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THE UPPER CENOZOIC GATUŇA FORMATION OF SOUTHEASTERN NEW MEXICO

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Abstract—The Gatuňa Formation of southeastern New Mexico has been studied in the field for two landfill projects and the Waste Isolation Pilot Plant project. Shafts, drilling and field mapping reveal the distribution, thickness and sedimentary features of the unit in an area where it was poorly known or assigned to other units. The Gatuňa is at least 300 ft thick in the study area. The formation was deposited in the north and east as elastic beds ranging from conglomerates to laminar claystones. Fining upward cycles are common, though depositional features and facies associations are consistent with braided river/stream environments, not meandering rivers. Laminar and thinly bedded siltstones to claystones were deposited in floodplain to playa environments. Pedogenic features superimposed on many fining upward cycles include soil fractures, slickensides, MnO_2, illuviated clay, bioturbation, probable ped structures and desiccation cracks. The upper Gatuňa more consistently includes pedogenic development. Beds of poorly indurated "orange" sand, consisting of rounded and well-sorted grains, are interpreted as eolian deposits. From southern Nash Draw to Orla, the Gatuňa is fine-grained and gypsiferous, including displacive crystals and probable subaqueous deposits. These outcrops represent low energy environments, including playas, which were near local base level. The age of the upper Gatuňa is reasonably constrained by the Lava Creek B ash (0.6 Ma) within the Gatuňa along Livingston Ridge. The age of basal deposits is poorly or not constrained. An ash within probable Gatuňa near Orla, TX, is about 13 Ma based on both radiometric and geochemical data. The Gatuňa represents an important piece of the geological history of southeastern New Mexico. Further studies could include efforts to better determine the age of the formation; to obtain paleontological data; and to map Gatuňa structural relationships to older and younger beds in detail to determine the timing of and spatial evidence for, dissolution of evaporites and collapse of overlying beds, including the Gatuňa.

INTRODUCTION AND OBJECTIVES

The Gatuňa Formation was investigated during the past few years in a broad area around Clayton Basin, Nash Draw and Pierce Canyon (Fig. 1). Here we report some geological information about the Gatuňa developed through two unrelated projects. A project for the Waste Isolation Pilot Plant (WIPP) was designed (1) to better understand Gatuňa lithofacies and their distribution, depositional environments and climatic implications, and (2) to understand the implications of the thickness, attitude and facies distribution for the timing and location of dissolution of underlying Permian rocks. Dissolution of Permian evaporites affected the hydrologic properties of the overlying units, including the Culebra Dolomite Member of the Rustler Formation. The distribution of Gatuňa facies may indicate possible patterns of recharge to and discharge from, the underlying units during the Pleistocene. The Gatuňa has also been recovered in cores obtained both at a potential site for a new landfill (Sand Point) in Eddy County and at the Loving landfill site that is now closed (Fig. 1, J). These cores provide additional vertical and lateral control on the distribution of the Gatuňa and its facies. The data will also be used as part of an application for a permit for a new landfill (Powers and Magee, this volume) and as part of the application for closure of the Loving landfill.

STATUS AND AGE OF THE GATUŇA FORMATION

The Gatuňa was first named and generally described by Lang (in Robinson and Lang, 1938) as an assemblage of terrestrial deposits that began to fill the Pecos River valley after maximum erosion. The formation was named for Gatuňa Canyon, about 17 mi north-northeast of the WIPP site (Fig. 1). Robinson and Lang (1938) originally spelled Gatuňa using a tilde. We continue this original usage even though many subsequent maps and reports have avoided using the tilde.

A Gatuňa reference section, measured by Bachman (1974) in the type area at Gatuňa Canyon, is about 54.5 ft thick. We also measured and described a composite section at Gatuňa Canyon. It differs from Bachman's description because of our choice of location and because Gatuňa lithofacies vary laterally; we observed less conglomerate. Several of our sections can be usefully considered additional reference sections, but the Gatuňa is variable enough that it is not particularly useful to designate them formally now.

Bachman (1973) suggested that the Gatuňa be restricted to the type area and Nash Draw until ages could be determined. The Gatuňa is

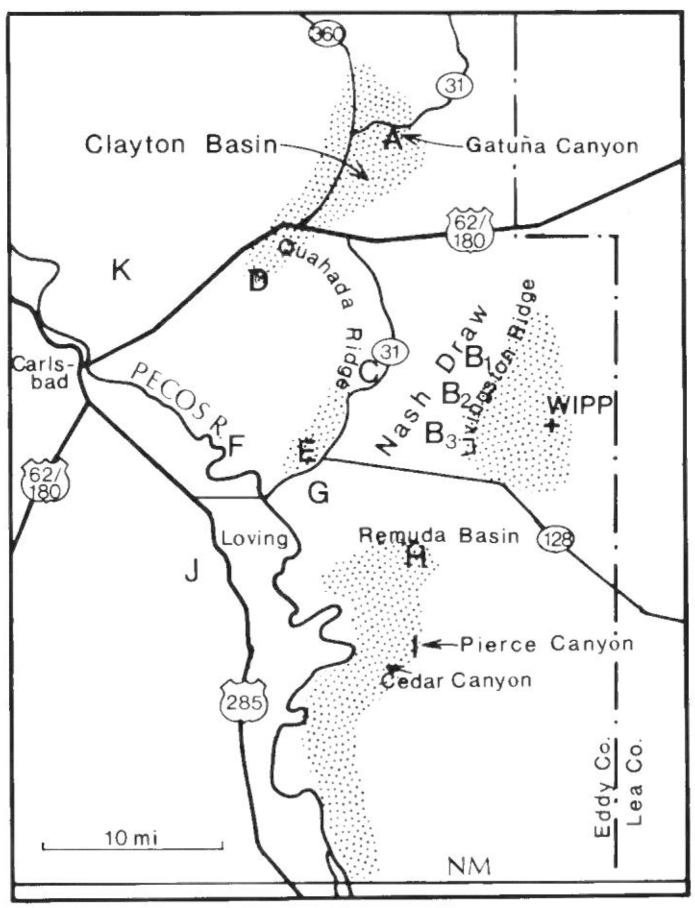


FIGURE 1. Stipple area represents principal outcrops and subcrops of the Gatuña Formation in the southeastern New Mexico study area. Letter designations refer to locations discussed in detail in the text. An outcrop area in Texas southeast of Orla along the Pecos River is about 30 mi south to southeast of the map area.

lithologically heterogeneous, but overall homogeneity and geographic continuity justify extending the formation throughout the study area. We have not examined northern outcrops Kelley (1980) attributed to the Gatuňa. Bachman (e.g., 1974, 1980) also extended the Gatuňa well beyond Nash Draw and Gatuňa Canyon. The formation may or may not be an adequate stratigraphic unit to include all of the little known thick "fill" of supposed late Cenozoic age in the Balmorhea-Loving trough along the Pecos valley (Maley and Huffington, 1953).

The age of the Gatuňa is not well constrained. Robinson and Lang (1938) indicated the Gatuňa was Quaternary. It has been considered Pleistocene(?) by the U.S. Geological Survey (Vine, 1963). Kelley (1971, 1980) suggested that part of the Gatuňa in the Pecos valley may be older than, or at least partially equivalent to, the Mio-Pliocene Ogallala Formation of the High Plains. This is certainly not true of many Gatuňa deposits. Outcrops and some cores east of the Pecos contain caliche fragments most likely derived from the Ogallala caprock. Bachman (1974) reported Ogallala clasts in the reference Gatuňa section and we have confirmed this. At least these parts of the Gatuňa must be younger than the Ogallala. In the central Pecos valley within the Delaware Basin, deeper and thicker deposits of uncertain age might represent older Gatuňa. Without direct evidence of the ages of this material, this question will not be resolved.

An upper limit to the age of the Gatuňa is better determined than the age of the base. Bachman (1980) found a volcanic ash in the upper Gatuňa Formation along Livingston Ridge (sec. 36, T2I S, R30E), the eastern margin of Nash Draw. Izett and Wilcox (1982) identified the ash as the Lava Creek B ash, dated at 0.6 Ma. The Gatuňa is overlain in many areas by the informal unit called Mescalero caliche (Bachman, 1974, 1976, 1980, 1981). Mescalero samples from near the WIPP site were dated by uranium-trend methods (Rosholt and McKinney, 1980), which indicated an age of 0.57 Ma 0.11 Ma for the lower part of the Mescalero and 0.42 Ma± 60,000 yrs for the upper part. Rosholt and McKinney (1980) also interpreted uranium-series data from Berino soil samples, which overlie the Mescalero, as indicating the Berino formed about 0.33 Ma± 75,000 yrs. The "Berino soil" probably represents a remnant B horizon for the Mescalero (Bachman, 1980).

About 17 mi southeast of Orla, Texas (near center of northwest line, sec. 28, H&GN Block 2, Reeves County), D. E. DeTar II discovered a volcanic ash within units mapped as Gatuňa, recognized its significance and submitted samples for radiometric age determination (personal comm., from P. Eager, 11/20/91, 5/24/93). Geochron Laboratories analyzed volcanic glass, which showed no devitrification, because sanidine and biotite phases proved too rare. The K-Ar of the glass yielded an age of 13.0 ± 0.6 Ma. This ash, from the upper part of the unit in that vicinity, could help unravel further the relationships of Pecos valley fill along its length. It is treated with caution, however, as K-Ar age determinations on volcanic glass are considered less reliable than on other constituents, such as sanidine. Work in progress at the University of Utah (F. H. Brown and M. E. Perkins, personal comm. 1993) on the geochemistry of glass from samples of this unit indicates the unit is a Miocene ash from a Yellowstone hot spot (YHS) source. It is similar to two tephra in the middle of the section in Stewart Valley (NV) and does not match any of about 240 other tephra layers considered. The two tephra most similar to the Gatuňa sample are about 13.5 Ma. Thus both lines of evidence are consistent with. an age of about 13 Ma.

