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Geology of the Pecos country, southeastern New Mexico

by Vincent C. Kelley

SOCORRO 1971

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Contents

TABLE

FIGURES

PLATES

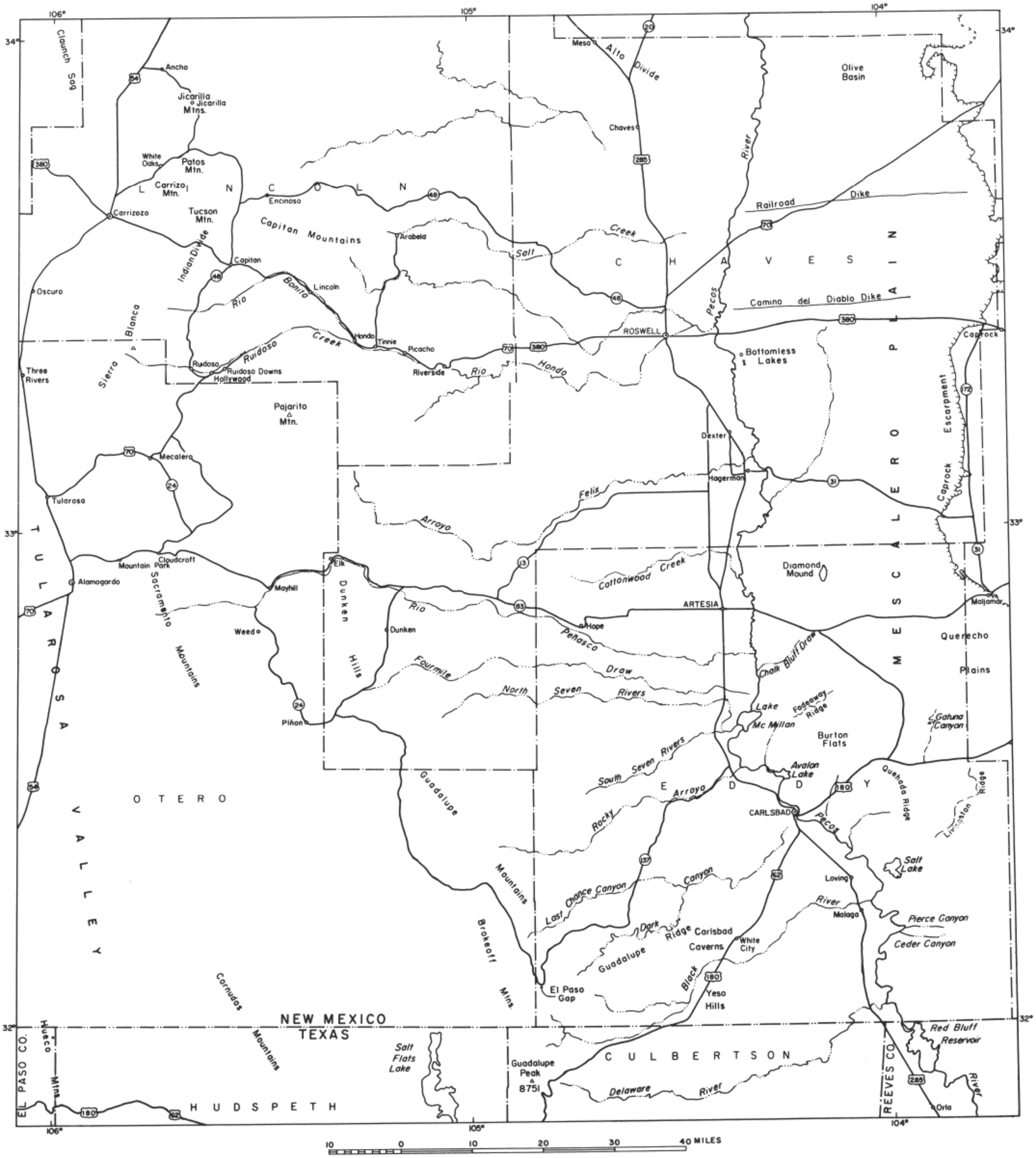

PLATE 6—GEOGRAPHIC INDEX MAP.

Abstract

The Pecos country of this report includes most of the Pecos Valley drainage area from 60 miles north of Roswell to the New Mexico-Texas line. The area of some 12,500 square miles is dominantly surfaced by Permian carbonate and evaporite rocks of the San Andres Formation and the Artesia Group, both mostly of Guadalupian age.

A wide swath of alluvium and terrace gravel covers the broad lowland of the Pecos River and its tributaries. Tributary drainage to the valley is quite asymmetrical as the result of the broad high uplifts to the west and the low Llano Estacado to the east. From the west nine major tributary systems 50 to 100 miles long contrast with the few short washes from the east.

Aside from one small inlier of Precambrian crystalline rocks at Pajarito Mountain, Leonardian siltstone, sandstone, gypsum, and dolomite of the Yeso Formation are the oldest rocks exposed in the area. At the Pajarito Precambrian area the Yeso is as little as a few feet thick, but in surrounding areas it ranges from about 1,000 feet in several exposures to its full thickness of 1,300 to 2,000 feet.

The San Andres Formation has been divided into three new members named, in ascending order, Rio Bonito, Bonney Canyon, and Fourmile Draw. Glorieta Sandstone tongues extend into the area from the north, and northward, not far beyond the mapped area, the Rio Bonito Member becomes the Glorieta Sandstone. The Bonney Canyon Member is thickest in the central part of the area. In the north it thins, and at least locally, grades into evaporite beds. To the south, the Bonney Canyon thins and is lost approaching the shelf margin in thick or massive beds. The Fourmile Draw Member is essentially the upper, noncherty member of Hayes in the back-reef country.

Formations of the Artesia Group are mapped individually as exposed east of the Pecos River and north of Roswell. Grayburg and Queen are mostly covered in the broad alluvial valley from the Seven Rivers area north to Roswell, where they are mapped together in an undivided sequence. Yates, Seven Rivers, and Tansill are mapped individually, but north of Hagerman, the Tansill is lapped out by Triassic beds or covered by alluvium. In the Capitan reef area, the Artesia formations are individually mapped close to the structureless reef or bank at the shelf edge. It is suggested the Lamar tongue near the top of the Bell Canyon Formation may project to near the base of the Yates Formation rather than high in the Tansill Formation.

The Castile Formation is mapped into lower and upper members, and it is suggested that both might be basin facies of the part of the Yates and Tansill Formations.

Known Mesozoic units are mapped where present, but not given special attention. Triassic Santa Rosa Sandstone is mapped east of the Pecos, stepping down northward across the area from Dewey Lake Formation in the south to Yates in the north. In the Capitan-Ruidoso country, Dakota Sandstone is mapped southward, stepping down from Triassic Chinle Shale to the San Andres Formation.

Chemical analyses of numerous samples of the San Andres show increase in dolomite content in the upper part, especially in Bonney Canyon and Fourmile Draw Members. Northward considerable increase in dolomite is also shown, especially in the Rio Bonito Member. Limestone makes up most of this member in the south as far as the northern end of the Guadalupe Mountains, but in the next dozen miles northward, dolomite increasingly replaces the limestone.

In the Pecos Valley much previously mapped Artesia is found to be Gatuna Formation. A number of field relationships suggest that the Gatuna may be late Tertiary rather than Pleistocene.

The structure of the area is dominated by a low eastward dip that is referred to as the Pecos slope. Much of the structural slope results from late Tertiary fault-block tilting of the Sacramento and Guadalupe uplifts that dominate the southwestern part of the area. In the northern half of the area, the Pecos slope is caused by the broad rise of the Mescalero arch which roughly coincides with the Permian buried Pedernal uplift. The western side of the Mescalero arch descends through faulted and igneous complications into the middle Tertiary Sierra Blanca basin.

The northwestern part of the area is the site of a large cluster of stock and laccolith centers known as the Lincoln County porphyry belt. Most of the intrusives lie to the west of the area, but the large Capitan intrusive, anomalous in its eastward trend, occupies an important position in the regional tectonics. Several stratigraphic and structural changes take place across the line of the intrusive. Fourmile Draw beds occur to the north, but not to the south of the intrusion, and the crest of the regional Mescalero arch is left offset about 10 miles.

Along the middle of the Pecos slope, the western part from the Capitan intrusion southward is separated from the eastern part by a north-south line of deformation, consisting of the Dunken uplift to the south and the Tinnie folds to the north. This belt of deformation in many respects separates the slope into two contrasting structural areas. The western part is dominated by the Sacramento uplift, the Mescalero arch, and the Sierra Blanca basin. East of the Dunken-Tinnie belt, the slope is relatively simple except for the long, narrow, northeastward-trending buckles. These buckles are right-wrench fold-faults which are undoubtedly Precambrian rooted and show evidence of activity at least as old as Permian.

Two faults, Barrera and Carlsbad, are mapped at the base of the Capitan reef escarpment. Offsets at the surface suggest that the basin side is downthrown, although not of a magnitude equal to that of the escarpment. Most of the relief of the escarpment is due to erosion of the relatively weak basin evaporitic facies. Little or no confirmation of these faults is found in subsurface vertical separations. Strike slip is considered possible, but the nature and origin of the faults are unknown.

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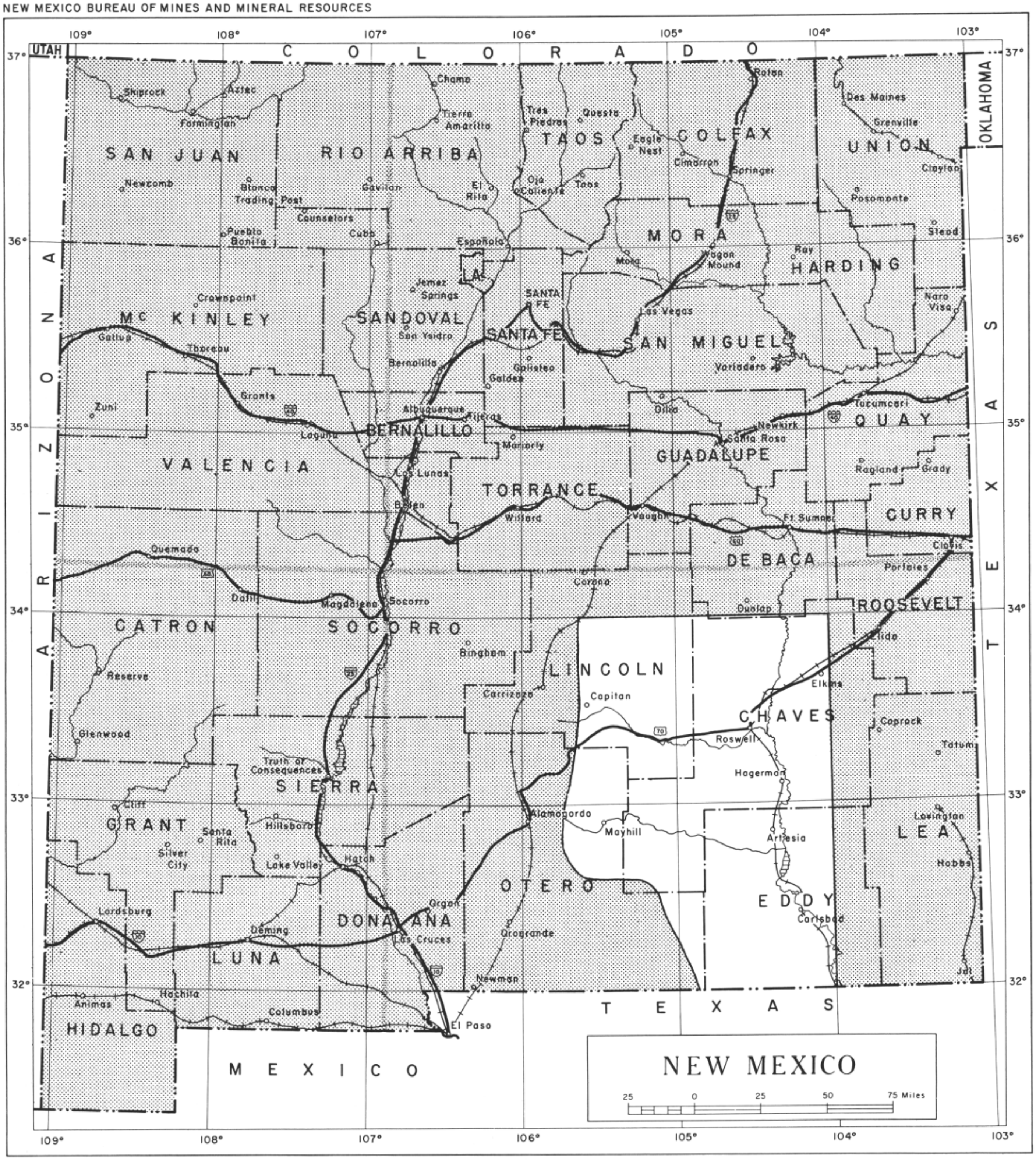

Figure I

INDEX MAP OF THE LOCATION OF THE AREA

Introduction

AREA AND PHYSIOGRAPHY

The area of this report includes essentially all of the drainage basin of the Pecos Valley of New Mexico south of De Baca County. It covers about 12,500 square miles between latitudes 32° and 34° north, and from 104° west on the east through the Pecos Valley to include most of the Guadalupe and Sacramento Mountains, and northward through the Ruidoso-Capitan country (fig.1). Most of the area lies west of the Pecos River on the great cuesta herein referred to as the Pecos slope. This slope rises from altitudes of 2,800 to 3,800 feet at the Pecos River to 6,800 to 7,400 feet in the Guadalupe Mountains, almost 9,700 feet in the Sacramento Mountains, 12,000 feet at Sierra Blanca, and 10,200 in the Capitan Mountains.

The Pecos slope is drained by nine major trunk streams which are, from north to south, Macho, Hondo, Felix, Penasco, Fourmile, Seven Rivers, Rocky, Dark, and Black. The first four are each about 100 miles in length; Fourmile, Seven Rivers, and others to the south which drain the nearer Guadalupe Mountains are only 40 to 50 miles in length. Each of the major tributaries to the Pecos has several large tributaries, some of which branch from the lower part of the trunk streams, such as the Salt from the Macho or several from the Felix and Seven Rivers, whereas the Hondo and Penasco have their largest tributaries well upstream.

Tributaries from east of the Pecos are only small draws or arroyos which drain westward or southwestward to the Pecos from a relatively near, low divide at the Llano Estacado or Cap Rock. The relief to the east does not exceed 800 to 1,000 feet.

The resistant Capitan Mountain stock stands as a great east-west anomaly in the physiography and drainage of the region. Its abrupt rise of some 3,000 feet above the surrounding slope causes a semiradial drainage pattern which modifies a 300-square-mile area between the Hondo to the south and the Macho to the north.

In the southern part of the area, the resistant Permian Capitan reef causes a long spur to branch eastward from the Guadalupe Mountains. This spur, known as Guadalupe Ridge, sets up another semiradial drainage in the slope, involving tributaries of the Black and Seven Rivers drainage systems.

Roswell, Artesia, Carlsbad, Ruidoso, Hagerman, Loving, and Capitan all lie within the mapped area.

APPROACHES TO THE WORK

Study of the Pecos slope was begun in September 1965, with support from Humble Oil & Refining Company. The major part of the field work was done during a semester of sabbatical leave from the University of New Mexico. The Humble work was completed in 1966 during vacations and week-end intervals. Subsequent to the company phase of the work, studies and mapping were extended as time allowed, with partial support from the University Research Allocations Committee and the New Mexico State Bureau of Mines and Mineral Resources. Minor field work continued into the winter of 1969-1970.

From the beginning, the work was planned as a regional approach to the stratigraphy and structure with emphasis on the outcropping San Andres Formation in the area of the buried Permian Pedernal highlands. Later stages of the work, "squaring out" the map to 1-degree sheets, of necessity emphasized the Artesia and younger formations. Igneous rocks have not been studied in detail, although thin sections of many of them have been examined. The numerous dikes and sills between Ruidoso and Capitan have been omitted because, at the scale of the map, they are so numerous that their inclusion would obscure the structure and formations.

Field mapping was done on Army Map Service high-altitude photographs (approx.1:54,000) and projected to bases prepared from AMS 2-degree sheets enlarged to a scale of 1:125,000. Topographic quadrangle sheets in the area, unfortunately, consist of a mixture of 7.5-, 15-, and 30-minute scales with many wide gaps for which nothing but the Army Map Service sheets are available. These have served well for the regional survey.

Most of the structure contouring was done from the AMS topography at the same scale as the geologic maps. Locally, other topography was used. In the Pecos Valley and in parts of the reef and Guadalupe areas, where the San Andres is in the subsurface, well tops furnished by Humble Oil and Refining Company, Pubco Petroleum Company, and Ben Donegan were used. For the final report, the original structure-contour maps have been reduced to 4 miles to the inch in order to show the entire structure on one sheet (pl. 5).

All the surface mapping is original with the exception of the area along the reef in the southern part of the Guadalupe Mountains and near Carlsbad, which follows with modifications the works of Hayes (1957, 1964), Hayes and Koogle (1958), and Motts (1962). Locally, where detail of geology was considerable (as for example west of Capitan and at Pajarito Mountain), larger scales of mapping were used, then reduced to the final map scale with generalization where necessary. Also, an extensive area west from Ruidoso and Cloudcroft nearly to Tularosa has been mapped at a larger scale, but because of complicating detail it will be published separately following this work.

Numerous gross measurements of the lower members of the San Andres were made, largely directed toward the distribution of the Glorieta sandstone beds. Seven special sections of the San Andres were measured and sampled, and the samples have been analyzed by wet methods for CaO and MgO content. A number of random samples of dolomite from other formations were analyzed. Some individual carbonate beds were sampled vertically and horizontally and analyzed for variations. A few thin sections of carbonate rocks were examined and some alizarin staining of these samples was done, but no significant observations resulted. Two partial sections of Seven Rivers and Yates were measured in the MacMillan Reservoir area in order to become familiar with lithologic details.

The San Andres Formation was one of the major objectives of the study. It is the predominant surfacing formation on the slope. The low dip and great expanse of the formation made it apparent that some division of the 1,000-foot section was necessary if it was to be understood and if a successful structural and paleotectonic picture was to be obtained. This work was begun in the Hondo region and three divisions were made which were named, in ascending order, Rio Bonito, Bonney Canyon, and Fourmile Draw members. This separation made structure contouring possible on a more rigorous basis and the top of the Rio Bonito was chosen because of its wide distribution on the maps.

A similar objective later developed for the Artesia Group which had been delineated into formations by Hayes in the near back-reef area but had been undivided to the north along the Pecos Valley; this was accomplished with the mapping of the separate formations, together with their truncation and overlap by Triassic beds to the northern boundary of the area.

