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Geology of the Fort Sumner Sheet, New Mexico

by VINCENT C. KELLEY

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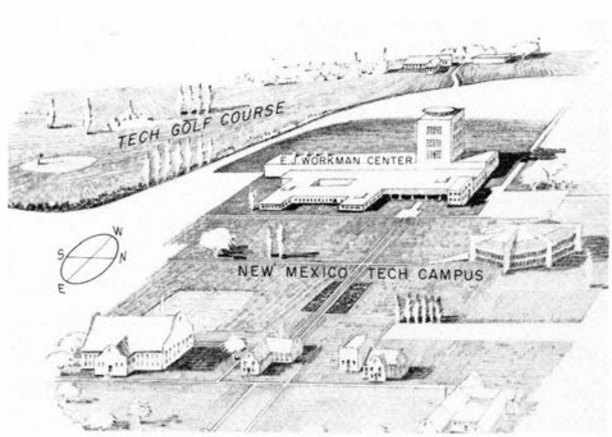

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Abstract

Rocks in the Fort Sumner Quadrangle range from Precambrian to Holocene. The oldest outcropping sedimentary rocks are the Abo Formation (Wolfcampian) which occurs as only very small inliers in the Gallinas Mountains. At the surface the Yeso Formation (Leonardian) lies on the Precambrian of the ancestral Pedernal Mountains in the western part of the map area. However, in the subsurface an eastward-thickening wedge of Abo (Permian) and Magdalena (Pennsylvanian) formations intervenes between the Yeso and the Precambrian basement. The major part of the area is surfaced by broad, irregular, north-trending outcrop belts which are, from west to east, the Yeso, San Andres, and Artesia formations of Permian age, and the Santa Rosa and Chinle formations of Upper Triassic age. In the extreme northeastern corner of the map area is a small area of Jurassic and Cretaceous formations which is more widespread to the northeast.

Considerable Ogallala is mapped west of the Pecos River at levels of 50 to 150 feet above the extensive pediment gravels on the widespread surfaces around Yeso and less-defined levels around Vaughn and Duran.

The well known Pedernal Hills, the original or type exposures of the Late Pennsylvanian to Early Permian buried ancestral mountains, are also a Laramide to late Tertiary uplift with distinctive fault development on the western side between the uplift and the late Tertiary Estancia basin. A new north-south alignment of gentle folds and small faults, described as the Vaughn trend, extends across most of the area near Vaughn; these structures align also with the western front of the Rockies near Las Vegas and with the Tinnie fold belt and Dunken uplift far to the south.

The Fort Sumner sheet includes an unusual number of physiographic features which bear importantly on the interpretation of the erosional history of eastern New Mexico. Some attention is given to several of the geomorphic problems including hypotheses for the origin of the Pecos Valley and the western extent of the Ogallala surface. The drainage system at overflow levels of old Estancia, Pinos Wells, and Encino lakes is traced into the Vaughn sag, and is concluded that surface drainage from the lakes did not reach the Pecos River.

FIGURE 1—Location map.

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Physiography

This report covers the 8,000-square mile area of the Army Map Service 1° x 2° Fort Sumner sheet (fig. 1). Five small towns, Santa Rosa, Fort Sumner, Vaughn, Corona, and Encino are within the area. Vaughn, near the center, is served by three U.S. highways and two transcontinental railways; U.S. Highway 54 and the Southern Pacific Railway run northeasterly, and U.S. Highway 285 runs northwesterly. U.S. Highway 66 traverses the northern boundary of the quadrangle. Santa Rosa and Fort Sumner are county seats of Guadalupe and De Baca counties, respectively. The county seats of Lincoln (Carrizozo) and Torrance (Estancia) are outside the area. A small portion of Chaves County lies along the southeast edge of the area; a small portion of Quay County is included in the northeastern corner of the quadrangle.

Altitudes range from high points of 8,615 feet at Gallinas Peak in the southwestern part of the area, and 7,500 feet at Pedernal Peak in the northwestern part, to about 3,700 feet where the Pecos River crosses lat 34° N. in the southeast. Despite these extremes the area is predominantly an undulating, eastward-sloping plain ranging from about 6,500 to 4,500 feet. A few small mesas, Duran, Leon, Aragon, and those near Corona, rise above the broad uplands. Along the northeastern border a small stretch of the prominent western escarpment of the High Plains extends into the area northward from U.S. Highway 60.

Drainage is diverse. The four separate drainage outlets, Pecos River, Canadian River, Estancia Valley, and Claunch are shown in fig. 2. Estancia is a basin onto itself, and the Claunch drainage probably reaches some part of the deep Sierra Blanca basin near Carrizozo. The Canadian drainage area in the extreme northeastern corner of the area leads to the Red River and ultimately to the Gulf of Mexico; the Pecos River to the Rio Grande.

Both Encino and Vaughn interior drainage areas ultimately feed in the subsurface

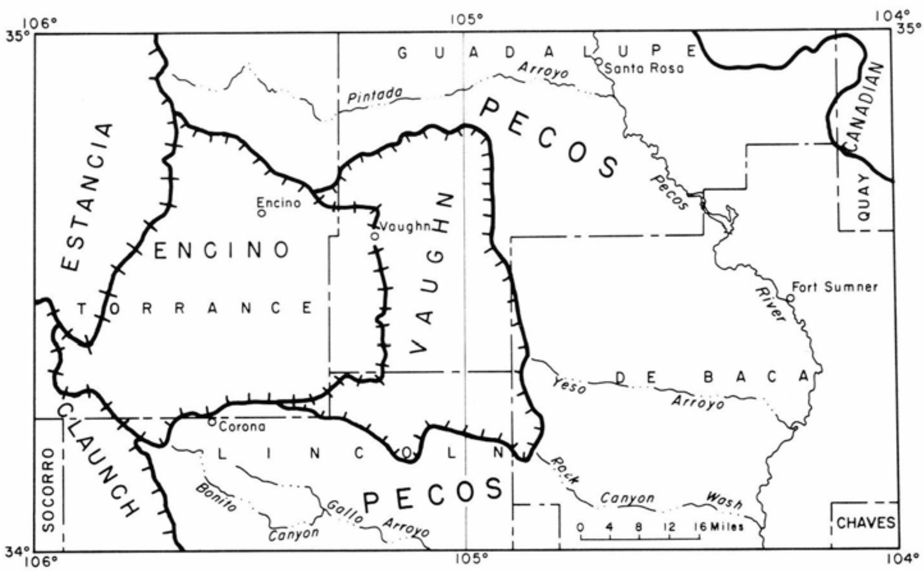
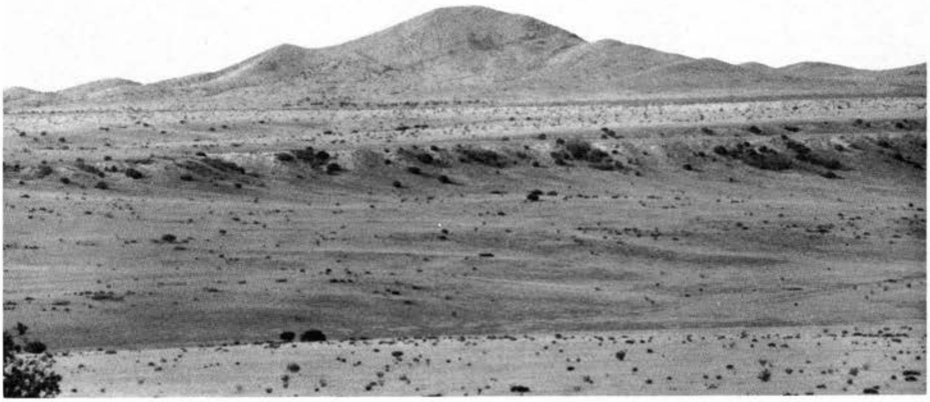


FIGURE 2—Drainage basins on the Fort Sumner sheet.

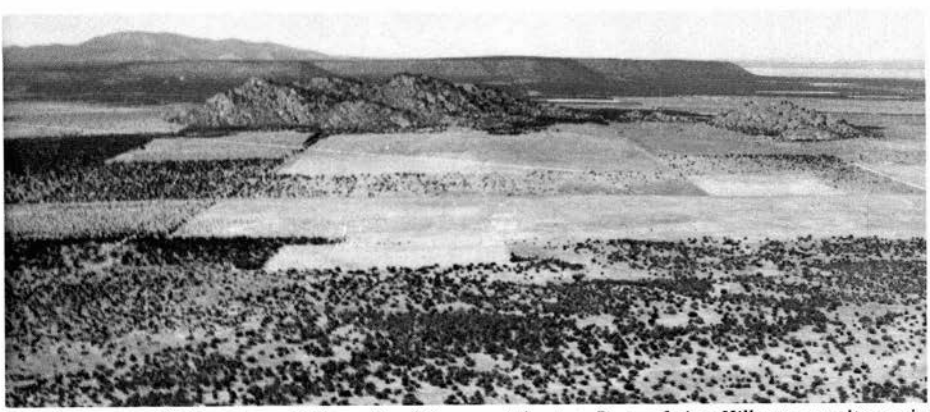
almost entirely to the Pecos; they flow with the regional dip which descends eastward from the Pedernal divide across the Pecos toward Texas. Thus, the Encino and Vaughn areas are really a part of the Pecos drainage system though not entirely by surface flow. The combined Pecos watershed, exclusive of the Estancia, Claunch, and Canadian areas, is about 6,940 square miles, 87 percent of the Fort Sumner Sheet. The Encino-Vaughn area, which lacks surface runoff to the Pecos system, totals 2,378 square miles or 34 percent of the combined Pecos watershed in the area.

Practically all the eastward surface flow east of Encino goes into sink holes along the western margin of the Vaughn area. This area is largely surfaced by San Andres beds. Karst topography is widespread and drainage lines are mostly rather short. For example, all precipitation in the city of Vaughn drains into a sink hole about two miles east of town. The straight north-south boundary between the Encino and Vaughn areas probably represents a fault or west-facing monocline. Much gravel has been dropped by eastward-flowing streams approaching this front and then descending into the subsurface.



Pedernal Peak as seen from the northeast. Flat-lying beds of the Yeso Formation underlie the surrounding mesas and valley.

Air view southwest of Cerro del Pino north of Cedarvale. The hills are Precambrian gneiss protruding through a bed rock of flat-lying Yeso Formation. The juniper forest stretching to distant Chupadera Mesa is controlled by a longitudinal Holocene dune field blown from Permian Glorieta Sandstone which caps the mesa.



Air view west of Chameleon Hill north of Corona. The two Precambrian Hills are granite gneiss protruding out of flat-lying Yeso Formation. The mesa beyond Chameleon Hill consists of Glorieta Sandstone capped by a thin rind of Bonney Canyon limestone.

Precambrian Rocks

Precambrian crystalline rocks occur mostly in the Pedernal Hills in R. 12 E., T. 5 to 7 N. They occur also at Cerrito del Lobo in Estancia Valley; in the Rattlesnake Hills area, south of Lucy; at Cerro del Pino, north of Cedarvale; at Chameleon Hill north of Corona; and in the Gallinas Mountains. All occur as inliers in either Permian or Quaternary beds. They are all part of a landmass that formed hills, ridges, and peaks from late in Pennsylvanian time until late in Triassic when the last of the highest peaks was probably buried. After deep burial during Jurassic and Cretaceous time the Precambrian was probably re-exposed in late Tertiary time, then in Quaternary time was again partly covered by alluvium and aeolian deposits from adjacent high areas and by caliche developed on broad flat exposures during a long arid period.

For the area as a whole pinkish granite gneiss is the dominant rock, followed in order by schist, quartzite, greenstone, and granite. Quartzite is confined to the northern end of the Pedernal Hills and gneiss along with schist and some greenstone make up the middle and southern part of the Hills. Gneiss dominates the Rattlesnake Hill area. Cerro del Pino, Chameleon, and the Gallinas areas are all gneiss. Greenstone, metadiorite and basalt occur generally in association with chlorite schist. Muscovite schist occurs mostly with the quartzite. Greenstone, epidiorite, metabasalt, or diabase associate with chlorite schist, phyllite, and amphibolite. Good exposures of these occur along U.S. Highway 60 several miles west of Negra and on the plain several miles south of Pedernal, stations along the Santa Fe Railway. Small aplite and pegmatite dikes occur locally in the granite gneiss. Gonzalez (1965) has recently given a good description of the petrography and metamorphism in the Pedernal Hills.

Foliation and bedding strike dominantly east to north-northeast throughout the area except at Rattlesnake Hills where marked banded gneiss foliation strikes about N. 40° W. and is nearly vertical. Quartzite in the Pedernal Hills strikes generally east-northeastward and dips southeasterly from vertical to as low as 10 or 15 degrees. The gneiss and schist of the Pedernal Hills dip consistently south to southeastward, but steeper than the quartzites and generally between 60 and 70 degrees. South of U.S. Highway 60, as in T. 4 N., R. 12 E., the strikes are east and the dips are north 70 degrees, and greater. The gneiss at Cerro del Pino, T. 3 N., R. 12 E., strikes north-easterly and dips steeply northwesterly; at Chameleon Hill, T. 1 N., R. 13 E., strike is east and dip is north at about 45 degrees.

Stratigraphy

The exposed sedimentary rocks range from Permian to Holocene (see table). Except for surficial Cenozoic deposits, Permian beds form the bedrock in about 65 percent of the area and occur mostly in the western part. Triassic rocks form the bedrock in about 30 percent of the area, especially along and east of the Pecos River. Minor areas of Cretaceous and Jurassic beds occur beneath the High Plains surface in the extreme northeastern corner of the area. Only the thin Cretaceous beds and a few thin sequences in the Yeso and San Andres are unquestioned marine. Most of the Permian consists of evaporitic sulfates and carbonates along with mudstone and sandstone of nonmarine or saline shelf environment. Some salt occurs at least locally in the subsurface of the eastern part of the area (McKee, Oriel, and others, p1. 2, 1967).

The thick Yeso Formation (Leonardian) is dominantly sandstone, siltstone, and gypsum, but with several relatively thin carbonate sequences distributed through the section. The overlying Glorieta Sandstone Member (San Andres) stands in contrast with the units above and below by reason of its white thick beds of medium-grained sandstone uninterrupted by any other lithologies through 200 to 300 feet of thickness. The Bonney Canyon and Fourmile Draw Members (San Andres) are dominated by gray carbonate beds but with much gypsum and some reddish siltstone and local sandstone. The Artesia Group is dominated by fine- to very fine grained sandstone, some siltstone and gypsum and local thin carbonate beds. In the entire Leonardian (Yeso to Artesia) section coarse-grained sandstone and conglomerate are absent, in marked contrast with the lithologies of the underlying Wolfcampian Abo or overlying Santa Rosa formations.

PERMIAN

Abo Formation

Throughout the Precambrian outcrop area of the Pedernal Hills, the Yeso is the oldest covering formation; but in the Gallinas Mountains (map 1) in the southwestern part of the area two small outcrops of Abo red siltstone, sandstone, and conglomerate, ranging from 50 to possibly 200 feet in thickness, intervene locally between the Precambrian and the Yeso. Meyer (1966, p. 72), however, projects considerable but variable thicknesses of Abo in the subsurface away from the Precambrian surface contacts. Thus, based on the Resler #1 Nalda (sec. 27, T. 1 N., R. 15 E.) well, in the southeastern corner of Torrance County, Meyer shows about 1,000 feet of Abo in a thick north-trending band only six miles east of the Chameleon Hill Precambrian outcrops. Eastward through Lincoln and De Baca counties, Abo red beds range in thickness from 250 to 500 feet with the eastern part increasing in limestone. In the subsurface of Torrance and Lincoln counties only Precambrian underlies the Abo, but in De Baca County Pennsylvanian shale, sandstone, and limestone form an eastward-thickening wedge up to 1,000 feet thick between the Abo and the Precambrian (Meyer, 1966, p. 68).

Yeso Formation

Outcrops of the Yeso are essentially confined to the western part of the area north of the Gallinas Mountains and west of about the longitude of Duran. However, small outcrops are present around, or in, the local uplifts caused by the intrusions in the

Stratigraphic units of the Fort Sumner Sheet

System, series			Group, formation, member	Thickness (feet)	Description
Holocene and Pleistocene			Assorted surficial deposits	0-100	Valley alluvium, terrace and pediment gravel, caliche soils, aeolian sand
Pleistocene and Pliocene (undivided)			Alluvium	0-300	Sandstone, sand, gravel, siltstone, limestone, red, brown, tan, gray, and yellowish
Tertiary			Ogallala Formation	15-50	Sand, gravel, mudstone, caliche
Cretaceous			Dakota Sandstone	25-30	Sandstone, thick bedded
			Purgatoire Formation Mesa Rica Sandstone Member	30-50	Sandstone, buff, massive, conglomerate at base locally, coarse grained
			Tucumcari Shale	30-40	Gray shale and buff sandstone, marine fauna
Jurassic			Morrison Formation	70-170	Green, red, and gray mudstone and buff, friable sandstone
			Exeter Sandstone	100-150	Sandstone, white, medium to fine grained, local middle limestone lentil
Triassic			Chinle Shale Cuervo Sandstone Member	700-1,300	Red mudstone, red and gray sandstone, local purplish limestone
			Santa Rosa Sandstone	100-350	Sandstone, red to gray, medium grained, irregularly bedded
Permian	Guadalupian	Artesia Group	Yates and Tansill Formations (undivided)	250-350	Sandstone, local dolomite, siltstone
			Seven Rivers Formation	0-300	Gypsum and siltstone
			Grayburg and Queen Formations (undivided)	0-400	Sandstone, gypsum, red mudstone and local dolomite
	Leonardian		San Andres Formation Fourmile Draw Member	0-700	Dolomite, gypsum, reddish mudstone; sandstone locally at top; thin bedded
			Bonney Canyon Member	0-100	Dolomite, local limestone; gray, light gray to black; thin to thick bedded
			Glorieta Sandstone Member (facies equivalent of Rio Bonito Member)	150-300	Sandstone with dolomite or limestone tongues in south and west; thick bedded
			Yeso Formation	0-1,400	Sandstone, siltstone, dolomite, gypsum; tan, red yellow, gray, white
	Wolfcampian		Abo Formation	0-200+	Red mudstone, sandstone
Precambrian			Granite gneiss, schist, quartzite, and greenstone		

Gallinas and Tecolote areas of northwest Lincoln County. In most of the Yeso area, outcrops are poor or nonexistent across wide valleys or plains as around Cedarvale and south of Pedernal Station.

In the Pedernal and Rattlesnake areas, Yeso lies in many places on Precambrian rocks. In the subsurface, short distances east of the Precambrian exposures, the Yeso lies on Abo beds, and as in most parts of New Mexico this contact is conformable. Where the Abo laps onto the Precambrian, considerable conglomerate or arkose are commonly found with the normal sand and mudstone lithology. By contrast the Yeso near Precambrian outcrops shows little or no coarse material, especially along the eastern side of the Pedernal. This situation is seen at the small inlier of Precambrian in Yeso at the southeast corner of T. 8 N., R. 12 E. where 200-foot exposures of Yeso sandstone exhibit only rare fragments of quartzite, even within a few tens of feet of the contacts. However, a few sandstone beds are locally arkosic. On the west side of the Pedernal Hills Kottlowski and Foster (1960, p. 1908-1909) described talus blocks in sandstone matrix in addition to scattered quartzite fragments. During the present work one small exposure of Yeso fanglomerate was found in NW1/4 sec. 8, T. 7 N., R. 12 E. Generally, however, owing to poor exposures, areas of Yeso fanglomerate can not be clearly distinguished from Holocene alluvium reworked from Yeso and quartzite outcrops.