There is no reported paleontological control on the age of the Gatuňa. Miller (1982) described the first Gatuňa fossil, the threadfin shad *(Dorosoma petenense)* discovered by J. P. Bradbury (SE SEV4 SE'/4 sec. 33, T23S, R29E) during a field trip in 1977. As the first reported fossil occurrence, it has no range implications. Vine (1963) reported sparse plant fragments from Pierce Canyon and some plant fragments were observed (by DWP) in the ash southeast of Orla. None are described or contribute age information. Bachman (1973) also reported two finds of mammoth remains in the general area of the type section. One location may be within the Gatuňa Formation and the other may be in post-Gatuňa gravels. The mammoth remains would also be consistent with the radiometric age of the Lava Creek B ash in the upper part of the Nash Draw outcrops.

The age of the upper Gatuňa is reasonably controlled, indicating deposition ceased about 0.5 Ma. The base, however, is poorly identified in many areas and is of uncertain age. The basal Gatuňa is almost certainly of variable age over much of this area, given the differences in facies and lateral extent/thickness. The volcanic ash near Orla indicates that the rocks attributed to the Gatuňa in southeastern New Mexico and west Texas range well into the Miocene in age.

DISTRIBUTION AND THICKNESS

The Gatuňa crops out well from Gatuňa Canyon to Pierce Canyon. Kelley (1971) attributed outcrops much farther to the west and north to the Gatuňa Formation and both the Pecos, TX, sheet (Bureau of Economic Geology, 1976a) and Hobbs, NM, sheet (Bureau of Economic Geology, 1976b) display Gatuňa Formation in various parts of the western half of each sheet. Kelley (1980) also included outcrops near the Pedernal and at Santa Rosa, NM, in the Gatuňa, but didn't include descriptions. Bachman (1976) mapped Gatuňa from east of Artesia, NM, south to near the state line. The Gatuňa is best known in southeastern New Mexico, but it may range from Santa Rosa to south of Pecos, Texas. We concentrated our work in southeastern New Mexico (Fig. **I).**

A reference section measured by Bachman (1974) in the type area is about 54.5 ft thick. Vine (1963) reported about 80 ft in the type area and in Pierce Canyon, as well as local thicknesses of 100 ft. He also inferred that the Gatuňa is at least 300 ft thick at the northern end of Quahada Ridge, based on descriptions (Lang, 1942) of the Fletcher potash core test (NW corner, sec. 1, T2I S, R28E). Lang (in Robinson and Lang, 1938) also noted that the Gatuňa is more than 100 ft thick at Pierce Canyon and 300 ft at the east end of Cedar Canyon. Kelley (1971) reported thicknesses approaching 300 ft along the Pecos River at the mouth of Pierce Canyon. Texasgulf, Inc. (P. Eager, personal comm. 11/19/91) cored at least 384 ft of poorly indurated fine-grained sediment, southeast of Orla (sec. 36, H&GN Block 1, Reeves County), considered equivalent to the Gatuňa in that area. Kelley (1971) also reported 150 ft of Gatuňa in the Pecos valley north of Carlsbad. Widdicombe (1979) reported thin (about 9 ft) Gatuňa at Willow Lake, south of Malaga, overlain by playa deposits with gypsum rosettes. Around the WIPP site, the Gatuňa is generally absent to very thin. In shafts at the WIPP site, the Gatuňa is about 20 ft thick (Holt and Powers, unpubl. reports to the U.S. Department of Energy, 1984, 1986, 1991). Thicker Gatuňa exists nearer the Pecos River valley. The unit is thinner to the east as it laps onto topographically higher areas.

We measured several sections within these thickness ranges. A composite section at the east end of Pierce Canyon shows at least 300 ft of Gatuňa. Most outcrops are less than 100 ft thick. During landfill project work, Powers (unpubl. reports to JOAB, 1992) described cuttings and cores from the Gatuňa at both Sand Point and Loving landfill (Fig. 1, D and J). At Sand Point, the Gatuňa is nearly 300 ft thick. At the Loving site, the Gatuňa is variably deformed by subsidence in areas of dissolution. The deepest drill hole yielded laminar core, with modest dips, at the total depth of 248 ft.

Thus, within the study area, the Gatuňa ranges to about 300 ft thick. Measurable outcrops are commonly 30 to 100 ft thick, though many outcrops do not reveal a basal contact.

GENERAL METHODS

The Gatuňa has been little described. Bachman (e.g., 1974) reported general lithology, including helpful pebble counts and diagnostic clast lithologies to determine provenance. We described several sections of Gatuňa outcrops in detail to interpret depositional environments of the unit and possible effects on recharge and discharge patterns during the time the Gatuňa was being deposited. Cores from the Sand Point site and the Loving landfill have also been described in detail (Powers, unpubl. reports to JOAB, 1992). From field descriptions, we identified lithofacies as commonly used in sedimentology today, based mainly on the summary characteristics tabulated by Miall (1978). No petrographic studies were undertaken for these projects.

Lithofacies were classified (Table 1; modified from Miall, 1978) based on lithology and sedimentary structures that have significance in

TABLE 1. Lithofacies identified in the Gatuña Formation.

Facies Identifier	Lithofacies	Sedimentary Structures	Interpretation
Gms	Gravel, massive, muddy matrix-supported	No imbrication or internal stratification	Debris flow deposit
Gm	Gravel, massive or crudely bedded; minor sand, silt, or clay lenses	Horizontal bedding, gravel imbrication, ripple marks, cross-strata in sand units	Longitudinal bars, channel-lag deposits
Gt	Gravel, stratified	Broad, shallow trough cross-strata, imbrication	Minor channel fills
Gp	Gravel, stratified	Planar cross-strata	Linguoid bars or deltaic growths from older bar remnants
Sm	Sand, well sorted	None observed	Possible eolian deposits
St	Sand, medium to very coarse	Solitary or grouped trough cross-strata	Dunes (lower-flow regime)
Sp	Sand, medium to very coarse;may be pebbly	Solitary or grouped planar cross-strata	Lingoid bars, transverse bars, sand waves (upper- and lower-flow regimes)
Sr	Sand, very fine to coarse	Ripple marks of all types, including climbing ripples	Ripples (lower-flow regime)
Sh	Sand, very fine to very coarse; may be pebbly	Horizontal lamination, parting or streaming lineation	Planar bed flow (lower- and upper-flow regimes)
Ss	Sand, fine to coarse; may be pebbly	Broad, shallow scours (including eta cross-stratification)	Minor channels or scour hollows
Se	Erosional scours with intraclasts	Crude crossbedding	Scour fills
Sl	Sand, fine	Low angle ($<10^{o}$) crossbeds	Scour fills, crevasse splays, antidunes
Sb	Sand	Bioturbation, structureless, mottled	Lingoid, transverse bars, floodplain sheet
Sg	Sand, fine, with gypsum	Gypsum: rosettes, lenticular, fibrous	Floodplain to channel, zone of saturation
Fl	Sand (very fine), silt, mud, interbedded	Ripple marks, undulatory bedding bioturbation, plant rootlets, caliche	Deposits of waning floods, overbank deposits
Fm	Mud, silt	Structureless; rootlets, desiccation cracks	Drape deposits formed in pools of standing water
Fr	Silt, mud	Rootlets, bioturbation	Incipient soil
Fsc	Silt, mud	Laminar to massive	Playa, lacustrine
Fg	Silt, silty claystone with gypsum	Gypsum: rosettes, lenticular, growth textures; often w/blocky structure, MnO_2 stain	Floodplain to playa, with soil processes; saturated zones to standing water
P	May be argillic unit, carbonate, or sulfatic unit	Ped structures, argillic accumulation, pedogenic carbonate or other mineral cumulate	Soil (subaerial exposure)

interpreting depositional environments. Sequences, or associations, of facies appear to be reasonably diagnostic of depositional environments, although the method is clearly not a solution for all needs. We believe the facies provide a framework for describing the Gatuňa and efficiently communicating basic information. We modified or extended interpretations, where possible, based on detailed information and we modified the classification to include gypsum and other facies.

GATUŇA FORMATION GEOLOGY

General lithology and character

In the Gatuňa Canyon area, the Gatuňa ranges from coarse-grained sands with gravelly to conglomeratic zones to siltstone and claystone. Vine (1963) also reported gypsum and claystone in the Gatuňa and Bachman (1974) found, as we did, crystalline gypsum about 6 ft thick in the south end of Nash Draw. We found more gypsum in the Loving area and the surficial deposits in the Pecos valley near Orla are quite gypsiferous. Beds with pebble and coarser sizes are relatively less important in these thicker sections than along eastern outcrops. Units in coreholes are composed of more siltstones and claystones than is evident from outcrops. Fining upward sequences are quite common and "orange sands" of probable eolian origin are an important element. Facies and thickness vary laterally due to both depositional environments and penecontemporaneous subsidence caused by local dissolution of underlying evaporites.