Perhaps the overriding major objective of the stratigraphic studies was to determine the interrelationships of the San Andres, Artesia, and younger formations to each other and to the generally known extent of the buried late Pennsylvanian to the Permian Pedernal positive area. For the younger as well as older history of the positive area, no better location could be studied than the Capitan-Ruidoso area and along U. S. Highway 70. In this area changes or lack of changes can be studied across the Pedernal and the coinciding Mescalero arch (Kelley and Thompson, 1964, p. 118) in sequences ranging from Leonardian Yeso beds through Mesozoic and early Tertiary units. The fulfillment of these objectives exceeded early expectations in that repeated activity of the Pedernal is indicated from Permian well into Tertiary.

Prior to this work, a picture of the structure on the broad, gently dipping homoclinal slope was limited to maps by a few who had mapped locally or in larger areas without publishing their work. The great diagonal "structural zones" had been mapped by Merritt in 1920 (p. 55-56), but details of their nature and regional relationships were lacking. These and other structures, especially in the Capitan and Hondo region, had been known to me in a cursory manner for many years. The opportunity to study all these features, as well as the total structure, was initiated and generously supported by Humble Oil & Refining Company.

The igneous intrusive relationships to structure and stratigraphy were also an early item of interest to several of the company geologists as well as to me, because of the belief that their positions and forms might reflect older structures and related stratigraphy. This was particularly true of the Capitan intrusive and this work has defined some of these relationships.

The expansion of the work to the Pecos Valley, to the reef, and to the Delaware basin generated two problems of note. One involved the late Cenozoic beds in the Pecos Valley which bear great resemblance to some of the Permian and Triassic rocks. However, subtle distinctions of composition and texture can be found, and several large areas mapped on the State Geologic Map (Dane and Bachman, 1965) as Permian have been changed to Cenozoic.

The other problem arose during the "squaring off" of the geologic sheets to the Texas line. This work necessitated a review of the reef escarpment and the accompanying facies changes between shelf and reef and between forereef and basin deposits. Problems such as how much difference of elevation originally existed between equivalent backreef and basin beds; whether the scarp is mostly original relief, erosional relief at a facies front between resistant and nonresistant lithologies, or tectonic are considered.

ACKNOWLEDGMENTS

This work would not have been initiated without the help of the Humble Oil & Refining Company. Charles V. Roberts and Paul H. Dudley, Jr., outlined the problems and objectives of the survey and encouraged the early progress. Others who were involved and interested in the progress and in the results include A. T. Gibbons, John A. Burleson, Joseph J. Robnett, Jr., H. Walter Praetorius, Richard Denham, and Hugh P. Bushnell. To all of these men I am grateful for their interest and help.

During the recent phases of the work, Philip T. Hayes, Ed Kinney, James S. Hinds, Richard L. Koogle, and James L. Albright, have helped through discussions of many of the problems. Richard L. Squires and Klyne Headley, graduate students working on theses in the area, have made contributions in ideas and local mapping. Tommy B. Thompson, who has mapped the Sierra Blanca country, helped with problems of junctioning our maps in the Ruidoso country, and his prior work made mapping easier in that area.

The Pubco Petroleum Corporation was especially cooperative in making subsurface files available and Marion Causey, Norman Barker, and Dennis Crowley of that company, were particularly helpful in discussing problems of the shelf and basin. Ben Donegan gave very special help with Bell Canyon tops and structure contouring in the Delaware basin.

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The University of New Mexico Research Allocations Committee awarded financial assistance amounting to several thousand dollars for aerial photos, field expenses, and chemical analyses. The New Mexico State Bureau of Mines and Mineral Resources also contributed more than seven thousand dollars toward field expenses and salaries and did the map drafting and color separations.

William E. Hale of the U. S. Geological Survey, Water Resources Division, and C. B. Read of the Paleontology and Stratigraphy Branch, made some of their facilities available that were of great help in preparation of the report.

My sons, John, Robert, and Paul, helped at times in field surveys, sampling, and chemical analyses. For the help recognized here, and to the countless ranchers in the country, the U. S. Park Service for assistance in access to the reef country, I express my sincere thanks. Finally, and perhaps most important, my wife, Anne, deserves my deepest appreciation for her patience, understanding, and forbearance during my many days away in the field and my long hours of preoccupation with map and report preparation.

General Stratigraphy

The only rocks older than Permian that crop out in the area are Precambrian in age. The exposed sedimentary rocks range from Permian to Holocene as shown in the accompanying stratigraphic table (table 1). Exclusive of the surficial deposits, Permian rocks cover about 90 percent of the area. The remaining 10 percent is surfaced by Triassic, Cretaceous, and Tertiary rocks along the Sierra Blanca basin in the Ruidoso-Capitan country and by Triassic along the eastern edge of the area. About 50 percent of the Permian outcrops are San Andres beds, the remainder being mostly of Artesia, Yeso, Castile, Salado, and Rustler. Two lithologies, carbonate and gypsum, dominate the surface outcrops of the Permian terrane with elastics making up only 15 to 20 percent. Numerous chemical analyses of the carbonates indicate that out of an area of nearly 6,000 square miles of carbonate terrane, about 80 percent is dolomite.

PRECAMBRIAN ROCKS

Precambrian rocks occur in the core of the Pajarito Mountain dome, T. 12 S., Rs. 15, 16 E. Until recently (Kelley, 1968) these rocks were believed by most geologists to be a Tertiary intrusion[1], but abundant fragments of the rock in the overlying beds and a radiometric date of 1,270 m.y. by K/Ar clearly show the Precambrian age. The rocks consist of somber-colored hornblende syenite, hornblende syenite gneiss, and some diabase, all intruded locally by leucocratic syenite and hornblende syenite pegmatite. Riebeckite and aegerine are fairly common in association with hornblende in many places. The area of exposure is about 2 square miles and the outcrops are among the most striking and unusual of any Precambrian rocks in the State.

Yeso immediately overlies the Precambrian in most places around the dome, but locally, San Andres beds overstep the Yeso onto, or nearly onto, the crystalline rocks. The top of the Precambrian has a well-developed soil profile beneath the Permian, in striking contrast to the near absence of weathering profiles on the present surfaces.

PRE-YESO FORMATIONS

No stratified rocks older than Yeso crop out in the area. Pre-Yeso rocks crop out prominently in the western escarpment and northern end of the Sacramento Mountains (Pray, 1961; Otte, 1959). The rocks range in age from the Upper Cambrian Bliss Formation through the Wolfcampian Abo Formation. Pre-Yeso rocks are absent along a wide crestal strip of the northward-trending buried Pedernal uplift in northeastern Otero County and south-central Lincoln County.

Scattered drilling has fairly well demonstrated that no pre-Permian rocks occur in the area northwest of about the Six Mile buckle. To the southeast of the buckle, in a reentrant formed with the Huapache monocline, older subsurface Paleozoic formations occur in a southeastward-thickening wedge beneath the Permian.

Northwest of and more or less coinciding with the Six Mile buckle, only Wolfcampian beds intervene between the Precambrian and the Yeso or Wichita Formations (Meyer, 1966, fig. 49, p. 71). Few wells have been drilled in the buried Pedernal area, but those drilled show thicknesses ranging from about 300 to Boo feet. Some (Meyer, 1966, p. 72, fig. 50) have presumed that the Wolfcampian, mostly Abo, is in excess of 1,000 feet in thickness along the top of the buried Pedernal. When it was thought that the Pajarito Mountain igneous core was a Tertiary intrusive such thicknesses were possible, but with the identification of the rock as Precambrian (Kelley, 1968) overlapped by Yeso and San Andres, the existence of such Abo thicknesses in the surrounding subsurface appears unlikely.

PERMIAN

YESO FORMATION

The greatest outcrops of Yeso are high along the crest of the Sacramento Mountains and in the large canyons such as Elk, James, Cox, and Penasco, along the eastern dip slopes of the range. However, outcrops in the high Sacramentos are heavily forested and exposures are mostly poor. Good partial exposures of Yeso occur in the valleys of the Hondo, Bonito, and Ruidoso (pl. 1). Lesser areas of exposure occur around the eastern part of the Capitan uplift, in the narrow anticlines of the Tinnie anticlinorium, around Pajarito Mountain, in the Bluewater, Manning, and Clemente anticlines. The best exposures are in the scarps of Stevenson Mountain and the northern part of the Guadalupe Mountains. Headley (1968, fig. 8, p. 12) measured three partial sections along the lower Guadalupe escarpment, one of which totalled 890 feet consisting of gypsum, gypsiferous siltstone, and dolomite. Nowhere in the area is the bottom of a full section exposed, although nearly 1,000 feet of section is present in the broad arch along Ruidoso Creek near Green Tree. Yeso outcrops are commonly disturbed by folding, collapse, or landsliding. Beds consist of reddish and yellowish sandstone, pulverent limestone, thin-bedded dolomite, gypsum, and silt-stone. Gypsum is rarely exposed, but most exposures are only of the upper 100 to 200 feet of the formation.

In the long, east-west stretch of exposures along the Hondo drainage system, carbonate becomes more abundant in the section toward the east. In exposures near Pine Lodge, near the northeastern end of the Capitan Mountains, a 50-foot ledge of dolomite resembling San Andres beds is present several hundred feet below the top of the Yeso. Bates (1942, p. 35) found that as much as 40 percent of an 1800-foot section of Yeso drilled on the Dunken anticline (pl. 4) is carbonate rock. No section of the Yeso was measured in the area, and in general, examinations of it were cursory.

Northrup and Pray (Pray, 1961) measured two sections of Yeso along the western side of the Sacramento Mountains, one in T. 13 S., and the other in T. 19 S. The southern section is 1,339 feet thick but the top was eroded an unknown amount. The northern section measured 1,200 feet,

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[1] M. L. Thompson (1942, p. 12) pointed out that a metamorphic rock inlier had been "observed" at Pajarito Mountain.

but neither the base nor the top was included. Pray estimated the Yeso to be 1,300 to 1,400 feet thick from these sections. During my work a complete section was measured in secs. 21, 22, T. 13 S., R. 10 E., about 4 miles west of Northrup and Pray's northern section. The total section at this locality (Coyote Ridge) measured 1,220 feet. In the subsurface of the southern part of the area Yeso and Yeso equivalents thicken to as much as 2,400 feet.

Both sections in T. 13 S. had about 220 feet of carbonate beds, but in Pray's southern section, T. 19 S., there is about 480 feet. The southern section had only 70 feet of gypsum; the northern, Northrup and Pray section, 240 feet; and the

TABLE 1. STRATIGRAPHY OF THE PECOS COUNTRY

			Formations & Members			Thick	Description
Holocene and Pleistocene			Assorted surficial deposits			0-300	Valley alluvium, terrace and pediment gravel, caliche soils, aeolian sand, travertine
Pleistocene-Pliocene			Gatuna Formation			0-200	Sandstone, sand gravel, siltstone, limestone, red, brown, tan, gray, yellowish
Oligocene			Sierra Blanca Volcanics			700-4,000	Andesite breccia and tuff; some flows
Paleocene			Cub Mountain Formation			500-2,000	Sandstone, mudstone, conglomerate, arkose; white, buff, lavender, purple, maroon
Cretaceous			Mesaverde Formation			500-1,500	Sandstone, shale, coal, conglomerate; buff, gray, black
			Mancos Shale			400-700	Shale, siltstone, with local thin sandstone and limestone; black, grayish-black
			Dakota Sandstone			100-150	Sandstone, conglomerate, black shale; gray to tan
Upper Triassic			Chinle Shale			0-300	Mudstone with some claystone and thin sandstone; reddish brown
			Santa Rosa Sandstone			0-300	Sandstone, conglomerate, mudstone; brown, buff, lavender
PERMIAN	Ochoan Series		Dewey Lake Formation			200-250	Sandstone, siltstone; orange-brown; commonly laminated
			Rustler Formation: Upper Member			150-200	Dolomite, gypsum, mudstone, white, red-brown, green, gray, deep orange; Magenta dolomite at base
			Lower Member			100-250	Dolomite, gypsum, mudstone, sandstone; white, red-brown, gray, green; salt in subsurface; Culebra dolomite at base.
			Salado Formation			0-2,500	Gypsum, mudstone, thin local dolomite; white, red, brown, green, deep orange; breccia residue at surface, thick salt, potash in subsurface
			Castile Formation Upper Member* (surface)			1,000±	Gypsum (anhydrite), salt; white, gray
			Lower Member (surface)			1,000±	Laminated gypsum (anhydrite) and limestone, laminated limestone, laminated gypsum; gray, black, white
	Guadalupian Series	Artesia Group	Tansill Formation	Capitan Ls.†	Bell Canyon Fm.*	200-300	Dolomite and siltstone (south); dolomite, gypsum, and anhydrite (north); Ocotillo siltstone tongue near exposed top
			Yates Formation			250-350	Siltstone, sandstone, dolomite, limestone and gypsum (south); gypsum, siltstone and thin dolomite (north)
			Seven Rivers Formation			450-600	Dolomite, siltstone (south); gypsum and siltstone (north)
			Queen Formation	Goat Seep Do.†	Cherry Canyon Fm.*	200-400	Dolomite and sandstone (south); gypsum, red mudstone, dolomite (north); Shattuck member near top
			Grayburg Formation			250-450	Dolomite and sandstone (south); gypsum, mudstone, dolomite (north)
			San Andres Formation: Fourmile Draw Member			0-700	Dolomite, gypsum, reddish mudstone; sandstone locally at top; thin-bedded
			Bonney Canyon Member			0-300	Dolomite, local limestone; gray, light-gray, local black; thin-bedded
	Leonardian Series		Rio Bonito Member			250-350	Dolomite, limestone, sandstone (Glorieta); gray, brownish gray; thick-bedded
			Yeso Formation			0-1,400	Sandstone, siltstone, dolomite, gypsum; tan, red-yellow, gray, white
Precambrian			Syenite, gneiss, and diabase				

* Delware basin facies only
† Reef facies only

Kelley section about 750 feet. All these sections have a fairly prominent medial dolomite member about 100 feet thick. I have mapped this unit extensively in the Tularosa Canyon area. Pray (1961, p. 113) mentions this unit and its persistency. A similar medial dolomite is prominent along the northern Guadalupe escarpment and was mapped by Headley (1968, p. 13).

Also, as mentioned above, carbonate becomes more abundant eastward in Hondo Canyon and perhaps generally eastward along the Pecos slope. By contrast, at Green Tree, which is near the top of the Mescalero arch and the Pedernal axis, there is very little carbonate and minor amounts of gypsum, even though nearly 1,000 feet of section is reasonably well exposed. Although this is only one case, there is a suggestion that the Pedernal may have been active enough during Yeso time so that the axial zone was above the sites of carbonate and evaporite deposition on either side.

The most significant exposures of Yeso are those at Pajarito Mountain (fig. 2). On most current geologic maps the crystalline rocks lying beneath the Permian at Pajarito Mountain have been designated as Tertiary intrusive (Motts and Gaal, 196o, p. 108). The recent geologic thinking has been that the dome is laccolithic and that the Precambrian might be at depths in excess of one thousand feet around the mountain (Meyer, 1966, p. 72). All the core rock of the dome is conclusively Precambrian.

Yeso and San Andres outcrops encircle the small uplift. The thickness of the Yeso intervening between the Precambrian and the San Andres ranges from 300 feet down possibly to a feather edge, owing to onlap of the Precambrian, and in part to overstepping of San Andres across previously upturned and eroded edges of Yeso. This situation appears to exist at Pajarito Peak where the San Andres beds which cap the peak dip only about five degrees westward. South of the peak in the slopes below the San Andres contact, Yeso beds dip west at 20 to 25 degrees. In the steep eastern face of the peak beneath the fire lookout tower the Yeso is very thin. A similar situation exists on the eastern side of the uplift, east of the bare, dome-shaped hill (fig. 2). Thus, a "thin" axis trending about N. 70° W. is evident in the Yeso, with thickening northward and southward away from the buried crest of the old ridge along both the east and west flanks of the uplift.

A pronounced weathered, old-soil profile zone exists in the Precambrian immediately beneath the Yeso in most places. In contrast, elsewhere the Precambrian outcrops are unusually fresh. The basal Yeso section, as much as 50 to 60 feet above the Precambrian, consists of thin- to medium-bedded feldspathic grit and breccia, fine-grained yellowish sandstone and siltstone, and thin fossiliferous gray limestone. Weathered fragments of Precambrian syenite and gneiss as much as 2 inches in diameter, are common in the breccia. Fossiliferous gray limestone beds containing "floating" feldspar fragments occur within a few feet of the Precambrian contact in places, and in one place a yellowish-gray feldspathic limestone bed was found in the San Andres about 90 feet above the base of the section and only about 5o feet below a Glorieta sandstone.

It is only about 12 miles northwesterly from the buried Precambrian high at Pajarito to the 1,000-foot section of Yeso near Green Tree (pl. 1). If, as supposed by Meyer (1966, p. 72), more than 1,000 feet of Wolfcampian beds cover the Pedernal in this area, then Pajarito Mountain would have been larger on the Permian landscape than it is today. A postulated buried topography with no Wolfcampian (Abo) beds in this area is shown in Figure 3.

SAN ANDRES FORMATION

General

Approximately 50 percent of the mapped area is surfaced by the San Andres Formation. The main body of the formation had never been subdivided prior to this work. As regional structure was one of the major objectives of this work, it was practically mandatory that some interior horizons be found in view of the thick low-dipping beds. After some reconnaissance north and east of the Capitan Mountains it was found that an upper evaporitic member could be mapped. This aspect of the formation was known by many prior to this work, especially in certain parts of the subsurface, but no attempt had been made to map it on the surface. Near the middle of the formation, and possibly somewhat below the upper part, an interval of 150 to 250 feet, termed Slaughter zone, is recognized in the subsurface in some places (Havenor, 1968, p. 10, pls. 5, 6). The base of the Slaughter is nearly equivalent to the base of the Bonney Canyon Member of this work. In the southeastern part of the area, also in the subsurface, a sandstone, referred to as Lovington, has been identified 100 to 150 feet from the top of the upper evaporitic member.

As mapping progressed it became evident that another interval could be widely recognized in the part beneath the evaporitic section. This consisted of a thin-bedded upper sequence above a more massive lower part. Consequently, three members were identified and mapped throughout the area. These have been named, in ascending order, Rio Bonito, Bonney Canyon, and Fourmile Draw. The Rio Bonito is the lower, thick-bedded part, the Bonney Canyon is the middle, typically thin-bedded, more porous part, and the Fourmile Draw is the upper, typically evaporitic part. The top of the Rio Bonito was selected as the horizon on which the structure contouring was done. Perhaps the most gratifying aspect of making these divisions was that the base of the Bonney Canyon Member, which was selected west of Roswell in Hondo Canyon, during mapping was traced southward into the base of the upper "noncherty" member of Hayes (1964, p. 24) in the Guadalupe Mountains. Thus, the Bonney Canyon and the Fourmile Draw Member together have essential identity with Hayes' and Skinner's (1946, p. 1864-1865) upper "noncherty" member and the Rio Bonito of this work is the cherty member of Hayes.