Complete measurable surface exposures of Yeso are lacking because of low dip, wide valleys, and absence of well-situated outcrops of Abo normally marking the Yeso base. One noteworthy partial exposure is along the north slope of Jumanes Mesa (T. 3 N., R. 9 E.) where perhaps as much as 200 feet of the uppermost Yeso can be seen. The best partial exposure is along the western base of Duran Mesa where as much as 400 to 500 feet of upper Yeso beds are well exposed beneath the steep slopes in the overlying Glorieta Sandstone. Exposure is enhanced by active dissection westward to Pinos Wells playa, and by two thin limestone units holding up narrow "steps" in the Yeso. The lower limestone is 10 to 20 feet thick and the upper, 20 to 30 feet. The intervening Yeso is typical, consisting of alternating gypsum, friable white sandstone, and red fine-grained sandstone and siltstone. In 1949 (p. 171) I estimated the Yeso to be about 1,000 feet thick in the Gallinas Mountains where both an Abo base and a Glorieta top were present, but igneous disturbance and rugged, forested terrain posed uncertainties. Perhac (1970, p. 10) thought the thickness might be about 1,500 feet. A well drilled along the eastern side of Estancia Valley (SW^1/4 sec. 20, T. 6 N., R. 10 E.) penetrated 500 feet of Yeso sandstone, red mudstone, and limestone below 95 feet of Quaternary valley clay, gypsum, and gravel (Bates, 1942, p. 89).

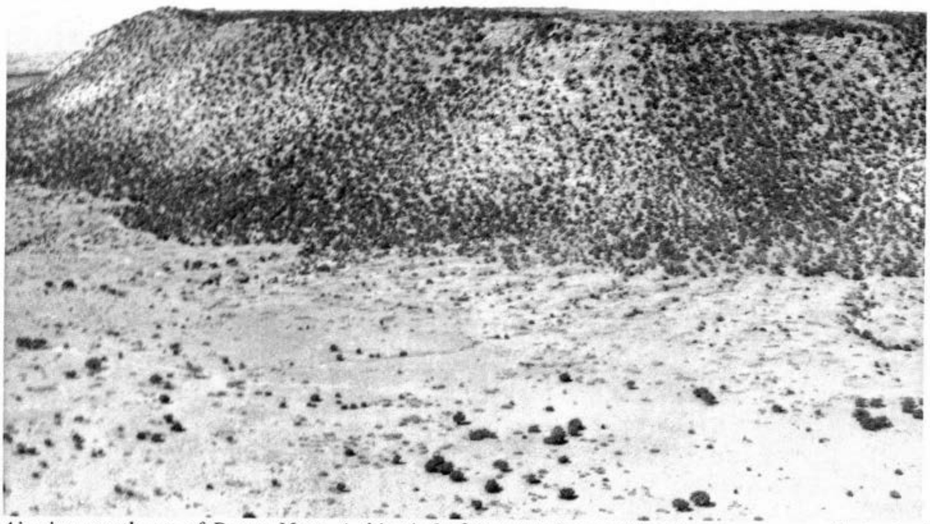
San Andres Formation

The same subdivisions of the San Andres Formation worked out in the Pecos country to the south are traceable throughout this area. These are from bottom to top Rio Bonito, Bonney Canyon, and Fourmile Draw Members (Kelley, 1971, p. 6). The carbonate rocks of the Rio Bonito of the southern region intertongue with the Glorieta Sandstone Member of this area. These units are facies equivalents. The facies change takes place by mutual intertonguing and some lithologic gradation. Coincidentally, the dominance of sandstone takes place at about lat 34 N., the southern boundary of the present work. Therefore, the Glorieta term is used in this report. The present mapping shows that what has been termed San Andres overlying Glorieta in much of central New Mexico is essentially Bonney Canyon, or in places, Fourmile Draw beds on Glorieta. The Fourmile Draw appears to pinch out or be overstepped by Artesia beds in T. 7 N., R. 15 E. along the outcrop; northward only Glorieta and Bonney Canyon may constitute the San Andres. However, since outcrop exposures are not continuous in some places, notably in the east, some Bonney Canyon may contain gypsum thereby making it indistinguishable from Fourmile Draw. A similar situation may exist west of the Pedernal landmass in central New Mexico where the Bonney Canyon Member disappears one way or another and Fourmile Draw lithologies directly overlie Glorieta. Thus, the Evaporite member identified by Kelley and Wood (1946), is possibly the Fourmile Draw of this and the Pecos slope areas.

Glorieta Sandstone Member

The Glorieta Sandstone crops out widely through a north-south belt in the middle of map 1. The best exposures are in the Duran, Trancheras, and Corona Mesas and around the Gallinas Mountains and westward to Jumanes Mesa. Northward from Duran, outcrops are much obscured by pediment deposits until northeast of Encino, where, in the Pintada canyons around Derramadera, there are good exposures, particularly of the upper beds. Additional good exposures occur near Palma and U.S. Highway 66 (T. 9 N., R. 15 E.). The best exposure of Glorieta in the whole region is in the west face of Duran Mesa where a 280-foot thickness occurs above Yeso and is capped by Bonney Canyon dolomite on top of the mesa.

This section is entirely sandstone which is white with only gray to yellowish staining. Bedding is predominantly parallel, and thickness ranges from one-half foot to seven feet. The thick massive beds usually show textured laminations or layers, without parting planes, ranging in thickness from 0.25 to 3 inches. Crossbedding is fairly common, ranging from 1 to 15 feet between parallel beds. These beds also are laminated and noticeably thinner and more regular than the slight waviness of some of the flat laminations. The cross laminations range from 0.05 to 0.2 inches in thickness. The crossbedded units are usually lenticular and grade laterally into parallel or non-crossbedded sandstone.



Air view northeast of Duran Mesa. A thin rind of Bonney Canyon limestone caps mesa. Contact of Glorieta Sandstone on Yeso Formation is about at the grass line.

The Glorieta is possibly the purest sandstone known in New Mexico. Perhac (1970, p. 13) determined petrographic modes of three samples from the northeastern part of the Gallinas Mountains in which quartz ranged from 91.3 to 97.2 percent. Comparison with a number of similar analyses of sandstones from Yeso (Perhac, 1970, p. 11) shows the Yeso lower in quartz (72.0 to 90.6 percent) and higher in feldspar (5.9 to 18.8 percent). The orthoquartzitic texture of the Glorieta samples noted by Perhac is mostly due to proximity to the intrusions. The Glorieta quartz is generally medium grained, subrounded and well sorted.

In most places the basal part of the Glorieta is thinner bedded than the middle or upper parts. In some places it is thin bedded near the base and appears to be almost shaly. Smith (1957, p. 33) described the basal contact as gradational into the Yeso, but this gradation probably does not occur in general. Likely it appears gradational where the upper beds of the Yeso consist of similar sand. However, where red sandstone, mudstone, or gypsum may be beneath the Glorieta, or where the Yeso top represents a pronounced change of conditions, or where the contact is uniform over a very wide area, more likely the relationship is disconformable.

Iron staining, iron concretions, ironstone, hematite or brown chert may be found in the Glorieta in many places. The iron is the work of ground water, in some places heated and activated by intrusions. Near Duran, where there are a number of sills, several prospects have been dug on small hematite veins or on sandstone heavily impregnated and replaced by hematite. The small butte about two miles north of Duran is capped by Glorieta ironstone, which from a distance appears to be a dark igneous sill. East of Encino and north of Carnero Station on the Santa Fe Railroad much hematitic material occurs in the Glorieta, much of which could be used for decorative or ornamental stone. In places the sandstone is reticulated with veins. Elsewhere it is a replacement or cementation breccia.

Within the area most of the significant tonguing from carbonate to sandstone occurs from Tecolote northward to about the Gallinas Mountains. Rawson (1957, fig. 3) measured two sections in the Tecolote district of the beds between the Yeso and his limestone member (Bonney Canyon) of the San Andres Formation. The sections are five miles apart and both consisted of several alternating sequences of carbonate and sandstone. The southern section, 147 feet thick, is 43 percent limestone; the northern section is 212 feet thick and only 13 percent limestone. Rawson's map clearly shows limestone tongues wedging out northward between the sections. North of Tecolote nearly to Bonito Canyon, limestone is seen in several places near the middle of the Glorieta. However, the intertonguing is not entirely clear or simple on a regional basis and needs more attention. For example, limestone occurs in the Glorieta in Estancia Valley at the "island" in the lake beds (T. 6 N., R. 10 E.).

In view of the intertonguing and gradation of the Glorieta facies with the marine carbonates of the Rio Bonito Member, the southern part of the Glorieta was probably deposited under marine or near-marine conditions.

Within the area of this report the Glorieta attains its maximum thickness, and maintains thicknesses in excess of 200 feet over a wide area. Fischer and Hackmann, (1964) measured two sections just east of Corona, each about 280 feet. Bates and others (p1. 5) found a 275-foot thickness on the north face of Chupadera Mesa south of Willard. At Bonito Canyon east of Gallinas Station the unit is 225 feet thick. Hock (1968, p. 13) found a thickness of as much as 205 feet near Derramadera in Pintada Canyon. Mourant and Shomaker (1970, p. 13) identified thicknesses in the subsurface of De Baca County ranging from 60 to 170 feet, the thinner intervals to the east. The thick, noncarbonate facies of the Glorieta is distributed in a long north-south lobe southward from the central part of Glorieta Mesa to near Corona. East and west of this lobe, as well as to the south, the sandstone thins and tongues with marine carbonate beds.

Bonney Canyon Member

This unit, with the underlying Rio Bonito Member and overlying Fourmile Draw Member, were named recently (Kelley, 1971) from widespread exposures on the Pecos slope west of Roswell and Artesia. The type locality of the Bonney Canyon Member is along the Hondo River 22 miles west of Roswell. It was mapped in the area west of Roswell around the east end of the Capitan Mountains and across the wide plains north of the mountains to the mesas east of Corona. The unit is more easily recognized as the underlying carbonates of the Rio Bonito give way to Glorieta Sandstone. The Bonney Canyon was traced westward along the southern flanks of the Gallinas Mountains and onto Jumanes and Chupadera Mesas south of Estancia Valley.

Northward from the Corona mesas the unit is covered by pediment gravel and caliche across the wide plain extending to Duran. In the Duran area the unit is again found as outliers capping the surrounding mesas. East of Duran the unit reappears in a narrow, readily identified outcrop band between Glorieta and Fourmile Draw outcrops in T. 3, 4 N. midway between Duran and Vaughn. Northwest of Vaughn the outcrop continues through Pintada Canyon and is easily mapped across the high mesas north of the Pedernal Hills and in the vicinity of Clines Corners and into the Estancia basin. The San Andres capping Glorieta Mesa in San Miguel and Santa Fe Counties now appears to be Bonney Canyon. Furthermore, the limestone beds near Clines Corners are probably continuous as far away as the thin capping of Bonito Canyon beds along the northern crest of the Guadalupe Mountains in T. 25 S. just north of the Capitan reef.

The Bonney Canyon is finely crystalline and gray to dark gray. Bedding ranges from about 0.5 to 5 feet in thickness. Some thin sandstone beds may be present locally. Chert is sparse to moderate locally.

Thickness of the Bonney Canyon in this area is variable but does not appear to exceed much more than 100 feet. The upper contact is usually very poorly or not at all exposed. In places the upper part appears to change partly or entirely to gypsum. In the northeast part of T. 6 N., R. 15 E. all but some 10 to 20 feet of the base changes to gypsum and thereby resembles the overlying Fourmile Draw Member. Locally, south of the Gallinas Mountains the carbonate lithology diminishes considerably. Rawson (1957, fig. 3) measured about 85 feet at Tecolote. Hock (1968, p. 15) measured a 70-foot section of San Andres near Clines Corners (sec. 12, T. 10 N., R. 12 E.) and a 110-foot section near Derramadera. At both places the top was the Grayburg Formation with the Fourmile Draw Member missing. Mourant and Shomaker (1970, p. 14) logged the Hawkins 1 Myrick well (sec. 25, T. 2 N., R. 25 E.) about 6 miles southwest of Fort Sumner and described an interval that is probably the Bonney Canyon and 110 feet thick beneath an upper interval of 625 feet that is probably the Fourmile Draw Member.

Although little work has been done in identifying the carbonate composition over so wide an area, both limestone and dolomite are present. In general, the dolomite characteristic of the unit south of this area appears to change northward to limestone. Most of the unit is exposed in a quarry at Gallinas Station. My chip samples across 30 feet of wall were analyzed by General Portland Cement Co. with the results approximating theoretical dolomite.

The Bonney Canyon Member is the only definite marine unit of the Permian in this area. In places, Bates and others (1947, p. 34) found abundant silicified shell fragments resembling a coquina. Hock (1968, p. 16) found several brachiopods in T. 8 N.

Analysis Bonney Canyon Member

Compound	*Wt.%*
SiO_2	3.26
Al_2O_3	0.56
Fe_2O_3	0.14
CaO	32.20
MgO	20.02
SO_3	0.00
Loss	44.31
Na_2O	0.005
K_2O	0.11

east of New Mexico Highway 3. During the present reconnaissance mapping many outcrops were found to have small fragments of fossils. Evidently the unit is marine.

Fourmile Draw Member

The Fourmile Draw Member was named from exposures along the draw near the northeastern base of the Guadalupe Mountains (Kelley, 1971, p. 13). North of the Capitan Mountains the unit spreads flatly across a plain for some 50 miles east and west and about 20 miles north and south between the Capitan Mountains and the Corona mesas. The outcrops continue in an expanse of some 10 to 20 miles to near Vaughn. In the Mesa Leon area north of Vaughn the belt constricts partly due to thinning and partly due to overlap by Triassic rocks. At Derramadera (T. 7 N., R. 15 E.) the unit wedges out between Bonney Canyon limestone on the west and Grayburg red beds on the east. A short outcrop of westward-dipping beds occurs along the eastern side of Estancia Valley (T. 7 N., R. 10 E.)

Karst topography and much caliche characterize the flatlying outcrops. Sink holes are exceedingly abundant in the outcrops, and the formation is responsible for numerous sinks in the overlying units.

The Fourmile Draw Member consists dominantly of interbedded dolomite and gypsum and lesser beds of reddish mudstone. Dolomite beds are mostly less than one foot in thickness. Dolomite intervals may be several tens of feet thick with little or no intervening gypsum and as much as 75 to 100 feet of gypsum without dolomite is found in places, especially near the top of the member. In some places dolomite and gypsum are found thinly interlayered; and some beds of dolomite contain inclusions of gypsum. The gypsum is usually white but locally light green or reddish brown.

The thickness of the Fourmile Draw Member is impossible to obtain from the surface owing to its flatness and wide expanse in most outcrops. Mourant and Shomaker (1970, p. 14) logged San Andres intervals of 536 and 640 feet in oil tests in the western part of De Baca County. Near the middle of the county and about six miles southwest of Fort Sumner the above authors logged 625 feet of San Andres that undoubtedly is a good full section of the Fourmile Draw (Hawkins 1 Myrick well, sec. 17, T. 2 N., R. 25 E.). Still farther to the east, and east of the Pecos River, salt appears in the section; the member west of the river may have become thinner than originally owing to sublation of salt and other soluble beds.

Artesia Group

To better define and relate the formations between the subsurface and the surface the name Artesia Group was introduced by the Roswell Geological Society in 1962 (Tait and others) to embrace five formations already named. The term Bernal had already been used for beds of this group in central New Mexico (Kelley, 1949, fig. 2;

Bachman, 1953). The Bernal, however, was often designated as an uppermost clastic and evaporitic member of the San Andres Formation, whereas the Grayburg, the lowest formation of the Artesia Group, overlies the highest San Andres beds.

During recent mapping in areas of the Carlsbad and Roswell sheets (AMS, Army Map Service), the Artesia was divided into its formations in large areas previously shown as undivided (Kelley, 1971, pls. 2, 4). During the Fort Sumner sheet mapping, the subdivisions were partly carried through all the known areas of the Artesia. In ascending order the five formations of the group are Grayburg, Queen, Seven Rivers, Yates, and Tansill. The Grayburg and Queen Formations have never been divided on the surface north of T. 20 S. because they are almost entirely covered by alluvium for 60 miles in the Pecos Valley. North of Roswell where the lower part of the Artesia reappears in considerable exposure, the break with the overlying Seven Rivers Formation has not been found. Therefore, from Roswell northward, the lower unit has been mapped as Grayburg and Queen Formations undivided, hereafter called "GrayburgQueen."

In the Pecos Valley at the latitude of Hagerman (T. 14 S.), the Tansill Formation became covered by alluvium and overlapped by the Triassic. The Yates and Seven Rivers Formations have been traceable northward throughout exposures in the Fort Sumner region. Due to the vagaries of stripping of the overlying Santa Rosa Formation (Triassic), some Tansill may be present at least locally in terrane mapped only as Yates; because of the lack of continuous good exposures and the similarity of lithologies these units were not separated. For a short distance in T. 2, 3 S. along the east bank of the Pecos River a good Yates sandstone underlies beds that could be Tansill. Here a dashed line is used to show at least the top of a Yates sandstone within a wider outcrop band that could be either or both Yates and Tansill. Northward and west of the Pecos River such lithologic distinctions above the Seven Rivers Formation are not evident, but the thickness as well as lithology favors Yates. The Tansill could have been stripped before Triassic deposition.

Subdivision of the Artesia from Roswell northward is largely based on the recognition of the Seven Rivers gypsum in the middle of the Artesia Group. Thus, the divisions are threefold upward: 1) Grayburg-Queen, 2) Seven Rivers, and 3) Yates or Yates-Tansill.

Grayburg and Queen Formations

The undivided Grayburg-Queen unit is widely exposed in the eastern part of the area. The best exposures are along the Pecos Canyon from north of the Alamogordo Reservoir to near Santa Rosa and along Pintada Canyon (map 2). In both these canyons the unit occupies the bottom and lower walls; the overlying Santa Rosa rims the canyons. In Pintada Canyon near San Ignacio small inliers of Fourmile Draw (San Andres) limestone and gypsum give a local base to the Grayburg-Queen unit.

Widespread outcrops occur in the drainage system of Arroyo de la Mora from about 9 miles east of Dunlap between R. 20 and 24 E. A smaller inlier occurs near the head of Arroyo Yeso north and west of El Morro Mesa, and another in the upper reaches of Arroyo Salado from R. 21 E. to near Vaughn. Poorly exposed red beds along the south and east sides of Mesa Leon, along the slopes of Mesa Aragon, and in the narrow belt north and south of Derramadera (T. 6 to 8 N., R. 15 E.) are also included in the Grayburg-Queen unit.

In the extreme northwestern corner of the area (map 1) small exposures occur west of the Pedernal uplift in T. 7, 9 N., R. 10, 11 E., and in scattered exposures through T. 2, 3 S., R. 9 to 12 E. south of the Gallinas Mountains. These exposures are so distant from the Artesia units in the Pecos drainage system, that their correlation is uncertain.