Vine (1963) called the Gatuňa moderate reddish orange; we find much Gatuňa colored light red to red (2.5 YR 6/6-4/6; Munsell soil color chart, 1971) to pink (5 YR 7/4) or light reddish brown (5 YR 6/4). These colors are broadly similar to the Dewey Lake Formation and Triassic Dockum Group, though the older units have higher color values. The Dockum appears deeper reddish-brown with a purplish cast. The Dewey Lake is a more intense and uniform reddish brown than is the Gatuňa. Greenish reduction spots on Dewey Lake siltstones help distinguish it from the Gatuňa. The lower Gatuňa in some areas includes zones of grayish or greenish-gray laminar siltstone or claystone.

Lithofacies and significance

Gatuňa facies (Table 1) range from very coarse to fine grain sizes and they are additionally defined using sedimentary structures and pedogenic features. Gravel facies include exotic pebbles from distant sources, which imply flow conditions may have been quite different from the modern Pecos River. Other facies commonly resemble some modern deposits (e.g., eolian sands) in the area, resulting from well-understood geological processes.

All four gravel facies (Gms, Gm, Gt and Gp) occur in these sections, indicating the units were deposited in different alluvial systems as well as through some debris flows. Gravel constituents can contrast greatly for some units. Large clasts dominated by Dewey Lake and even Gatuňa sources are more common in eastern outcrops. In these outcrops, quartzite and chert pebbles from the Dockum are also common, mixed with Ogallala clasts and varying proportions of volcanic pebbles from the Sierra Blanca (NM) area. Toward the west, Permian limestone clasts dominate. In the Pecos valley in the Pecos and Orla, TX, area, the Davis Mountains to the south may have been sources of volcanic clasts, but we have not further examined this possibility.

Sand lithofacies (St, Sp, Sr, Sh, Ss, SI and Sb) have been expanded to include two additional facies, Sm for massive or structureless sand and Sb for sand bioturbated by root zones. Zones of pronounced bioturbation are included in pedogenic lithofacies (see below). Most sands have been deposited under lower flow regimes, despite gravels in some zones indicating intermittent strong flow regimes. We interpret Sm facies as eolian sands because the sand size is rather uniform and grains are mostly rounded, based on field examination. We did not find lateral accretion sets indicative of deposition on point bars of meandering streams or rivers.

Fine-grained lithofacies (Fl, Fm, Fr, Fsc) have been expanded by adding Fg: siltstone with gypsum rosettes, bottom growth textures and lenticular gypsum associated with probable pedogenic features. Some fine-grained floodplain deposits exist, while other siltstones or claystones are likely playa deposits developed on floodplain or other low areas. Some lows were created syndepositionally by dissolution of halite or sulfate beds in the underlying Rustler or Salado Formations.

Pedogenic lithofacies (P) here include soil features other than pedogenic carbonate. Bioturbated sandstone has both open and filled interconnected pores with small diameters (usually <·/8 in.) and, in the upper part of the formation, much blue-black staining by probable manganese oxides ($Mn0_2$ in this report). The pores are evidence of root zones within paleosol horizons. Illuvial clay coats some pores and ped surfaces and there are more argillaceous zones interpreted as illuvial concentrations (Bt) within paleosol associations. Some incipient soil features (bioturbation, root casts) are included in other facies, as in Fg. The lithofacies P has been assigned where pedogenic features are more prominent.

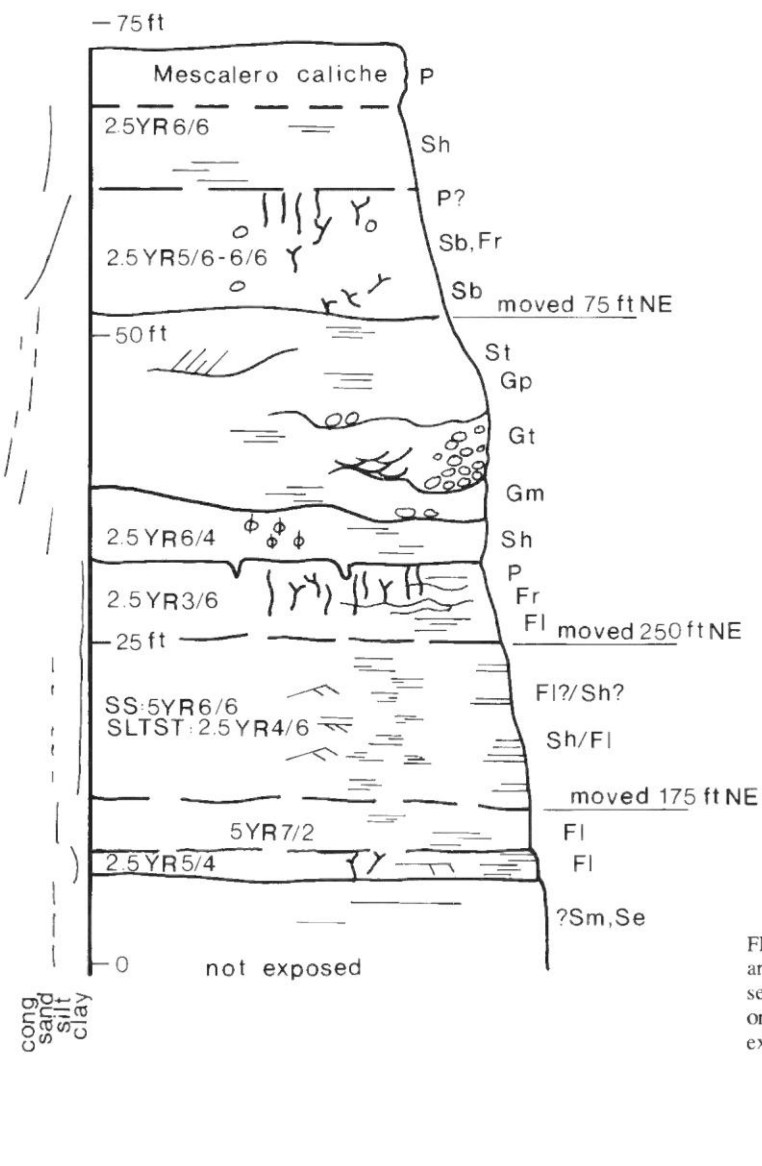
Measured sections

A series of outcrops and cores have been described in the area (Fig. **I)** that display the variety of lithofacies and differences in thickness for the Gatuňa. Each section is discussed here and several graphic sections are included for reference.

Gatuňa Canyon

The Gatuňa Canyon section (Fig. I, A; Fig. 2; NW1/4 sec. 1, T205, R30E) differs from that reported nearby by Bachman (1974). We describe more sand and silt facies and less gravel. The basal part of the section (Figs. 3, 4) is dominated by low energy overbank and waning flood deposits. Laminar deposits may include playa or shallow lacustrine sediment, but no specific evidence is diagnostic. Some laminae or zones are yellowish-gray or gray, as in similar facies elsewhere, especially at Sand Point. Several pedogenic units show desiccation cracks, bioturbation and blocky textures with $Mn0_2$.

A conglomeratic unit, about 16 ft thick, comprised of Gm, Gt, Gp and St facies fits well the distal gravelly river (Donjek type) association



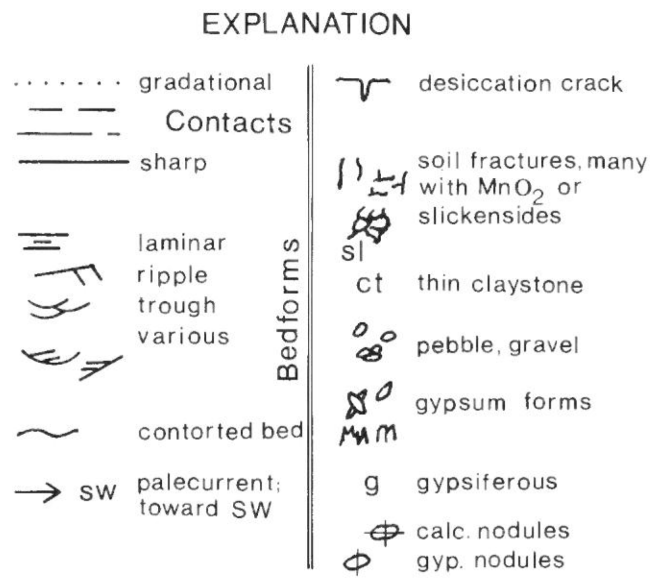


FIGURE 2. A partial stratigraphic section of the Gatuña Formation in the type area (Fig. 1, A) at Gatuña Canyon (NW1/4 sec. 1, T20S, R30E). The line of section was moved along the canyon by tracing lithologic units. Colors are based on Munsell Soil Color Chart (1971 ed.). Lithofacies identifiers (Fl, etc.) are explained in Table 1. Grain size estimates are based on field descriptions.

FIGURE 3. Outcrop of lower exposed Gatuña in the Gatuña Canyon section (Fig. 1, A) illustrating laminar beds with interbedded reddish brown (dark) and Greenish-gray (light) siltstone. Note hammer for scale

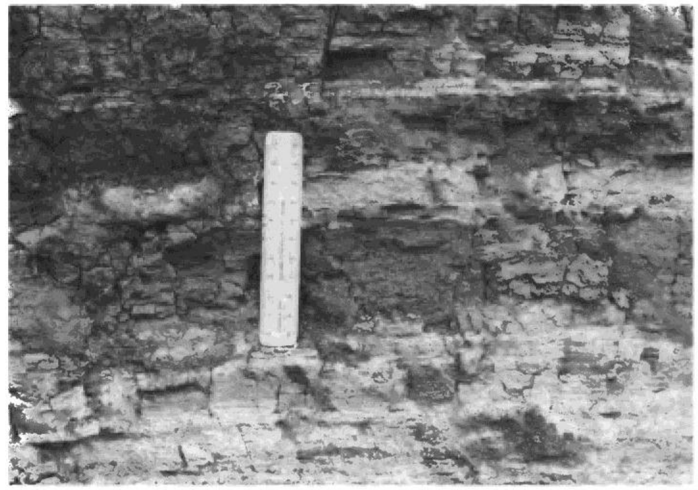


FIGURE 4. Detail of part of laminar beds in Fig. 3. Bedding ranges from thin parallel laminae to slight rippling. Scale is 10 cm long.