The type locality of the San Andres, as named by Lee (1909, p. 12-13, 29) and defined by Needham and Bates (1943, p. 1664-1666) near Rhodes Pass in the San Andres Mountains, is inadequate as all the Fourmile Draw Member in the San Andres Mountains was not deposited as such, or was eroded in pre-Triassic and pre-Dakota times. Dickey (194o, p. 40-42) extended the San Andres into the Permian basin subsurface where it became widely recognized. A really significant top was more or less automatically put on the San Andres when the Artesia Group was given formality by the Roswell Geological Society (Tait et al., 1962).

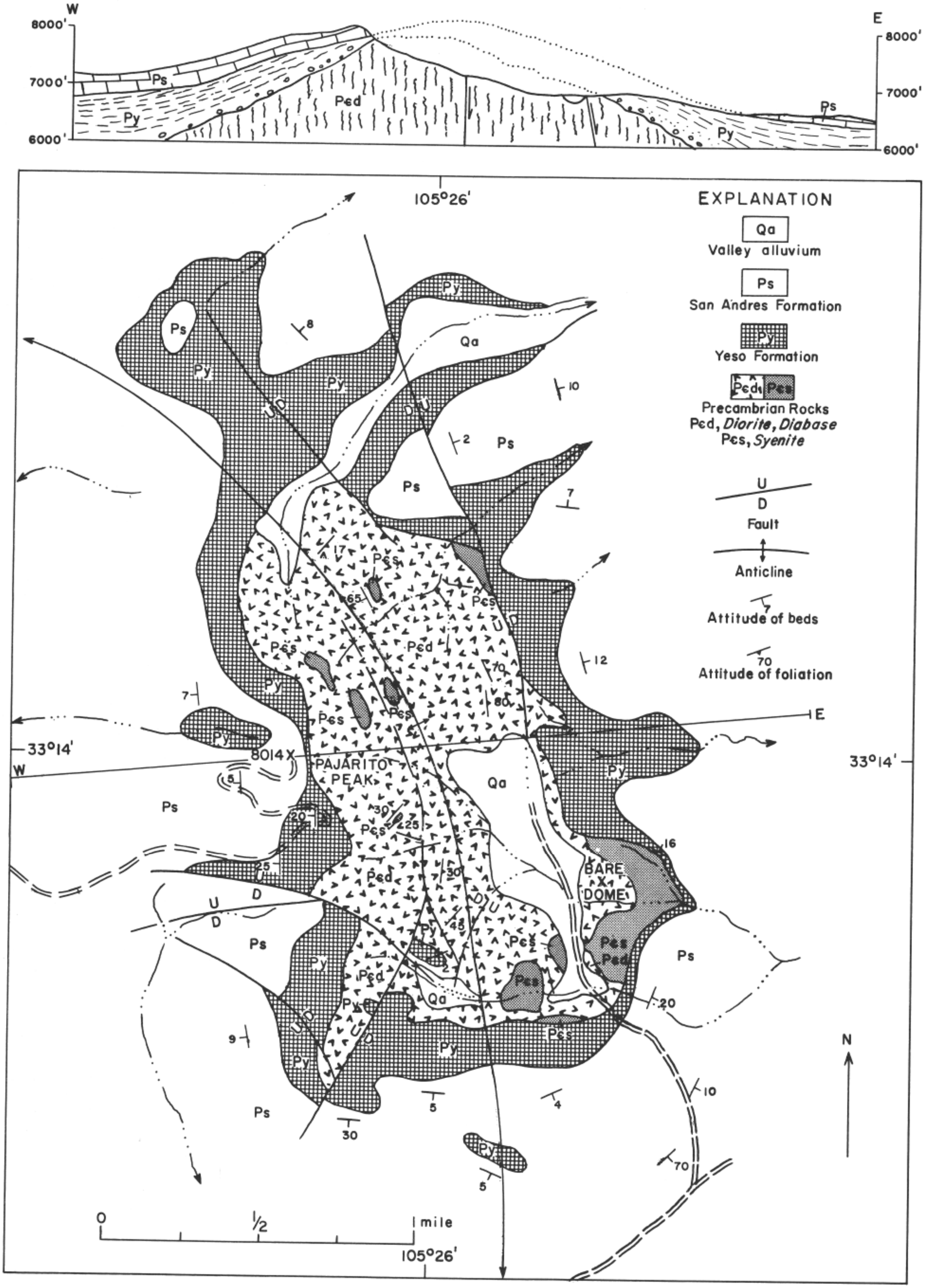

Figure 2.

GEOLOGIC MAP AND STRUCTURE SECTION OF PAJARITO MOUNTAIN

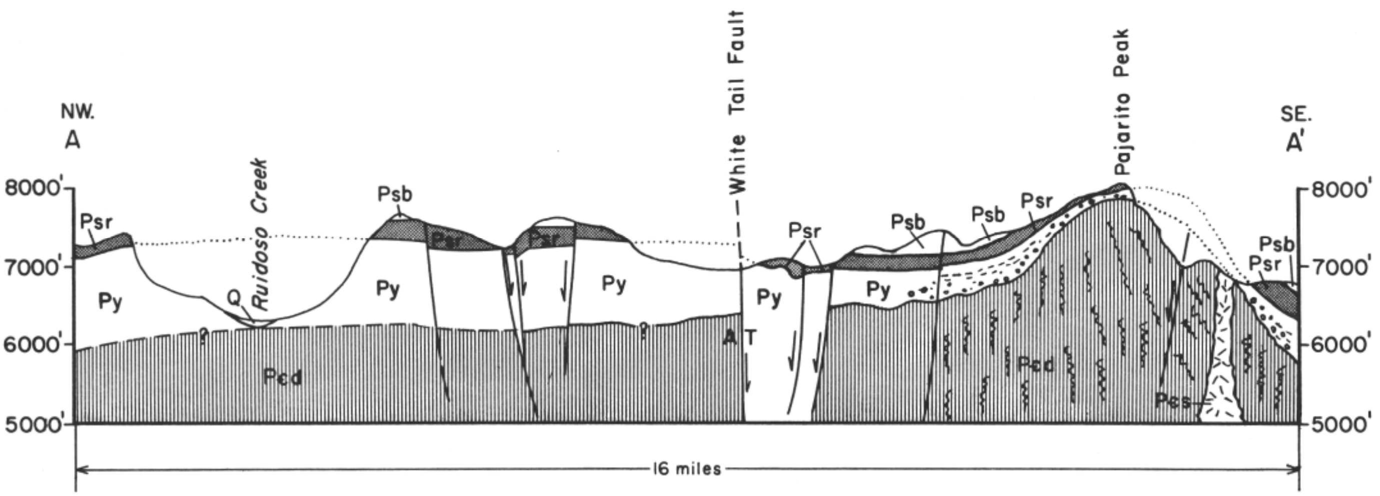

Figure 3
STRUCTURE SECTION FROM PAJARITO MOUNTAIN TO RUIDOSO VALLEY

Thus, the San Andres Formation includes all the beds between the top of the Yeso and the base of the Artesia Group as defined by the base of the Grayburg Formation. These two boundaries are not generally in close proximity; however, they are nearest in the northern part of T. 24 S., R. 20 E. where Hayes (1964, p. 25) measured about 1,200 feet across some faulting. Near the northern end of the Guadalupe Mountains in secs. 18, 19, T. 20 S., R. 18 E. the Rio Bonito measures 620 feet thick: 5 miles east in sec. 5, T. 20 S., R. 19 E. the Bonney Canyon measures 204 feet; and the Fourmile Draw Member measures 384 feet along Fourmile Draw 10 miles to the northeast. The pieced-together surface sections for the region of the northern part of the Guadalupe Mountains is 1,208 feet. Farther north, complete surface sections to the top are difficult to determine, owing principally to structural irregularity, poor exposures, and low dip of the Fourmile Draw Member. Subsurface data along the Pecos Valley suggest considerable variation in the thicknesses (Kinney and others, 1968, fig. 7), ranging from about 500 to about 1,700 feet. This considerable difference is likely to be largely due to complications arising from faulting, erosion, and ground-water subtraction. For the area as a whole, two general isopachous changes are noted; (I) in the western outcropping area, from 700 feet in the north to almost 1,300 feet in the south, and (2) in the eastern subsurface area from about 900 feet in the north to as much as 1,700 feet in the south.

In five sections sampled, including the Rio Bonito and parts of the Bonney Canyon Members, dolomite increases from south to north at the expense of limestone. Along with a general increase of dolomite northward across the shelf there is a slight lightening of shades from dark gray to gray or light gray, and lightening overall of the faint brownish tints.

In the measurement of more than 2,000 feet of the section, 38 percent of the Bonney Canyon beds are less than 1 foot thick, and only 17 percent of the Rio Bonito beds are less than 1 foot thick. Beds of Bonney Canyon more than 3 feet thick constitute about 20 percent of the section. Beds of Rio Bonito 3 to 6 feet thick constitute 50 percent of the section; and above 6 feet thick, 20 percent. Beds more than 6 feet thick are absent in most sections of Bonney Canyon, or where present are confined to the lowest part.

There is little or no consistent difference in texture or fabric between the Rio Bonito and Bonney Canyon beds of similar composition. However, grainstone and packstone fabrics (Dunham, 1962, p. 117) are more common in dolomite whereas wackestone is more common in limestone. Individual beds, or thin zones of beds, have remarkable continuity throughout wide areas, both compositionally and texturally. On the other hand, the heterogeneity of beds one above the other in places is equally remarkable. Thus, in a roadcut one might see a laminated dolomite bed superseded by a dark-gray, massive, dense dolomite, in turn superseded by a gray diacrystic dolomite, and contrastingly so on up or down section.

Rio Bonito and Glorieta Members

The Rio Bonito is the lower, thicker-bedded part of the San Andres Formation. It is the part characteristic of the type locality in the San Andres Mountains. Along the Pecos slope it crops out most prominently in the walls of numerous canyons that dissect the slope. Bedding is mostly thick, although thin- and medium-bedded areas or sequences are common. Bedding commonly changes along an exposure from thin to thick. Although named from the Rio Bonito where there are excellent exposures, its type locality is designated at the Sunset section (pl. 2) and near the locality where the Bonney Canyon-Rio Bonito contact was first designated. It is common for light-gray and gray sequences to alternate, causing banded exposures along canyon walls that may be traced for considerable distances. In general the lower 50 to 70 percent of the section consists of lighter grays and gray-brown tints than the upper part.

The Rio Bonito consists predominantly of beds 2 to 6 feet thick, but locally, beds are as much as 30 feet thick, with little apparent bedding. Although bedding is remarkably parallel, local lenticularity may be found. Cross-bedding is rare, but there is a remarkably well-developed 4-foot bed in a quarry near U. S. Highway 83 in sec. 8, T. 17 S., R. 19 E. The bed lies among noncrossbedded layers. The forsets are 2 to 4 inches thick, dip N. 60 E. at 10 degrees, and are developed regularly for 100 feet along the quarry face. They consist of oolitic dolomite.

Most of the emphasis in the San Andres study has been on chemical composition and little thin-section, staining, or optical study has been done. Nevertheless, hand-lens examination of many samples reveals that the dominant fabrics are grainstone and packstone (Dunham, 1962, p. 117). Wackestone depositional fabric is uncommon, and mudstone is rare except in the limestone sections in the southern part of the area where wackestone, with some packstone and mud-stone, predominates. Oolitic beds are fairly common and in the Cooper Ranch and Sunset sections (pl. I) of the northern area, several prominently oolitic beds are encountered, ranging in thickness from 3 feet to as much as 28 feet. However, no oolite was noted in the Manning anticline or Stevenson Ranch sections. Diacrystic textures are common in many beds of dolomite and in the Stevenson Ranch section the limestone was quite diacrystic.

Fossils or fossil fragments were fairly common but sporadically developed. In this work, little attention was given to fossils other than where their presence was obvious. Fusulinids, brachiopods, and ammonites were commonly noted. Much fragmented fossil material was seen and especially noted in the few thin sections that were examined.

In the Stevenson Ranch section, fossils are distinctly more abundant in the limestone of the upper part of the Rio Bonito than at the same horizon where the section is dolomite.

Chert is not generally a characteristic of the San Andres formation, except in the southern part of the Guadalupe Mountains where it is abundant in the lower part, especially below and in the vicinity of the Cherry Canyon Sandstone.

One or two Glorieta sandstone tongues occur in the lower part of the Rio Bonito throughout the central and southern parts of the area. South of the Capitan Mountains in the Hondo drainage system the top of the highest bed ranges from 100 to 150 feet above the base of the member (pl. 7). In some sections there is a sandstone at the base, but as a rule 40 to 70 feet of dolomite occurs below the first sandstone. The sandstone beds range to 60 feet in thickness but southward to the Guadalupe Mountains the beds become thinner, finer grained, and are not everywhere present.

The Glorieta interval continues around the eastern end and to the north of the Capitan Mountains. Exposures to the north of the mountains are poor, and it has not been possible to get good stratigraphic positions on the sandstones except in the southeastern part of the Jicarilla Mountains. In the Jicarillas there are 65 to 70 feet of sandstone in two beds separated by 12 to 20 feet of dolomite. In the Tecolote area, Rawson (1957, p. 12) measured 185 feet of gypsum with some interbedded limestone in the upper member. Northward through Bogle dome into the Corona mesas, sandstone increases and dolomite diminishes until in the north the Glorieta Sandstone is at least 225 feet thick.

Based on a regional study of the Hondo of Lang, and other sandstones in the San Andres of the Lincoln County, Harbour (1970) concluded that the Hondo was different from the Glorieta. However, sandstones in the Glorieta of central New Mexico differ from bed to bed, and regional mapping has shown that the Hondo sandstone becomes an indistinguishable part of the Glorieta. It is recommended that the term Hondo be dropped. There is little doubt that the Hondo sandstone of Lang (1937, p. 850) is a Glorieta tongue. The thickening of the Glorieta is at the expense of the Rio Bonito Member, and the Glorieta of north-central New Mexico and Rio Bonito, are facies of one another. In the north the Rio Bonito is as tongues in Glorieta; in the south Glorieta occurs as tongues in the Rio Bonito. Although the evidence is not wholly clear, it appears that the Yeso may rise from below at the expense of perhaps 50 feet of the lower part of the Rio Bonito, by either tonguing or lithologic gradation of dolomite into red beds.

In an east-west distance of some 35 miles along the Hondo drainage system there is no evidence of stratigraphic rise or fall of the Yeso-Rio Bonito contact. In the southern part of the area, exposures of this contact are spotty, but because of regularity of the base in outcrop and only small increase in thickness to the south, there appears to be little stratigraphic fall of the Rio Bonito base to nearly the shelf margin southward through the area. However, there may be more strati-graphic downtonguing in a southwesterly direction into the Tularosa basin.

The exact position of the upper contact of the Rio Bonito was selected with three purposes in mind, (1) separation of the thin-bedded Bonney Canyon unit, (2) cartographic feasibility, and (3) development of a widespread horizon on which to structure contour. The contact was first chosen in the Hondo Canyon near Riverside and in Bonney Canyon, a tributary which branches southwestward just east of the Border buckle. The contact in this area was chosen on a light-gray band that lies along the canyon side above the spur from the south wall just east of the McKnight Ranch headquarters. The contact crosses U. S. Highway 70 almost at the top of the grade out of the canyon and just before entering the big double road cut. If only the thin beds were to be included in the Bonney Canyon Member the contact would be above this prominent shoulder. However, mapping at the higher position results in an inordinate amount of contact-line suturing on the map and innumerable outliers. A higher contact was, however, mapped experimentally over large areas in order to more carefully control the position of the mapped lower contact, especially for outcrops of the Rio Bonito that are separated some distance from one another. These two boundaries were actually traced throughout large areas for as much as 25 to 30 miles to the north and south of the type locality of the Bonney Canyon Member. During this procedure it was discovered that the Bonney Canyon thickened southward and thinned northward from the type area.

The contact between these two units does not everywhere display the same expression as around the type area, of being at the base of the first prominent steepening below the gentle upland areas. In places the contact may be midway down steep canyon walls, near canyon bottoms, or locally, out on the open uplands. However, I am confident that the contact as drawn does not miss stratigraphically by more than 50 to 75 feet over more than 75 percent of the area in which it is

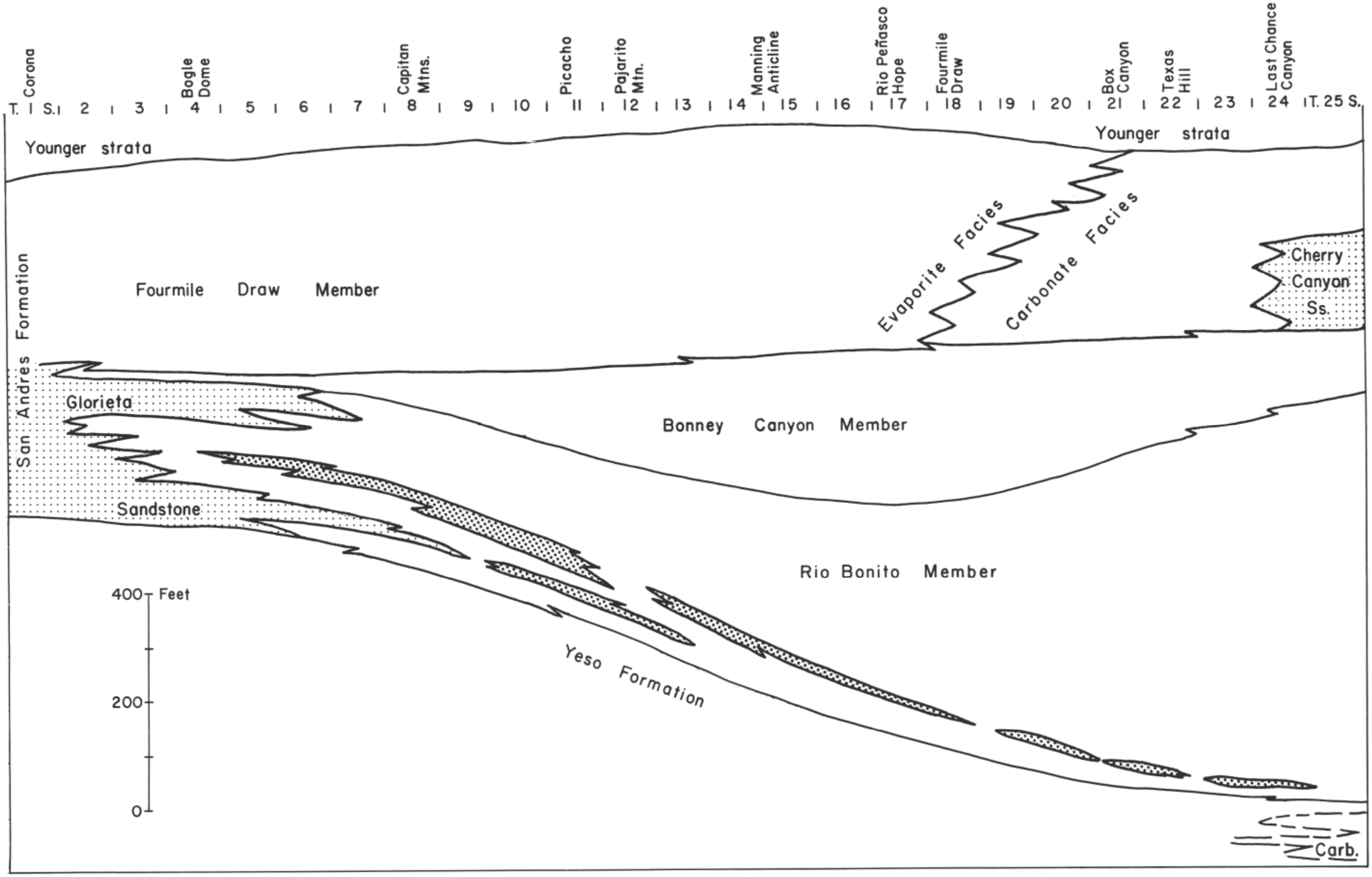

Figure 4

NORTH-SOUTH STRATIGRAPHIC DIAGRAM OF THE SAN ANDRES MEMBERS mapped. Its delineation proves very useful to the structure and stratigraphy. It becomes very difficult to locate or follow, however, where vegetation is heavier, as in the high areas of Otero County.