Because they rest on Fourmile Draw beds, we might logically assume these exposures are lowermost Grayburg. If they were higher in the Artesia then, somewhere among the wide exposures of the Pecos drainage system, one could expect to find overlap of lower units by upper units. No such overlap has been found. Erosional stripping and cover by Cenozoic beds obscure many critical areas, however, and perpetuate the uncertainty. In the Pecos country work (Kelley, 1971, p. 16) Grayburg was mapped in the Capitan and Ruidoso areas; these outliers were also far removed (50 miles) from the continuous outcrops in the Pecos Valley to the east—also reason for uncertainty. Similar, though lesser, uncertainty exists for the Artesia units north of the Fort Sumner sheet northward to the type locality of the Bernal near Bernal and Chapelle, New Mexico. The term Bernal Formation, therefore, should not be abandoned as proposed by Tait and others (1962). It should be retained and used for the uncertain Artesia facies north of about lat 35° N. and west of the longitude of Vaughn. The term Bernal should be used in the areas of Capitan and Ruidoso, the Tularosa Valley and northward through the Carrizozo, Claunch, Estancia Valley, along the Pecos River drainage upstream from the elbow in T. 10 N., R. 21 E., and on Glorieta Mesa. In most places the Bernal is too thin and uniform to fit a group terminology. Furthermore, the name is well entrenched in the literature.

Grayburg-Queen beds are poorly or not at all exposed. Where seen, the sequence consists of tan-brown or light-gray, fine-grained, and very fine grained sandstone with some reddish-brown or greenish-gray mudstone and some interbedded gypsum. Dolomite is rare and usually in the lowermost beds of the southernmost exposures. Gypsum occurs mostly in the lower part of the section. Gypsum decreases, thins, and becomes lenticular and irregular in distribution northward through the area; and is essentially absent in the upper part north of T. 7 N. Gypsum in the lower part continues north of the area to about the latitude of Colonias in T. 10 N.

Unusually good exposures of Grayburg-Queen occur along a south fork of Salado Arroyo in the southern part of sec. 27, T. 4 N., R. 20 E. The base of the unit is covered. The section consists of 75 to 100 feet tan-brown and white, fine-grained sandstone. Bedding is expressed in prominent one- to five-foot ledges; a few thin

Tan-brown and white sandstone of the middle part of the Grayburg-Queen interval. North side of arroyo in sec. 27, T. 4 N., R. 20 E.

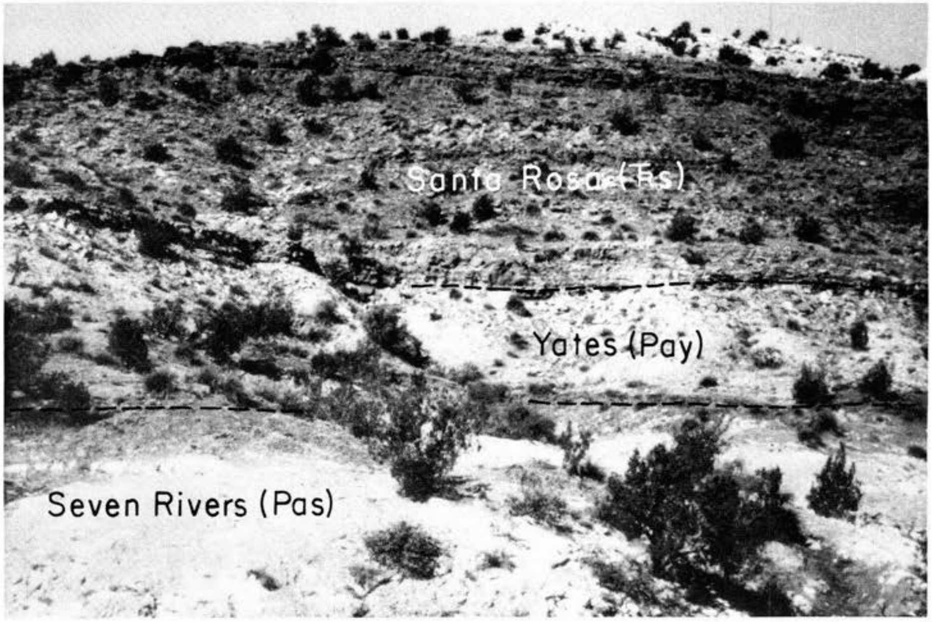
red-brown siltstones occur in slopes between the sandstone beds. This exposure resembles those of the Bernal. Considerable section is above the prominent arroyo exposures east toward the outliers of Seven Rivers, pediment caps, and Yates in the interfluve between the fork and the main part of Yeso Arroyo (pl. 2). The San Andres is probably not more than 50 to 100 feet beneath the white sandstone which floors the arroyo at this locality. The formation may be 150 to 200 feet thick in this area; this range of thickness probably holds for most of the area except in the northwest and in the Derramadera area where it may be only 50 to 100 feet thick. Thicknesses in these areas, however, are not original as they have been thinned by Triassic erosion.

The contact with the underlying Fourmile Draw Member is a problem. This boundary is commonly considered to be at least a mild erosion surface. Evidence is mostly in irregularity of the contact in detail and the infilling of red beds into a slumped or brecciated upper surface on the carbonates; but much of this is a ground-water effect. In many places the base of the Artesia is mapped on carbonate, but in other places, as west of Dunlap, it is on gypsum. Gypsum is common in the Fourmile Draw and also in the lower part of the Grayburg-Queen especially southward toward Roswell. Some red beds also occur in the Fourmile Draw, but generally the delineation of the contact is made on carbonate versus red clastics. This situation has given rise to problems of picking the boundary, both on the surface and in the subsurface. In this work, for example, the gypsum in the Rocky Canyon Wash area west of Dunlap is mapped as part of the San Andres, but Mourant and Shomaker (1970, map 1) assigned the gypsum to the Artesia, as shown on the state geologic map (Dane and Bachman, 1965). Red beds overlie this gypsum in the Dunlap area, but to the west along U.S. Highway 285 in sec. 7, T. 3 S., R. 21 E. some thick ledges of dolomite lie above the gypsum. Some similar white gypsum occurs just above the mapped dolomite inlier of Fourmile Draw near the head of Arroyo Salado (T. 5 N., R. 19 E.), but was mapped with the Grayburg-Queen because of poor exposures.

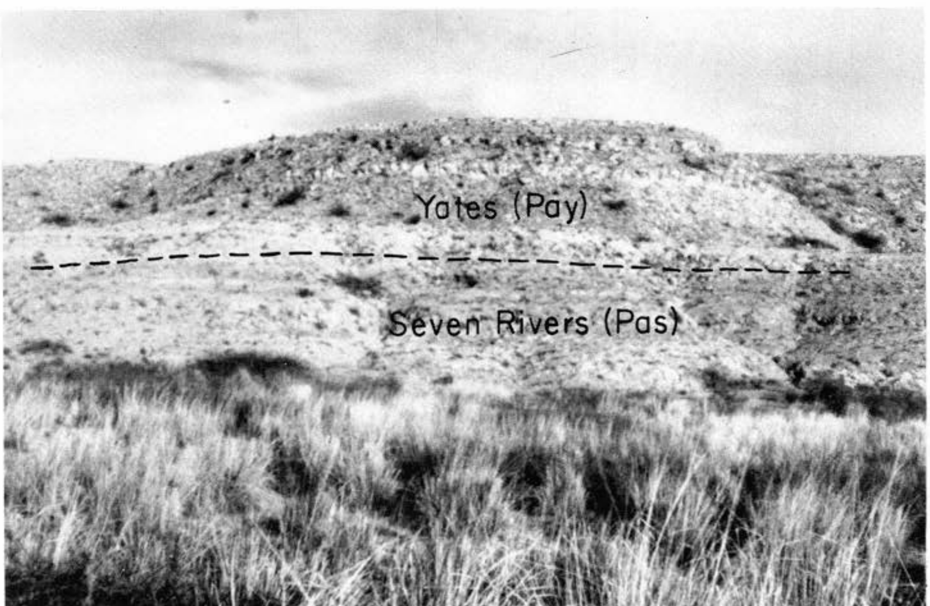
Seven Rivers Formation

The Seven Rivers is widely exposed in the area and extends from prominent outcrops in bluffs along the Pecos River (T. 3 S., R. 25 E.) northwesterly along the sides of several of the major Pecos tributaries. It is especially widespread at the surface east, north, and northeast of Dunlap. It surfaces wide areas around Gillespie, Blanco, and Conejos Creeks (T. 1, 2 S., R. 23 to 25 E.). Northwest of Dunlap good exposures occur in Gramma Valley around El Morro Mesa and on into the upper parts of Arroyo Yeso. Good exposures also occur along Arroyo Salado especially in T. 4, 5 N., R. 20 to 22 E. However, the formation does not extend far north of Arroyo Salado; somewhere in T. 5 N. beneath the pediment cap of Guadalupe Mesa it wedges out along with the overlying Yates beneath northward plicating Santa Rosa Sandstone (fig. 6).

The Seven Rivers Formation is distinctive, and is readily followed in most places, especially with air photos. This is due to the dominance of white, dense (alabaster), usually thick gypsum beds. The beds are resistant and usually stand physiographically in contrast with the thinner weaker beds above and below. Thin greenish or reddish mudstone beds intercalate with the gypsum locally, especially in the lower part. The basal part also has thin, tan-brown, fine- to very fine grained sandstone beds at least locally. In many places the interbedded gypsum and mudstone of the basal part are incompetently distorted in an outcrop band that makes the boundary more readily identifiable. Where exposures are good the upper contact with Yates sandstone or siltstone is fairly abrupt. Although Yates overlies the Seven Rivers in most places, in the mesas east of Ramon Triassic erosion has brought the Santa Rosa down across the Yates onto the Seven Rivers. Also along Arroyo Salado in T. 4, 5 N., R. 21 to 22 E.,



Seven Rivers, Yates, and Santa Rosa Formations in sec. 3, T. 1 N., R. 20 E., 6.5 miles west of Overton ranch.



Seven Rivers overlain by Yates in the east bank of the Pecos River, sec. 34, T. 2 S., R. 25 E.

and notably along the south side, the Santa Rosa cuts down through Yates onto Seven Rivers.

As noted in earlier work (Kelley, 1971, p. 18) quartz crystals known as "Pecos diamonds" occur near the top of the Seven Rivers. They are abundant in many places in this area as around the head of Arroyo Yeso and in T. 3 S., R. 25 E. Crystals of diagentic dolomite and anhydrite also occur.

Yates and Tansill Formations

As indicated above the beds described here are predominantly Yates, but in places, especially in thicker exposures, an upper part may include some Tansill. Surface distribution of these rocks extends from small exposures east of the Pecos River (T. 2, 3 S., R. 25 E.) northwestward through the Mora to Salado tributaries of the Pecos River. Throughout the area, Yates outcrops are closely associated with those of the Seven Rivers. However, differential erosional stripping of the weaker Yates beds in the Conejos and Blanco drainages northeast of Dunlap, has left numerous thin outliers of Yates scattered across a terrane of Seven Rivers.

In all exposures of the base, the Yates lies on the Seven Rivers, usually with little or no transition. This is the most distinct contact within the Artesia Group. The top of the unit is, in most places, in contact with the Santa Rosa Sandstone. This contact is a truncating erosional surface, hence the upper beds of the stratigraphic level for Yates and Tansill in contact with the overlying Santa Rosa are not the same over extensive stretches.

The Yates Formation has been mapped into this area by outcrops east of the Pecos River north of Carlsbad, a distance of about 100 miles. For many miles north from the Capitan reef the typical sandstone of the Yates is obscured in abundant gypsum and mudstone; in the area east of Artesia to Roswell the Yates is largely covered by surficial Quaternary material, and is not readily traced until, northeast of Roswell distinctive Yates consisting of olive-drab, fine-grained sandstone and siltstone is seen above the river bluffs. Northward along the bluffs of the Pecos River into the southeastern corner of the Fort Sumner area the Yates begins to develop fine exposures (sec. 3, T. 3 S., R. 25 E.). Here in what could be a good surface reference section, Yates rests sharply on Seven Rivers. The upper part may include a partial Tansill section. The lower beds, perhaps strictly Yates, are light-gray to greenish-gray fine-grained sandstone and siltstone, and are about 50 feet thick. Above the bluffs the section is red and green mudstone, with some thin dolomite beds, the combined section being as much as 100 to 125 feet thick. Southward the section appears to thicken some owing principally to stratigraphic rise of the Santa Rosa Sandstone base. Exposures, however, are not good. One especially good exposure of the Yates has been measured in bluffs east of the Pecos River where a section was measured on the Van Eaton ranch about 27 miles south of Fort Sumner.

The Yates is not well exposed in most other outcrops of the area, especially down to the underlying Seven Rivers, except near the head of Arroyo Yeso just northeast of a Santa Rosa outlier butte in the NW1/4 sec. 3, T. 1 N., R. 20 E. where a section was measured in the base of the cliffs.

TRIASSIC

The Triassic rocks of eastern New Mexico have long been assigned to the Dockum Group. The term Dockum was proposed by Cummins (1890, p. 189) for extensive occurrences in the vicinity of Dockum, Dickens County, Texas, about 65 miles east of Lubbock. Cummins recognized the characteristic conglomerate, coarse often

Section of Yates Formation at Van Eaton Ranch
(sec. 34, T. 2 S., R. 25 E.)

Bed	Lithology	Bed thick. (ft)	Total thick. (ft)
	Santa Rosa Sandstone (Triassic); Overlain unconformably by 2-foot, light-gray dolomite pebble conglomerate with reddish-brown coarse sandstone; 10-foot dark-gray petrified log at top.		
11	Sandstone; tan to reddish-brown; very fine grained; several 1-inch dolomite beds in lower part	15	95
10	Dolomite; gray, granular, laminated and unlaminated	1½	80
9	Sandstone; red and red-brown fine grained; lower one-half is locally gypsum	12	78½
8	Siltstone and claystone; greenish olive drab; small limonite after pyrite nodules common	18	66½
7	Dolomite; light gray; dense and laminated	2	48½
6	Sandstone; tan-white, very fine grained; weathers yellowish brown or rusty, in 1- to 3-inch beds	7	46½
5	Sandstone; white; very fine grained; small pyrite and marcasite concretions common	5	39½
4	Sandstone; tan-white, very fine-grained; weathers yellowish brown; in 1- to 3-inch beds	8	34½
3	Sandstone; white; very fine grained; pyrite or marcasite concretions common	3½	26½
2	Sandstone; tan-white; very fine grained; weathers to a rusty yellow-brown; 1- to 3-inch beds	12	23
1	Sandstone; light gray; very fine grained; ½-inch beds	11	11
	Rests conformably on Seven Rivers gypsum		

Section of Yates Formation
(NW¼ sec. 3, T. 1 N., R. 2 E.)

Bed	Lithology	Bed thick. (ft)	Total thick. (ft)
	Santa Rosa Sandstone; overlain by 18 ft. white to tannish and purplish-tan, medium-grained, micaceous sandstone		
	Unconformity		
	Top of Yates		
6	Sandstone; reddish brown, very fine grained	1	54
5	Sandstone; greenish gray, fine grained very thinly bedded to weakly shaly	4	53
4	Sandstone; reddish brown, very fine grained, silty	3	49
3	Sandstone; greenish gray, fine grained, shaly to chippy and mostly thin bedded, a few 1- and 2-foot beds weather spheroidally	36	46
2	Sandstone; reddish brown to tan brown, fine grained	10	10
	Base of Yates (Seven Rivers gypsum)		

micaceous sandstone, and mudstone, all dominated by buff to reddish-brown colors. The age was recognized by fossil reptiles. Silicified wood and fresh water Unios were also found from the beginning. Although early workers (Cope, 1903, Gould, 1906, and Case, 1914) generally recognized that these beds extended into New Mexico, the term was not directly applied to specific areas until Darton used the term Dockum Group in 1922 (p. 183). He applied it to all the red-bed sequence between his Chupadera (Permian) and Wingate (Exeter) Sandstone. He also first introduced the term, Santa Rosa Sandstone, which he suggested occupy an equivalent superposition to the

Shinarump Conglomerate of Arizona. Darton appears to have been motivated to a group designation by the unstated assumption that the thick red bed and mudstones above were Chinle. Even in his "Red Beds" bulletin of 1928 he used only Dockum Group and Santa Rosa Sandstone for Triassic occurrences east of the Rio Grande. Most attention was given to the Santa Rosa Sandstone, and apparently Darton (1928, p. 288-290) intended to specify the exposures around the northern edge of town as a type locality. The term Chinle was never used directly for the thick Triassic sequences above the Santa Rosa in the eastern part of the state except on page 270 he refers to "the bright-red shale of the Dockum Group (or Chinle?)" in a discussion of the Wingate Sandstone. In a study of the Triassic of the West Texas Permian basin Adams (1929, p. 1045) stated "the names Santa Rosa and Chinle, as used for the Triassic of central New Mexico, are extended to include the equivalent formations in the Texas section." The first published geologic map showing the distribution of the Santa Rosa and Chinle in eastern New Mexico appeared in 1962 (Bachman and Dane).

In 1942 Bates (p. 151) used the term Chinle Shale for the thick Dockum mudstones and sandstones of eastern San Miguel County in eastern New Mexico. In 1946 Dobrovolny and Summerson singled out a top part of the Chinle as the Redonda Member, and in 1959 Griggs and Read recommended separation of this unit from the Chinle and termed it the Redonda Formation. However, in the present work owing to poor exposure and minor emphasis on this part of the section, this unit has been combined with the Chinle.

Santa Rosa Sandstone

The Santa Rosa is best exposed in the canyons of the Pecos River and its western tributaries. The formation is also well exposed on Mesa Aragon, on and west of Mesa Leon, and in ridge and mesa escarpments south of Buchanan Station. For many miles

Santa Rosa Sandstone lying on Grayburg-Queen. View north 1.5 miles south of Puerto de Luna in the western wall of Pecos Canyon.

Pecos Canyon south of Santa Rosa is floored by Permian beds overlain sharply by strong Santa Rosa ledges holding up the canyon rims. To the east of the rim the contact with the overlying Chinle Shale is near the canyon edge in several places. On the pediment north of Pintada Canyon and along U.S. Interstate 40 the Santa Rosa is at or near the surface for some 40 miles west of Santa Rosa.

In some respects, the Santa Rosa is like a vast pediment sheet because of the manner in which the formation regionally plicates older formations. East of Artesia the Santa Rosa rests on Rustler beds (highest Permian). Northward east of Roswell the Santa Rosa rests on the Yates and probably continues in that position until near Fort Sumner. Contacts have been eroded over great areas west of the Pecos. Near Capitan, however, the Santa Rosa is stratigraphically lower, resting on the Bernal. Northward from Capitan the Santa Rosa appears to ride consistently with the lowest Artesia beds into central New Mexico. Westward from the Pecos River area some interesting relationships, missing in the southern Pecos country, begin to appear. These are shown in the three large canyons tributary to the Pecos: Yeso, Salado, and Pintada (map 2).

Along Yeso Arroyo north of Conejos Mesa, Santa Rosa beds are on Yates in T. 22, 23 E., but 10 miles farther west at the head of Yeso Arroyo, are down on, or nearly on, the Seven Rivers gypsum. Along Salado Arroyo the situation is more complicated; and in R. 22 E. the Santa Rosa rests partly on Yates and partly on Seven Rivers, the latter especially along the south side of the canyon. Near the head of the Salado the Santa Rosa rests on Grayburg not far above San Andres beds in the bottom of the arroyo (T. 19 E.). In the eastern part of Pintada Canyon (R. 20 E.) the base of the Santa Rosa rests on Grayburg-Queen, and stays in this position for about 30 miles westward up the canyon. All the Yates and Seven Rivers that lay between the Grayburg-Queen and the Santa Rosa in Salado Arroyo, 20 miles to the south, is wedged out about midway between the two canyons.

A type locality and measured section for the Santa Rosa have never been given. Several sections were measured, the first designated as the type section.