(Miall, 1978). In addition to locally derived clasts, some come from Sierra Blanca (NM) (Bachman, 1974). Sand facies (Sb, Sh) above the conglomerate are consistent as lateral facies within distal gravelly river environments. The units include evidence of possible extended subaerial exposure and incipient soil formation. Large clasts from the Ogallala caprock indicate important westward drainage. Local paleocurrent directions are not clear from sedimentary structures at this outcrop.

Livingston Ridge

The northernmost described section along Livingston Ridge Fig. 1, B,; NW$^1/_4$ SW$^1/_4$ sec. 1, T22S, R30E) includes gravels (Gt, Gp, Gm) and related sand units (SI, Sh, Sr) broadly similar to distal gravelly river facies (Donjek type). Sandy beds include granular and concretionary gypsum. Some sandstones are bioturbated, with a possible paleosol within the section. Bachman (unpubl. report to Sandia National Laboratories, 1985) mapped Gatuňa fill thickness leading to this outcrop and interpreted a short paleovalley leading to drainage in the Nash Draw area. These interpretations are consistent with the observations of this study.

The rocks in two adjacent sections at this location (B,) are highly variable in gypsum content and sedimentary structures. Their significance is uncertain because it is not clear these two short sections are truly coeval. Undulating topography on the erosional Dewey Lake surface and poor outcrops limit our information about correlation. In general, the western section is more sulfatic. Carbonate and soil features below the Mescalero suggest the sulfate predates the development of the Mescalero; the sulfate is possibly both clastic and deposited at the top of the phreatic zone.

Finer-grained gypsum beds in the western part of the arroyo show both rounded grains and gypsiferous cements. Rounded grains may have been transported either as water-laid traction deposits or as eolian grains, as is common in areas adjacent to Holocene sulfatic playas. Porous lenticular gypsum crystals and gypsum rosettes along nearly horizontal planes mark the saturated zone within these sediments soon after deposition. Porous textures may also indicate subsequent infiltration of meteoric water (e.g., Chen et al., 1991). Root zones in the sulfatic unit indicate that soil and water quality permitted plants to grow; gypsum concentration of the saturated zone coated and preserved the root bioturbation, if it did not also kill the growth. The gypsiferous Gatuňa along this arroyo may be younger than most of the coarser siliciclastic sediment in the eastern part of the arroyo. The gypsiferous deposits appear to be set into siliciclastic deposits along the trend of Nash Draw. The eastern part of the arroyo displays facies consistent with the distal gravelly river units along much of the Gatuňa outcrops in Nash Draw and Clayton Basin. Outcrops of Gatuňa at 132 (Fig. 1) (NE$^1/_4$ NE$^1/_4$ sec. 11, T22S, R30E) consist mostly of sand facies (Sh, SI, Sr, Sm, Se) with lesser gravel (Gm) and four surfaces with soil features (P). Lenticular channels within the deposit are adjacent to low-angle crossbedding, some trough crossbedding and ripple bedding and horizontal bedding. Bedded units adjacent to the channels are similar to small cross-channel or diagonal bars in sandy braided stream facies (e.g., Walker and Cant, 1984; Powers, unpubl.).

Near the southern end of Livingston Ridge (B); SE$^1/_4$ sec. 21 and SW$^1/_4$ sec. 22, T22S, R30E), thicker Gatuňa (about 55 ft) crops out in an arroyo we call "gypsum canyon" because beds are quite gypsiferous. This section displays a range of facies (Fig. 5). The basal unit (about 10 ft thick) is gravel (Gt) to sandy beds (Sr, SI) overlying an erosional surface on the Dewey Lake; relief is similar to the thickness of the unit. Above the basal beds, the outcrop consists of sandy to fine-grained gypsiferous deposits (Sg, Fg) and a few beds displaying pedogenic features and bioturbation. Zones of calcareous concretions are common and also are located about 3 ft below pedogenic zones displaying blocky fractures, MnO_2 and bioturbation. About 6 ft of sandstone under the Mescalero shows ripple and low angle cross-strata (Sr, Sh) facies. The gravel and sand lithofacies are reasonably consistent with the distal gravelly river facies (Miall, 1982).

Early or syndepositional gypsum occurs as scattered nodules, lenticular gypsum, coatings to fillings of root structures, thin zones of gypsum rosettes and possible bottom-growth gypsum in a small channel. Gypsum concentration varies laterally. Within the lower part of the section, fibrous gypsum fills some late-stage subvertical cracks or fractures that are probably post-Mescalero and related to significant dissolution and collapse in Nash Draw. Much of the gypsum in this outcrop formed in saturated sediment, probably near the top of the phreatic zone. Bottom-growth gypsum may show standing fluid within a small abandoned channel filled with fine-grained sediment. No clastic gypsum was observed.

Central Quahada Ridge

The Gatuňa along Quahada Ridge (Fig. 1, C; sec. 10, T22S, R29E), west-southwest of the IMC plant site consists of two distinct sequences of beds each grading upward from Gms to Sm (Fig. 6). Some units may also be assigned to Gm facies. The two sequences are separated by a clear surface. A small block of sediment, collapsed or transported in the upper part of the lower sequence, is truncated by the surface. The upper sequence includes clasts of Permian limestone, whereas the lower does not.

The individual beds are best interpreted as debris flows based on textures, lack of crossbedding and minimal imbrication. Gm facies may also indicate bars and lag deposits. Gms-dominated deposits are commonly attributed to proximal gravel rivers associated with alluvial fans, whereas Gm facies indicate distal gravel river segments.

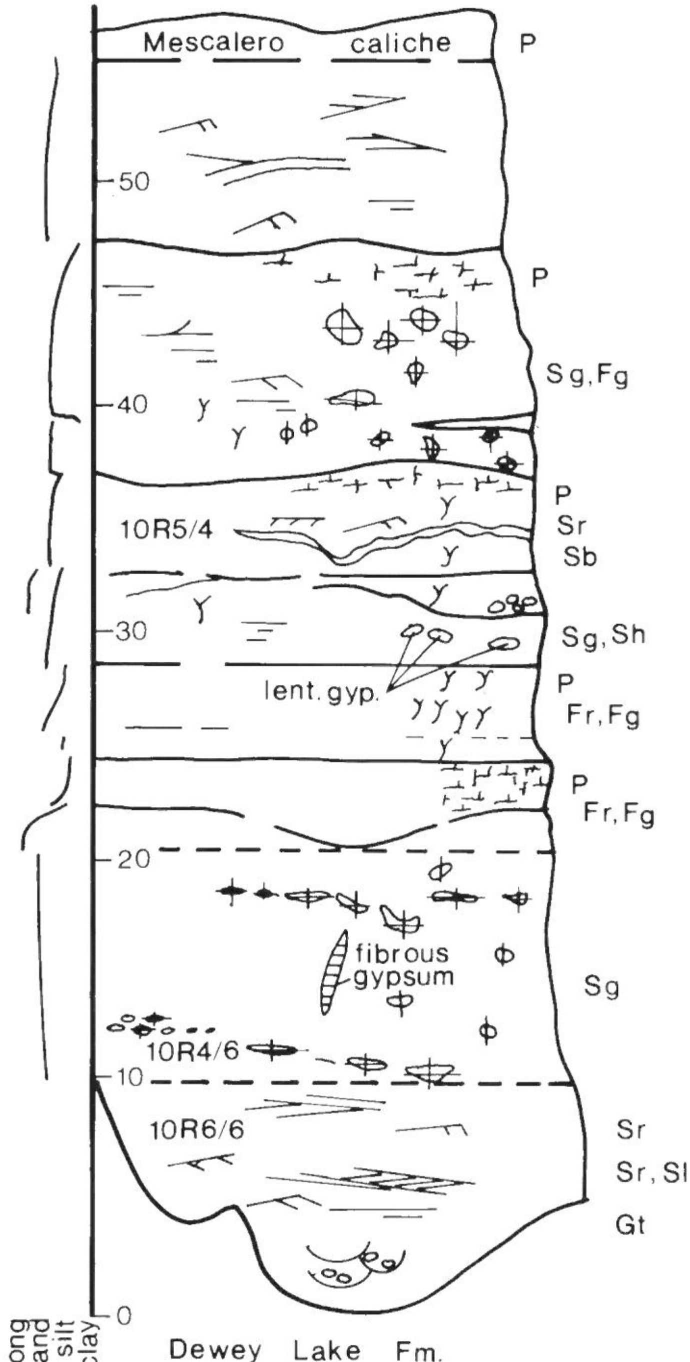


FIGURE 5. Stratigraphic section of the Gatuña Formation at "gypsum canyon" (Fig. 1, B₃) (SE¼ sec. 21 and SW¼ sec. 22, T22S, R30E). See Fig. 2 and Table 1 for symbol explanations. A few colors are provided for reference because this outcrop has more red color than do most other Gatuña outcrops. Thickness is in feet.