It has been necessary to discuss the nature of the upper contact in order to set final remarks regarding the thicknesses of the Rio Bonito. It ranges irregularly throughout most of the central and northern parts of the area from about 250 to 320 feet, and a real change can hardly be distinguished from changes due to errors in mapping and measurement. It is noteworthy, and perhaps significant, that the average thickness of the Rio Bonito in the central part of the area is comparable to that of the Glorieta in the northern area where there are few Rio Bonito beds remaining. South of about T. 15 S., the member thickens gradually while the Bonney Canyon thins. This thickening is most noticeable in comparing the measured section at Manning anticline with the Stevenson Ranch and Lewis sections (appendix and pl. 10). In the former, the thickness is only about 300 feet, whereas in the Stevenson and Lewis sections thicknesses are 550 to 650 feet. On the basis of partial intermediate outcrops it is believed that most of the increase occurs in Ts. 18, 19 S. nearer to the Stevenson and Lewis sections, these being at the approximate latitude of the northern end of the Guadalupe Mountains.

Bonney Canyon Member

The Bonney Canyon Member is the middle part of the San Andres Formation. It is named for exposures in Bonney Canyon, a tributary of the Hondo River south of Riverside. It generally occupies the upper 100 to 200 feet of the walls of the deeper canyons, and is spread widely across the gentle slopes of the upland interfluve areas. Beds are typically thin and one 5-foot interval was noted near the middle of the section a mile or so south of Bonney Canyon along the Border buckle that consisted of varved laminations. Aerial photos of these exposures have strikingly sutured, banded patterns, not unlike those of birdseye maple. The photo pattern is of contrasting light and dark layers which are mostly variations in the soil or vegetation between either alternating resistant and non-resistant layers, or porous and nonporous layers (fig.5). On the ground most outcrops appear light gray, but fresh samples of sections of the member reveal considerable alternation between layers that are on fresh surfaces, dark grayish brown, medium gray, and light gray,

Figure 5

OUTCROP PATTERNS OP BONNEY CANYON BEDS IN T. 14 S., R. 20 E.

Exposures are between Crooked Canyon (top) and Squaw Canyon (lower left). Trace of Six Mile buckle diagonally crosses left side of picture. Contrasts in shade of beds are caused by difference in sparse vegetation.

with much subtle brownish tinting, especially in the medium-gray rocks. Textures of fresh rocks are fine- to extremely fine-grained and lithographically dense. Less-firm or thin-bedded layers are commonly marked by bush or grass "lines" that are generally indicative of greater permeability. Where seen in road cuts, especially in the high part of the member, as along U. S. Highway 70 west of Border Hills to the descent of the road into the canyon, numerous silty and sandy carbonate beds of pale yellowish color are evident. Sandy-appearing rock is often pulverulent calcite and is probably a secondary recrystallization in the presence of ground water. Considerable disturbance of beds in the upper 5o feet of the member strongly suggests the former presence of gypsum and anhydrite in places. It is not often seen at the surface but has been noted often in the subsurface from this interval. Only a small lens of gypsum was found in this interval in sec. 17, T. 18 S., R. 18 E. Chert is sparingly present in the dolomites. Fossils and fossil fragments are common even high in the section. Ammonites 2 to 3 inches across are fairly common in many sections.

A type locality is designated for the Bonney Canyon Member in the north side of Hondo Canyon in sec. 24, T. S., R. 20 E. where the base of the section is mapped at the top of the cliffy rise above the road. A section 151 feet thick was measured and sampled (app. III), and the uppermost bed at the top of the canyon was readily traced eastward to a position immediately beneath the overlying Fourmile Draw Member near the White Ranch headquarters. The Bonney Canyon Member at the type locality is thin to medium bedded and consists dominantly of light- to medium-gray, brownish-gray, fine-grained dolomite and limestone. An oolitic bed is present in the middle of the section and cherty nodules are sparingly present.

In the Hondo Canyon area, the Bonney Canyon thickness is usually about 150 feet, but in Ts. 12, 13 S., only 5 to 10 miles to the south it thickens to as much as 300 feet. The Bonney is mapped into the Guadalupe Mountains where it appears to thin, and becomes unrecognizable in T. 25 S. A gross section 207 feet thick was measured south of Long Canyon in T. 25 S. Northward the unit thins gradually to about 140 feet east of the Capitan Mountains, and to the north of the mountains, as at the Downing buckle, it appears to be only about 60 feet thick. The unit is not well exposed north of this locality in the mapped area.

The subsurface Slaughter zone of porosity, widely recognized around Roswell and east, is roughly equivalent to the Bonney Canyon Member. The Slaughter zone may include a thin lower part of the Fourmile Draw Member in some areas.

Fourmile Draw Member

The Fourmile Draw Member is the upper, evaporitic part of the San Andres Formation. The name is taken from exposures along the draw in T. 18 S., Rs. 19-21 E. A gross thickness was measured in extended sections from the top of the Bonney Canyon, which was cherty, to the base of the Grayburg red beds. The section along Fourmile Draw, with some thin gypsum and gypsum-bearing dolomites in the upper part, was 384 feet thick. The unit was also measured as 387 feet thick in the canyon re-entrant of the south sideof Rocky Arroyo Canyon, between cherty beds below and red sandstone of the Grayburg on the flat top above the canyon (app. VII). A section 342 feet thick was also measured along Box Canyon. It contained no gypsum. The type section was placed in Fourmile Draw, rather than in Rocky Arroyo because the lithology along the draw section was more typical of the unit as a whole, especially where mapped far to the north. The Rocky Arroyo section is the shelf-margin transition facies of the same unit. Hayes (1964, p.25) noted local unconformities between the Fourmile Draw Member and his "lower" member. None could be determined in the great length of contact in the area to the north.

The Cherry Canyon sandstone tongue makes up much, if not all, of the Fourmile Draw Member at Last Chance Canyon. As shown by Hayes (1964, p.26), it grades northward into the member, and at the next exposures in Rocky Arroyo it is no longer present, although the large fusulinids, which are common in the sandy dolomites at Last Chance Canyon, are much in evidence in the lower part of the member along the canyon walls of Rocky Arroyo.

North of Texas Hill, in the Guadalupe Mountains at about Segrest Canyon, T. 21 S., R. 21 E., gypsum begins to appear in the Fourmile Draw Member. It occurs in separate lenses or beds, and pods or nodules in dolomite *(see* Fiedler and Nye, 1933, pls. 19-22, fig. 10). The two dolomite key beds shown on pl.4 near the Chaves-Eddy county line, Ts. 18-20 S., stand out, owing to underlying gypsiferous intervals.

North of the Fourmile embayment (pls. 4, 5) the member is incompletely exposed, owing to alluvium and the Pecos Valley Gatuna Formation. To the west and northwest of Roswell, and on to north of the Capitan Mountain in the Hasparos embayment, there are great expanses of the unit.

Gypsum becomes much more abundant in the Fourmile Draw Member from T. 9 S. northward, and intervals 50 to 100 feet thick are common in the upper part. Throughout the Hasparos embayment the Fourmile is greatly pockmarked by small sink holes (fig. 6). Gypsum and dolomite are predominant, but reddish, pinkish, or yellowish mudstone is present in small exposures in many places. Locally there are red beds of siltstone that can be followed over several square miles. At, or near the top of the member, in the western part of the embayment, a clean white sandstone interval as much as 20 or 30 feet thick is present. Exposures of this interval may be seen near the Triassic contact in the east-central part of T. 6 S., R. 15 E., along the ranch road through the southwestern part of T. 6 S., R. 15 E., along the ranch road through the southwestern part of T. 5 S., R. 14 E., and in the central part of T. 4 S., R. 13 E. The best exposure of this sandstone in an orderly sequence with reference to the overlying Grayburg is outside the area in sec. 15, T. 5 S., R. 11 E. (pl. 5, Smith and Budding, 1959).

The evaporitic nature of the upper part of the San Andres was recognized long ago by Darton (1922, p. 181), and Fiedler and Nye (1933, p. 67), but until now no one has mapped it regionally. However, Rawson (1957, fig.1), working under my supervision in the Tecolote district, Lincoln County, mapped the upper member much as has been done here. The Hasparos embayment appears to open westward into the Claunch sag (Kelley and Thompson, 1964, p.111), and as the Fourmile is followed westward it appears

Figure 6

POCKMARKED (PSF) SOLUTION ON FLAT-LYING FOURMILE DRAW OUTCROPS IN T. 4 S., R. 14, 15 E.
Hasparos Creek cuts through Bogle dome an inlier of Glorieta (Psg).

to become more evaporitic, as at Tecolote and near Ancho, where it could be more readily separated in mapping than at any place seen to date. In sec. 15, T. 5 S., R. 11 E. about 800 feet of gypsum with a few thin beds of dolomite and a clean white sandstone ledge at the top has been measured during this work. The Fourmile Draw Member can be mapped far to the west and north of the present area. An attempt to do so would greatly improve our understanding of the San Andres Formation and aid in understanding the subsurface, especially along the Pecos northward from Roswell to Tucumcari. Results of this work strongly indicate that much of the San Andres, as described and mapped in north-central New Mexico is the Fourmile Draw Member. The evaporite member of the San Andres Formation of Kelley and Wood (1946) may be equivalent to the Fourmile Draw Member.

ARTESIA GROUP

General

In this study, background for an understanding of the nomenclature of the Artesia needs to come almost simultaneously from two areas, central New Mexico and the Permian Basin. The now-abandoned Chupadera formation was introduced by Darton (1922, p. 180 to include the Yeso and San Andres Formations because in large areas, particularly near Chupadera Mesa, he saw Yeso-like lithologies extensively in the San Andres. Because of this, he probably included some Bernal beds in the high part of his Chupadera Formation as he was embracing all Yeso-like lithologies.

In the Permian basin, Nye (Fiedler and Nye, 1933, p. 44) introduced the term "Pecos Formation" (now abandoned) for all the beds between the San Andres and the Triassic, thereby including not only the present Artesia Group but also the Castile and Rustler Formations of present usage. Correlation of Artesia beds (Seven Rivers Formation) was made very early with Whitehorse and Quartermaster beds of Oklahoma by comparative paleontology (Beede, 1910, p. 134). Whitehorse was first used in connection with the presently accepted formations of the Artesia Group by DeFord and Lloyd (1940, p.8) for subsurface and surface of southeastern New Mexico. This midcontinent term was mildly undesirable for New Mexico, and the nomenclature was further complicated by Lang (1937, p. 856), who introduced the term "Chalk Bluff Formation" for some 1,000 feet of beds between the San Andres and the "Salado halite." There is really nothing very wrong with this definition except for the interval being several hundred feet too thin and the fact that most of the lower half of the formation lay beneath valley fill to the west of Chalk Bluff, located a few miles north of Lake McMillan. The nomenclature then lay in sort of suspended uncertainty for some twenty years, until the late fifties.

In the meantime, Read and his associates with the U. S. Geological Survey in Albuquerque, recognized a Yeso-like unit above the San Andres throughout central New Mexico. The term Bernal was taken for these rocks from the exposures near Chapelle and Bernal villages along the Pecos River in San Miguel County. At the time it was not possible for the name to be formalized because of the wartime inactivity of the Survey's Nomenclature Committee. It was, however, referred to as the upper member of the San Andres Formation, and on the map by the symbol Pb (Read and others, 1945). Many geologists and students knew the unit as the Bernal formation, and in 1949 (Kelley, fig. 2) the term was put into print alongside "Chalk Bluff" even though the "Bernal" was without formal sanction. It was not until 1953 (Bachman, 1953) that the name was given the formality of a type locality.

Read and his colleagues expanded the usage and recognition southward toward the Permian basin (Dobrovolny, et al., 1947). In the late fifties efforts were begun by Roswell Geological Society members and others to clarify the confusion, and in 1962 Tait and others proposed the new term Artesia Group to replace "Whitehorse," "Chalk Bluff," and "Bernal." Artesia includes all beds from the top of the San Andres to the top of the Tansill Formation.

In ascending order, the formations of the Artesia are: Grayburg, Queen, Seven Rivers, Yates, and Tansill. These were in use prior to Artesia Group and all terms are currently used in surface as well as subsurface work. Grayburg, Yates, and Tansill originated in the subsurface, and Queen and Seven Rivers came from surface exposures and were extended to subsurface. However, all now have surface type sections. Boundary problems for the formations are not serious for most subsurface workers except possibly for the Yates-Seven Rivers and the Queen-Grayburg separations. On the surface, however, delineations of the formations have been a very difficult problem owing to interruption of exposures in large areas, lack of clear lithologic differences in large areas, and insufficient effort in tracing and mapping of the formations. Prior to this work the formations were only mapped south of Lake McMillan. In this work, all the outcropping units have been mapped (pls. 2, 4) as far north as latitude 34° with the exception of the Grayburg and Queen which have been combined north of Roswell (fig. 7).

Tait et al. (1962) recommended the abandonment of Bernal. However, this work suggests that the term Bernal may be useful for a thin northern facies that represents only part of the Artesia Group.

The Artesia beds are perhaps most notable for their considerable display of differing lithofacies away from the great Permian Capitan reef complex. The change from the structureless or massive complexes of the reef zone northward into the elastic and evaporitic facies of the back reef and shelf is often almost unbelievably rapid. On the geologic map (pl. 4) some of this change is shown by intertonguing and some by lines across formations showing first appearances of gypsum.

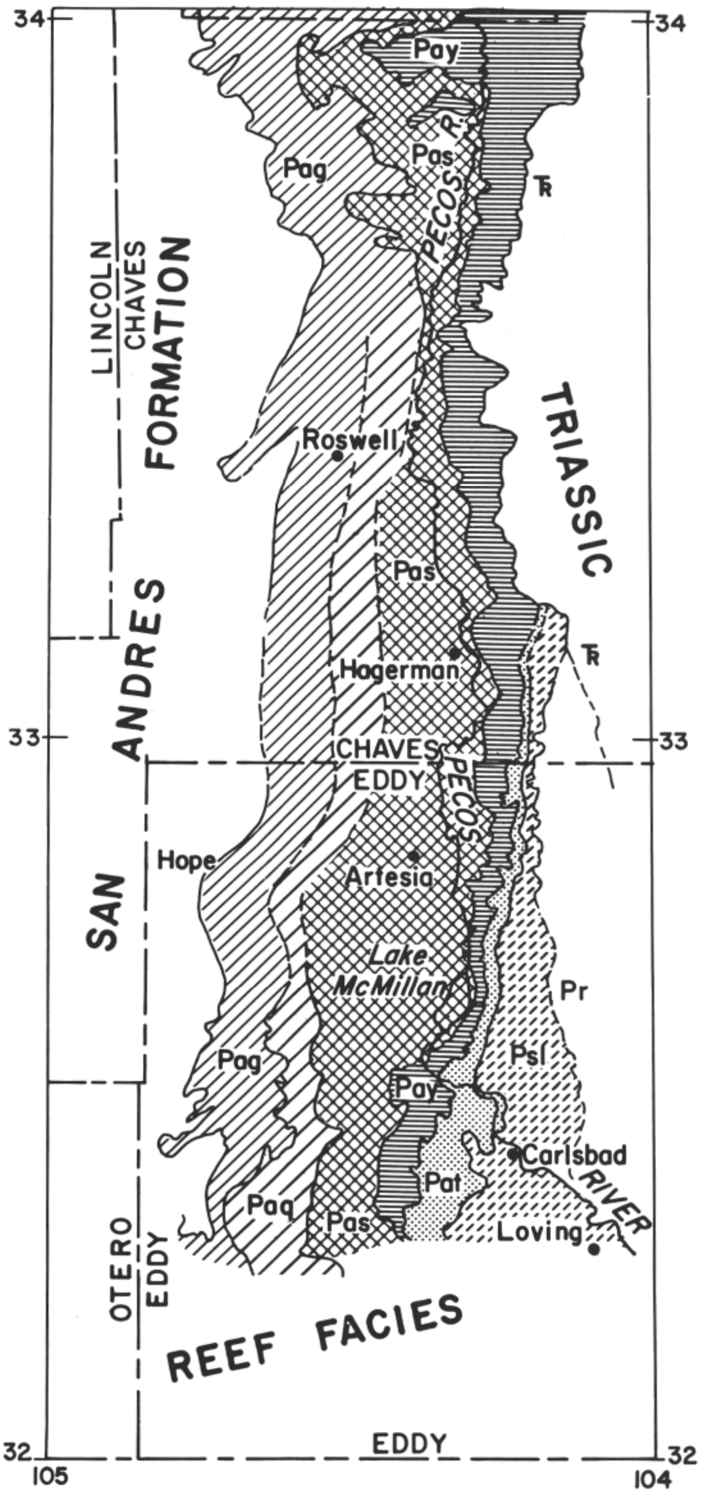

Figure 7
DISTRIBUTION OF ARTESIA FORMATIONS ALONG THE
PECOS VALLEY

Grayburg Formation

Grayburg was named by Dickey (1940, p. 44-45) from well occurrences in sec. 7, T. 17 S., R. 30 E., Eddy County, New Mexico. Moran (p. 147-150) proposed a surface type section near Sitting Bull Falls, and Hayes and Koogle (1958) with only slight modification of the base at the type locality mapped the formation throughout the Guadalupe Mountains. Hayes' (1964, pl. 1) Grayburg contacts were picked in the present work with only slight modifications and extended northward from his area. North of T. 19 S. only small patches are mapped to Roswell. However, north of Roswell Grayburg and Queen beds are mapped as one unit.