Type Section of Santa Rosa Sandstone
(SW¼ sec. 35, T. 9 N., R. 21 E., 1 mile north of Santa Rosa)

Bed	Lithology	Bed thick. (ft)	Total thick. (ft)
	Top eroded (probably less than 20 feet):		
13	Sandstone; buff to white, medium grained, medium bedded, local crossbeds and lenticular local thin greenish mudstone	115	216
12	Conglomerate; tannish gray, pebbly, local silicified wood	5	101
11	Sandstone; white, coarse grained, massive	13	96
....			
10	Conglomerate; buff, pebbles–chert, quartz, sandstone, limestone	9	83
9	Sandstone; white to light buff, medium grained, massive	3	74
8	Conglomerate; light buff to white, pebbly, thin bedded	2	71
7	Sandstone; white to light buff, medium grained	12	69
6	Conglomerate; light buff, pebbly, massive, bleached portion of #5 beneath base of cliff	6	57
5	Conglomerate; purplish brown, pebbly sandstone fragments, thin bedded	17	51
4	Sandstone; light purplish brown, medium grained, thick bedded	9	34
3	Sandstone; buff to light tan, medium grained, with scattered granules and angular pebbles	5	25
2	Sandstone; buff to light purplish brown, medium to coarse grained, medium and thin bedded, crossbedded	13	20

1	Sandstone; buff to light tan, medium to coarse grained, with scattered granules and pebbles of sandstone	7	7
	Rests unconformably on Permian tan-brown sandstone about 75 feet above Pecos River		

Section of Santa Rosa Sandstone at Pecos River
(NW¼ sec. 20, T. 8 N., R. 22 E., 4 miles southeast of Santa Rosa)

Bed	Lithology	Bed thick. (ft)	Total thick. (ft)
	Top eroded (probably less than 10 feet):		
11	Sandstone; brownish gray, medium grained, medium bedded	4	187
10	Sandstone; brownish gray, medium grained, thin bedded	6	183
9	Conglomerate; light brown, limestone pebbles, thin bedded	5	177
8	Sandstone; yellowish brown to buff, medium grained, thin laminated bedding with local mudstone lenses	6	172
7	Sandstone; light tan to buff, medium grained, medium bedded, some thin mudstone lentils	78	166
6	Sandstone; white to light gray, medium grained, medium to thick bedded, forms rim of canyon	15	88
5	Conglomerate; grayish brown, sandstone pebbles	4	73
4	Sandstone; yellowish gray, medium grained, medium bedded, locally crossbedded	11	69
3	Sandstone; light purplish brown, medium grained, medium bedded, many ledges crossbedded	54	58
2	Conglomerate; limestone pellets and pebbles	3	4
1	Sandstone; light gray to white, medium grained. *Rests unconformably on fine grained, tan-brown Permian sandstone*	1	1

Section of Santa Rosa Sandstone at Pintada Mine Road
(NW¼ sec. 14, T. 8 N., R. 19 E.)

Bed	Lithology	Bed thick. (ft)	Total thick. (ft)
	Top eroded (probably less than 20 feet):		
25	Sandstone; light buff, medium grained, medium bedded, poorly exposed, probably a few thin greenish mudstone lentils	17	217
24	Mudstone; greenish gray, local intercalated sandstone	6	200
23	Sandstone; buff, medium grained, medium bedded	19	194
22	Mudstone; greenish gray, thin bedded	4	175
21	Sandstone; buff, medium grained, medium bedded with local crossbedding	35	171
20	Conglomerate; pebbles of sandstone	3	136
19	Sandstone; buff, medium grained, medium bedded	2	133
18	Mudstone; greenish gray, thin bedded	3	131
17	Sandstone; yellowish buff, medium grained, thick bedded, forms rim of mesa	29	128
16	Conglomerate; rusty yellow to buff, angular pebbles and cobbles of sandstone, thin bedded	6	99
15	Sandstone; yellowish buff, medium grained, thick bedded; conglomerate welded into top 2 feet consists of angular cobbles and pebbles of sandstone	7	93

14	Sandstone; light yellowish brown, medium grained, medium bedded with local granule and pebble lenses	6	86
13	Sandstone; light purplish brown, medium grained, thick bedded	14	80
12	Sandstone; light purplish brown and gray, thin bedded, conglomeratic	3	66
11	Sandstone; light purplish brown, medium grained, thick bedded	8	63
10	Sandstone; greenish gray, medium grained, thick bedded, conglomerate in bottom 1 foot and upper one-third	8	55
9	Sandstone; purplish brown, medium grained, thin bedded, locally crossbedded	15	47
8	Conglomerate; angular brown, sandstone pebbles and cobbles	1	32
7	Mudstone: reddish brown	3	31
6	Sandstone; medium brown, medium grained, medium bedded, micaceous	5	28
5	Mudstone; reddish brown	3	23
4	Sandstone; purplish brown, medium grained, thin to medium bedded	6	20
3	Mudstone; reddish brown and grayish green	2	14
2	Sandstone; light purplish brown, medium grained, medium crossbeds	11	12
1	Sandstone; white, medium grained, thin bedded	1	1
	Rests unconformably on tan-brown fine-grained Permian Sandstone at base of steep part of road.		

The fine dotted line dividing each of the sections marks the principal two fold division of the formation. The lower unit is characterized by lavender to purplish-brown color and more conglomerate, whereas the upper unit is generally buff with massive, well-cemented sandstone in the lower part, with less conglomerate except possibly at the base. The contact between the two units is probably an erosional unconformity. Gorman and Robeck (1946) divided the formation into four informal members in a small area adjoining map 2 north of Santa Rosa. Their "lower member" appears to be the lower unit of my tables: their upper three members are probably equivalent to my upper unit. Their shale member, indicated to range in thickness from 0 to 55 feet, is absent or undetected in the sections around Santa Rosa. They mapped the members separately and found that the lower member was cut out along the Pecos Canyon in T. 10 N., R. 21 E. by their "middle sandstone member" cutting down to the Permian beds.

Read and others (1943, personal communication) found the section in the Guadalupe mining district (sec. 6, T. 7 N., R. 20 E.) to consist of lower, middle, and upper sandstone units aggregating a thickness of 140-160 feet with the top eroded. Their lower unit, 64 feet thick, is equivalent to my type locality lower unit. Their middle (copper-bearing) and upper units are roughly equivalent of the type locality upper unit. Black shale and siltstone occurred at the boundary of their middle and upper sandstone units.

Chinle Shale

The Chinle Shale was named by Gregory (1915, p. 102) for outcrops near Chinle, Arizona. It has been extended widely throughout New Mexico. The Chinle is typically a thick red-brown mudstone but contains numerous sandstone and conglomerate beds, lentils, or tongues, none of which have the great continuity of the formation. In many places the formation has been divided into local members characterized by sandstone or distinctive mudstone-sandstone sequences. However, overall mudstone is dominant.

In the Fort Sumner area, and in particular to the east and north of Santa Rosa, numerous sandstone beds are scattered through the Chinle. An especially well-developed sequence of gray to buff sandstone beds, more or less midway in the Chinle, makes possible the division of the Chinle into three parts: Lower shale member, Cuervo Sandstone Member, and Upper shale member.

Chinle outcrops lie mostly east of the Pecos River. Some small outliers are present just west of the river on benches above the Santa Rosa, but for the most part these outcrops are covered by soil, alluvium, or gravel. Minor outliers are preserved locally beneath pediment and caliche high above Santa Rosa walls along Pintada Canyon east of Derramadera (map 1). Chinle occurs widely east of the Pecos, but in general is poorly exposed. Considerable gravel covers the formation northeast of Alamogordo Reservoir, and alluvium and thin pediment blankets cover many other areas of Chinle up to the bases of Luciana and Taiban mesas in the northeastern part of the area. South from Fort Sumner the Chinle is mostly covered by pediments and aeolian sand.

The Lower shale member occupies the first bench above the Pecos Canyon and is seen in a number of places along U.S. 84 between Santa Rosa and Fort Sumner. This unit is especially well exposed in badlands east of Alamogordo Reservoir in T. 5 N. A short distance south of Santa Rosa the unit is 150 to 200 feet thick. It appears to thicken southward at the expense of the Cuervo Sandstone Member and possibly also the Santa Rosa. In the vicinity, of Fort Sumner the lower Chinle may increase to four or five hundred feet in thickness. The contact with the underlying Santa Rosa is transitional in an irregular way partly owing to thin sandstone beds or tongues, and possibly to some collapsing of the Santa Rosa into the soluble underlying Permian beds. The upper contact of the Lower shale member is exposed along State Road 156 about 5 miles east of Santa Rosa.

The Cuervo Sandstone Member is named here for excellent exposures along Cuervo Creek and for the town of Cuervo a few miles north of the Fort Sumner sheet. A readily accessible type section occurs in a cut along and adjacent to State Road 104.

Type Section Cuervo Sandstone Member
(sec. 4, T. 12 N., R. 25 E.)

Bed	Lithology	Bed thick. (ft)	Total thick. (ft)
	Top eroded (probably less than 10 feet)		
9	Sandstone; buff, medium grained, medium to thick bedded, grayish brown near top	35	224
8	Sandstone; buff, medium to coarse grained, thin to thick lenticular bedding, numerous 6 in to 1 ft pebble beds	32	189
7	Siltstone; gray and reddish brown, shaly, 1 or 2 6-inch medium grained sandstone beds	10	157
6	Sandstone; yellowish buff, medium grained and micaceous, thin to thick lenticular beds and some crossbedding, local lenticular pebble conglomerate beds	41	147
5	Siltstone and sandstone; gray, thin bedded, pebble conglomerate in top 3 ft	13	106
4	Sandstone; gray and buff, medium grained, medium to thick bedded	12	93
3	Conglomerate; gray, pebble fragments are sandstone, limestone, quartz	2	81
2	Mudstone; reddish brown, local red-brown pebble conglomerate in lower 15 ft	60	79
1	Sandstone; greenish gray, medium grained, thin bedded and crossbedded, conglomerate in bottom	19	19

Less accessible exposures of Cuervo Sandstone Member occur across the Alamogordo Creek drainage in T. 6-9 N., R. 25, 26 E. as shown on map 2. The measured section is about 26 miles east of Santa Rosa.

Section of Cuervo Sandstone Member at Alamogordo Creek
(sec. 31, T. 8 N., R. 26 E.)

Bed	Lithology	Bed thick. (ft)	Total thick. (ft)
11	Sandstone; gray, medium grained, thin bedded, some gray mudstone intercalated locally, red-brown Chinle mudstone above	13	155
10	Sandstone; gray, medium grained, thick bedded, laminated crossbedding in places	25	142
9	Conglomerate; gray, limestone granules and pebbles and concretionary-like pellets	2	117
8	Sandstone; gray, medium grained, thick bedded with crossbeds laminated in northerly dips	12	115
7	Conglomerate; gray, limestone granules and pebbles and concretionary-like pellets	6	103
6	Sandstone; gray, medium to coarse grained with local seams of limestone pebble conglomerate, thick bedded and local crossbedding	27	97
5	Mudstone; gray and reddish brown, thin bedded	6	70
4	Sandstone; light gray, medium grained, medium bedded with thin crossbedding dipping mostly southerly but some northerly	30	64
3	Sandstone; greenish gray, coarse and medium grained, locally granulitic, thin bedded and locally crossbedded	24	34
2	Conglomerate and mudstone; gray and reddish brown, pebbly and nodular with limestone concretions	5	10
1	Sandstone; reddish brown, medium grained, thin and laminated bedding, Chinle reddish brown mudstone below	5	5

The outcrops along Alamogordo Creek are covered southward through T. 3 to 6 N. except for small exposures of shale along Truchas Creek. North and west of Taiban in T. 3 N. Triassic beds are again well exposed but without sandstone resembling the Cuervo bed to the north. A thin, 20- to 30-foot sequence is meagerly exposed about 1 1/2 miles north of Taiban along State Road 252; this unit occurs south of Taiban also. Although poor the exposures do suggest that the Cuervo thins and splits into thin beds around T. 6 N.

North of the good exposures along Alamogordo Creek the Cuervo is widely exposed in numerous mesas along the Conchas River drainage system, and can be traced nearly to Las Vegas.

The Upper shale member is perhaps most typical of the Chinle Shale. This upper member is largely shale except for local reddish-brown sandstone beds in the lower part. Its thickness in the eastern part of the Fort Sumner sheet is about 350 feet, equaling or exceeding the combined thickness of the Lower Shale and Cuervo Sandstone Members. The total thickness of the Chinle is not as great as in the Tucumcari basin where 1,200 feet was logged by R. L. Bates in a well in sec. 3, T. 13 N., R. 29 E. (Dobrovolny and Summerson, 1946, sheet 2).

Redonda Formation

In the Fort Sumner sheet the Redonda is confined to the northeastern corner around Luciana and adjoining lesser mesas. The Redonda overlies the Chinle and is overlain by the white Exeter Sandstone (Jurassic). The Redonda contrasts with the Chinle by even beddedness and a distinctive orange-red coloration. It ranges in thickness between about 50 and 200 feet within the area, but at the type locality at Redonda Mesa Dobrovolny and Summerson (1946) measured thicknesses of as much

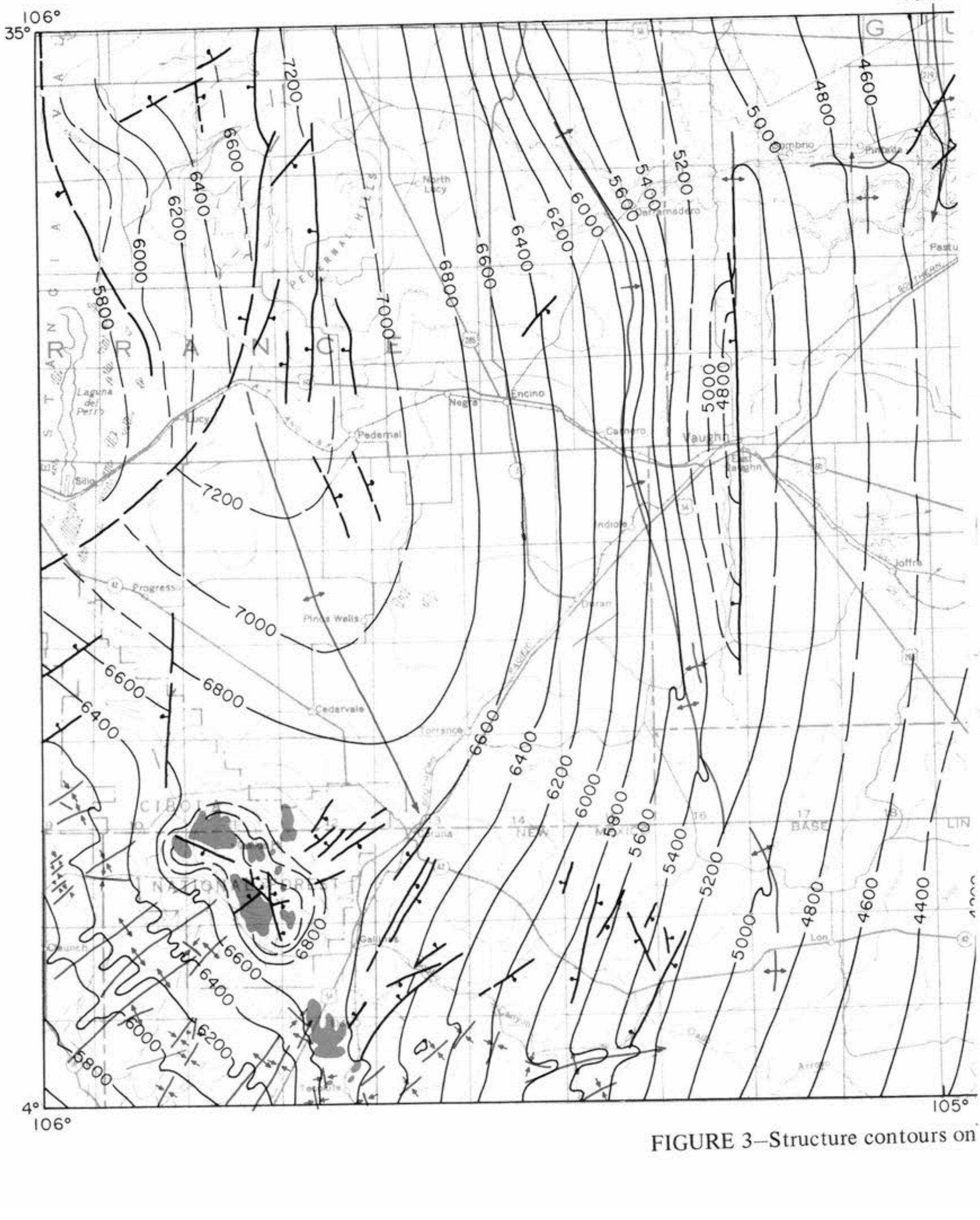
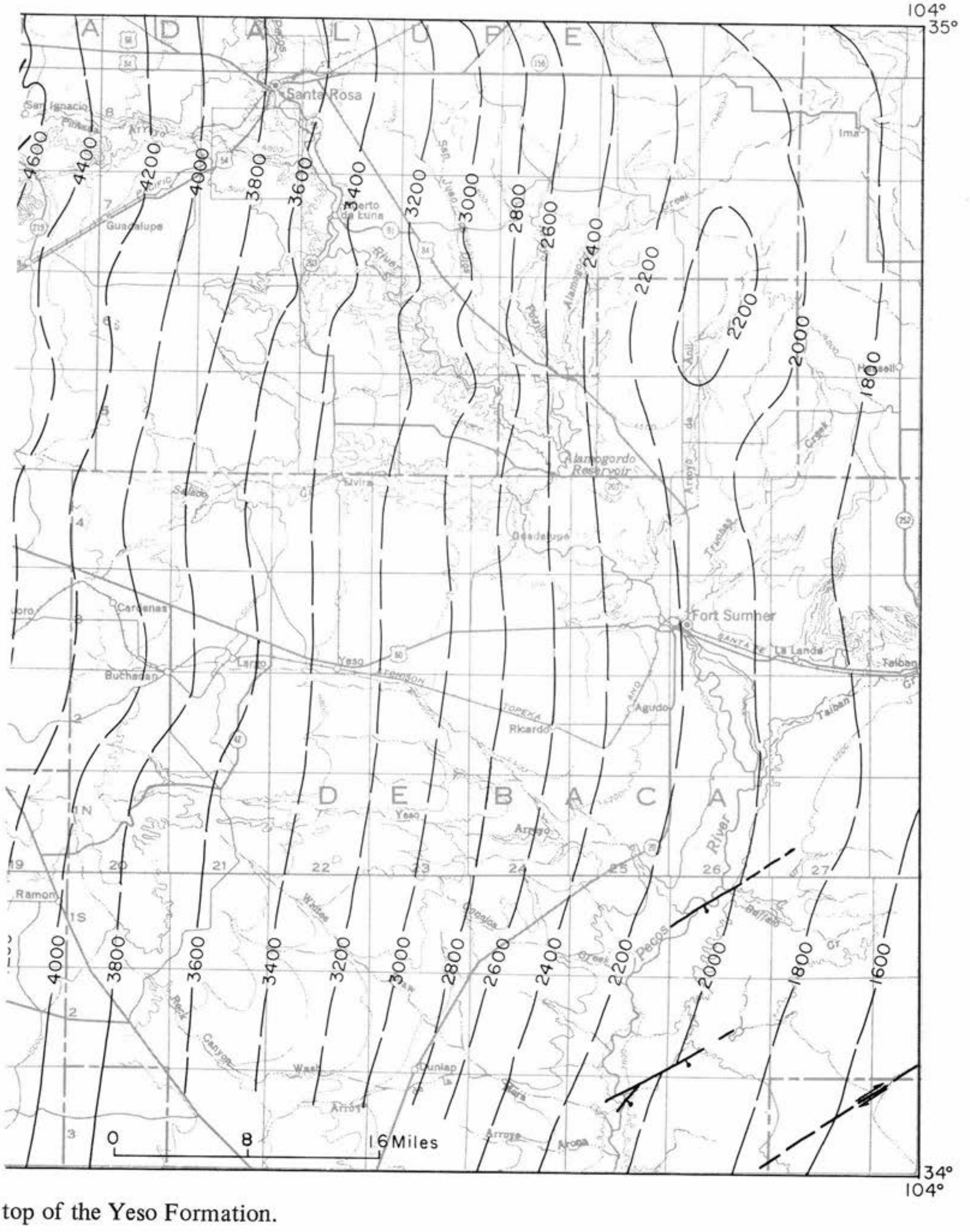


FIGURE 3–Structure contours on



top of the Yeso Formation.

as 450 feet. Griggs and Read (1959, p. 2005) suggested a correlation with the Wingate Sandstone of the Colorado Plateau.