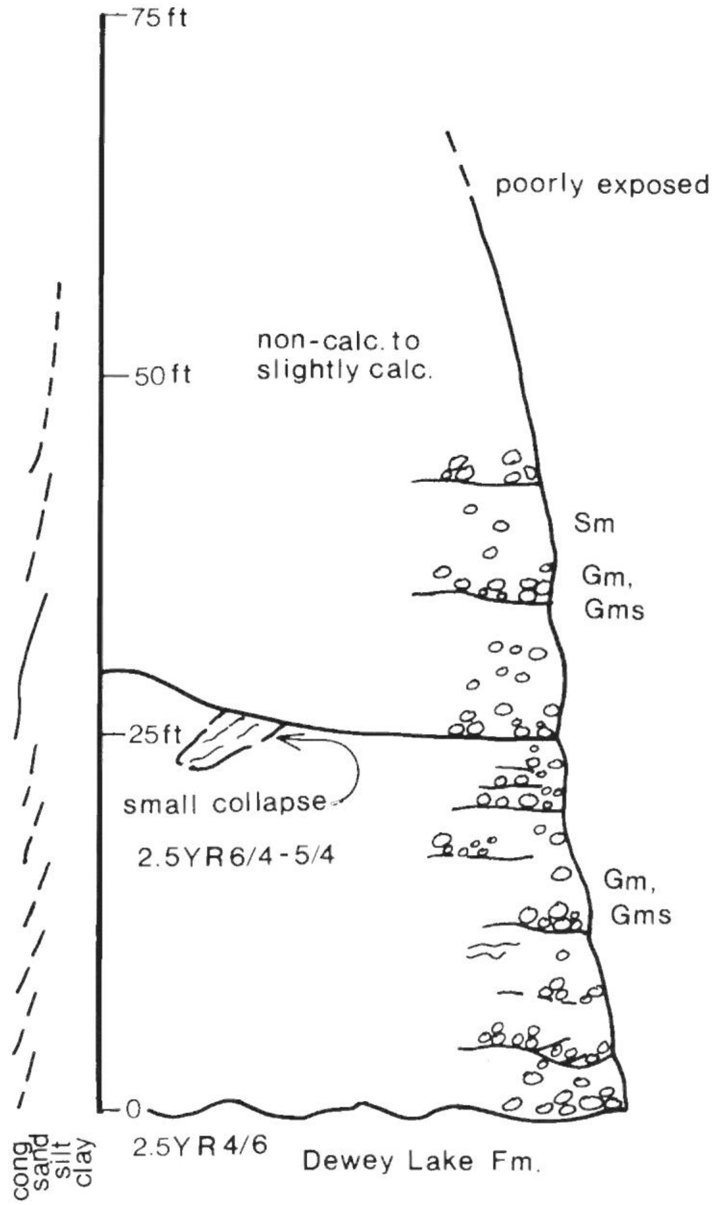


FIGURE 6. Partial stratigraphic section of Gatuña Formation along Quahada Ridge (Fig. 1, C) (sec. 10, T22S, R29E). A small feature indicates some collapse within the formation. A few colors are provided for reference. See Fig. 2 and Table 1 for symbol explanations.

These outcrops may be associated with distal river deposits (in contrast to a major alluvial fan) in view of the very low proportion of Permian limestone clasts. It is likely, however, that local topographic changes, perhaps due to coeval dissolution of underlying halitic or sulfatic beds, also resulted in localized debris flows. Gms facies in many Gatuňa sections in the study area, though not normally dominant, are consistent with local gradients and topographic changes that produced more localized debris flows without major alluvial fans.

Sand Point landfill site

Cores and cuttings from numerous drill holes at this site (Fig. 1, D; NW¼ sec. 11, T21S, R28E) demonstrate the local lateral variability of the Gatuña in a thick sequence. The deeper drilling from early site characterization show the overall features and relationships (Fig. 7). Four major features of the Gatuña are most noticeable here: low proportions of conglomerates; laminar zones, including some that are grayish-green; significant "orange sands" of probable eolian origin; and common pedogenic features in the upper Gatuña.

Gravels and conglomerates are minor and the clasts show variable provenance. Clasts from drill holes SP G/H-1 and G/H-4 are mostly from Dewey Lake sources. About 0.25 mi to the southeast, Dewey Lake outcrops and subcrops below Mescalero caliche (exposed in pipeline trenches) are more than 200 ft higher topographically than the top of Dewey Lake in the drill holes; this higher area is the likely source of the clasts.

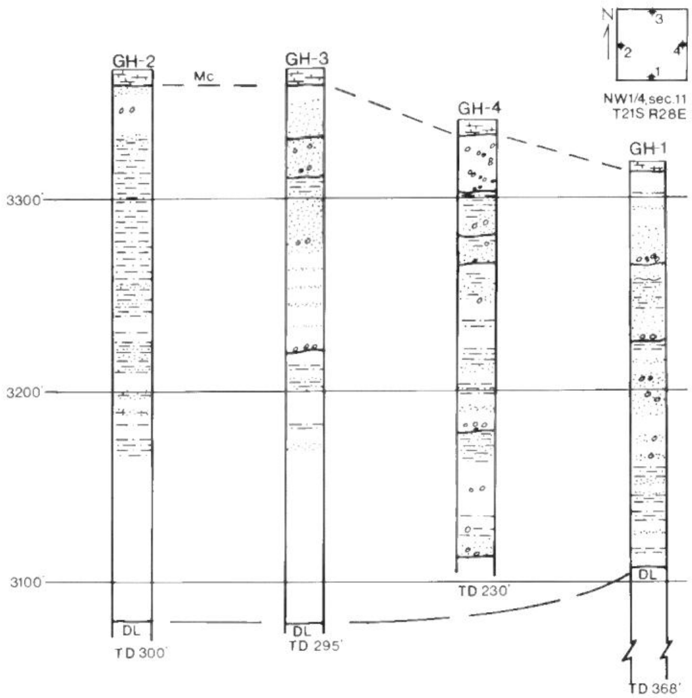


FIGURE 7. Generalized lithologies and relationships within four drill holes at the Sand Point (Fig. 1, D). Total depth (TD) and elevations are in feet. Mc represents Mescalero caliche and DL indicates Permian Dewey Lake Formation. Dewey Lake clasts in the Gatuña in GH-1 and -4 are probably from nearby sources to the southeast. Portions without lithologic symbols were poorly sampled or were not recovered. Much of these zones returned fine sand cuttings to the surface during drilling.

Some drill holes encountered significant thicknesses of thinly bedded or laminar argillaceous beds. Deeper drill holes included argillaceous laminar beds with grayish-green zones, similar to the lower outcrops in Gatuňa Canyon. Some drill holes included more than one such interval; we do not infer chronologic correlation of these intervals.

Drill holes at Sand Point encountered thin to thick zones of unindurated sand to poorly indurated sandstone with moderately well sorted and rounded grains. The color of most of these units is about 2.5 YR 5/6 ("red"; Munsell Soil Color Chart, 1971 ed.), and they appear "orange" in outcrop and when dry. Opaque grains were visually estimated as about 1% in these beds. A few sandstones are more argillaceous near their base. Bedding and other sedimentary features were rarely observed. These units were first distinguished while describing the Remuda Basin outcrops and they are interpreted as eolian deposits. The sands are visually indistinguishable from surface dune sand at Sand Point.

The upper part of the Gatuňa at Sand Point exhibits nearly universal bioturbation, calcareous zones, illuvial clay zones and bluish-black MnO_2 stains on pores and ped surfaces or soil fractures. The zone of strongest pedogenic features is about 40 ft thick in several of the drill holes. These features are interpreted as the result of several episodes of stability and soil development well before the Mescalero caliche began to form. The affected Gatuňa tends to have colors that are more brown or have less red (e.g., 2.5 YR 4/4 rather than 2.5 YR 5/6 or 5/8). This change is generally noticeable in thicker outcrops and we earlier called this informally the "McDonald Ranch member" (after the name of the ranch in the lower Pierce Canyon) of the Gatuňa.

South end Quahada Ridge (intersection NM-31 and -128)

The outcrops (Fig. 1, E; sec. 5, T23S, R29E) are dominated by sand facies (Sh, SI, Sr, St, Se) with minor gravel (G, Gm) and two zones with probable pedogenic horizons (P). The deposit is most consistent as an assemblage within the sandy braided river environment. Several zones were exposed for longer periods of time as stable areas to produce pedogenic features and concretionary zones associated with small gravel channels. Within this exposure, no laminar to massive fine-grained deposits or sulfatic accumulations exist to show evidence of playa or ground water accumulations.

Herradera bend of the Pecos River

About 36 ft of Gatuňa Formation crop out along Herradera Bend (Fig. 1 , F; sec. 33, T22S, R28E) below the Mescalero caliche. The lower 20-23 ft are dominated by sand (Sm, Sh) and fine-grained facies (Fsc) with some bioturbation and carbonate concretion development. The upper 13-16 ft of gravel and sand in crossbedded facies (Gt, St) overlies a sharp erosional contact. The assemblage suggests distal gravelly river to sandy braided river environments. One fine-grained bed near the base appears to have been deposited in a channel or broad low area, indicating low flow regimes and possible ponding or saturated conditions.