The southernmost outcrops are in north McKittrick Canyon (T. 26 S., R. 21 E.) where they grade with the lowermost overlying Queen Formation into the reef or bank deposits of the Goat Seep dolomite. Grayburg is also mapped along the east flank of Sierra Blanca basin extending in a band from the Capitan Mountains southward through Fort Stanton to the Ruidoso area. Along this belt the Grayburg rests on Bonney Canyon beds of the San Andres with all the Four-mile Draw Member missing. Tan, brown, medium- to fine-grained sandstone is the principal lithology, and south of Fort Stanton thicknesses appear to reach 400 to 500 feet in a few miles. In several places near the junction of U. S. Highway 380 and the Fort Stanton road, a cherty gray dolomite is found near the top and often just below cherty conglomerate beds of the Santa Rosa Formation.

Another band of Grayburg occurs north of Capitan Mountains in Ts. 5,6 S., Rs. 13,14 E., where it overlies the Four-mile Draw Member of the San Andres Formation and is overlain by the Santa Rosa Sandstone. Absence of Fourmile beds south of the Capitan Mountains, and their presence beneath the Grayburg along the western end of the Capitans and northward, suggests post-San Andres uplift south of the Capitan fault and consequent removal of high San Andres beds before Grayburg time. Such movement on the Capitan fault is the opposite to that indicated by the present displacement.

In the area of the type locality of the Grayburg, along the Huapache monocline and in the adjoining Guadalupe Mountains, the dominant lithology is very light tan, almost lithographic dolomite and calcareous dolomite with intercalated fine-grained sandstone. Sandstone beds are somewhat more common and thicker bedded in the lower part. Bedding ranges mostly from a few inches to about one foot, although some beds reach 10 feet in sandstone. All bedding thickens noticeably as the reef is approached, where massiveness takes over and carbonate increases.

Northward of the type locality, sandstone and dolomite give way to reddish, more friable, thinner-bedded sandstone and mudstone, and in T. 22 S., R. 22 E. gypsum first appears. Northward, gypsum is more common, and in the sink holes at Antelope Springs southeast of Hope (T. 18 S., R. 23 E.), red- and white-banded gypsum several tens of feet thick is evident.

In the northern part of the area, from about Macho Draw and U.S. Highway 285 northward, wide expanses of undivided Grayburg-Queen are seen both west and east of the highway. In this area, red mudstone and muddy gypsum predominate, but thin dolomite beds are present, especially in the lower part of the sequence.

Irregularities in detail, present along the base of the Gray-burg, together with considerable solution weathering and collapse breccia in the top of the Fourmile Draw Member of the San Andres, suggest at least a disconformity in the Pecos Valley region. The absence of the Fourmile Draw Member in the Ruidoso-to-Capitan belt suggests either a rise of the Mescalero arch-Pedernal axis during a post-San Andres to pre-Grayburg interval, or a low positive area in Fourmile Draw time, during which no deposition occurred.

Queen Formation

The Queen Formation was named by Crandall (1929, p. 940) from exposures near Queen along State Road 37, high on the Guadalupe Mountains. Moran, in 1954, designated a type section in Dark Canyon about 5 miles east of Queen, and Hayes (1964, pl. 1) mapped the formation widely in the southern Guadalupe country. In this work, mapping of the Queen closely follows that of Hayes, except that it is extended farther into the massive Capitan limestone facies.

North of the type locality, the mapping is extended to Fourmile Draw. North of Roswell, Queen beds are probably in the eastern part of the undivided Grayburg-Queen unit. The Queen has been widely recognized in the subsurface along with the other Artesia formations.

As described by Hayes (1964, p. 30-31), the Queen is lithologically similar to the Grayburg in the near-reef and reef areas, but with almost twice the proportion of clastic beds. Perhaps because of this fact, the outcrops and outcrop soils are slightly darker than the Grayburg and the overlying Seven Rivers Formation.

As with the Grayburg, Queen lithology of the near reef type changes northward into thinner beds of red sandstone and mudstone with dolomite. North of Rocky Arroyo, gypsum appears and shortly becomes a nearly dominant part of the formation, especially in the upper part. Thin dolomite beds are gray or gray and magenta. The upper contact around Rocky Arroyo is above a prominent sandstone ledge.

In the Guadalupe Ridge area the Queen appears to be almost 400 feet in thickness (Hayes, 1964, p. 31); however, to the north in the Seven Rivers embayment, the thickness does not appear to exceed 200 feet, although no section was measured.

Seven Rivers Formation

The name Seven Rivers was given by Meinzer, Renick, and Bryan (1926, p. 13-14) in the form "Seven Rivers gypsiferous member," part of the now-discarded Chupadera formation. It was applied to the mudstone, gypsum, and sandstone beds beneath the dolomite of Lang's (1937, p. 868) Azotea tongue of the Carlsbad Limestone. For reasons not entirely clear from the literature, the original top of the Seven Rivers at the base of the Azotea has been elevated to include the Azotea. The base at the type locality, if it can be called such, is not exposed. The present selection of the base of the Seven Rivers appears to be the work of Hayes (1964, pl. 1) perhaps partly modified from King (1948, pl. 3) and certainly influenced by Moran's top on the Queen at its type locality (1954, p. 147-150).

A principal reference section for the Seven Rivers Formation, better than the type section, might be in the shelf-reef margin, in accordance with the location of surface-type sections of the other Artesia formations. Perhaps some additional work in either Bear or North Slaughter Canyons (Hayes and Koogle, 1958) could establish a good principal reference surface section. Nevertheless, as pointed out earlier by Crandall (1929, p. 938), the Seven Rivers is a distinct formation throughout the carbonate part of the shelf margin. The upper contact, which is readily defined at the overlying Yates, and the basal contact, were both picked from Hayes' mapping and carried northward during this work (pl. 4) through the Seven Rivers Hills where the name was first applied.

The transition to reddish gypsum, mudstone, and thin lithographic dolomite beds begins roughly along a northeastward-trending line which extends from El Paso Gap west of the Guadalupe Mountains through the East Hess Hills about along Johnson Canyon and into the subsurface. The dolomite Azotea tongue extends about another 1 3 miles northwest of the projected line of first appearance of gypsum in the lower half of the Seven Rivers. The Azotea wedge edge at the outcrop is just north of Lake McMillan, where surface outcrops of the Yates descend gradually to the Pecos River alluvial plain. Just north of Chalk Bluff Draw, the Artesia-Vacuum arch brings the Seven Rivers again into the bluffs that form the eastern edge of the Pecos Valley. Except for a short stretch east of Lake Arthur and Hagerman, where Cenozoic Gatuna beds fill an old valley, the Seven Rivers evaporite facies is continuously traceable to as far north as T. 5 S. This is a distance of about 70 miles in which the Seven Rivers forms the bluffs east of the Pecos River. The exposures are especially prominent east of Roswell in the Bottomless Lakes area. Near the intersection of U. S. Highway 70 with the Pecos River, the Seven Rivers outcrop crosses to the west side of the valley. From there northward to beyond the northern edge of the mapped area (pl. 2), the low-dipping Seven Rivers Formation occupies a band 3 to 12 miles wide, across eastward-descending valleys and low mesas.

The dominantly carbonate facies of the Seven Rivers is 7 to 9 miles wide from the transition to the evaporite facies on the northwest to the transition to basin facies near the reef escarpment. Generally, only 0.5 to 2 miles of this would be considered reef, including some massive beds on the shelf and some forereef beds on the basin side. Completely structureless material in what may be considered the core of the reef appears to be as little as 0.25 mile wide in some canyon exposures.

Within the carbonate facies, beds increase in thickness from a few inches in the northwestern part to 10 feet or more near the reef. Most of the carbonate band is dolomite, but for some reason, changes to calcareous dolomite and limestone in and near the reef. Back of the reef in an irregular zone, pisolitic textures are abundant, and these give way shelfward to oolites and dense lithographic dolomite.

In Bear Canyon (sec. 33, T. 24 S., R. 23 E.) Hayes and Koogle (1958) measured 460 feet of Seven Rivers above the Queen, but as much as 50 feet may have been eroded at the top.

As the reef zone is approached from the Seven Rivers, contacts may be projected in places with aid of aerial photos along the canyon walls well into the massive facies of the shelf edge or reef.

Hayes (1964, p. 33) measured the Seven Rivers as 459 feet thick in Bear Canyon (SE1/4 sec. 33, T. 24 S., R. 23 E.) about 2 miles north of the reef and estimated that the formation thickened toward the shelf edge to 600 feet. During the present work a partial evaporite section, 162 feet thick beneath the Azotea tongue, was measured east of the lower end of Lake McMillan. This was surmounted at the top of the McMillan bluff by 35 feet of dolomite of the Azotea tongue. The 162-foot gypsum section contained about 20 percent thin (1 to 8 inch) dolomite beds scattered through the exposure.

Yates Formation

The Yates name comes from occurrence in the Yates Oil field, Pecos County, Texas (Gester and Hawley, 1929, p. 487-488). It is one of the most widespread horizons, used for structure contouring in the Permian basin. It was brought to surface outcrops near Carlsbad by DeFord, Riggs, and Wills in 1938. It has been mapped widely in the reef and shelf near-reef areas by Hayes (1957), Hayes and Koogle (1958), Motts (1962), and Hayes (1964, pl. 1). Some additional near-reef area has been mapped in this work northwest of Carlsbad, and a carbonate tongue and an evaporite tongue of the formation have been delineated (pl. 4) west and northwest of Carlsbad *(see* especially T. 21 S., R. 25 E.). In this area the lower carbonate member of the Yates is really an upper transitional part of the Azotea tongue of the Seven Rivers Formation. It consists of alternating carbonate, mostly dolomite, interbedded with siltstone, fine-grained sandstone, and minor gypsiferous siltstone beds. This unit extends almost as far north as the distal end of the Azotea tongue. The upper evaporite number is a tongue into the carbonate belt of the reef and is best displayed in secs. 33, 34, T. 21 S., R. 25 E. In early Yates time the shelf carbonates spread as much as 8 to 10 miles farther northwestward away from the reef than in late Yates time.

North of the intertongued carbonate and evaporite members, the Yates outcrop is predominantly gypsum with only occasional thin (1- to 2-foot) key beds of dolomite. The Yates outcrop generally occupies a belt on a flat bench east of the Seven Rivers bluffs for nearly 100 miles to the northern boundary of the mapped area. About 33 miles up the Pecos River from Roswell, the Yates crosses in part to the west side of the river. In Ts. 4, 5 S., partly stripped thin outcrops are spread across broad mesas around Horse and Higgins Creeks.

North of Lake McMillan gypsum dominates the Yates outcrops to about Roswell. North of Roswell, and especially north of U. S. Highway 70, greenish-gray to olive-drab silt-stone and fine-grained thin sandstone dominate the lower part of the Yates. Higher in the Yates, however, gypsum and some red mudstones are dominant, as may be seen below the Triassic Santa Rosa Sandstone in T. 7 S., R. 27 E. In Ts. 5, 6 S., and Rs. 24, 25 E., Yates sand outcrops with occasional thin dolomite beds are well exposed. Limonite ironstone concretions are common in the sandstone and siltstone.

At the north end of Lake McMillan in secs. 28, 29, T. 19 S., R. 27 E., a thickness of 405 feet of Yates was measured from the top of the Azotea tongue to the base of the Tansill, which here consists of gypsum and thin minor dolomite beds. The Yates section is dominated by gypsum that is generally white, but locally reddish and greenish. The base of the section consists of II feet of poorly bedded reddish-brown siltstone. In the lower one-third of the section there are two distinctive white dolomite beds 1 to 2 feet thick, which may be traced for miles north and south of the measured section line. About 100 feet from the mapped top of the section, two grayish-green and brown siltstone and fine sandstone intervals 6 and 16 feet thick are present, but were not traceable very far from the area of exposure.

In the near-reef shelf area gypsum pinches out basinward 8 to 10 miles north of the reef proper. In the lower part of the Yates, dolomite, siltstone, and sandstone continue to the reef with gradual increase in dolomite. Locally, as shown around the common corner of Ts. 23, 24 S., Rs. 24, 25 E., considerable development of red and green mudstone occurs, especially in the upper part of the Yates within 3 to 4 miles of the reef. However, as the reef is approached, dolomite and sandstone increase, beds thicken, and bioclastic, oolitic, and pisolitic textures increase. As with the Seven Rivers, the Yates laps out or becomes a part of the structureless reef. However, at Walnut Canyon near White City, the top of the Yates can be mapped and projected to the reef escarpment at about creek level where it is in juxtaposition beneath a few feet of gravel, with uppermost Castile and low Salado beds of the basin (pl. 4). Numerous outliers of uppermost Yates are present along the top of Guadalupe Ridge all the way to the Texas line, and these lie above massive Capitan limestone reef facies in the canyons.

Hayes (1964, p. 35) measured 328 feet of Yates in North Rattlesnake Canyon and Motts (1962) believed the thickness to range from zoo to 300 feet west of Carlsbad. At the type subsurface section (Tait et al., 1962, p. 508) in the Humble's Federal Bogle well 1 in sec. 30, T. 16 S., R. 30 E., the Yates is "picked" with a thickness of 261 feet. In the surface section at the north end of Lake McMillan, which was mapped from the outcrops in reef marginal area, the measured section is 405 feet. This thickness is 144 feet greater than in the subsurface type section 24 miles to the northeast. Although the surface section may be too thick by as much as a so-foot error in measurement and in mapping, it also appears that the subsurface pick of the base of the Yates may be in error as compared to the original surface picks by Hayes (1957). It is also to be noted that the New Mexico subsurface picks for the Seven Rivers (Tait et al., 1962, p. 508) are about 100 feet thicker than the surface exposures as mapped. Tait et al. (op. cit., p. 513) show the subsurface Yates thinning northward from the type section to a thickness of about 130 feet in T. 4 S., R. 31 E., near Elida, New Mexico. Although no surface sections have been measured north of Lake McMillan it appears that the last "full-width" outcrop exposure in T. 15 S., R. 17 E., is thinner than the one measured in T. 19 S. Aside from errors inherent in surface measurements, a greater thickness around the northern end of Lake McMillan, as compared to the Humble Bogle well section, could be due to the fact that the latter locality is nearly on the Artesia Vacuum arch, whereas the surface section is along the sag to the south of the arch. Such an interpretation would, of course, imply activity on the arch during Yates time. The dominant surface evaporitic lithology is also rather different from the more typical subsurface sandstone Ethology.

During mapping east of the Pecos many localities were encountered where small quartz crystals, known as Pecos diamonds, are strewn on weathered surfaces. In time it was noticed that their distribution is stratigraphically related. This is so commonly true that they might be used as a stratigraphic indicator. Most all occurrences are in a zone perhaps 100 to 200 feet thick from the upper part of the Seven Rivers into the lower part of the Yates. They have been found scattered through a belt extending from T. 18 S., R. 27 E., east of Atoka, to an area southwest of Yeso in De Baca County 65 miles north of Roswell. Additionally Albright (Albright and Kruckow, 1958, p.99) has noted occurrences still farther north in Guadalupe and San Miguel Counties.

Finding crystals imbedded is not common, as the usually weathered gypsum gives up the crystals easily. Where found in place they may lie at almost any angle with respect to the bedding. Prisms doubly terminated by positive and negative rhombohedrons are the usual forms, but, also locally common, are pseudocubic crystals formed by the positive rhombohedron. Crystals range from microscopic up to 3.5 inches in length and 1 to 1.5 inches in diameter. Large crystals are generally less perfect than small ones. Colors may be yellow, pink, brown, orange, green, white, or black, and some especially large ones may be variegated in mottled reddish, creamy, gray, or white. Relic lamination bedding runs across many crystals. Although most crystals are in gypsum, one occurrence of sand-size, perfect crystals, thickly grown in dolomite of the Yates Formation, was found in the Abo oil field east of Artesia.

Associated minerals include aragonite, dolomite, and anhydrite in addition to the usual embedding gypsum. At one locality (sec. 18, T. 1 N., R. 21 E.) rhombs of pure dolomite 1 to 1.5 inches in diameter were found associated with numerous 3-inch quartzoids and anhydrite laths up to 2 mm long.

Tarr (1929, p. 24-25), who early described the Pecos crystals, suggested that the silica for the crystals was "evidently the result of solutions coming from the associated sandstones and possibly shales" with gypsum causing "coagulation and precipitation of silica."

Tarr and Lonsdale (1929, p. 50-51) described the occurrence of the crystals in the bluffs south of U. S. Highway 83 and noted that gypsum immediately below a red sandy shale was especially rich and in places "literally a mass of crystals." They noted also that color such as red in the crystals appears to be inherited from hematite red in the gypsum. Albright (op. cit., p. 99) pointed to the occurrence of the crystals in the Artesia Group and indicated that crystals are found in drilling at a depth of 1,160 feet in Lea County. Other than being diagenetic the origin is not well understood. The occurrence at depth precludes a near-surface vadose origin, but whether they formed diagenetically shortly after Yates time or whether formed at a later time, perhaps at depth, is uncertain. Perhaps liquid-inclusion studies on the crystals may shed light on their origin. Rather special geochemical conditions during Artesia time appear to be called for as crystals are not found with similar lithologic or stratigraphic conditions in the Yeso, San Andres, or Ochoan sequences.

Tansill Formation

The Tansill was named by DeFord and Riggs (1941) from exposures at the type section in the W 1/2 sec. 26, T.

21 S., R. 26 E. along U. S. Highway 285 about 2 miles northwest of Carlsbad. This is along the eastern limb of the Tracy anticline where the base on the uppermost sandstone of the Yates is easily seen in a short canyon cut into the anticline. What are essentially the top beds of the Tansill are exposed locally east of the highway along the Pecos River bed. Contact with overlying Salado gypsum and siltstone is found in several places in the hills west of Carlsbad.

The Tansill is predominantly dolomite in the reef shelf margin. The beds are thick and strong like those of the San Andres Formation, causing structures such as the anticlines west of Carlsbad, to stand out in hills whose surfaces are near dip slopes on the high part of the Tansill. Approaching the reef the Tansill beds become even thicker and massive as they grade into and lap onto the nearly structureless Capitan reef. However, there is essentially no place where attitudes in the Tansill or its possible Capitan reef equivalent cannot be obtained, and this is especially true of the upper part, as at the mouth of Dark Canyon. At the base of the reef escarpment in the west-central part of T. 24 S., R. 26 E. high Tansill beds are nearly in juxtaposition with Salado beds (included in upper Castile beds by Hayes, 1957) across the Barrera fault along U. S. Highway 62.