JURASSIC AND CRETACEOUS

In the extreme northeastern corner of map 2 Jurassic and Cretaceous rocks cap Luciana Mesa over an area of about 70 square miles. Most of the outcrops have been mapped in some detail by Dobrovolny and Summerson (1946). The formations include in ascending order above the Chinle 1) Exeter Sandstone (Jurassic), 2) Morrison Formation (Jurassic), and 3) Purgatoire Formation (Lower Cretaceous). Luciana Mesa is capped and held up by the Mesa Rica Sandstone Member of the Purgatoire Formation. A thin upper member, Pajarito Shale, has been removed in this area prior to the deposition of the thin Ogallala Formation (Tertiary) which caps the Mesa. The combined thickness of the Jurassic and Cretaceous rocks is only about 400 feet. The term Exeter Sandstone is preferred (Baldwin and Muehlberger, 1969) to Entrada Sandstone as mapped by Dobrovolny and Summerson in 1946.

CENOZOIC

Some time after the Cretaceous Period the area was uplifted and stripped of considerable thicknesses of Cretaceous and older formations over a wide expanse. Pedimentation proceeded westward down across successively older formations and by Pliocene time appears to have cut its way into the Precambrian of the Pedernal Hills. As planation developed westward the earlier cut surface to the east began to be buried by alluvial outwash and windblown sand from the west. These deposits are known as the Ogallala Formation (Darton, 1898, p. 732-742). They are pre-Pecos Valley sediments whereas all the other Cenozoic deposits are derived from Pecos Valley sediments, except small areas in the Estancia and Claunch drainage basins (fig. 2).

Ogallala Formation

The principal deposits of Ogallala occur on the High Plains over vast areas of western Nebraska and Kansas, eastern Colorado and New Mexico, and in northwestern Texas. Remnants of the Ogallala east of the Pecos River are mainly on a high surface known as the Llano Estacado. Only a small part of the Llano known locally as Luciana Mesa and Taiban Mesa extends into the area of this report.

The expanse of the formation as well as its content of Precambrian rock fragments indicate that the deposits formerly extended much farther west than its present limits along the high escarpment of the eastern edge of the Pecos Valley. Darton (1928, p. 58) long ago identified outliers of the Ogallala west of the Pecos and specifically identified deposits extending "along the east slope of the Pedernal Hills." He also pointed to the possible equivalency of the formation with the Santa Fe Formation of the Rio Grande area; on the State Geologic Map (1928) he showed Ogallala on a number of large areas including the large Buchanan Mesa, the high deposits east of Pedernal Mountain. The most recent State Geologic map (Dane and Bachman, 1965) changed these deposits to a younger pediment category. Mourant and Shomaker (1970, p. 18, pl. 1) also mapped the mesas west of Fort Sumner in De Baca County as pediment deposits younger than the Ogallala.

The Ogallala consists of variable proportions of sand, gravel, silt, clay, or caliche. In places as on Luciana Mesa at State Highway 156 near Ima, the Ogallala is nearly all caliche. Perhaps the most abundant material is fine sand. Clay, silt, and gravel are lenticular in their occurrences. The caliche is almost ever-present and in places approaches 50 feet in thickness. It is usually gradationally zoned downward through 1) a cap of more or less pure, dense, grayish travertine-like limestone, 2) white, friable sandy limestone, and 3) sand or gravel only slightly impregnated by calcium carbonate. The development of the three zones varies considerably, and in some places one or another of the zones may dominate. The caliche cap is widely covered by thin veneers of soil and windblown sand.

In 1955 the General Portland Cement Company made analyses of Ogallala caliche collected by me.

Analyses of Caliche

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Loss
18	15.24	1.20	0.28	44.26	1.68	0.12	0.18	37.00
19	15.08	1.68	0.32	44.05	1.95	0.15	0.29	36.54
20	5.56	0.58	0.16	51.11	1.26	0.06	0.06	41.70
21	4.20	0.46	0.08	51.82	1.20	0.05	0.04	42.37
22	3.80	0.68	0.12	51.92	1.11	0.05	0.05	42.33
24	17.98	1.24	0.16	42.62	1.43	0.09	0.17	35.38

Locations

No. 18 sec. 16, T. 3 N., R. 28 E. otc. sample 21 feet
No. 19 sec. 16, T. 3 N., R. 28 E. State Road 252 roadcut
No. 20 sec. 30, T. 5 N., R. 28 E. State Road 252; screened crushed aggregate from caliche pit
No. 21 sec. 18, T. 5 N., R. 28 E. State Road 252; screened crushed aggregate; same pit as No. 20
No. 22 sec. 20, T. 9 N., R. 27 E., otc. pick sample
No. 24 sec. 27, T. 4 N., R. 17 E., 4.7 miles southeast of Vaughn along U.S. 285; 15-foot pick sample from pit wall

The high silica content is due to sand grains which can be seen loose and in dense broken samples. Samples 20 and 21 show cleaning up of quartz that results from screening.

Differentiating Ogallala levels west of the Pecos is not certain in all places. As with many instances of separate pediment levels, Ogallala levels merge or nearly merge in places. However, west of the Pecos several areas show two principal remnant pediment levels of some extent. South of Vaughn generally west of U.S. Highway 285, a pediment surface is 100 to 150 feet above the expansive younger surface of Buchanan Mesa to the east. Also rising above the Buchanan surface in the vicinity of Buchanan Station are several buttes surmounted by thick caliche caps. One is High Hill Mesa; and two smaller remnants southwest of Buchanan (T. 2 N., R. 20 E.) likewise rise about 150 feet above the expansive Buchanan surface.

Pastura is situated on Guadalupe Mesa (map 2) a northern extension of Buchanan Mesa. The long east-west Mesa Aragon rises 100 to 200 feet above the Guadalupe level; and the western summit area (map 1) has a caliche blanket 10 to 15 feet thick, also probably Ogallala. To the west, Mesa Leon has similar caliche and gravel at its northern end, and on equal levels to the west of the mesa, also mapped as Ogallala.

Similar higher levels, probably Ogallala, are present west of Vaughn; this level is distinguishable southward along the eastern Torrance County line east and southeast of Duran (map 1). Thus, the gravel and caliche plain south of Duran to the Corona mesas was once very likely coextensive with the Ogallala surface. Finally, the deposits and surface east and north of Pedernal Peak were probably once continuous with those east of Palma and with the Ogallala of the High Plains.

At the height of this great pedimentation and deposition of the Pliocene Ogallala alluvium, the area was a great plain with few hills. The surface probably extended to the Sandia-Manzano uplifts. Some features, however, appear to have stood above the erosional plain. These were the Gallinas Mountains, the Corona, Trancheras, and Duran Mesas, Chameleon Hill, and some of the Precambrian of the Pedernal Hills. The Estancia Valley probably did not exist in Ogallala time, because little Pliocene sediment is known within it. The most prominent feature on the regional landscape were the Rockies to the north. The Glorieta Mesa stood as a foothills border to the Ogallala plain. To the south the "porphyry" mountains including the Capitan, Sierra Blanca, and other mountains stood much as they do today when viewed from the east. Most of the eastward drainage from the Manzano and Sandia mountains probably came across or around the southern part of the Pedernals and through or around the Duran Mesa country and on to the east. On the old Ogallala plain, drainage from the southern end of the Rockies spread in a distributary system southeastward across a great area between Clovis and Tatum.

West of the Pecos the Ogallala may have divided as it extended itself into the foothills and mountains. It was probably less of a broad sheet than to the east; and deposits may have spread into separate wide valleys. The remnant levels of these deposits would therefore be less uniform in altitude. Some channel deposits could be expected beneath wider spreads of the western Ogallala. The north-south ridge at Vaughn consists mostly of Fourmile Draw carbonate beds, but, for a stretch of about three miles at Vaughn, the ridge consists of older gravel capped by caliche probably at the Ogallala level. Therefore, the underlying gravel is also Ogallala. Similar reasoning can be applied to the thick gravel in the sag belt west of Vaughn.

Pecos Valley Pediments

The Pecos Valley, especially from about T. 1 N. northward, is dominated by a terrain of wide mesas or terraces flanking the inner valley and canyon of the Pecos. They slope gradually southward and toward the river. The pediment of the mesas to the east of the river are inclined slightly more than those to the west and are slightly lower. This appears to be the result of the short distance to the High Plains escarpment, softer bed rocks, and the southeasterly, slightly diagonal course of the Pecos River valley. The thickness of pediments on the east side vary from about 5,000 feet east of Santa Rosa to about 4,200 feet east of Fort Sumner. The best-developed part of the eastern surface is east of Alamogordo Creek and Arroyo Potrillo.

The pediments on the west side are slightly higher, more expansive, and somewhat less sloped. Altitudes range from about 5,100 feet west of Santa Rosa to about 4,400 feet west of Fort Sumner. The pediment is 42 miles wide across Buchanan Mesa, and 32 miles wide across Guadalupe Mesa. Their north-south expanse is about 55 miles. The slopes on the eastern part of the pediment are as low as 5 to 10 feet per mile, but to the west they increase to 10 to 30 feet per mile. The southern side of this great pediment may have extended for many miles to the south. Eventually it would have been terminated by the high bedrock divide at Poquita Mesa just south of the Fort Sumner sheet at the junction of U.S. Highway 285 and State Highway 20 (map 2). Originally the wide valley around Dunlap between Buchanan Mesa on the north and the high pediment along U.S. Highway 285 on the southwest was largely a divide of low hills between the pediments. When the recent canyon cutting took place, the hills, without an armoring pediment, were more readily eroded and formed an inversion of relief.

The pediments on the west have well-developed caliche caps which in many places are as thick and well-cemented as those of the Ogallala surfaces. Thicknesses of 10 to 15 feet are not uncommon. Caliche on the east side pediment is less developed.

In many places the cut pediment surfaces have little sediment other than caliche or a little soil. Toward the Pecos River, sand and gravel beneath the pediments increase markedly, especially where weaker rocks as the Chinle are present. Gravel beneath pediments stripped on Santa Rosa tends to be thin or absent, but is mapped in most places where thicknesses are significant. However, where map scale does not permit, and the gravel is thin, it is commonly included in the pediment map unit.

Map 2 shows considerable pre-pediment gravel beneath the eastern end of the Buchanan Mesa. Also much is mapped around the eastern end of Conejos Mesa and the southeastern end of the Guadalupe pediment. Much of the pre-pediment gravel shown here has been mapped formerly as Chinle Shale, or as hillside alluvium; but I have been able to find horizontally-bedded gravel and sand exposures in a number of places formerly presumed to be Chinle. On map 2 the pre-pediment gravel is shown through vertical intervals of nearly 400 feet beneath the pediment, specifically west of Fort Sumner along U.S. Highway 60 and southeast of Ricardo along Arroyo Yeso to the Pecos River. In T. 1 N., R. 25 E. between Santa Rosa outcrops on Arroyo Yeso and the pediment cap to the north, at least 200 to 250 feet of pre-pediment sand and gravel appears. Good evidence indicates that the base of this old alluvium slopes toward the present valley bottom on both sides of the Pecos; and the overall relationships indicate an early (perhaps early Pleistocene) cutting of the Pecos Valley, especially in the Fort Sumner area. This period must have then been followed by considerable aggradation as well as subsequent pedimentation.

Terrace Deposits

Gravel-capped surfaces or benches paralleling the Pecos or other stream courses are mapped in several places. Most noteworthy are those following the Pecos. Two levels, as found north of Roswell (Kelley, 1971) appear to be situated south of Fort Sumner. One is at 50 feet above the river, the other possibly 100 to 150 feet. The gravel on these terraces is rounded to subrounded and generally pebble-size. The pebbles consist mostly of chert or chalcedony, but a large variety of quartzites, limestone or dolomite, granite gneiss, schist, and greenstone fragments are also present.

Lake and Playa Deposits

Three large depressions and a number of small ones have been occupied formerly by perennial bodies of water, as shown on the geologic maps by the lake bed symbol. Several studies have been made of old Estancia lake since the early recognition. One of the best is by Titus (1969) who assembled all past information and presented a thorough up-to-date analysis of the origin and nature of the ancient lake and its deposits. The lake deposits are about 100 feet thick and are underlain by as much as 300 to 400 feet of alluvium. The only vestiges of the Pleistocene lake are numerous playas and their ephemeral lakes in blowouts on the old lake floor.

Lakes also existed in the Pinos Wells and Encino depressions. Both have shallow playas on their old lake floors. In places the original lake floors have been modified by wind "blowout" holes which also have small playa floors.

Numerous sink holes and solution depressions are scattered through the area, and many occupied by ephemeral water. Some of the larger ones have playa flats, notably old Terrero Lake southeast of Pastura (map 2). A shore line is evident along the east side about 30 feet above the playa floor. Several other rather large solution depressions occur over Yeso bedrock west to north of Pinos Wells lake. Most of the sinks without open holes in the bottom have a considerable thickness of black soil and mud, probably resulting from weathering of siltstone and carbonate rocks.

Aeolian Deposits

Holocene aeolian sand deposits are widespread in the area. Most of the large pediments have soil and sand coverings, mostly aeolian. Most are fixed by vegetation. **On** the geologic maps many small patches of active sand are mapped as they appeared on the air photos. However, many of the deposits on the 1954 photos are now stabilized by a considerable cover of vegetation. Others have been modified, and new ones discovered in a few places. Prevailing winds are from the west, therefore, the east sides of mesas, canyons, and hills commonly have goodly piles of sand.

The deposits are of two principal types 1) arcuate lenticular bodies and elongate longitudinal strings or ridges east of blowouts, and 2) long east-trending dune fields to the lee of ridges or mesas, especially where outcrops of the Glorieta Sandstone occur to the windward. The most striking of the dune types is that associated with the blowouts on lake floors. Titus (1969, p. 100-110) has described these in some detail on the Estancia lake floor. The blowout depressions here are at least partly collapse features. The leeward dunes, or great dunes as Titus termed them, are as much as 130 feet high, 3,000 feet long, and 500 feet wide. They developed in two periods: an early smooth-crested dune lying next to the blowout, and a late, higher, sharp-crested dune blown over and somewhat to the lee of the early dune. Numerous small dunes are scattered on the old lake floor among the large dunes and blowout holes. The small dunes are rarely more than 10 feet high and have teardrop-shaped outlines whose long axes are east-northeast. Some have barchan shapes. Titus found them to be the first to form after the disappearance of the lake. Their slopes are stabilized by gypsite crusts and bush or grass. Analyses of the material of the small dunes by Titus showed that gypsum comprised 60 to 75 percent of the sand. Analyses of sand from the large dunes showed 30 to 36 percent gypsum; 38 percent clay; and 15 to 20 percent calcite. Titus' study of lineations in the late large dunes revealed that the winds blew from the S. 62°-67° W.; and in the small, early dunes, from S. 76° W.

The second type of aeolian deposit is a dune field having a large continuous area of sand. The largest of these lies across State Highway 42 about six miles west of Cedar-vale. The dune area is about 24 miles long and as much as 3 miles wide. It begins on Jumanes Mesa and ends on the old Pinos Wells lake floor (map 1). The field is broadly arcuate to the northwest with the southwest part trending N. 55° E., and the northeast part trending N. 75° to 78° E. On air photos the dune field is largely expressed by a mix of white sand and trees. Retention of moisture by the sand has favored a good growth of juniper trees in contrast to the grass cover on the adjoining caliche-covered surfaces. The dune field is made up in places of small longitudinal dunes that may be 50 to 100 feet long and 10 to 25 feet high. The field is largely stabilized at present owing to climatic change and growth of trees.

In the eastern part of Pinos Wells lake is another dune field having characteristics of both the above types. **On** the lake floor are large dunes leeward of the playas; but longitudinal streak-type dunes extend about two miles up the slope to the east of the lake. These dunes trend N. 73° E., a direction not conforming to the longitudinal dunes impinging on the lake floor from the west.

Although many other dune patches are mapped, only one stands out by reason of size. It lies east of Corona and generally north of the Glorieta-capped Corona mesas. This field is about 18 miles long and 1 to 5 miles wide. Overall, its trend is about east. The somewhat anomalous direction in terms of the above-described dune trends appears to be determined by the easterly trend of the northern side of the mesas.

Valley Alluvium

This is an area of expansive valley plains, isolated hills or mesas, and linear valleys. It is also an area of numerous small closed drainage basins. The Holocene or active alluvial deposits assume positions and types accordingly. The usual long linear strings of alluvium follow the major stream courses. West of the Llano Estacado escarpment a narrow apron of alluvial fans, and similar fans, form around the Gallinas Mountains and the Duran mesas. Perhaps the largest alluvial deposit is the great spread northward from the Gallinas Mountains. Here, at its outer flattening edge, this deposit coalesces with pediment surfaces. Many sinks have alluvial fills without playa centers, perhaps owing to sparse rainfall and easy leakage of water through the bottom. One of the most unusual alluvial patterns is the centripetal arrangement around the Pinos Wells lake bed (map 1).

Igneous Rocks

GALLINAS MOUNTAINS INTRUSIONS

The Gallinas Mountains lie in the southwestern part of the mapped area, mostly in T. 1 S., R. 11 E. The mountains result from resistance and doming of the intrusive masses. The original determination of the laccolithic nature and stratigraphic position of emplacement of the principal intrusion at, or a short distance above, the top of the Precambrian was made during U.S. Geological Survey strategic minerals surveys in the middle 1940's (Kelley, 1949, fig. 33). The mountains were restudied as a doctoral dissertation in the late 1950's (Perhac, 1964, 1970).

The intrusions consist dominantly of two large laccoliths and one stock. The laccoliths have numerous satellitic sills. The southern laccolith is the largest and consists mostly of trachyte or syenite porphyry. The northern laccolith around Gallinas Peak is a rhyolite porphyry. The stock is separated from the main part of the mountains and forms a large hill known as Cougar Mountain (map 1). The rock is a distinctive syenite porphyry.

Glorieta outliers roof both laccoliths in the high ridges and peaks of the mountains. The floors to the laccoliths are nowhere exposed. However, moderately inclined roof flanks of Glorieta and Yeso are common around both intrusives. The depth to a possible floor in the northern laccolith is at least 1,400 feet, and the southern one, at least 1,100 feet. Overall their form is laccolithic, differences in the upper roof contact between the Glorieta and Yeso, in places rather abrupt, indicates deviation from simplicity caused by offshooting or local discordance.