Laguna Grande de la Sal deposits

The exposed section of Gatuňa at the island in the middle of the salt lake (Fig. 1, G; sec. 16, T23S, R29E) is dominated by sand and fine-grained facies (St, Sh, Sr, Fg, Fl, Fsc) with one bed (<2 ft) with gravel clasts (Gms) (Fig. 8). Some fine-grained gypsiferous deposits also show pedogenic features and have been considered pedogenic facies (P). Overall, the facies association is most similar to noncyclic sandy braided rivers, though fine-grained deposits, pedogenic features and gypsum show the importance of low energy areas in floodplain, abandoned channel and/or playa environments. Two thin zones show highly probable subaqueous gypsum growth within siltstone units 4 to 8 in. thick. The base of each shows a thin siltstone (<1/2 in.) with small gypsum crystals overlain by vertical gypsum growing competitively. Above the growth textures, siltstone includes lenticular and rosette gypsum, with beds decreasing in sulfate content toward the top. The basal silt washed into a playa or low floodplain area, small crystals grew in the sediment while flooding persisted and gypsum then grew competitively on the bottom silt. Additional silt filled the low area, probably without additional standing water.

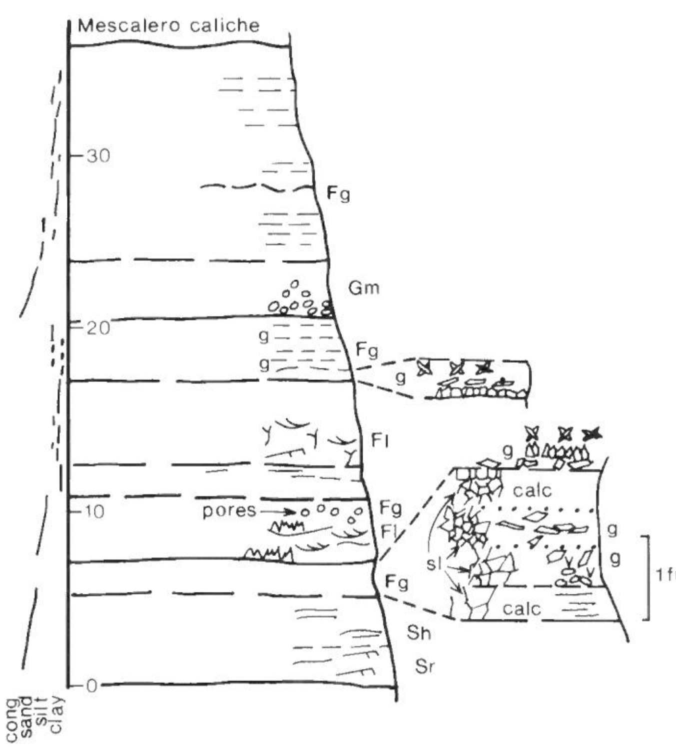


FIGURE 8. Partial stratigraphic section of the Gatuña at the island at Laguna Grande de la Sal (Fig. 1, G) (NW¼ sec. 16, T23S, R29E). The beds dip variably through the described section. Thickness is in feet. A few colors are provided for reference. See Fig. 2 and Table 1 for symbol explanations.

Clasts in the gravelly unit are composed of quartzite and chert derived from Triassic beds and clasts of Culebra and Magenta Dolomite Members of the Rustler Formation. All are available from local outcrops, most likely in Nash Draw east of Laguna Grande de la Sal. No sedimentary structures in the outcrop were sufficient to infer paleocurrent or paleoflow directions.

Deposits along east side of Remuda Basin

The Gatuňa along Remuda Basin (Fig. 1, H; SW$^1/_4$ NE$^1/_4$ sec. 32, T23S, R30E) overlies the Dewey Lake Formation in outcrop and may lap onto upper Rustler Formation units nearby. The Dewey Lake appears to have been partially eroded before the Gatuňa was deposited. The outcrops are dominated by crossbedded sand units (Sh, Sr, St, SI) and three prominent apparently structureless "orangish" sands (Sm) (Fig. 9), which are uncemented to very poorly indurated. The Sm units represent about 20% of the total thickness.

Two conglomeratic units exist in the Remuda Basin deposit. One crops out about 18 ft above the base and the other is preserved just below the Mescalero caliche. The lower unit is slightly gravelly, mainly in small channels, with clasts about 50% Dewey Lake and 50% chert, quartzite and other types not locally derived (Fig. 10). The upper gravelly unit (Gm, Gt) includes large Dewey Lake clasts (to I ft diameter) and much smaller (1-1$^1/_2$ in.) clasts from other sources. Fine-grained facies (Fl, Fr, Fsc?) and pedogenic facies (P) are minor.

This section is generally consistent with the deposits of a sandy braided river (e.g., Walker and Cant, 1985), with very local sources of some large Dewey Lake clasts. Paleocurrent indicators show transport toward the northwest, in the direction of the modern Laguna Grande de la Sal. Sands in the Sm facies are well rounded, well sorted and very friable to unconsolidated. These are interpreted as probable eolian deposits. Two beds overlie crossbedded sand of fluvial origin; the channel bars and braid plain may have been the source of sand for eolian deposits. The other Sm unit overlies a bioturbated fine-grained unit, with pedogenic features, deposited farther from a channel or braid plain source of sand. Pedogenesis implies stability over time and some lateral and vertical distance from fluvial activity.

Deposits at Remuda Basin indicate reasonably integrated drainage, probably originating on a low plain to the east. The gradient here was toward the local base level, probably near the position of Laguna Grande de la Sal. In contrast to deposits at Laguna Grande and southern Livingston Ridge, the Remuda Basin Gatuňa contains no certain sulfate (tiny plates of mica or sulfate occur in the basal bed). This area was better drained, as there are no identifiable carbonate concretions, either. Some coarser beds, however, are well cemented.

The lower, well indurated pebbly to conglomeratic sandstones in the Remuda Basin section also resemble Triassic rocks in the Delaware Basin. We assign it to the Gatuňa on the basis of clasts that apparently were derived from both Triassic and Ogallala(?) caliche sources. We did not note any Tertiary igneous clasts in these beds.

East end of Pierce Canyon

The Gatuňa at the east end of Pierce Canyon (Fig. 1, I; SE$^1/_4$ sec. 21 and SW$^1/_4$ sec. 22, T22S, R30E) appears to be more than 300 ft thick (Fig. I 1), though the attitude of the beds creates some uncertainty. Each of the two sections, believed to be sequential, is thicker than any other outcrop described by us. Sandstone facies dominate, but several gravel or conglomeratic units are both prominent in outcrop and significant parts of the section.

Most of the gravel facies show little internal stratification (Gm, some Gms); an upper gravel shows both trough crossbeds and massive facies (Gt, Gm). Basal gravels (lower 50 ft) contain large proportions of locally derived Dewey Lake clasts and Gatuňa intraclasts. Gravels higher in the section (more than 150 ft above the base) are dominated by Permian carbonates, quartzite and chert pebbles and a few clasts of andesite. Dewey Lake clasts were not observed in these upper units. The basal gravels and sandstones show beds that are thinner and truncated to the west (in the present down-dip direction). Lacking imbrication or other indicators of paleocurrent directions, this relationship suggests that the earlier gradient was, at least locally, to the east. Synsedimentary subsidence or other gradient change formed a debris flow deposit (Gms) that includes Gatuňa clasts, near the top of the basal gravels. The present dip to the southwest was superimposed.

Sandstone facies are quite variable (Sr, Sh, St, Se, Sm, Ss, Sp), with Sr and Sh most abundant and thickest. Gravel facies are associated with sand facies Sh, Sr, Sm and St. A distinctive sandstone sequence above the basal gravelly units is about 80 ft thick and is dominated by rippled sand (Sr). The sequence includes some laminar fine-grained (Fl) beds interbedded with rippled sand and interfingering with a unit of rippled sand (Fig. 11, at 90-100 ft in A). Few units show significant fining upward within distinctive beds. An "orange" Sm bed is probably eolian.

Fine-grained deposits are minor and they are dominated by siltstone to silty claystone. They consist mainly of laminar to rippled deposits (Fl) and a few beds with laminar or massive (Fsc) aspect. Several very thin claystone beds are distinctive enough in lithology and color to be traced across parts of the outcrop.

Bachman (1980) identified three facies in the Gatuňa in the Pierce Canyon area. These are broader depositional facies compared to specific facies we recognize on lithology and sedimentary structures. He identified pale-reddish-brown sand and sandy clay; light-yellowish, well-sorted sand; and lenticular gravel. Reddish-brown sand and sandy clay were interpreted as flood plain deposits by Bachman (1980). The well-sorted sand was reported to be thickest on the east side of the gravel

FIGURE 9. "Orange" sand (O) outcrop in the Remuda Basin section (Fig. 1, H). Unit thickness, between arrows, is about 5 ft. These sands are mainly structureless, poorly indurated or friable and composed of moderately sorted and rounded grains; we interpret them as probable eolian sands.

FIGURE 10. Prominent conglomeratic sandstone in the lower part of the Gatuňa at Remuda Basin (Fig. 1, H). Trough, planar and low angle crossbedding occur within the bed; apparent current directions are toward the northwest (the modern position of Laguna Grande de la Sal). Clasts are about 50% Dewey Lake, derived locally; 50% chert, quartzite and other rocks.