The dolomite facies of the Tansill extends in outcrop about 10 miles north of the type locality to essentially the same latitude as the Azotea tongue before it gives way to evaporites. Northward of the transition, the Tansill evaporite facies is mapped as a narrow, irregularly outcropping belt rarely more than one mile wide between Yates to the west and Salado on the east. At the type Humble well subsurface section some salt is found with anhydrite, and salt becomes more common in Texas (Tait et al., 1962, p. 508). The northernmost exposure is in T. 14 S., R. 27 E. southeast of Hagerman (pl. 2). To the north it is covered by pediment gravel and Pleistocene Gatuna beds, but somewhere beneath these in T. 13 S., R. 27 E., the Triassic Santa Rosa Formation truncates down onto the Yates with no intervening exposure of Tansill. Thin dolomite beds continue in the Tansill evaporite facies to its northern exposures.

The Tansill is 300 to 325+ feet thick in near reef exposures (Hayes, 1964, p.36). It thins steadily shelfward through the type locality where it may be about 130 feet thick, to about 100 feet at the type subsurface sections in T. 16 S., only about 12 miles east of obviously thin surface exposures.

REEF AND FORE-REEF FACIES

Goat Seep Dolomite

The Goat Seep was named by King (1942, p. 588-589) and termed Goat Seep limestone (King, 1948, P.38-41) from exposures along the west side of Shumard Peak near the southern end of the Guadalupe Mountains. Later Newell et al. (1953, P.42-43) proposed to restrict the name to "reef and forereef talus facies." Boyd (1958, p. 15) and Hayes (1964, p. 18) followed the suggestion and Hayes pointed out the dominance of dolomite.

In the upper part of North McKittrick Canyon it is almost impossible to find a rock that is not dolomite. Dozens of outcrops and boulders along the creek derived from Gray-burg, Queen, Seven Rivers, or Goat Seep were tested with acid and none reacted perceptibly. One chemical analysis of a sample taken at the creek loop 1.5 miles below the head of the canyon contained 30.9 percent CaO and 22.7 percent MgO, essentially pure dolomite. This chemical character of the Goat Seep, at least in New Mexico, contrasts sharply with that of most of the Capitan which is dominantly limestone and minor "dolomitic limestone" (Hayes, 1964, p. 20). Hayes (1964, p. 32, 34, 36) has described the chemical transition from dolomite to limestone in the Seven Rivers, Yates, and Tansill as the reef is approached. During the present work a sample taken in McKittrick Canyon at creek level about 0.5 mile up the canyon from the mouth analyzed 36.1 CaO and 16.7 MgO. The sample is creamy to light gray, coarsely crystalline and bioclastic. It is slightly impure in noncarbonates. If pure, the analysis would be only about 3 percent less in MgO than pure dolomite.

Capitan Limestone

The Capitan was named by Richardson (1904, p. 41) for exposures at El Capitan in the southern end of the Guadalupe Mountains. As presently applied, it refers to a reef facies consisting of massive bedded material, structureless core, and forereef sloping beds that occur in the reef escarpment and its deeper canyons, from near Guadalupe Peak, Texas, to near the mouth of Dark Canyon (Motts, 1962). It extends much beyond the outcrops eastward into the subsurface. It is commonly referred to as the "Capitan Reef" and Newell et al. (1953, p. 153) used "Capitan reef complex" to include organic reefs, sand banks, and other types. It is unique in southwestern stratigraphy and sedimentology. It formed a great barrier to sedimentary depositional processes during Permian time, as it forms a great physiographic barrier to travel today.

The base of the Capitan is well exposed, overlying the Goat Seep in upper North McKittrick Canyon. It inter-tongues with Bell Canyon beds in the reef escarpment and in McKittrick and Big Canyons. Its top has been eroded as has its basinward side. The shelfward transition is well exposed and well known from the works of Hayes and many others. In the larger canyons the Capitan can be seen to tongue shelfward and downward through part of the Tansill, all the Yates, and much, if not all, of the Seven Rivers.

The Capitan reef proper has been most carefully studied and described by Newell et al. (1953). The highlights of their study are as follows:

(1) The Capitan was a barrier reef, or complex of reefs which spread basinward several miles as it grew vertically about 1,300 feet. By contrast the Goat Seep reef grew upward without much spreading.

(2) Growth or deposition was in large part by organic skeletal accretion.

(3) The forereef margin of the Capitan reef displays an abundant variety of forereef dips, turbidites, slides, intrastratal flow, and submarine slides, perhaps contemporaneous downwarping.

(4) The nearly awash reef top stood at a maximum of about 1,800 feet above the stagnant basin floor.

(5) The in-situ core of the reefs are totally without stratification.

(6) Undolomitized primary-reef texture consists of undisturbed fossils, bioclastic calcarenite, and microcrystalline limestone,

the latter type being interpreted as a recrystallization product of coarse primary textures because of relict ghost fossils; primary lime mud is not likely in the reef.

(7) The faunal assemblage is low latitude in character and there are striking faunal differences among the basin, reef, and shelf biofacies due to sorting, selective destruction, and transport.

(8) Upwelling nutrient-rich basin waters fed the reef organisms and flowed across the reef to the great shelf evaporation pans.

Considering the prevalence of what has been thought to be foreset bedding inclinations along the basin side of the reef, there is a surprising lack of coarse debris or talus breccia in most of the exposures. Breccia is present, however, and some blocks are quite large (Newell et al., 1953, p. 67-71), and in places at some distance from the reef. In and near the reef, breccia is generally patchy in sandy or even finer matrix. Newell et al. (op. cit., p. 175) point out that in places recrystallization obscures outlines of talus fragments. Breccia occurs high in the reef and fine examples may be found at the reef crest in Tansill beds west of the U. S. Park Service headquarters.

Achauer (1969) has recently presented the view that the Capitan Limestone is a fine example of an ancestral organic bank rather than a classical wave-resistant barrier reef as it has been pictured. He has also found that the Capitan consists of a lower dolomitic part and an upper limestone part, each with several biota and textural facies but with silt- and sand-size debris predominating. Achauer (op. cit., p. 2321) observed most breccia to be in the lower dolomite unit near the margin of the shelf but not in relationships indicating an origin by wave attack on a reef core.

Delaware Basin Facies

The oldest rocks exposed in the Delaware basin of the mapped area are the Bell Canyon Formation, the youngest sequence of the Guadalupian Delaware Mountain Group (King, 1948, p. 53). Above the Bell Canyon, in apparent conformity (op. cit., p. 68) and with some thin transitional-type beds between them, is the evaporite Castile Formation. The Castile has been considered to be Ochoan in age together with the very thick overlying Salado Formation and the thinner Rustler and Dewey Lake Formations, which, in order, constitute the uppermost Permian in the region.

Bell Canyon Formation

Only the upper part of the Bell Canyon exists within the area, all in the southern part of T. 26 S., R. 22 E. This upper part has been named the Lamar Limestone Member (Lang, 1937, p. 874-875). It consists of thin-bedded, often flaggy, dense, fine-grained dark limestone that is as much as 150 feet thick near the reef (King, 1948, p. 57-58). It is marine and abundantly fossiliferous, especially near the reef. The member, like others below in the formation, is intertongued with fine-grained, light-buff sandstone beds. Into the basin the limestone decreases rapidly to a thin edge, and at the type locality in Texas some 12 to 15 miles southeast of the near-reef New Mexico exposures, the member is only 15 to 30 feet thick. In the New Mexico area near the reef the Lamar is overlain by 15 to 20 feet of light-colored fine-grained laminated sandstone that was considered by King (op. cit. p. 59) to be uppermost Bell Canyon Formation. These beds are overlain by a similarly laminated to slabby limestone unit that is thought to constitute the basal beds of the Castile.

At the reef, and especially in the mouths of McKittrick and Big Canyons, intertonguing of the Lamar dark limestone with the Capitan reef facies is strikingly exposed. Especially at Big Canyon along the lower east wall, the details of pinching out, and lithologic gradation of dark, thin-bedded limestone into light-gray, massive limestone of forereef position can be readily observed. Also well exposed is the buildup of massive Capitan-type limestone above the Lamar, and these marine basin-margin beds continue to "tower up" several hundred feet above the uppermost Bell Canyon, and well up the escarpment, locally contain some laminated dark limestone.

In the basin the influx of Bell Canyon sediment, especially the sand, was rather suddenly shut off after Lamar time. And, by prevalent current thought, the basin stood with little or no deposition while the reef and shelf beds of the Artesia Group continued to be built up hundreds of feet.

Castile Formation

The name Castile was first given by Richardson (1904, p. 43) to all the evaporitic beds between the Delaware Mountain beds on the Rustler Formation. The present usage of the term follows that of Lang (1935, p. 268) who restricted the name Castile to the lower part of the original Castile and proposed the name Salado for the upper part. At present the Castile is generally considered to be Ochoan in age and hence younger than the Guadalupian Artesia Group (Hayes, 1964, p. 12). The Castile appears to overlie the Bell Canyon conformably, and it underlies the Salado and Rustler unconformably.

In this work the Castile has been divided into a lower laminated member, consisting of gray-to-white gypsum and dark limestone, and an upper member consisting of massive, generally white gypsum and dark limestone, and an upper member consisting of massive, generally white gypsum (pl. 4). Both members are based on surface exposure, and both have salt in the subsurface to the east of the outcrops.

The lower member is well exposed in the Yeso Hills, T. 26 S., R. 24 E., but west of the hills through the upper tributaries of the Black River the member is widely covered by outwash from Guadalupe Ridge. A few tens of feet of the lowermost part of the member are exposed in a hill south of U. S. Highway 62 at the roadside park across from the side road to the Gray (Parker) ranch about 9.5 miles west of the New Mexico line, in Texas. On the western side of the hill the basal few tens of feet of the unit as exposed consist of laminated, light- and medium-tan, fine-grained, crystalline limestone with some laminated, fine-grained, yellowish sandstone intercalations. These overlie fissile siltstone and sandstone of the Bell Canyon.

In the Yeso Hills laminated gypsum with only paper-thin, gray, or black limestone predominate. Locally, however, black laminated limestone beds 1 to 3 feet thick are present. Also unlaminated anhydrite layers as much as several feet thick are present. Brecciation by collapse, flowage, or replacement is common. In places, dikes and pipes of dark-gray, granular limestone with incorporated laminated fragments intrude the section. Dean (1967)has given the most comprehensive account of the sulfate-carbonate laminations of the Castile to date. In the subsurface, the top of the laminated strata is not constant (Adams, 1944, P. 1604).

The upper member is a monotonous expanse of massive white gypsum, usually with crude irregular bedding. It is especially well exposed along Hay Hollow in T. 26 S., R. 26 E., where, in the sides of the shallow arroyo, continuous outcrops extend for miles.

Thickness of the Castile may be determined from well data along R. 26 E. where wells collar near the top of the Castile or the base of the overlying Salado. Several wells here have good tops on the Delaware sands and the Castile thickness, as determined, ranges from 1,600 to 1,850 feet. In the northwestern part of T. 26 S., R. 25 E., at the foot of the Huapache monocline, a similar determination gave 1,600 feet, but only 2 miles west at the top of the monocline the Castile appears to have thinned to about 890 feet. This apparent thinning of the Castile appears to result from overstepping of the Salado and Rustler onto eroded Castile at the monocline.

In the New Mexico part of the Delaware basin the Castile outcrops are within as little as a few tens of feet of the carbonate shelf edge rocks. It is generally presumed that the Castile in these outcrops overlaps the carbonate rocks (King, 1948, p. 68; Hayes, 1964, p. 15-16).

SHELF-BASIN RELATIONS

Stratigraphic correlation of basin and shelf units has long been a problem of the Permian of the region. The monumental work of King (1948) mostly in Texas, carefully defined the problems and did much to solve the correlations which are widely accepted at present. Hayes (1964) continued this work in New Mexico, refining the shelf stratigraphy of the middle and upper Guadalupian rocks, especially in their relationships to the Capitan. In addition to the above surface-oriented studies, numerous industrial and independent geologists, using subsurface data, added to the understanding of correlations between shelf and basin over a wide area. Among these are the works of Newell and others (1953), Adams and Frenzel (1950), Silver and Todd (1969), and Tyrrell (1969), and all are in essential agreement on correlations of the basin Bell Canyon units with shelf units. The essentials of these correlations as relevant to the Capitan and adjacent rocks of the Barrera escarpment are that (1) the base of the Capitan more or less coincides with the base of the Seven Rivers on the shelf side and with the base of the Hegler Limestone Member of the Bell Canyon Formation on the basin side (Burr and Silver, 1969, p. 2235) and, (2) the top of the Capitan essentially coincides with high parts of the Tansill on the shelf side and with the top of the Bell Canyon Formation on the basin side. The base of the Tansill equates with the base of the Lamar and the top of the Lamar is high in the Tansill but with some Tansill or Capitan above the Lamar.

Tyrrell and Lokke (Tyrrell, 1969, p. 83-84) tie the correlations down with a zonation by fusulinids especially between the Tansill and Lamar. Tyrrell (op. cit. fig. 3) appears also to more or less equate the Ocotillo siltstone tongue (De-Ford and Riggs, 1941, p. 1717, 1722) near the top of the shelf Tansill with the post-Lamar beds of the basin. Tyrrell also shows significant Tansill dolomite above the Ocotillo, and therefore, the top of the Lamar can not be quite as young as the top of the Tansill. However, the top of the Bell Canyon would in most places by prevalent thought be nearly equal to the top of the Tansill and the Artesia Group. King (1948, p. 59) thought that the "20 to 35 feet of thin (Bell Canyon) sandstone and limestone beds that lie between the Lamar member and the Castile formation" would represent the part of the Capitan that lies in the escarpment above the Lamar.

Judging from the considerable thickening of the Seven Rivers and Yates as the Capitan is approached, the edge of the shelf and hence the basin must have been gradually subsiding. Likewise moderate inclinations of the dark laminated Lamar beds in the lower part of the escarpment indicate continued downflexing at the shelf-basin margin in post-Bell Canyon time. The thin-bedded, commonly laminated Lamar beds may be used to survey the geometry of the margin and check the correlations between the Lamar and the Tansill.

Figure 9 shows the relationships at 1.1 vertical and horizontal scales along the northeast wall of Big Canyon. Significant points for the explanation are marked A, B, C, and D. Points C and D are surveyed stadia elevations and the control on point C (top of the Lamar) supports point B. Point A is an estimated position for the top of the Lamar based on Hayes' assumption that the base of the Lamar equates with the base of the Tansill. Its position in space is also based on observed basinward dips of only about 4 degrees at the top of the anticlinal bend. The Lamar, which is about 175 feet thick near Grays cabin (fig.9), can be walked to its pinch-out edge at point C and this point has been shot in for position on the Carlsbad Caverns West topographic sheet from Grays Cabin (elev. 4,940) for control in construction of the cross section from the sheet.

The altitude of point C (tip of the Lamar, 5,625 feet) is 1,175 feet lower than point A (top of the Tansill, 6800 feet). Points A and C are 1,500 feet apart horizontally, and the tangent of the ratio 1,175/1,500 yields an angle of 38 degrees between the two points. Thus, the upward projection from the tip of the Lamar to the top of the monocline is nearly twice as steep as the dip of the beds at the tip. Furthermore, bedding continues upward beyond the Lamar tip to the structureless Capitan limestone at point B. The projection angle from point B to point A is 45 degrees.

If correlation of the top of the Lamar with the high part of the Tansill is followed then a simultaneous deposition surface must also be followed through the structureless core between the Lamar and the Tansill. If, on the other hand, any bedding surface in the forereef, such as the extended Lamar, is thought to abut, within a few feet or tens of feet, the edge of a flat-topped reef surface then the time surface should be extended through the structureless part at a low angle. In Figure 9 the slight curvature upward traces what is presumed to be part of the anticlinal bend at the top of the monocline.

The crux of the problem of time equating shelf units with basin units lies in the solving of the above two possibilities. Nearly all the beds that I have observed on the forereef side of the structureless core do not show abundant talus or the coarseness that could be expected if a steep and high reef edge stood above them.

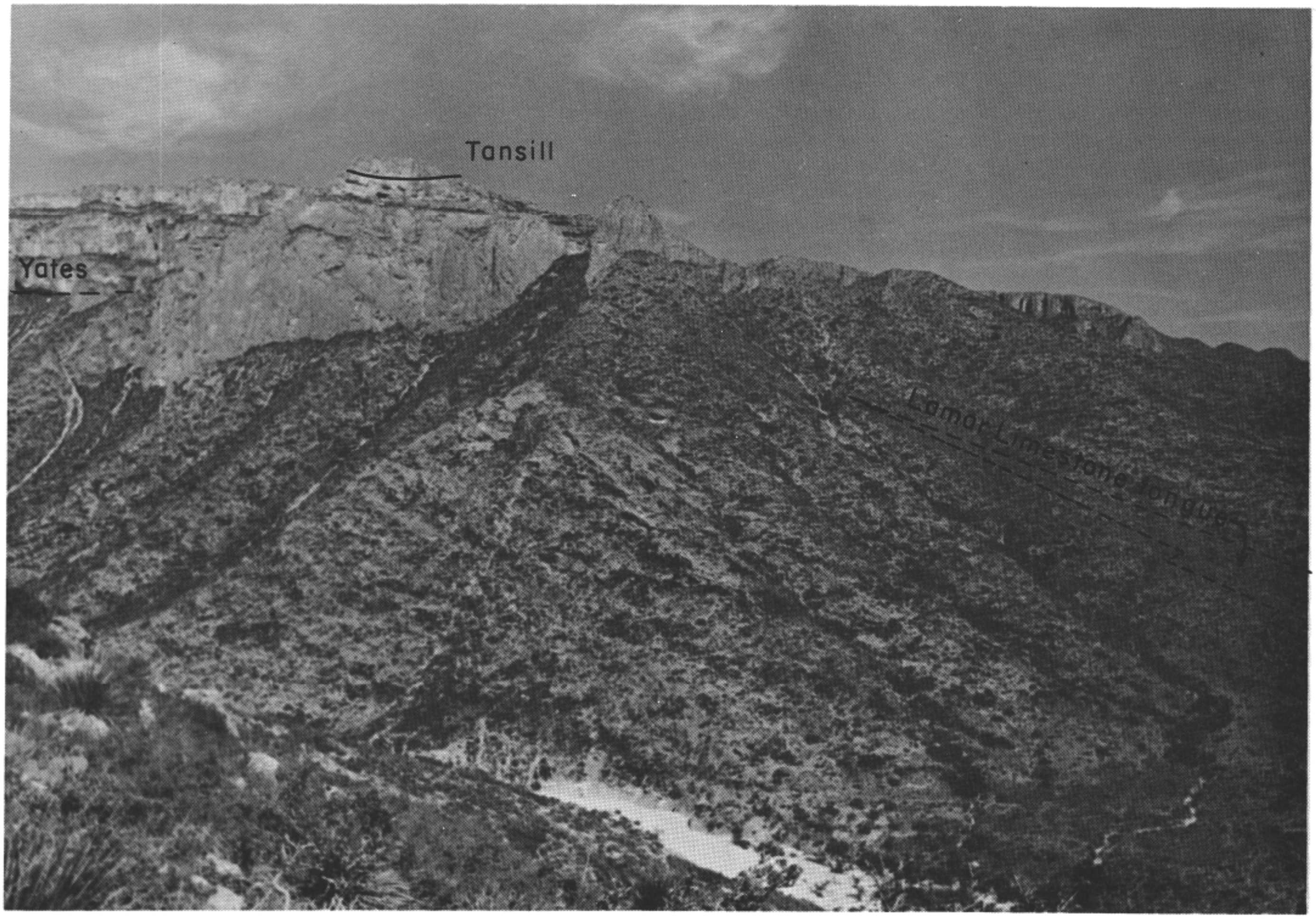

Figure 8
VIEW OF THE NORTHEAST SIDE OF BIG CANYON
Compare with Figure 9.

