5.6 miles W. jct. N.M. 88 and U.S. 70 in Portales, Roosevelt Co.
221 1 mile WNW of Elida, Roosevelt Co.
222 12.3 miles S. of Santa Fe RR tracks E. of Clovis, and 7.2 miles W. of Texas state line, Roosevelt Co.
223 8 miles N. U.S. 60 and 70 at Texico, and 0.7 mile W. of Texas state line, Curry Co.
224-225 0.5 mile NW of Ragland, Quay Co. (Ragland section)
226 11.1 miles W., and 2 miles S. of Ragland, on N.M. 156, Quay Co.
227 9 miles E. jct. U.S. 66 and N.M. 156 near Santa Rosa, on N.M. 156, Guadalupe Co.