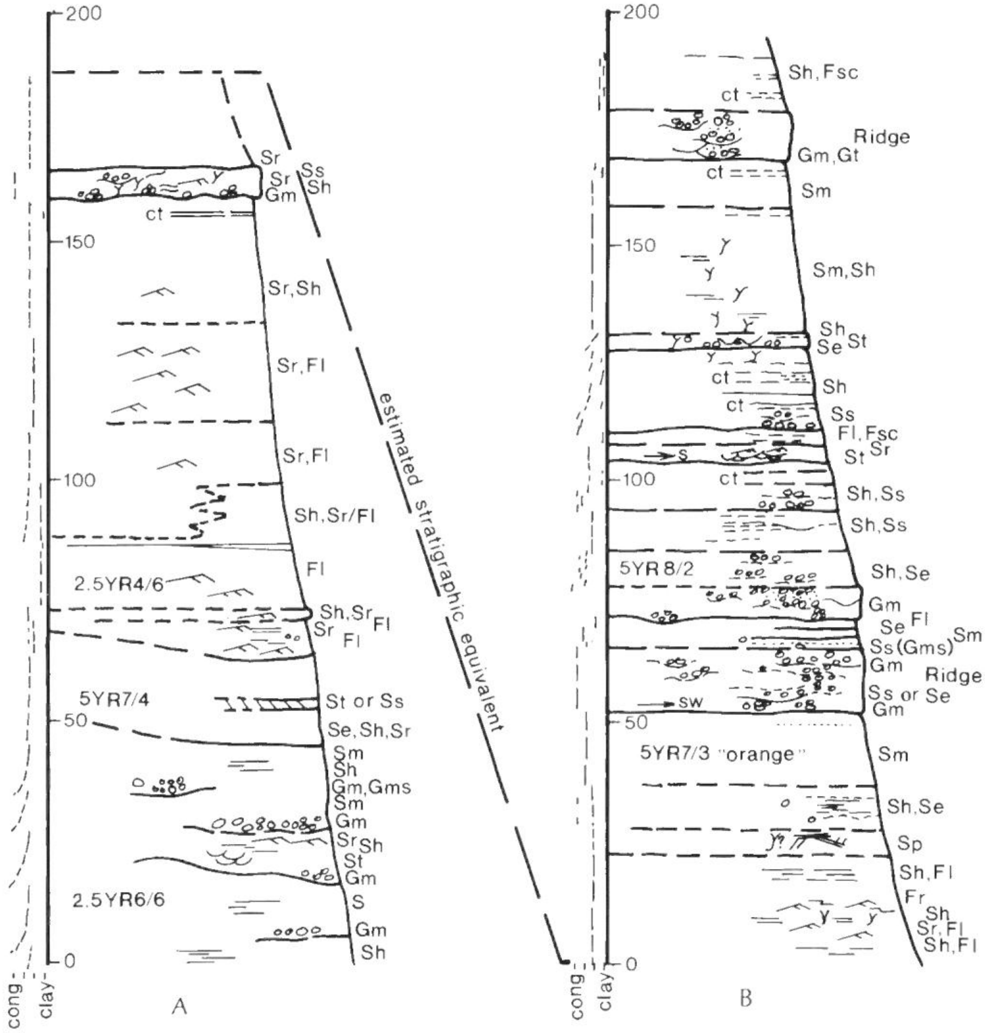


FIGURE 11. Partial stratigraphic section of the Gatuña at the east end of Pierce Canyon (Fig. 1, I). Section A is from the W½ sec. 30, T24S, R30E; section B is from the SE¼ sec. 25, T24S R30E. Lithologic units have been traced to provide the estimated stratigraphic equivalence between A and B. The units dip variably; most of B dips to the south-southwest. Dips reflect both synsedimentary local changes (base of A) and postdepositional changes (most of B) due to local dissolution of underlying evaporite units. Thickness is in feet. A few colors are provided for reference. See Fig. 2 and Table 1 for symbol explanations.

deposits and was considered eolian by Bachman. The gravels represent stream channel deposits.

We interpret the deposits at Pierce Canyon to be distal gravelly rivers and sandy braided rivers with associated overbank deposits. There are variations from both environments. The basal unit shows changes in gradient and small fan deposits, probably in response to local solution and collapse. The fan deposits are overlain by lower energy sands lateral to main channel deposits. This area along the eastern end of the canyon then became more the locus and main channel position as gravels were more frequently deposited in the upper two-thirds of the sequence. An eolian sand unit was deposited laterally to the main sand and gravel channels. Some higher gravels indicate transport toward the east and southeast and some sand deposits show current directions toward the south and southwest. The uppermost conglomerate is unconformable with slight to pronounced (at least 20°) angle to underlying sandstone units, showing that changes in gradient and local base level continued during deposition, most likely in response to solution and subsidence.

We agree generally with the facies interpretations by Bachman (1980), although we are unable to confirm the lateral relationship of eolian (Sm) facies to gravels. With the possible exception of the basal conglomerate, the deposits of Pierce Canyon are the result of well-integrated drainage systems. These deposits were formed in a more active system, as there are few pedogenic features implying stable surfaces.

The nearby Cedar Canyon outcrops of Gatuňa were examined but not described in detail. They are similar to those at Pierce Canyon, though without the conglomerates.

Loving landfill site

The Gatuňa at the Loving landfill site (Fig. 1, J; NE¼ sec. 32, T23S, R28E) is notable because it is much thicker than expected and contains significant gypsum ranging from isolated crystals to thicker beds. The formation is deformed by subsidence and/or collapse following dissolution of underlying Permian evaporites. Dips range to vertical in cores and high angles in trench exposures (now filled and covered).

The deepest drill hole was 248 ft, of which the last 48 ft were cored with virtually complete recovery. Laminar beds from this interval ranged from nearly horizontal to 20°+ dips in short segments. Most of this drill hole was not cored, so it is not possible to correct thickness accurately for attitude. Considering bed attitudes and data limitations, the Gatuňa is estimated to be at least 150 to 200 ft thick (Powers, unpubl. report to JOAB, Inc., 1992).

Gypsum in the Gatuňa at this site is both confusing and enlightening. There is little gypsum in the formation in outcrops north of Loving. Exceptions at Livingston Ridge and Laguna Grande de la Sal are mainly crystals within siltstones rather than gypsum beds. Notable gypsum beds in the Gatuňa were observed at the south end of Nash Draw by Bachman and by us. The Gatuňa in Texas (see below) is also very gypsiferous, including some gypsum beds. Without these observations, the gypsum at Loving would most likely be mapped at the surface and interpreted in core as part of the Rustler or Salado Formations, which crop out in the area. However, interbedded elastic units and sedimentary structures, general gypsiferous nature of unquestioned Gatuňa beds in the area and sulfate thickness (much less than important units of the Rustler) all favor interpreting the entire sequence encountered during landfill drilling as Gatuňa.

Sulfate in the Gatuňa in this area confirms that the surface/near-surface hydrology at the time was relatively stagnant, with high evaporation rates. Local thicknesses of sulfate beds may be also attributed to syndepositional subsidence due to dissolution, resulting in local ponding and gypsum precipitation. Because sulfates also occur with more fine-grained elastics, we interpret the area as near local base level. It is not clear how to correlate deposition of the Gatuňa at the landfill site with Nash Draw deposits. Radiometric data from the Orla area (see below), which also includes very gypsiferous deposits, suggests these rocks may have been deposited earlier than the Gatuňa in more northern areas.

Gatuňa deposits along the Pecos River near Orla

Extensive outcrops along the western side of the Pecos valley southeast of Orla have been attributed to the Gatuňa Formation (Bureau of Economic Geology, 1976a). The outcrops and core we examined from this area show poorly indurated claystone to fine sandstone lithologies. Color ranges from light reddish brown and light brown to gray or greenish gray; the hues are less intense in these outcrops than in New Mexico.

Gypsum is common in outcrops and forms a unit about 25 ft thick in the Texasgulf core about 65 ft below the surface (Texasgulf drill hole PR-90-1; sec. 36, H&GN Block 1, Reeves County, TX). The core displays laminar bedding and possible crossbedding in sandstones and siltstones, though sedimentary structures were not observed in much of the core. In outcrop, thin beds occur in some areas and other areas show few indications of bedding. Evidence of gypsum ranges from disseminated gypsum in puffy ground to crystalline gypsum along bedding planes or as part of beds. Crystalline forms include rosettes and lenticular forms within clay-rich beds that also show mottling and possible clay illuviation from exposure and soil-forming processes.

Most outcrops in this area show little to no gravel, are finer-grained, have more parallel bedding and are more gypsiferous than Gatuňa deposits described in New Mexico. Gravels and reddish outcrops at higher topographic areas along the Orla-Carlsbad highway (US-285) may be more nearly equivalent to the Pierce Canyon and other Gatuňa outcrops. The Gatuňa along the Pecos valley southeast of Orla appears to represent a much lower energy and more saline depositional environment than most of the Gatuňa in New Mexico. These strata are best interpreted as playa and low-energy floodplain deposits and may have formed at or near a local baselevel. It is not clear how much standing water may have existed, as we have not observed regular bottom growth (competitive) gypsum textures.

Gatuňa deposits near Alacran Hills

A prospective site for a new landfill in the southern half of sec. 16, T215, R27E was investigated in 1991 by mapping surface features and outcrops (Powers, unpubl. report to JOAB, Inc., 1992). The site was rejected as a landfill site because of active sinkholes and shallow ground water. Outcrops along a small escarpment at the south end of this site revealed red beds of fine sandstone, siltstone and silty claystone, all with bedding. Nearby road ditches unearthed dipping beds of greenish-gray siltstone. A pedogenic calcrete, believed to be the Mescalero caliche, overlies these beds and forms a surface resistant to erosion.