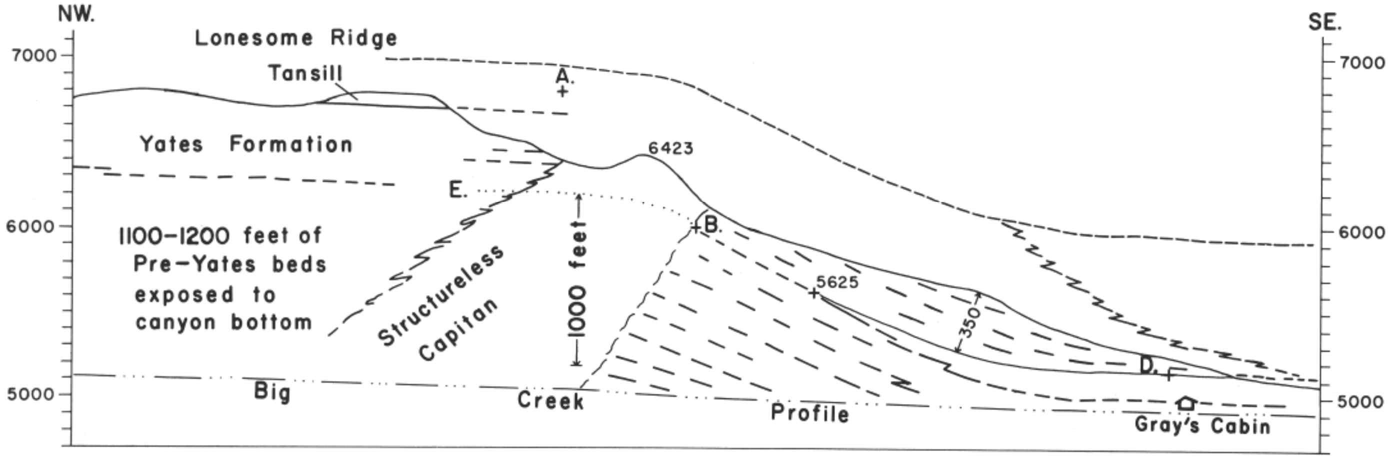

Figure 9
STRUCTURE SECTION AND CORRELATION THROUGH THE CAPITAN REEF AT BIG CANYON

Adams and Frenzel (1950, p. 309) estimated that the depth of water in the Delaware basin at the end of Bell Canyon time reached as much as 2,000 feet. Hayes (1964, p. 53) estimated the basin bottom to have been 1,500 feet lower than the "lagoon floor" just northwest of the Capitan limestone core. The former men appear to have believed the relief to have been entirely the result of construction of the reef and, therefore, nearly all the dip seen in the reef margin would be original. Hayes' lesser figure may result in part from the fact that he recognized part of the relief to be tectonic and possibly Laramide (op. cit., p. 44). He estimated that the original dip was 20 to 30 degrees in the "reef breccia beds of the Capitan Limestone," and that later deformation added as much as 10 degrees (op. cit.). This statement could be interpreted to indicate the present dips range from 25 to 40 degrees, figures which I would judge to be about 10 degrees too high for the most part. Nevertheless the division of the dip between original and tectonic is a problem which has had little or no special attention. There are probably several ways in which the problem might be attacked. If it could be assumed that some organisms would grow vertically even on a sloping forereef deposit, then tilt of such organisms as determined from oriented polished slabs could indicate the proportion of the present dip that is tectonic. The Yates and especially the Tansill are parallel bedded above the Capitan, and in places the beds bend over the Capitan and descend to the base of the escarpment. Some of these instances, such as east of White City, appear surely to be tectonic and may be in part what Hayes called upon.

Another evidence lies in the Lamar limestone basin facies. These thin, even-bedded black limestones and associated fine sandstones were hardly deposited on slopes of more than a very few degrees. In many outcrops the thin limestone beds are internally laminated and one could even argue for horizontality of the depositional surface. At present in Big Canyon, McKittrick Canyon, and Bear Canyon just north of Pratt's Lodge (King, 1948, pl. 3) these beds can be found "half way" up the canyon walls with dips of 15 to 25 degrees. These beds, as well as those above, below, and in continuity up dip and probably arose out of monoclinal flexing and only a small proportion (perhaps 20%) should be considered original dip. Using Figure 9 again as an example, the height of the monocline is 1,000 feet. If 20 percent of this is original then the original depositional basin relief up to the reef top would be 200 feet and this could be essentially the same as the water depth at the end of Lamar time. If the Lamar horizon is projected through the structureless core to point E (fig. 9) then this would also be the basin relief near the end of Seven Rivers time.

If a projection or correlation is made in Figure 9 from B to E then the top of the Lamar is near the top of the Seven Rivers Formation and this leaves all the Yates and Tansill beds, some 800 feet of thickness, to equate to the 20 to 35 feet of beds noted by King (op. cit.) above the Lamar and below the Castile in the Delaware basin. In Figure 9 some 350 feet of Capitan limestone remains on the escarpment spur above the Lamar. The escarpment is most certainly much eroded and considerably more Capitan structureless, and forereef bedded rock must have existed above the Lamar, perhaps several hundred feet. By prevailing correlations the eroded thickness plus the 350 feet have to equate with the 150 feet or so of Tansill shown above point A and also with the "20 to 35 feet" on the basin side, a rather unlikely situation. It appears more reasonable just on the exposed geometry that the 350-foot Capitan remnant section was in continuity with the Yates as deposition occurred.

Geologists seem to have ignored the considerable erosion of the escarpment and seem to assume that the surfaces that they view today on the faces between the canyons essentially represent the surface of the reef or bank as it existed at the close of Capitan time. They no more represent the reef face than triangular facets on fault block ranges represent the fault surface. Erosional laying back is considerable in both instances.

Most students of the reef subscribe to a prominent constructional bank or reef standing above a Delaware sea at the end of Artesia and Bell Canyon or Delaware time. It is also thought that the sea had deepened to its maximum (1,500 to 2,000 feet). The whole region must have subsided, but depositional build-up along the reef or bank and the shelf to the rear kept relatively shallow waters in that area. The Castile evaporites are thought to have then considerably filled the basin while the shelf area was removed one way or another from sedimentary accumulation during all of Castile time, which is considered to be post-Guadalupian or Ochoan time. This sequence of events involves (1) a strong build-up on the shelf and shelf margin in latest Capitan or Tansill time while little or no deposition occurred in the Delaware basin, followed by (2) a large accumulation of evaporites in the basin while no deposition or marked erosion occurred on the shelf or shelf margin.

The interpretation given above and suggested through Figure 9 is that the basin may not have been deep, that the geometric relief is largely tectonic, that the post-Lamar beds are Yates and Tansill. It further appears possible that the Castile is, to a large extent, a facies of post-Lamar Capitan Limestone and the Yates and Tansill Formations. Many geologists have entertained this possibility but only a few have adopted the idea with much conviction. Cave (1954, p. 118-123), and Hall (1960, p. 85-88), have believed strongly in such relationships and Cave (oral communication) has observed intertonguing of Capitan and anhydrite in wells penetrating the zone of possible transition to the east of the outcrop. Nowhere along the reef escarpment is the Castile found next to or near to reef rocks in normal contact. Along the western part of the escarpment where there is no faulting, the Castile exposures are at some distance from the Capitan exposures, and there is adequate space in which a transition could have existed.

POST-REEF BEDS

Post-reef Permian beds are considered here to include the Salado, Rustler, and Dewey Lake Formations. The Salado is the first unit to cross the Capitan reef from basin to shelf.

Salado Formation

The Salado was named by Lang (1935, p. 262) to include the upper part of the salt-bearing evaporites; earlier, Richardson (1904, p. 43) included all in the Castile. In the Delaware basin, it lies on the Castile, apparently onlapping it westward to near the base of the Huapache monocline in T. 26 S., R. 25 E. In Rs. 26, 27 E., southward from Black River to the Texas line, it consists principally of pinkish silt-stone and gypsum. Thin sandstone beds occur in the upper part (Adams, 1944, p.1609). Discontinuous thin dolomite beds occur in the lower part, and these are used to distinguish it from the dolomite- and color-free Castile gypsum below (pl. 4). North of the Barrera fault (T. 24 S., R. 26 E.), the Salado lies on the Tansill, and this relationship is mapped northward east of the Pecos River and across the shelf nearly to Hagerman in T. 14 S., where it is covered by Cenozoic surficial deposits. North of about T. 20 S., R. 27 E., the Salado evaporite lies on Tansill evaporites rather than dolomite and the contact becomes difficult to recognize. It is generally done by the orange-red "polyhalite" color of the Salado gypsum together with greenish and reddish clay in chaotic outcrops. This condition is thought to be a collapse breccia residue due to ablation of salt near the surface.

Thickness of the Salado in the outcrop area is difficult to determine, but is estimated to range from about 50 to 300 feet. However, in the subsurface to the east, the thickness increases to about 2,500 feet (Jones, 1954, p. 08) where 80 to 90 percent of the thickness is salt. The Salado is only o to 20 percent anhydrite with minor elastics, compared to 60 to 75 percent in the Castile in the central halite part of the New Mexico Delaware basin.

The original western depositional edge of the Salado is not known, but in New Mexico it may have been as far west as R. 24 E. There a few tens of feet of Rustler dolomite outliers may represent the formation. If so, Salado beds may have once lain across part of Guadalupe Ridge prior to its uplift and erosion.

Rustler Formation

The Rustler was named by Richardson (1904, p. 44). It was described later in New Mexico by Lang (1938, p. 83-84) and by Adams (1944, p. 1612-1615) for a larger part of the Permian basin. Recently Vine (1963, p. B6) described well-exposed outcrops east of the Pecos River in which he designated five members. The 335-foot section is dominated by a basal 120-foot unit of siltstone, gypsum, and sandstone, and a 115-foot middle unit of gypsum, but the section is perhaps most typically marked by two dolomite members, the lower vuggy Culebra Dolomite Member and the upper pink Magenta Member (Adams, 1944, p. 1614). The dolomites hold up the Rustler Hills west of the Pecos River and help to widely identify the unit east of the Pecos.

The lower 100 to 250 feet beneath the Culebra may be difficult to distinguish from the Salado of the outcrop, and it is likely that some part of the Salado shown on the geologic map, Plate 4, in Rs. 27, 28 E. of the Delaware basin may include some of the Rustler of the subsurface. However, the lower Culebra dolomite is the most easily recognized mappable horizon.

In the present work, lower and upper members of the Rustler, based on two dolomite horizons, are mapped, and U.S. Highway 285 south of Malaga marks the boundary fairly well between the lower member to the west and the upper member to the east of the highway (pl. 4).

North of the Barrera fault in the Frontier Hills embayment, Rustler dolomite holds up the hills which parallel the monoclinal reef flexure southwest of Carlsbad.

The Rustler is only sparingly exposed north of Carlsbad, but east of Artesia and north of U.S. Highway 83, a good basal part of Rustler is exposed for 15 miles overlying Salado outcrops in low benches and mesa edges. The dolomite analyzes CaO, 29.30 and MgO, 21.61 percent which is the highest MgO/CaO ratio (.738) analyzed anywhere in the basin. In this area, T. 16 S., Rs. 27, 28 E., some of the more definitive outcrops are preserved. The Rustler overlaps the Salado and rests on the Tansill Formation. The unconformity of the Rustler on older rocks has long been recognized (Adams, 1944, p. 1614-1615) in the Delaware basin and, in the present work, this is strikingly evident (pl. 4). In T. 26 S., Rs. 25, 26 E., the Salado, as defined by its base, dips eastward at about 75 feet per mile, whereas the slightly truncating Rustler, as calculated by outliers in the Yeso Hills (sec. 5, T. 26 S., R. 25 E.), dips eastward at only about 35 feet per mile.

In many outcrops, the Rustler is greatly disturbed by small collapses and piercements involving solution and/or flow of the Salado in relation to the overlying Rustler. These are shown in profusion on Plate 4 by small circles south of Malaga, both west and east of the Pecos River, and again along the Rustler outcrops 1 o to 12 miles east of Artesia in the Crow Flats and Turkey Track grabens.

Dewey Lake Formation

Dewey Lake beds were described first by Lang (1935, p. 262-270) from a core taken at the Means r well in Loving County, Texas. He named the rocks "Pierce Canyon red beds" from exposures at the canyon near the Pecos River, New Mexico, in T. 24 S., R. 29 E., however, the beds on the south side of Pierce Canyon are Gatuna Formation. About the same time, others noted the high Permian red beds and in 1940, Page and Adams (p. 62-63) described and named the same sequence "Dewey Lake Formation" from a well in the Midland basin. They traced the unit widely in the subsurface above the Rustler and beneath the Triassic Tecovas Shale (op. cit., fig. 2). Although the two terms were retained as late as 1963 (Vine, p. 25), "Pierce Canyon" was, about the same time, abandoned by the U.S. Geological Survey in favor of "Dewey Lake."

The Dewey Lake occurs in only two small outcrops along the eastern edge of the area, the best exposures being at Livingston Ridge along Nash Draw, a few miles to the east in T. 22 S. The formation is perhaps 200 to 250 feet thick (Vine, 1963, p. 19) and consists of well-laminated, reddish-orange to brown sandstone and siltstone. Thin white beds are occasionally intercolated with the red beds and both possess thin cross laminae. Small, white, bleach spheres are also common in the sand.

The Dewey Lake beds have been mistaken by some workers for Triassic rocks on the one hand, and Pleistocene Gatuna beds on the other. Both of these sequences overlie the Dewey Lake beds in places and have in part been derived from them.

SOME PERMIAN CARBONATE CHEMISTRY

About 330 carbonate chemical analyses of samples - from measured sections and special outcrops of the San Andres Formation and 8 from scattered outcrops of Artesia and Rustler have been made during the study. All analyses were done by EDTA volumetric methods in the Geochemistry Laboratory of the Department of Geology, University of New Mexico, under the supervision of John W. Hustler. Analyses have been checked for an accuracy of 0.1 percent for CaO and MgO. Results of these analyses are given mostly in the Appendix within the seven tabulated measured sections. About one-third of the measured-section intervals had two or three samples analyzed where there were some obvious differences in the lithologies within the unit. A preponderant number of the samples had little or no residue from the digestion of the carbonate. Quartz sand is the usual insoluble residue.

A number of analyses were made to determine uniformity of bed units, both laterally and across single beds; for example, a 4-foot dolomite bed near the top of the Rio Bonito Member in Hondo Canyon (sec. 27, T. 11 S., R. 18 E.) was sampled from the ends and the middle of a 1,000-foot continuous outcrop with the following results:

	CaO	MgO	MgO:CaO Ratio
West end	31.41	18.72	.597
Middle (upper)	31.26	18.92	.605
Middle (lower)	31.28	18.77	.600
East end	29.87	18.96	.635

The two samples taken midway of the traverse from the upper and lower parts of the bed are essentially identical in CaO, and the differences in the CaO of all samples is only 1.54 percent. The MgO content varies only 0.24 percent.

Near the Sunset measured section (sec. 29, T. 11 S., R. 19 E.) a massive 30-foot ledge, devoid of internal bedding surfaces was sampled in the upper third, middle third, and lower third, at two places about loo feet apart with the following results:

	(West)		(East)	
	CaO	MgO	CaO	MgO
Top	30.40	20.05	31.00	20.03
Middle	31.33	19.80	31.40	19.37
Bottom	35.30	16.45	32.27	18.75

The MgO content increases upward in both places. In a 25-foot massive bed in Alamo Canyon (sec. 21 NW, T. 11 S., R. 16 E.) the upper part ran 18.59 MgO and the lower part, 19.54. In an s 8-inch bed from the Seven Rivers dolomite (sec. 26NW, T. 21 S., R. 24 E.) the basal MgO content was 21.66, the upper, 22.20. More checking of what appears to be a slight increase in MgO upward in single beds is needed and this investigation is continuing as good samples are obtained.

Figure 10 shows MgO: CaO ratios of samples from the measured sections given in Appendix I-VII. The following table gives principal information concerning the sections and their carbonate compositions.

Between the Manning and Stevenson sections a pronounced change to limestone occurs, especially in the thickened middle part. At the Lewis section in the northern part of the Guadalupe Mountains, the increase in limestone along with increase in thickness is striking. Just north of the Lewis section (pl. 4) in sec. 18, T. 20 S., R. 20 E., outcrops locally are thickly massive and suggestive of bank or reef development.

The analytical sections of Figure 10 are chiefly of value at this stage for their detail of compositional data. Trace-element analyses of some of the samples are in progress.

The carbonate composition shows considerable variation vertically and very little correlation laterally, at least as far as MgO content is concerned. It is noted that the base of the White Ranch section is essentially the base of the Bonney Canyon Member and, hence, equivalent to the Psr/Psb boundary of the Sunset section. This relationship was established in the field by mapping the Sunset contact to the White Ranch section farther down the Hondo Canyon. Yet these two equivalent sections are considerably different in carbonate composition, the Sunset-Bonney Canyon containing more limestone than the White Ranch section.

The lower part of the Rocky Arroyo section may include some or all of the thinned Bonney Canyon and include beds that may be continuous with the Bonney Canyon of the upper part of the Lewis section.

The Rocky Arroyo section of the Fourmile Draw Member is remarkable for its consistently high MgO content. Much of the section approaches pure dolomite.