TECOLOTE INTRUSIONS

The Tecolote intrusions are named from a station on the Southern Pacific Railroad in T. 3 S., R. 12 E. A number of small hills and ridges reflect the resistance and doming by the intrusions. The dominant form is an elongate laccolith. Bonney Canyon dolomite (San Andres) is the principal surfacing rock around the hills, but the doming and arching by the intrusions has turned up the older Glorieta and Yeso beds in annular outcrops around the intrusions.

The largest intrusion is a northerly trending laccolith of monzonite porphyry in the northern part of the hills; and Tecolote Peak (7,290 feet) is on the crest of the laccolith.

Near the middle of the hills is an east-west elongated laccolith of unusual composition and form. Diorite forms the axis or elongate core with monzonite porphyry in a peripheral position. Rawson (1957, fig. 1) has differentiated these into what resembles either multiple intrusions or zoning. In a few places the diorite has small lenticular bodies of miarolitic leucosyenite. Also within the diorite along the northern flank is a small circular pipe made up principally of a hornblende-rich melaphyre with numerous inclusions of the diorite as well as some monzonite. In places the monzonite intrudes diorite, and, in turn, the hornblende melaphyre intruded both the diorite and the monzonite.

In the southern part of the Tecolote intrusive field are seven small monzonite bodies in the cores of east- to northeast-trending anticlines. These bodies appear to be the crests or apexes of larger laccolithic intrusions a short distance below the surface. To the east in T. 3 S., R. 14, 15 E. are two additional anticlines which may have igneous rock below the surface.

A number of small satellitic sills and dikes occur around the large intrusives in the northern part of the field. They all are monzonitic and most of the small iron deposits in the district are related to them.

DURAN SILLS

Dane and Bachman (1965) show several patches of intrusions north of Duran. These patches appear to be similar to the other large intrusive areas to the south in Lincoln County. On map 1, these patches are mapped as sills in the Yeso Formation. Three or four major sills appear to be at distinctly different stratigraphic positions but all are within an interval no greater than about 200 feet in the upper part of the Yeso. The largest is about 100 feet thick, well exposed on the western slope of Duran Mesa. Two or three 1-foot sandstone beds part the sill in the upper 20 feet. The lowest sill, shown on map 1 just below a caliche cap, is well exposed in a gulley north of the ranch road through the middle of T. 3 N., R. 14 E. Here the mapped sill consists of as many as a dozen sills closely spaced through an interval of 50 feet. Individual sills range from 2 inches to 10 feet and may have partings of sandstone beds a few inches to a few feet thick. The rock is basic and appears to be variously basalt, diabase, or medium-grained diorite.

DIKES

Other than occurrences closely satellitic to the Gallinas and Tecolote intrusions, dikes in the area are few, small, and scattered in the western part of the area. South of Duran a monzonitic dike strikes N. 55° E., is as much as 40 feet wide and extends for about 11/2 miles. A dike about 2 miles long is shown in the extreme southwestern corner of the area in T. 3 S., R. 10 E. It is essentially unexposed, but, in a negatively expressed soil zone about 15 feet wide between dolomite "walls," occasional vestiges of the dike may be detected by feldspar grains. This dike strikes N. 75° E. Northwest of Corona along State Highway 42 two narrow dikes may be seen in road cuts. They appear to be monzonitic although much altered. Because of the closeness of spacing only one dike is shown on the map. Numerous short dikes of northerly trend are shown in the northern part of the Pedernal Hills, and a considerably weathered andesite dike occurs in the schist railroad cut in T. 5 N., R. 11 E.

Structure

REGIONAL SETTING

Overall Paleozoic and Mesozoic structure of the area is rather simple, consisting dominantly of a low (60 feet per mile) dip to the east (fig. 3, centerspread). The plunging termination of the Sangre de Cristo prong of the Eastern Rockies lies a short distance northward of the western part of the area. East of the Rockies is the foredeep Raton basin; and off the northeast corner of the area is the shallow cratonic Tucumcari basin. East of the area, the low structural slope continues for many miles with only a slight swing of the regional dip to the southeast. To the south the regional dip continues mostly as part of the great Pecos slope toward the Midland basin. The southwestern corner of the area plunges southwestward into the Claunch sag (Kelley and Thompson, 1964). To the west of the area are the Estancia basin and the large uplifts which border the Rio Grande depression. Most of the area is a part of the Pecos slope as used by Kelley and Thompson (1964, p. 110), and is underlain by a Paleozoic-Mesozoic wedge belt which thickens eastward. The western border of the area includes the late Paleozoic buried landmass which was rejuvenated in the Tertiary time to form the present Pedernal uplift.

PEDERNAL UPLIFT

The Pedernal uplift forms a structural divide between the Estancia basin on the west and the wide gentle Pecos slope on the east. It is a combination of an ancient buried high and a modern Tertiary uplift (Darton, 1928, p. 283). The ancestral Pedernal uplift formed in Late Pennsylvanian and in Early Permian time and has been variously referred to as the Pedernal ridge (Darton, 1922, p. 202; 1928, p. 279), the Pedernal landmass (Thompson, 1942, p. 12), and the Pedernal axis (Read and Wood, 1947, p. 226). The modern structure which resulted from faulting and flexing on the western side of the uplift in Tertiary time has received little recognition prior to this work. The term ancestral Pedernal mountains is suggested for the Paleozoic mountains.

The ancient mountains were almost completely buried before the end of Permian time, being overlapped mostly by Yeso, especially in the Pedernal Hills area. The ancestral Pedernal mountains were considerably wider than the presently exposed Precambrian in and near the hills. On the west, they probably extended about to the middle of the Estancia Valley. The eastern boundary would best be selected somewhere between the wedge-edge of the Pennsylvanian Magdalena Formation on the east and the wedge-edge of the Abo Formation just west of Duran. Thus, the eastern extent of the ancestral Pedernal mountains probably is somewhere between Duran and Vaughn.

The modern or present Pedernal uplift is a faulted broad low dome (fig. 4) whose northerly trending axis extends from about Corona to the southern end of the Rockies southeast of Santa Fe, New Mexico (Kelley, 1972). The eastern flank essentially has no limit in the long flat Pecos slope, but the western flank is relatively steep with dips up to 18 degrees in the north (T. 8 N., R. 10 E.) and 9 degrees in the south (T. 5 N., R. 10 E.). The western flank is much obscured by surficial deposits, but bedrock exposures show a staggered system of normal faults down toward the Estancia basin coupled with antithetic conjugate faults in places. For the observed faults, throws do not appear to exceed two or three hundred feet. Complications in the broken segments of the west limb are puzzling. Obliquely tilted blocks occur especially in the northern

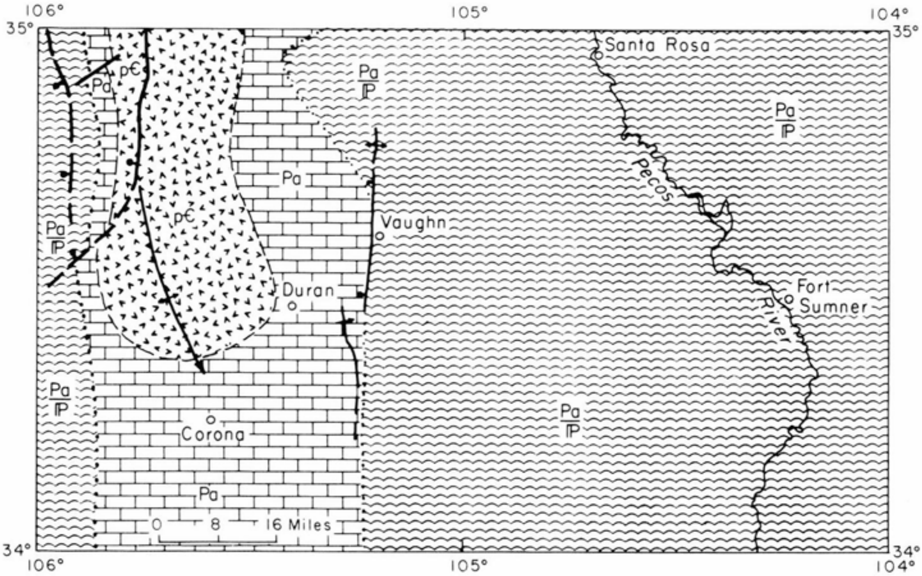


FIGURE 4—Sub-Yeso geologic map. pЄ, Precambrian; Pa/IP, Abo Formation over Pennsylvanian.

part as shown on map 1 in T. 7, 9 N., R. 10, 11 E. suggesting some lateral movement. The principal exposure of the western flank beds lies in R. 10 E. southeast of the Precambrian Cerrito del Lobo. The arcuate outcrop here expresses a shallow westward-plunging syncline that, overall, is part of the curving of the western flank.

Some of the structurally significant exposures are the westward-dipping Glorieta at Lucy, and northward to the big outcrop in the lake floor (sec. 10, T. 6 N., R. 10 E.). These, as well as the northern outcrops, project Glorieta and San Andres below the Lake Estancia floor. To connect the Glorieta and San Andres in the mesa with the subcrops beneath the valley, either a monoclinal flex or a fault (fig. 3) between Jumanes Mesa and the basin must be postulated. This postulated fault is shown extended northward to the exposed fault in T. 7 N., R. 11 E. Projections of structure contours on the top of the Yeso Formation in the south-central part of the uplift are poorly controlled, and their positioning is based on elevation and attitude control along Jumanes Mesa and around Corona. The surprising outcome of the mapping and structure contouring (fig. 3) is that the southeastern corner of the Estancia basin must be depressed structurally some 1,000 feet by faulting, flexing, or possibly solution collapse.

On the basis of involved formations the uplift must be at least post-Triassic. The faults along the western side of the Pedernal Hills have some physiographic expression which make late Tertiary origin tempting. If the uplift and the faulting is late Tertiary, more relief is necessary, especially along the southeast margin. Furthermore, much more alluvial material is required in the southern end of the basin than presently known. Laramide age is more likely because the Manzano uplift was not the obstruction to erosion in the Estancia Valley as it is today. Scarps would have had time to reach their present subdued nature and the resulting outwash could have been removed from the Estancia country. The present work shows that a modern Pedernal uplift should be clearly distinguished from the Paleozoic landmass. Also the western margin of the uplift is complex, and additional study should be undertaken.

FAULTS AND FOLDS OF GALLINAS COUNTRY

In the southwestern corner of the area, is a 30-mile wide belt of northeasterly trending folds and faults. The belt continues southwesterly out of the corner of the area into the Chupadera Mesa and Gran Quivira country. A few fractures and physiographic expressions of the trend extend almost to Duran. Overall the individual folds and faults converge to the northeast near Duran. Southwest of the Gallinas Mountains the structures are predominantly narrow anticlines. Some of the anticlines have igneous dikes along their cores in the Gran Quivira country just beyond the area of this report (Bates and others, 1947, pl. 1), but none of the anticlines in this area was observed to be occupied by dikes. Nearly all the folds die out at the igneous trend formed by the Gallinas and Tecolote centers; and faults dominate the belt to the northeast.

Narrowness and abruptness of the anticlines is their special characteristic. Locally the limbs are nearly vertical in the larger folds of the central part of the belt. The surface formation in the area is dominantly the Fourmile Draw and much gypsum is exposed in the areas between the anticlines. The anticlines generally have brought up the stronger Bonney Canyon and Glorieta beds and as a result the folds are usually expressed in ridges. Several short diagonal folds and faults cross the belt. These fall principally into obtuse northwesterly trending diagonals as in T. 1, 2 S., R. 9, 10 E., and acute northeasterly trending diagonals as in T. 1, 2 S., R. 10 E.

The faults northeast of the igneous areas are of no great stratigraphic displacement, and they are about equally up and down on the southeast sides. Little in their arrangement or in drag effects indicates strike slips. Two of the faults (T. 1 S., R. 11 E.) in the Gallinas Mountains parallel the northwest-trending small folds mentioned above.

The distribution patterns of neither the folds nor faults show any regularity of arrangements with respect to the Gallinas or Tecolote intrusive centers. In fact, one fault of the belt in T. 1 S., R. 11 E. cuts the monzonite laccolith suggesting that the fault system is younger than the intrusions. According to Bates and others (1947, p. 38-39) the igneous rocks occupying part of this belt as at Chupadera Mesa are hornblende diorite and diabase; in this respect they resemble the Duran intrusives and not the more acidic types of the porphyry centers. Perhac (1970) found no basic igneous rocks in the Gallinas Mountains.

VAUGHN TREND

This term is introduced here to encompass a north-south belt of variable minor deformation extending across nearly the entire area through Vaughn. On a regional basis the Vaughn trend is directly on line with the structural front of the Rockies terminating near Las Vegas.

The southern end of the trend consists of several small disconnected staggered anticlines (map 1). In T. 1, 2 N. the trend consists of a long narrow fault zone along which slices of Glorieta sandstone and Bonney Canyon carbonate beds are brought to the surface in an otherwise wide flat terrane of Fourmile Draw beds. The Bonney Canyon beds are narrowly sheeted in 1- to 2-foot strips mostly parallel to the shear zone. In several places the sheeting is left diagonal across the zone indicating some right wrenching or offsetting along the zone. At least in this section of the trend, here termed the Nalda shear zone, the east side shifted south with respect to the west side. The Nalda shear zone appears to diverge acutely northward from the general direction of the Vaughn trend and merge beneath a pediment cover with a long gentle monocline. The east-facing downflex first appears in T. 3, 4 N., R. 16 E. crossing U.S.

Highway 54; its subtle expression may be followed north through Derramadera where it curves northwesterly and dies out in T. 8 N., R. 14 E. This gentle flexure is termed the Derramadera monocline; regionally it is part of the Vaughn trend.

Beginning about where the Nalda shear zone dies out, and about 3 miles to the east in T. 2 N., R. 16 E., a long stretch of older (possibly Ogallala) gravel and Holocene alluvium abuts against a ridge of the Fourmile Draw Member. This feature is referred to as the Vaughn fault. It trends due north and is 25 miles long. Surface drainage from the west is dammed along the sag against the raised escarpment except for one crossing just south of Mesa Leon. Some 200 to 300 feet of gravel lies in the sag west of the fault. At the northern end in T. 6 N., R. 16 E. eastward-dipping Santa Rosa Sandstone passes southward in subcrop for some distance. These Santa Rosa beds projected eastward would abut Fourmile Draw beds at depth and the vertical displacement upward to the east could be 500 to 1,000 feet in the northern part of T. 5 N., R. 16 E. Six miles south of Vaughn eastward-dipping Fourmile Draw beds, which are high in the formation, must abut against beds low in the formation; and separation, up to the east, may be about 500 feet. To the north the Vaughn fault passes into a gentle buckle consisting of an anticline on the east and a syncline on the west whose axes are 0.6 to 0.9 of a mile apart. The effect is a short monocline facing west against the low eastward regional dip. This feature, termed the Leon monocline, is traced through interrupted exposures from Mesa Leon on the south to Pintada Canyon on the north, a distance of about 13 miles. To the north the trend is either absent or hidden beneath pediment material.

Overall the Vaughn sag lies between the Leon monocline-Vaughn fault on the east and the Derramadera monocline on the west. The sag widens northward from about four miles to about seven miles at Pintada Canyon. The Vaughn sag is the principal part of the Vaughn trend, and the sag differs markedly from the southern part dominated by the Nalda shear zone. The two appear related, and the entire trend may express a deep-seated extension of Colorado Rockies structure southward from its last strong surface expression at Las Vegas (Kelley, 1972).

PECOS RIVER FAULTS

Two faults, which may be rather significant in the overall regional structure, cross the Pecos River in south-central De Baca County. They are parallel, striking N. 62° E. and are both downthrown on the south. The northern fault lies across the sharp loops of the Pecos River in T. 1 S., R. 26 E.; and is exposed for only about 1.5 miles. Downthrow to the south is shown in good exposures on the west side of the river in the northern loop. At this place the fault is only a slightly broken, southward-facing monocline. The breaking is at the top of the monocline which dips 40 to 45 degrees and is only about 50 feet high. This fault could be a southwestward extension of the Benita fault (Bates, 1942, p. 148) some 60 miles to the northeast.

The southern fault is fairly well exposed for only about 1.5 miles, but appears to extend beneath cover for at least 8 miles in subcrop through Urton Lake. Santa Rosa beds are dropped against Permian and the vertical separation or stratigraphic throw appears to reach 300 to 400 feet just east of the river. Santa Rosa beds are turned up sharply on the south side between the main and branch faults. On the north side the upthrown Seven Rivers and Yates are involved in a narrow down-drag next to the fault. From the geometry of the drag and the branch fault some right slip along the fault appears likely.

Just south of the area in T. 4 S., R. 26 E. (Kelley, 1971, pl. 2) a northeast-trending buckle fault is downthrown on the northern side. Based on surface lineaments, a possible extension of the fault into this area in the pediment subcrop is suggested through T. 3 S., R. 27 E.

SANTA ROSA COLLAPSE BASIN

The town of Santa Rosa is situated along the northeastern edge of a large, circular collapse feature. The basin is about six miles in diameter. It contains sand, mud, and gravel whose thickness appears to be as much as 100 to 200 feet. In new road cuts along U.S. Highway 54 the bedded fill is undulated and tipped, indicating disturbance by collapse. The fact that the sediment in the basin is thicker than that seen on the surrounding mesas suggests that some basin fill occurred during and after subsidence. Solution of soluble rocks in the Permian such as salt, gypsum, and limestone undoubtedly caused the collapse. The sediment is probably the same that occurs around Fort Sumner and on the high mesas west of Santa Rosa. Santa Rosa Sandstone can be seen beneath the fill especially along the river in the town; and a small patch of Chink Shale capped with terrace gravel occurs at the base of the downflex south of the river and north of town.

The boundary of the basin is marked by faults alternating with monoclinal flexures. These are arranged in concave inward bights as though the collapse grew radially as karst collapse progressed. Small sink holes have formed in abundance along the flexures as well as on the adjoining uplands. The holes are largely concentrated on the west and north sides where Pintada Creek and the Pecos River enter the collapse basin. The possibility of future subsidence or sudden collapse is a potential minor hazard to the habitations in the basin. However, the major part of the subsidence appears to have ended several tens of thousands of years ago in view of the fact that both the Pecos and Pintada Rivers and their short tributaries have considerably eroded the basin fill and carved small canyons into the resistant Santa Rosa beds of the surrounding low escarpments.

Geologic History and Geomorphology

Before the end of Precambrian time ancient sedimentary and igneous rocks in this area were strongly deformed and metamorphosed. The deep-seated orogenic deformations trended easterly; essentially all foliation is easterly to east-northeasterly. Deep erosion bevelled the Precambrian mountains to a vast peneplain by the beginning of Paleozoic time. Lower and middle Paleozoic seas and thin marine deposits may have spread across the area, but were stripped by early Pennsylvanian time when expansive seas transgressed the entire area and layed down in succession the Sandia clastics and the Madera limestone and mud.

In middle to late Pennsylvanian time the first orogenic uplift began since Precambrian, a long stable period that continued in this area for about one billion years. This uplift extended northerly through most of New Mexico and is named the ancestral Pedernal mountains from the prominent Pedernal Peak in the northwestern part of the area. Details of the rise of these mountains are poorly known because of lack of exposure of the boundaries. Most of the evidence for the nature of the rising mountains is recorded in the sediments eroded from the uplift. Much sand, arkose, and gravelly material is found in the late Pennsylvanian through Permian Wolfcampian or lower Leonardian sediments deposited in the east- and west-flanking seaways and floodplains. The ancient Pedernal mountains were probably high and rugged. The bordering shore lines were pushed outward from the land by continued rise of the mountains and by alleviation on the adjacent plains. The early Pennsylvanian marine rocks were probably mostly stripped from the rising landmass during late Pennsylvanian time and reworked into these sediments along with Precambrian debris. Quite likely a combination of downbending and downfaulting of the preorogenic Pennsylvanian rocks was followed by overstepping of the succeeding late Pennsylvanian and Wolfcampian beds; if exposures were available, flanking angular unconformities would very likely be found.