We attributed these beds to the Gatuňa Formation in 1991, though previous mapping (Dane and Bachman, 1965) at a scale of 1:500,000 indicated outcrops of the Rustler. Experience gained during 1992 while investigating other sites leads us to confirm this outcrop as Gatuňa, though Rustler rocks also crop out around the area. A block of conglomerate in a borrow pit is of uncertain origin, though it too would be consistent with the Gatuňa. The quality of bedding in this outcrop has not been reported for the Rustler Formation, though Powers and Holt (1990) laid ground work showing facies vary laterally within the Rustler. In view of this work on the Rustler, well-bedded elastic facies might be expected within the Rustler in this area. Nonetheless, the outcrops are most consistent with the Gatuňa, which is known to occur nearby and to display the features observed within the outcrops.

Environments of deposition

The Gatuňa Formation, as exposed in the type area, northern Livingston Ridge, Quahada Ridge, Remuda Basin and eastern Pierce Canyon areas, reveals lithofacies assemblages generally consistent with distal gravelly rivers, lateral flood plain and abandoned channel environments. Special lithofacies are related to paleosols, eolian sands and debris or mud flow deposits.

Paleosol features are most common or best developed in the upper part of the Gatuňa. Paleosols formed during periods of relatively stable subaerial exposure and minor pedogenic carbonate may indicate more rainfall than is normal today. Structureless to massive sands and poorly indurated sandstones, from Pierce Canyon north, are interpreted as eolian deposits. Bachman (1980) believed these are more abundant on the east side of coarse units, but we are presently unable to confirm or reject this association. That association would be expected, if wind directions were mainly from the west as they are today.

Coarser Gatuňa facies are broadly consistent, with more nearly perennial gravel and sand river systems. The lack of accretionary deposits of meandering systems and localized facies may suggest ephemeral systems as well. Gravelly deposits at Pierce Canyon are apparently more tabular units several hundred feet wide, though it is also possible the outcrops parallel a narrower channel deposit. These deposits are similar to ephemeral River Gash in Sudan (Abdullatif, 1989) as well as to the Trabeg Conglomerate of southwest Ireland (Todd, 1989). Debris-flow deposits are also due to separate, ephemeral processes. Thus the coarser deposits are mostly consistent with perennial flow, with some certain and some possible times of ephemeral flow.

Some gravel or conglomeratic deposits with matrix-supported clasts are interpreted as debris or mud flows. The middle part of Quahada Ridge and the basal Pierce Canyon sections are dominated by such deposits. The flows are generally thin and are not here associated with alluvial fans. Because they are localized, the debris- or mud-flow deposits are interpreted as a response to local changes in slope caused mostly by dissolution and subsidence. Erosion may also have changed the local base level. Sheet-flow probably occurred on slopes to form the flow deposits.

The Gatuňa along Livingston Ridge and on the island in Laguna Grande de la Sal is dominated more by finer grained facies, pedogenic features and gypsum deposited both subaqueously and in saturated sediment. The outcrops at Loving and southeast of Orla are consistent with very low energy flow, possibly including subaqueous deposition in playa and floodplain environments and few (if any) developed channels. Outcrops and drill holes are insufficient to determine if the unit was deposited as a continuous, thick sequence or if local thicker deposits accumulated in solution/subsidence areas. Given the present distribution, we infer that the Gatuňa was probably 100 ft thick or more over a rather large part of the Pecos drainage in southeastern New Mexico and into Texas. Thicker intervals, such as in the Pierce Canyon area and farther south, may be related either to an ancestral Pecos valley or to lower areas controlled by combined dissolution/subsidence/erosion.

We infer that for much of the time and area of Gatuňa deposits the drainage system was well integrated, carrying clasts originating from at least as far away as Sierra Blanca (NM), as well as from the Ogallala Formation along the eroding edge of the High Plains. The finer grained, low energy, sulfatic sediments are evidence of a local base level and sediment saturation, if not ponding of water, toward the south. Evaporation was important, but rainfall may have been greater than for the modern climate as the "upland" areas did not develop strong carbonate paleosols. There is a large source area for sulfates to the west and north, lessening the need for evaporation to account for sulfates.

Gatuňa environments must be interpreted on our understanding of age relationships among these deposits and these are still poorly understood, though improving. It is difficult to determine if the low energy, playa and saturated area in south-central Nash Draw area and farther south is exactly coeval with the remainder of the Gatuňa deposits showing more integrated and through-flowing drainage. Paleocurrent directions in the middle of the Remuda Basin deposits are toward the possible low area in south central Nash Draw. Nonetheless, gravels and conglomerates to the north and south show indicators of more north to south flow and it is inconsistent to expect that these channels can discharge into or transit such a low area without leaving more evidence of coarse materials and high rates of sedimentation. It seems more probable that the low energy deposits, including sulfates, in the Nash Draw area may have been deposited later in response to continuing subsidence over areas of continuing dissolution.

In contrast, gypsiferous, fine-grained deposits in the southern part of the study area are associated with a tephra that is about 13 Ma. There may be little or no overlap in age between the northern outcrops and southern outcrops attributed to the Gatuňa, based on the apparent high stratigraphic position of the volcanic ash. Based on the age data available, some portion of the rocks attributed to the Gatuňa may be chronologically equivalent to the Ogallala Formation.

Further discussion

Thick deposits at the eastern part of Pierce Canyon at one time represented a stacked sequence of at least 300 ft prior to slumping and rotation. The base of this section is at an elevation of about 3050 ft. This implies that the pre-rotation top of Gatuňa was at an elevation of at least 3350 ft. The top of Gatuňa Canyon deposits are at about 3400 ft, as are very thin deposits of Gatuňa at the WIPP site. Given the suggestion (Holt and Powers, unpubl. report to U.S. Department of Energy, 1988) that there has been little, if any, dissolution of underlying halite at the WIPP site, the elevations suggest a general pre-Mescalero high point of Gatuňa deposition. The southeastern corner of Pierce Canyon and Cedar Canyon to the south have undergone localized solution to cause rotation, but there probably has not been subsequent dissolution along the northeastern end of Pierce Canyon. If one were to restore any additional significant thickness to an underlying unit there to account for salt dissolution, the restored thickness of Gatuňa would be higher than at the WIPP site, an unlikely condition. The area of Gatuňa Canyon may have had slight dissolution or significant pre-Mescalero erosion, but this is not a necessary condition. The volcanic clasts from the north confirm, however, that sediment was passing through, requiring a general downgradient from north to south.

RESEARCH NEEDS

The Gatuňa is a key unit in reconstructing the late Cenozoic geological history and environment of southeastern New Mexico. It is not restricted to Pleistocene age, but is the main record of this time interval from the area. Our study shows that the Gatuňa is more extensive than was previously demonstrated, though many outcrops had been previously identified.

A petrologic survey of the Gatuňa would identify basic components and detailed problems concerning provenance. Coarse clasts from specific sources were identified by Bachman, but mainly from the upper Gatuňa. The sand fraction from the entire unit should reveal additional details of provenance.

The petrography of paleosol units and features should help classify paleosol character. Some of the paleosols may yield enough pedogenic carbonate for stable isotope work and other chemical analyses of the soil profiles may be of interest.

Selected outcrops should be more carefully examined for possible ash beds or tuffaceous units amenable to dating. Correlation of the volcanic ash from the Orla region with units of known age would help establish the age range of the Gatuňa. The outcrops should also be carefully searched for additional vertebrate remains, especially microfauna, that could provide additional age and environmental constraints.

Gatuňa thickness and surface relationships to the Mescalero caliche require more detailed mapping to establish both age and geographic distribution of pre-Gatuňa to post-Mescalero collapse. This study would greatly enhance knowledge of the processes and timing of evaporite dissolution.

The Mescalero caliche should be better characterized for its features, distribution, chemistry and age. The unit is critical to assumptions of timing of Pleistocene events in the area and the available data are both sparse and far less than the state of the art for uranium-series methods.

CONCLUSIONS

Recent studies for the **WIPP** and for landfill sites in southeastern New Mexico have improved significantly our information about the thickness, distribution and depositional features of the late Cenozoic Gatuňa Formation. The unit is more confidently identified throughout the study area and some outcrops previously attributed to other units are now placed in the Gatuňa, based on experience both with this unit and the Permian Rustler Formation, the most likely alternative.

The Gatuňa, to the north and along much of the eastern area of outcrops and subcrops, consists mainly of clastic sediments deposited in fluvial environments. These facies contain conglomerates to laminar claystones, and some sections include beds of poorly consolidated rounded and well-sorted sands of probable eolian origin.

Southern to central outcrops and subcrops consist of clastic beds with variable gypsum content as cements, fibrous fillings of pores or fractures, displacive crystals, probable subaqueous bottom-grown crystals and beds of fine to coarse crystalline gypsum. Overall, these areas indicate poor drainage and periods of playa environments. Gypsum and gypsiferous deposits are generally within fine-grained clastics, consistent with low energy environments indicated by gypsum.

Rocks attributed to the Gatuňa clearly range in age from at least Miocene to later Pleistocene. Two important research areas include better determination of the range in age of the unit and close inspection for fossils that could aid paleoenvironmental reconstruction of the Pleistocene and even earlier times. It is possible that part of the Gatuňa rocks in the study area are chronologically equivalent to the Ogallala Formation on the High Plains.

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West bluff of Pecos River from NM-31 bridge northeast of Loving (Day 1, mile 161.3). Stage IV-V calcrete caps 40-ft section of "quartzose" conglomerate and sandstone beds in Gatuña Formation.