By the end of Abo time (Wolfcampian or Leonardian) the eastern two-thirds of the area was a low alluvial plain and the western one-third consisted of the low, old-age Pedernal hills undergoing erosion. A number of isolated granitic and quartzite ridges and peaks stood above otherwise low hilly country. A few of the peaks along the axis of the geanticline appear to have stood as much as 1,000 to 1,500 feet above the alluvial plain to the east (fig. 4).

The region then subsided as part of a great near-sea-level shelf and the energy of succeeding Yeso sedimentation was considerably reduced from Abo time. The sea spread widely across this shelf from time to time as the shelf subsided. Aeolian sand and fluvial muds, silts, and sands spread onto the shelf from the north so that environment of deposition may have alternated from above to slightly below sea level. The shallow marine waters were usually too salty to allow marine life although marine limestone was deposited widely at one or two times during the 1,000-foot subsidence overall during Yeso time. At most times and places the shelf waters were considerably restricted and saline, giving rise to precipitation of extensive beds of gypsum. Salinity was high during most of the time and gypsum and calcareous material were commonly deposited with the muds. The Yeso sediments were mostly derived from Abo and Pennsylvanian beds, but the processes of derivation were slow, and the "dirty" arkosic aspect of the source materials was largely and widely obliterated. Yeso sediments, except for in lowermost beds, contrasted with the underlying fluvial deposits in grain size, parallel beddedness, and cleanness.

The end of Yeso time was marked by an incursion of the sea across the shelf that freshened the Yeso saline environment with normal marine waters. Terrestrial mud and silt were winnowed out by rising erosional and depositional energies. The Glorieta sands resulted from an interaction of the transgressing sea and the strong aeolian input from the north. At the end of Glorieta time, or about middle San Andres time, sand influx from the north ceased. The higher ridges and peaks of the ancestral Pedernal mountains still stood above deposition during Glorieta time; Glorieta deposits locally lapped onto the Precambrian west and east of Pedernal Peak. Angular fragments of quartzite and gneiss occur locally in the Glorieta. The highest peaks of today are lapped by Yeso and Glorieta. Along the border of Estancia Valley south of Cerrito del Lobo, however, rocks as young as San Andres, Bernal, and Santa Rosa lie in close proximity to the Precambrian. The crest of the present uplift appears to lie considerably east of the crest of the ancestral Pedernal mountains. Apparently the ancient uplift had its more abrupt side on the west, even as today, as shown by more coarse debris in the Yeso on that side.

Low energy conditions returned to the region during evaporitic carbonate and calcium sulfate precipitation and reddish mud deposition of Fourmile Draw time (late San Andres).

Artesia time was inaugurated by the return of fine sand while carbonate precipitation essentially ceased. However, water on the shelf became more saline as calcium sulfate continued to be deposited. Northward and westward across the area calcium sulfate precipitation decreased either because saline water covered less area or was freshened by rivers.

The early Artesia shelf deposition extended farther than the San Andres into central and northern New Mexico (fig. 5) and throughout the area of this report, a condition which probably did not hold for middle and late Artesia time. Thus, either the Pedernal mountains rose very slightly or subsequent erosion stripped middle and upper Artesia deposits. By late Grayburg-Queen time saline water conditions largely disappeared because very fine, clean, reddish sand continued to be laid down.

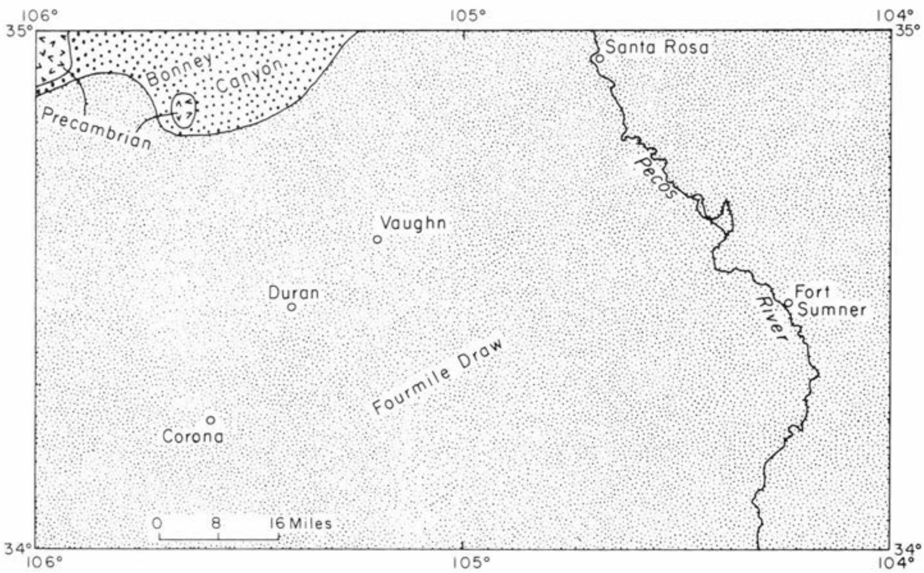


FIGURE 5—Sub-Grayburg geologic map.

Midway through Artesia time the Seven Rivers saline water body spread widely from the south and east into the area mostly to the east of about longitude 105° W. This body of saline water precipitated extensive sheets of white gypsum with some alternating mud and very fine sand. During Seven Rivers time supply of calcium sulfate from the saline marginal sea continued to dominate deposition. Immediately following the episode of calcium sulfate precipitation, fine sands of the Yates spread widely across the great shelf and the conditions of deposition were in sharp contrast with those of Seven Rivers time. Although the Yates sands are very fine grained they are too coarse to be loess; and they lack the bed forms to be terrestrial aeolian. Their thin regular bedding clearly signifies an origin by water. Their vast overspread of the Seven Rivers evaporites suggests a prograding regressive sand sheet with the clastics supplied from landward.

Tansill time was one of renewed spreading of the sea onto the shelf as strikingly shown by the Azotea carbonate tongue of the shelf margin north of Carlsbad. However, to the north of the carbonate precipitation belt, the shelf water was saline and precipitating calcium sulfate in alternation with mud and very fine sand. Also at times the waters precipitated thin nonfossiliferous carbonates. Northward the waters precipitated less and less evaporites and fine sands with only thin lenses of sulfate. Most, if not all the Tansill record is not observable, however, owing to overstepping of the Artesia by Triassic beds.

Events of Ochoan time (late Permian) are missing in the preserved sedimentary record. While continued subsidence and thick deposits of evaporites and basin muds were accumulating far to the southeast in the heart of the Permian basin, the Fort Sumner region was either in a static condition or being slowly stripped of its highest Guadalupian beds. The record is missing from Late Permian through Early Triassic. Erosion must have occurred toward the latter part of this time because the basal Santa Rosa (Late Triassic) sands and muds bevel stratigraphically downward across the area from Tansill in the southeast to Grayburg in the west and north (fig. 6).

Some broad gentle tilt eastward appears to have occurred concurrently with the rise

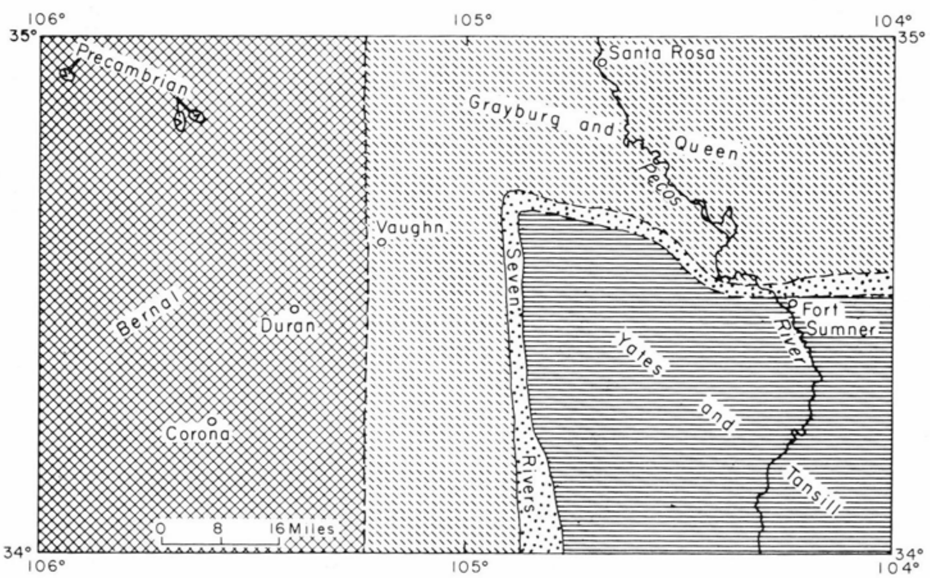


FIGURE 6–Sub-Triassic geologic map.

of more remote areas to the north, erosion of which furnished the first plicating materials that coursed across the area; and the buildup of Upper Triassic clastic fluvial materials began. During this time almost the entire area became a vast alluvial plain, although very early a few small peaks of resistant Precambrian may have stood above the plain along the crest of the ancient Pedernal mountains.

Subsidence continued allowing 800 to more than 1,000 feet of alluvial material to accumulate by the end of Triassic time. This was followed by a period in which the fluvial supplies ceased, possibly owing to complete erosion of the source but more likely to a change in the regional epeirogenic warping. As a result some slight stripping and dissection of the upper alluvial surface may have occurred. Gradually during Early Jurassic time the area tilted northward as part of the northern flank of a long, broad east-west upwarp across south-central New Mexico. Aeolian sands spread across the area during Exeter time (Middle Jurassic), followed by a modification during Morrison time to include widespread lacustrine conditions throughout the area. However, during Jurassic time the hinge line of the southern upwarp probably crossed the middle or southern part of the area. Upwarping to the south and shedding of continental muds and sands to the great interior basin on the north continued through Late Jurassic and most of Early Cretaceous time. By Late Cretaceous time the southern arch was reduced to sea level, and the northern area was flooded by the Cretaceous seas. Gradually the southern shores transgressed the whole region which in the end subsided into the Rocky Mountain geosyncline. The entire Fort Sumner area may have subsided two or three thousand feet and was buried by marine and nonmarine muds and the sands of the Cretaceous seas and floodplains. The evidence for Cretaceous and Jurassic deposition comes largely from surrounding areas because only small remnants of the deposits remain in the southwestern and northeastern corners of the area.

The entire area may have been without deposition from the end of Cretaceous time to Pliocene time. Early Tertiary beds such as those of the Raton or Cub Mountain Formations may have once extended into the area, but if so, they were removed through middle Tertiary time.

The surrounding areas experienced orogeny during Laramide time, and quite likely some broad warping and local open folds were formed in this area. In particular the Pedernal uplift may have been arched with faulting along its western flank. Faulting and folding along the Vaughn trend probably also occurred at this time. In early to middle Tertiary time intrusions of laccoliths and sills occurred in the southwestern corner of the area near Corona and Tecolote. Perhaps beginning in late Laramide time the entire area was uplifted, as part of the general continental rise, and given some of its present low eastward tilt. Erosion stripped most of the Cretaceous deposits and truncated a vast pediment across the area by Pliocene time. During Pliocene time the Ogallala sediments gradually covered the widely plicated surface, first in the east and then gradually onlapping westward as erosion cut well down into older beds. Planation may have continued across the Pedernals and westward toward the Rio Grande ranges which were rising during Pliocene time. By the end of Pliocene time the region was a great alluvial plain of low eastward gradient. In the western part a few buttes, mesas, and small mountains stood above this plain.

At the culmination of the deposition of the vast Ogallala pedimentary surface, the Pecos River was not draining southward through eastern New Mexico. The upper Pecos River and other streams issuing from the southern end of the Rockies debouched upon the Ogallala surface and flowed south and southeastward in a great system of alluviating channels. In addition to the Rockies, other highland sources of eastward-flowing streams were the Sandia-Manzano uplifts east of the Rio Grande depression, some small Pedernal "islands," the Duran, Trancheras, Corona Mesas, all the Lincoln

County porphyry mountains as the Gallinas, Jicarilla, and Capitan centers, the Sierra Blanca, and probably a low early upwarp of the Sacramento Mountains.

The Pecos River of today, especially south of Fort Sumner, flows almost at 90 degrees to the last drainage system on the Ogallala plain. How did this come about? At most, the head of the Pecos might have extended to near Carlsbad. There is no way the Pecos could have eroded headward across a dozen or more east-flowing streams to reach Fort Sumner without some other agency defining the course. The rise of the Guadalupe, Sacramento, Mescalero, and Pedernal uplifts at the end of Ogallala time rejuvenated the eastward-flowing streams making any beheading by the Pecos even more difficult. The best evidence of the early rejuvenation and incising by the Ogallala streams is the Portales Valley which has been eroded through the Ogallala surface and has obliterated the High Plains escarpment in a broad band extending west from Portales toward Fort Sumner. The upper Pecos River appears to have flowed eastward through the Portales Valley prior to capture from the south at Fort Sumner.

It has been long accepted that the Pecos valley of southeastern New Mexico has been eroded about as much by subsurface solution as by normal surface erosion. The north-south belt of soluble anhydrite, gypsum, and carbonates above and below the Fourmile Draw and Grayburg interval lies in R. 21-23 E., some 20 miles west of the present course of the Pecos River. A projected and restored base of the Ogallala would be mostly in the belt of R. 21, 22 E. This entire north-south belt, especially across the principal east-flowing channels, could have had concentrations of sink holes, collapse sags, and karst development that would divert or impound stream flow. These features might have eventually developed north-south collapse sags or trenches similar to the Red Lake and Turkey Track grabens east of Artesia (Kelley, 1971, pl. 5). In time they may have enlarged, especially longitudinally, and perhaps linked with one another. They would have intercepted the western parts of the Ogallala streams and cut off much of the source of water to the beheaded streams on the Ogallala surface to the east. In the early stages the drainage would have had no outlet other than to the subsurface eastward flow, much like the streams of today flow and disappear into the Vaughn sag. As uplift and eastward tilting continued and trench growth progressed, overflow, especially toward the south, could have occurred. Also, eroding headwardly to the northwest the Pecos River may have captured the interior trenches as suggested in figure 7. How and where capture of the Pecos would have occurred in the Fort Sumner area is still a problem.

Another rather different hypothesis for the origin of the Pecos Valley deserves consideration. Suppose the Pecos River flowed southward through eastern New Mexico prior to the development of the Ogallala surface, perhaps in middle Pliocene time or earlier. There would have been no Sacramento or Guadalupe uplifts, no Guadalupe Ridge or Delaware basin of physiographic expression, no Pedernal uplift, and the Mescalero arch around Capitan would have been subdued. Only the porphyry mountains and few Pedernal Precambrian hills would have stood on the otherwise vast plain to the south and east of the Rockies. The Pecos River may have drained southward as a wide valley system whose course was likewise determined or aided by the weak and soluble Permian rocks. It may or may not have eroded to levels of the present valley, but if it did, and in the end filled nearly to the Ogallala surface, the divide to the east and northeast would have been quite low. Then the east-flowing stream which cut the Portales Valley may have captured the Pecos River by some regional rejuvenation prior to that which later began for the Pecos. Soon after, however, the present Pecos had to recapture its head leaving the broad Portales Valley beheaded. This hypothesis includes an ancestral Pecos Valley (Bretz and Horberg, 1949, **p.** 483-487; Kelley, 1971, p. 31-32), and the pre-Ogallala or early Ogallala sediments in

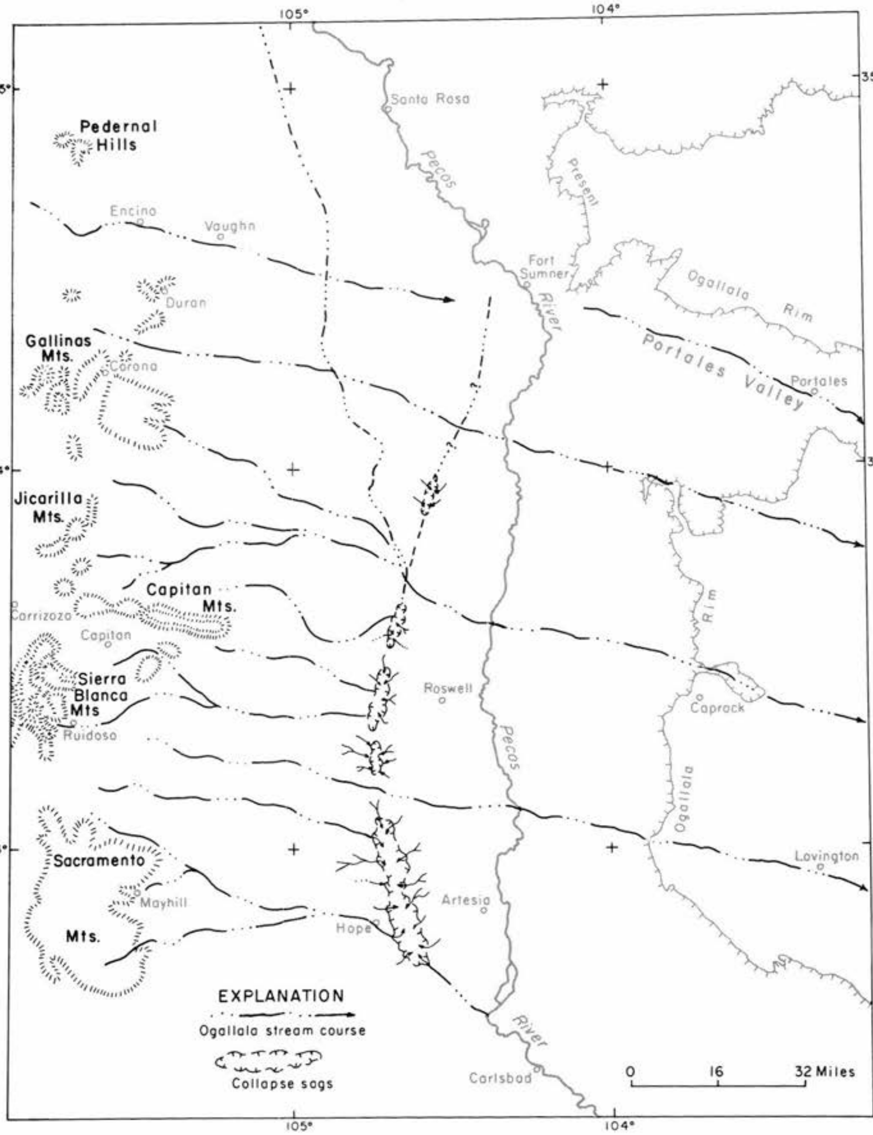


FIGURE 7—Schematic Ogallala surface, and development of the Pecos River.

the Pecos Valley could have escaped removal during the post-Ogallala development of the present valley. It may be by this hypothesis that only those high deposits west of Pecos in the Fort Sumner Sheet had continuity with the High Plains Ogallala; those in the Roswell and Carlsbad country, even though age correlatives, perhaps having continuity with beds south and slightly lower than the Ogallala.

In all hypotheses concerning the development of the Pecos Valley, the river and the erosion has always shifted eastward, as it does today along nearly the entire course from Santa Rosa southward into Texas. The explanation is the preponderance of western tributaries, in size and in contributing loads, in comparison to the fewer short eastern tributaries.

The Estancia physiographic basin probably originated in latest Pliocene and early Pleistocene time as the Manzano and Sandia Mountains culminated their rise accompanied by additional downwarping of the western side of the Pedernal uplift. This basin (fig. 8) became the site of a lake as carefully described by Meinzer (1911). If the lake ever had an outlet, it had to be over a broad low sill at the southeastern corner of the basin at an altitude of about 6,225 feet; although locally some have been pointed out at elevations very near to the required outlet level (Titus, 1969, p. 79). Possibly, therefore, old Lake Estancia did overflow at times. However, since the last overflow, a large dune field has spread across the eastern end of the lake and the sill area. Titus (1969, p. 79) believed that he found remnants of older high shorelines north of Cerrito del Lobo in sec. 21, T. 19 N., R. 10 E. at elevations of 6,340, 6,355, and 6,360 feet, but they may be only bluffs adjacent to arroyos above the highest lake level. The early Lake Estancia sill is about 6,300 feet and, therefore, a late lake stage; down-cutting of the wide outlet valley by 50-60 feet would be called for. Bachhuber (1971, p. 66) found the shore lines shown on map 1 in T. 8 N., R. 10 E. and noted that they were about at 6,280 to 6,300 feet. These altitudes agree with the estimated sill elevation of 6,300 feet (fig. 8).

Overflow went to the Pinos Wells depression which has well-marked remnants of shorelines along the south side at about 6,100 feet. Any outlet from this basin had to go northeasterly over a sill at about 6,240 feet. Along the northern rim of the depression is a cross swale that leads to a playa depression in T. 4 N., R. 13 E. Shorelines are present around the sides of this feature at about the 6,240-foot sill elevation. Elsewhere around the Pinos Wells depression Holocene alluviation would have erased most high-stand shore lines. The maximum depth of a full lake would have been about 180 feet.

Overflow if any from old Pinos Wells Lake went northeast only a short distance to the Encino depression which has well-marked shore lines up to about 6,175 feet. The floor of the playa is about 6,110 feet. The lowest outlet from this basin is to the east following U.S. Highway 60 and the Santa Fe Railroad. The sill here is about two miles east of Carnero Station through a deep cut traversed by the railroad. Good elevations on the rail bed are available. The original Llano Summit divide was about 6,260 feet, clearly lower than the 6,310-foot divide suggested by Bachhuber (1971, p. 71) for a possible high-stand overflow northward into Pintada Canyon. This course was also

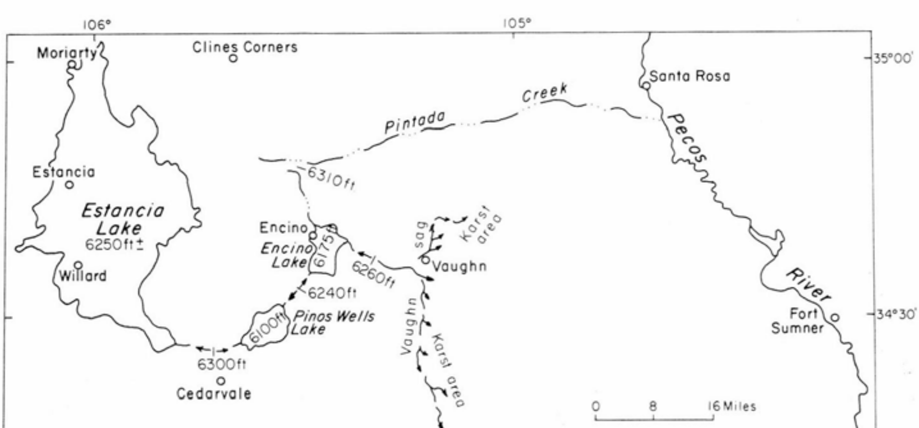


FIGURE 8—Quaternary lakes drainage systems.

suggested by Titus (1969, fig. 13). Assuming that the Encino depression may have received enough water from its drainage basin and the upstream Pinos Wells and Estancia lakes, the overflow would go eastward into the Vaughn sag, a distance of about five miles. At present runoff entering the sag flows southward for about ten miles into narrow five-mile long depression which would have to impound to a depth about 100 feet to overflow. The overflow would be in a wide karst area in the Fourmile Draw carbonate and evaporites. A well-defined through-going channel is missing, therefore, anything short of a persistent strong flow could probably not exist in the area. The Vaughn sag appears to be underlain by the Fourmile Draw Member where the Encino outlet stream enters; and the upthrown barrier ridge on the east side of the sag also consists of the cavernous rocks. Small sink holes are common along the fault or downflex at the base of the ridge. None of the several stream courses which enter the sag in a 17-mile stretch south of Vaughn flows out to the Pecos River system; the runoff all goes into the subsurface. A low divide crosses the sag just west of Vaughn. Northward along this part of the sag several stream courses enter from the west and join in a single valley through the ridge just south of Mesa Leon. However, this stream is likewise lost in a Fourmile Draw karst terrane a short distance east.

Considerable gravel occurs east of the Llano Summit near Carnero Station. This gravel is tilted into the sag against the Vaughn fault. Possibly early lakes of the Estancia system may have flowed across the sag before the faulting which produced the sag. All of the Vaughn Ridge, except a 3-mile stretch just south of Vaughn, consists of Fourmile Draw Member; this 3-mile stretch consists of gravel, probably Ogallala filling an old channel. This gravel, just east of the Encino outlet course, is probably too old to be related to the Estancia lake system unless downthrow of the sag is younger than the lakes.

In conclusion, a late Pleistocene-Holocene Estancia lake probably could not form higher than 6,300 feet, the sill altitude for the Estancia depression a few miles north of Cedarvale. If flow from Estancia and runoff in the Pinos Wells-Encino depression caused overflow, the highest shore line could not exceed the Llano Summit elevation of 6,260 feet, which is 20 feet higher than the sill elevation for Pinos Wells lake; otherwise the two would form one lake. Nor does present physiographic evidence indicate that the Estancia to Encino lake chain ever fed a surface stream tributary to the Pecos River.

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SEDIMENTARY ROCKS

Qa | Qpl | Qe | Qt | Ql | Qp | Qc

Surficial Deposits
Qa, alluvium of stream and valley bottoms; Qpl, playas, Qe, wind-blown sand and dunes; Qt, terrace gravel; Ql, old lake beds; Qp, pediment surfaces underlain by caliche (Qc), gravel, and/or sand

QTo
Older alluvium at several levels, especially thick deposits beneath pediments

To
Ogallala Formation
Pinkish sand, gravel, silt, and caliche

QUATERNARY — TERTIARY

Kd
Dakota Sandstone
Sandstone, conglomeratic locally

CRETACEOUS

Ꞧc
Chinle Shale
Reddish-brown shale and mudstone with several sandstone horizons

Ꞧs
Santa Rosa Sandstone
Red, brown, purplish and gray sandstone, conglomerate locally of assorted pebbles including limestone

TRIASSIC

Pag | Page
Grayburg and Queen Formations
Reddish-brown, and tan sandstone with gypsum and dolomite especially in lower part. Page, lower evaporite unit

San Andres Formation

Psf
Fourmile Draw Member
Gypsum and dolomite with local mudstone and buff sandstone

Psb
Bonney Canyon Member
Gray and dark-gray limestone and dolomite

Psg
Glorieta Sandstone Member
Medium-grained well-sorted white sandstone with local limestone especially in the southern and western parts.

Py
Yeso Formation
Tan-brown and buff fine-grained sandstone; gypsum, and limestone

Pa
Abo Formation
Reddish-brown sandstone and shale

PERMIAN

p€g | p€s | p€q | p€gr
Precambrian Rocks
p€g, granite gneiss (with granite locally); p€s, mica and chlorite schists; p€q, quartzite; p€gr, greenstone and metabasalt.

PRECAMBRIAN

TERTIARY INTRUSIVE ROCKS

Ti | Tir | Tit | Tia | Tib | Tid | Tim | Til | Tis

Ti, undifferentiated; Tir, rhyolite; Tit, trachyte; Tia, andesite; Tib, basalt; Tid, diabase; Tim, monzonite; Til, latite; Tis, syenite

Contact
Dashed where approximate; dotted where concealed

Fault
Dot on downthrown side; dashed where approximate; dotted where concealed

kdo
Key beds or zones within formations

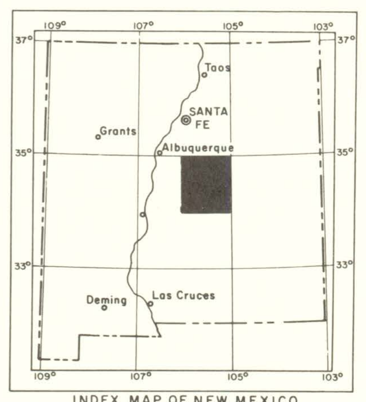
Anticline
Showing trace of axial plane

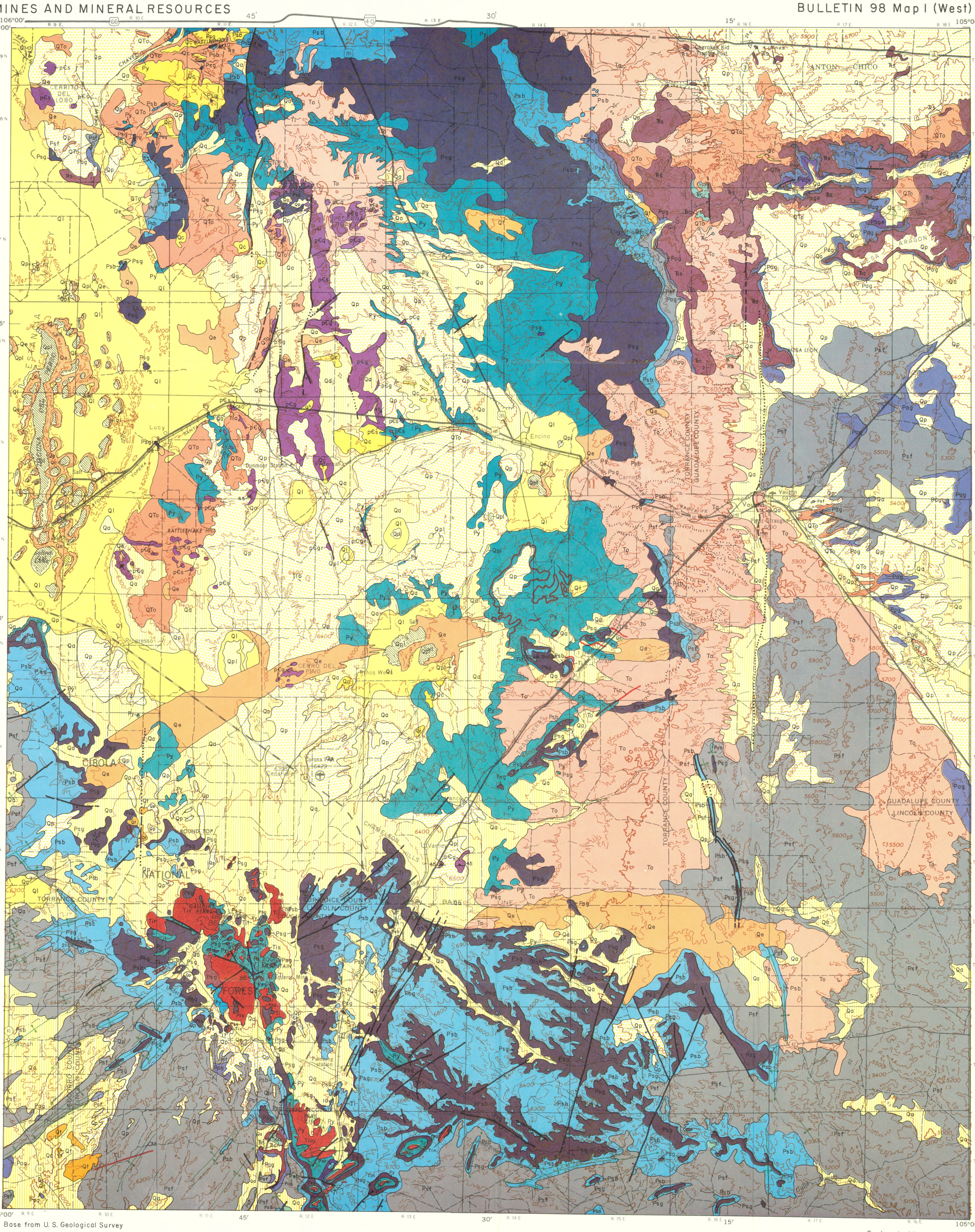
Syncline
Showing trace of axial plane

S
Traces of anticlinal and synclinal bends

horizontal *vertical* *inclined*
Attitude of beds

4
Line of measured section





Base from U. S. Geological Survey

Geology by Vincent C. Kelley

GEOLOGIC MAP OF THE PEDERNAL HILLS - GALLINAS MOUNTAINS - VAUGHN AREA

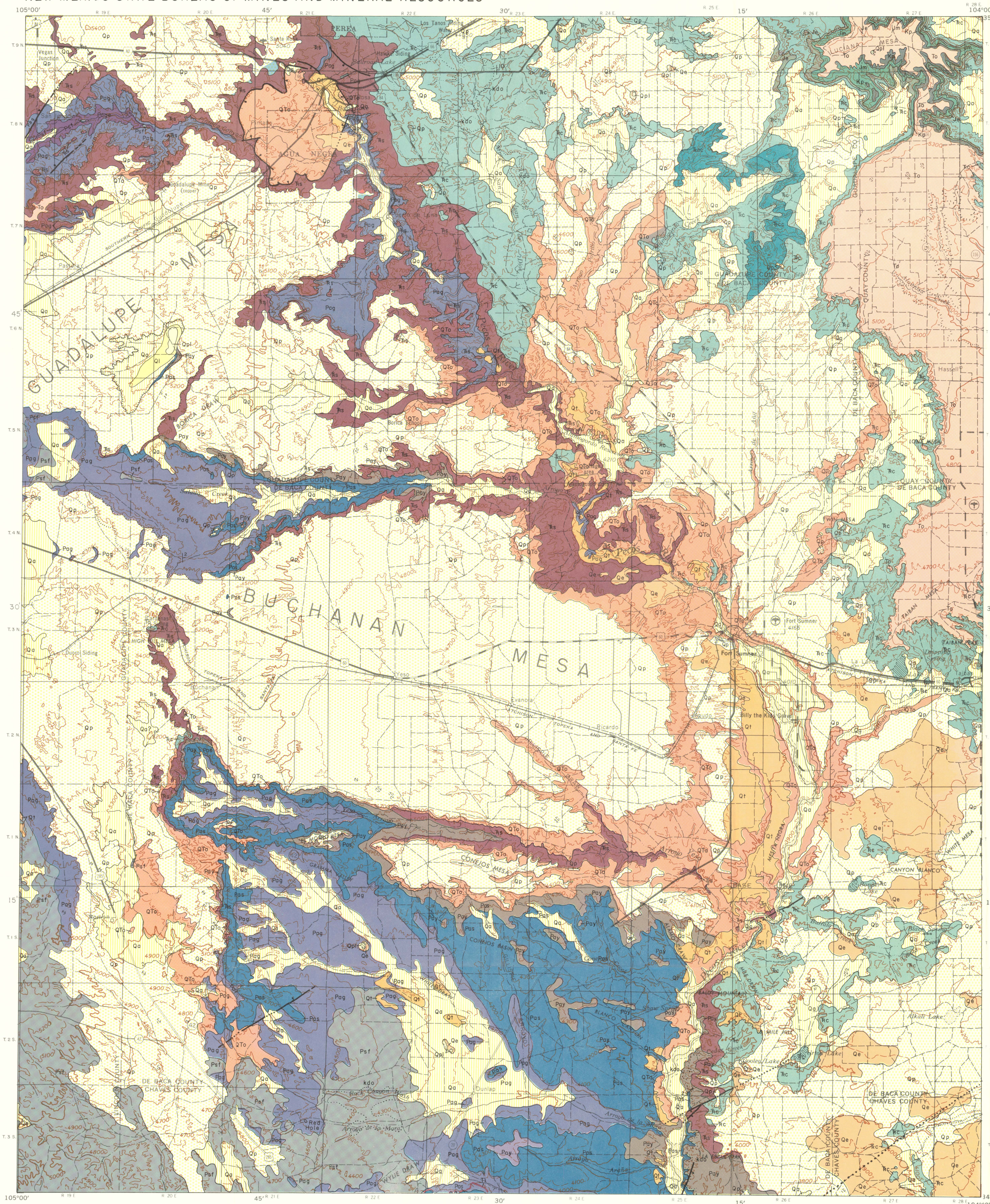
WEST HALF FORT SUMNER SHEET

5 0 5 10 Miles

Contour interval 200 feet
with supplementary contours at 100 foot intervals

NEW MEXICO STATE BUREAU OF MINES AND MINERAL RESOURCES

BULLETIN 98 Map 2 (East)



SEDIMENTARY ROCKS

Qa	Qpl	Qe	Qt	Ql	Qp	Qc

Surficial Deposits
Qa, alluvium of stream and valley bottoms; Qpl, playas; Qe, wind-blown sand and dunes; Qt, terrace gravel; Ql, old lake beds; Qp, pediment surfaces underlain by caliche (Qc), gravel, and/or sand

QUATERNARY

QTo
Older alluvium at several levels, especially thick deposits beneath pediments

To
Ogallala Formation
Fluvial sand, silt, and gravel with caliche in upper part

TERTIARY

Kp
Purgtoire Formation
Mesa Rica Sandstone and Tucumcari Shale

CRETACEOUS

Jm
Morrison Formation
Variegated mudstone and claystone, and gray or buff, medium-grained sandstone

Je
Exeter Sandstone

JURASSIC

Ћc Ћcc
Chinle Shale
Reddish-brown shale and mudstone with several sandstone horizons; includes Redonda Formation at top; Ћcc, Cuervo Sandstone Member

Ћs
Santa Rosa Sandstone
Red, brown, purplish and gray sandstone, conglomerate locally of assorted pebbles including limestone

TRIASSIC

Pay
Yates and Tansill Formations
White, gray, olive drab, and reddish fine-grained sandstone with some siltstone, gypsum, and limestone locally

Pas
Seven Rivers Formation
White gypsum with local intercalations of greenish and reddish mudstone

Pag Page
Grayburg and Queen Formations
Reddish-brown, and tan sandstone with gypsum and dolomite especially in lower part

Psf
Fourmile Draw Member of the San Andres Formation
Gypsum and dolomite with local mudstone and buff sandstone

PERMIAN

TERTIARY INTRUSIVE ROCKS

Ti
Diorite sill

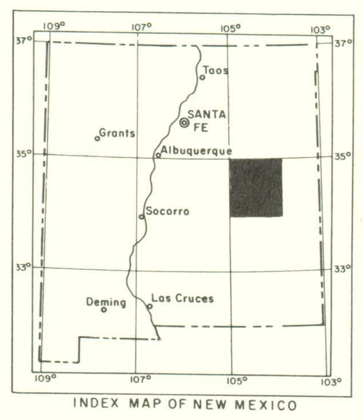
Contact
Dashed where approximate; dotted where concealed

Fault
Dot on downthrown side; dashed where approximate; dotted where concealed

kdo
Key beds or zones within formations

5
inclined
Attitude of beds

3
Line of measured section



GEOLOGIC MAP OF THE PECOS RIVER VALLEY-FORT SUMNER AREA

EAST HALF FORT SUMNER SHEET

5 0 5 10 Miles

Contour interval 200 feet
with supplementary contours at 100 foot intervals