In figure 11 the composition variation of the samples without regard to stratigraphic position is shown with MgO and CaO content plotted against each other. These figures demonstrate a considerable gap between dolomites and limestones. In nearly all the sections there are few or no "mixed" samples between about 25 and 75 percent calcite. Only about so percent of all the samples analyzed fall between MgO/CaO ratios 0.05 and 3.5 or an MgO content of 5 to 14 percent. The Manning anticline samples are exceptions to this statement, but more concentration still shows near the dolomite end. Perhaps more significant is the short spread of points away from the calcite end where most analyses are no more than about 3 percent CaO away from pure calcite. At the dolomite end, on the other hand, the spread away from pure dolomite is 5 to 7 percent MgO, and in the Manning anticline samples, about 10 percent. This difference in clustering of points around the dolomite and calcite "poles" appears to conform to the well-known greater isomorphous substitution of calcite in dolomite. With the solid solution of dolomite in calcite both Ca and Mg are added, and as a result, the slope of the spread cluster is flatter along the CaO line, with MgO being added rarely in excess of 2 percent.

The lack of more of a spread of points away from the calcite pole may indicate that many of the dolomites are primary rather than replacements of limestones. The greater spreads away from the dolomite pole could be the result of replacement of original dolomite by calcium carbonate.

TRIASSIC

The Triassic in this region, as in most of New Mexico, is divisible into the lower Santa Rosa Sandstone (Darton, 1922,

Measured	Location		Thick	Thickness		Av. Do.	Av. Sec.	1 Approx.	2 Approx.
Sec.	T	R	feet	Psr	Psb	Ratio	Ratio	MgO%	Dolo.%
Cooper	9	8	438	283	155	.458	.419	15.5	71%
Sunset	11	19	432	269	163	.599	.482	15.9	73
Manning	15	17	609	307	302	.488	.413	15.3	70
Stevenson	19	16	553	553	0	.516	.190	8.4	38
Lewis	20	18	801	663	138	.580	.143	6.2	28
White	11	20	152	x	152	.598	.598	18.8	86
Rocky	23	21	387	Psf		.657	.657	19.7	90

[1] All units, [2] $CaMg(CO_3)_2$

Notes. Pure dolomite ratio is .721 with an MgO content of 21.9%. Ratio of a 1:1 dolomite and calcite rock is .254. Average dolomite and average section ratios are weighted to the thickness of the sampled interval. The average dolomite ratio is calculated from only greater than the .254 ratio of 1:1 calcite: dolomite.

p. 183) and the upper Chinle Shale. Combined, they are referred to as the Dockum Group. Triassic outcrops occur in two widely separated areas, one east of the Pecos and the other in the Capitan country. Outcrops east of the Pecos are all Santa Rosa Sandstone, with the Chinle being covered eastward in the subsurface, largely by Quaternary surficial deposits. East of the Pecos, outcrops extend in interrupted exposures from T. 16 S. to the northern boundary of the area and beyond (pl. 2). They lie irregularly between about 3,600 and 4,000 feet with altitudes rising generally from south to north. Locally, northeast of Roswell in T. 8 S., R. 26 E., Santa Rosa outcrops south of Bob Crosby Draw are only about 2, miles east of the Pecos River and at about the 3,700-foot contour, whereas, only a few miles to the northeast, just north of the Railroad Mountain dike, they are at 4,000 feet. Their low position in this area may be caused by general slumping along the Pecos Valley, but it also may be due in part to downthrow of the south side of the dike coupled with some depression of the northwest side of the Y-0 buckle which may extend at least in the subsurface to a position just southeast of the low Santa Rosa outcrops.

The best exposures of the Santa Rosa east of the Pecos occur along a prominent west-facing mesa escarpment in Ts. 6, 7 S., R. 27 E. In this area the Santa Rosa unconformably overlies the Yates near the base of the escarpment in a contact that appears, where exposed, to be slightly undulating through 25 to 50 feet stratigraphically. The exposed section between the Yates and caliche-gravel cap is 100 to 150 feet. The beds are predominantly thick sandstone of grayish to reddish browns with mauve tones in a few beds. Bedding is generally parallel but gently undulated or channeled with crossbedding subordinate. Where principally observed, however, in secs. 7, 8, T. 7 S., R. 27 E., a thick, grayish-brown, coarse sandstone at the base of the section had large south-southwestward dipping foresets 15 to 20 feet high. Conglomerate is not abundantly evident although locally, through the basal 50 feet, rounded to subrounded pebbles of Permian sandstone are common with little or no chert or quartzite. The sandstone is arkosic and both feldspar and muscovite are conspicuous. Red, brown, and variegated mudstone in thin beds is present between some of the thick and massive sandstone ledges.

Triassic rocks of the Capitan country extend from near Ruidoso northward around the western end of the Capitan Mountains and northwestward toward the Jicarilla Mountains. In this belt the Triassic mostly rests on Grayburg sandstone and is overlain by Dakota Sandstone. However, across the west end of the Capitan uplift the Santa Rosa rests on the Fourmile Draw Member of the San Andres.

The Dakota steps regularly down across the Triassic, first wedging out the Chinle Shale in sec. 29, T. 10 S., R. 14 E. and then overlapping the Santa Rosa onto Grayburg in sec. 23, T. 11 S., R. 13 E. In the Capitan country, the Santa Rosa consists of reddish-brown and buff sandstone and red silt-stone, together with a distinctive buff chert conglomerate at the base. The conglomerate is lenticular and ranges from a few feet to about 70 feet. The Santa Rosa is 150 to 300 feet thick with a gradational or intertongued transition into the overlying Chinle Shale.

The Chinle Shale consists of reddish-brown mudstone with interbedded clayey and ferruginous sandstone lenses. Around Capitan the Chinle is 150 to 200 feet thick but it thickens gradually northward on a regional basis. The upper few tens of feet of the Chinle may be somewhat variegated, causing it to resemble in a minor way some of the lithology of the Jurassic Morrison Formation. However, these colors appear to be caused by weathering on a pre-Dakota surface. No Jurassic rocks were found in the area and they probably pinch out several miles north of Vaughn, New Mexico.

CRETACEOUS

DAKOTA SANDSTONE

The Dakota crops out as prominent ledges in a narrow strip from south of Ruidoso northward to the Capitan fault where it is offset westward to a strip over the eastern part of Tucson Mountain. It continues into the southwest corner of the Hasparos embayment where it forms a low eastward-facing cuesta which is terminated and turned westward in T. 6 S., R. 14 E. by faulting and the general swing of the northern edge of the Sierra Blanca basin.

The Dakota consists of massive, brownish-weathering ledges of coarse-grained, locally cross-bedded sandstone. It ranges from 100 to 150 feet thick. It commonly becomes thin to medium bedded in the upper 50 feet in an alternating transition interval into the overlying Mancos.

From the northern exposures of Dakota in T. 6 S. of this area where it may rest on 200 or 300 feet of Chinle, the Dakota steps gradually downward to meet the Santa Rosa in T. 10 S., the Grayburg in Ts. 11, 12 S., and the Bonney Canyon Member of the San Andres from Ts. 12 to 15 S.

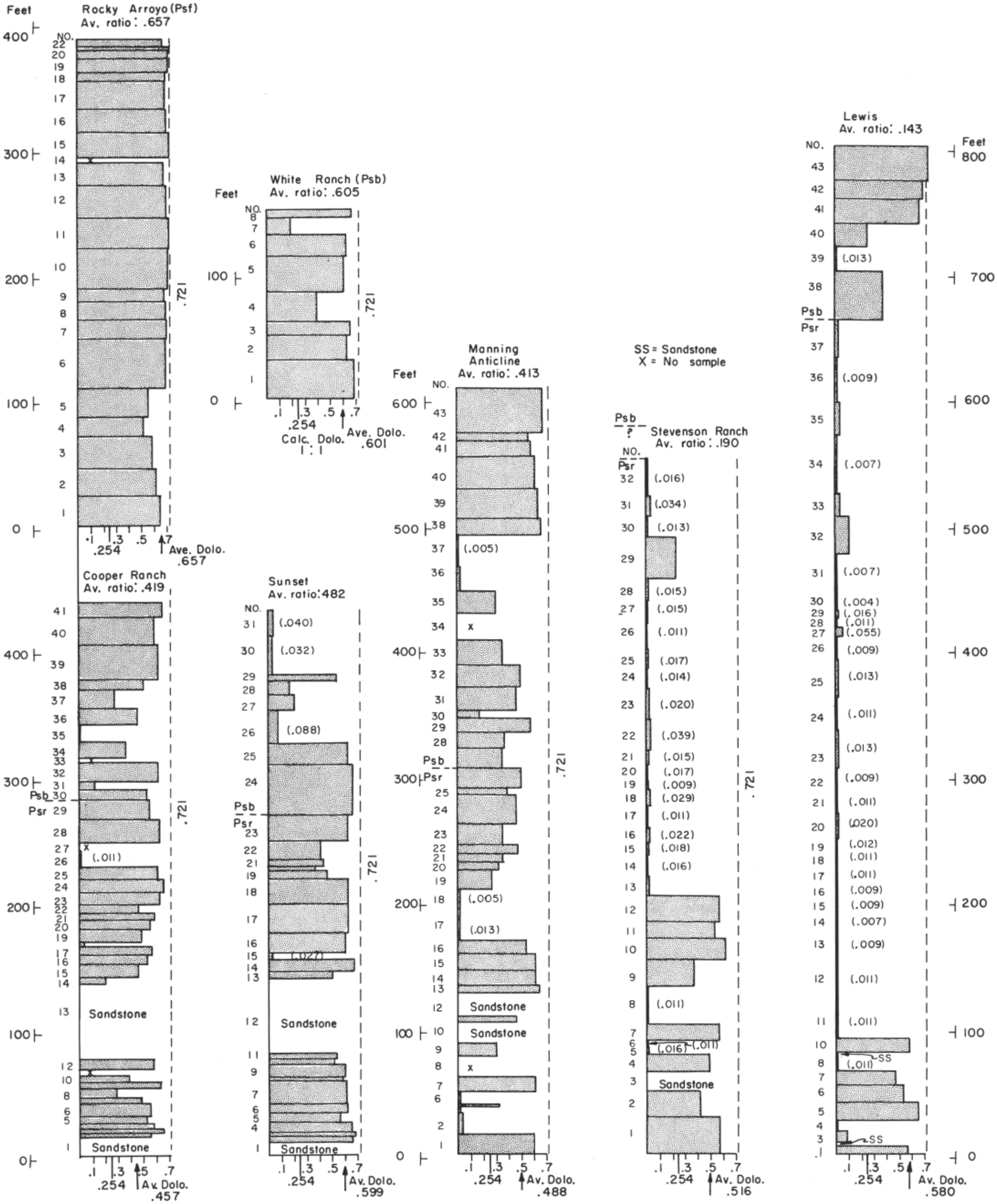

Figure 10

GRAPHIC SECTIONS OF THE SAN ANDRES FORMATION SHOWING CARBONATE COMPOSITIONS BY Mg0:Ca0 RATIOS

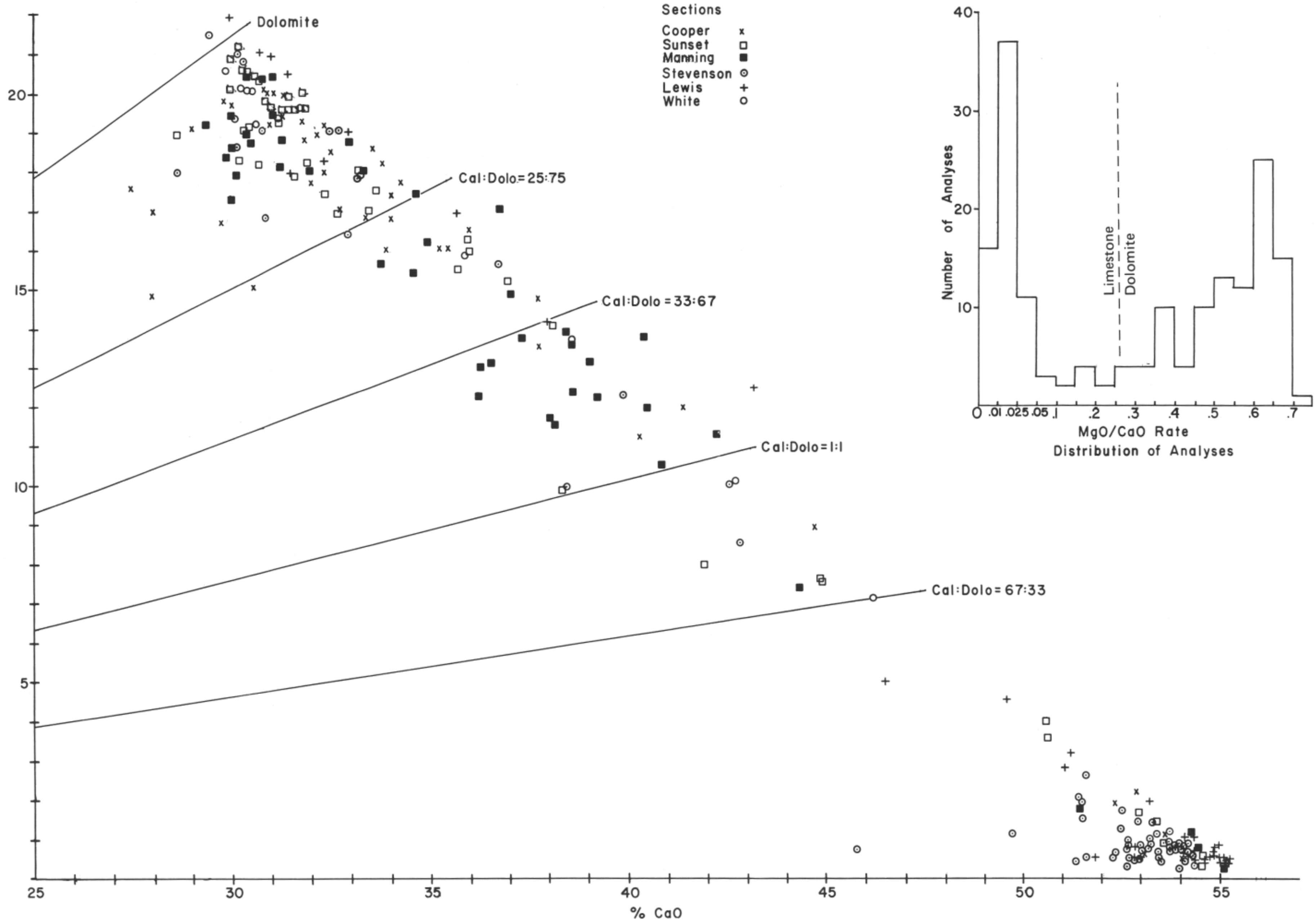

Figure 11

GRAPH AND DISTRIBUTION OF CHEMICAL COMPOSITION OF SAMPLES FROM SIX MEASURED SECTIONS

This is an angular convergence of 25 to 30 feet per mile, which is too steep a gradient for the Dakota to have been spread as a blanket. Therefore, the underlying rocks must have been tilted northward and levelled between Jurassic and Early Cretaceous time by something like 20 to 25 feet per mile.

MANCOS SHALE

The Mancos crops out everywhere just to the west of the Dakota in more or less the same belt except where it spreads out in wide valleys between Patos and Capitan Mountains and is generally poorly exposed or absent. It consists typically of black shale, but often may be interlaminated with grayish siltstone or may contain thin dark-gray limestone beds and lenses. A limestone interval 50 to 70 feet thick, which may be the Greenhorn, may be found in places not far above the Dakota (Allen and Jones, 1951). It ranges in thickness from about 400 to 700 feet.

MESAVERDE FORMATION

The Mesaverde occupies a strip 2 to 6 miles wide west of a line from Capitan to Ruidoso. It makes up most of the Tucson and Vera Cruz Mountains. It is prominent around White Oaks and extensive around, and probably lies beneath, the Carrizo and Patos laccoliths. Its outcrops are generally much disturbed by faulting, and between Carrizozo and Capitan along the highway across Indian Divide and along the highway between Capitan and Ruidoso, the Mesaverde is commonly interspersed in fault slices with the adjacent beds of the Cub Mountain or Sierra Blanca volcanic formations.

In the Capitan coal field, the Mesaverde consists of three units: a lower sandstone interval about 150 feet thick; a middle shale and coal section 150 to 200 feet thick, and an upper sandstone section l00 to 150 feet thick. The sandstone ranges from massive to medium bedded, white, buff, or brownish, and is fine to medium grained. The shale interval is light gray to black, commonly weathered to various shades of brown, and has occasional thin siltstone, sandstone, or coal beds. The coal beds range from less than one foot to as much as 4.5 feet thick (Bodine, 1956, p. 25-27).

South of Capitan the tripartite division becomes less obvious, and the upper sandstone, in particular, is lost south of T. 9 S. Northwestward of Capitan in the east face of Tucson Mountain, the lower and upper sandstone intervals become thicker and more massive, apparently at the expense of the middle shale interval. The combined thicknesses of 350 to 400 feet hold up the steep slopes and prominent cliffs of Tucson Mountain. In high local areas of Tucson Mountain and at Sheep Mountain (sec. 26, T. 7 S., R. 13 E.) there is a shale interval which is as much as 550 feet thick. This high part of the Mesaverde is also present in the upper part of Vera Cruz Mountain around the stock and to the north along both limbs of the Dignan syncline between Tucson and Carrizo Mountains. Probably the Mesaverde beds along U.S. Highway 380 west of Indian Divide are also the high part of the Mesaverde formation, but much faulting, numerous dikes, and poor exposures make identification difficult.

EARLY TERTIARY

CUB MOUNTAIN FORMATION

The Cub Mountain Formation of Bodine (1956, p. 8-10) consists of varying shades of purplish mudstone and buff, coarse-grained, arkosic sandstone of continental origin. The rocks are not as indurated as the Mesaverde and the sandstone is commonly friable. Several conglomerate and conglomeratic sandstone beds are present and these in particular are rather friable. Typical beds may be seen at several places in the roadcuts along the highway south of Capitan to Bonito Creek and along U.S. Highway 380 2.5 to 5 miles west of Capitan. It is much in evidence in the dissected western slope of Indian Divide south of U.S. Highway 380 to State Road 37. Along this slope the formation is much sliced by northnortheastward-trending faults and intruded by numerous dikes. A reliable thickness is essentially impossible to measure. However, the formation appears to be as much as 500 to 600 feet thick.

Locally, the Cub Mountain appears conformable with Mesaverde, as west of Capitan, but regional mapping brings out an unconformity. Near Ruidoso a small area of Cub Mountain rests on Mancos; west of Capitan it is on low Mesaverde; and in the western slope of Indian Divide it is probably on high Mesaverde. In a general way it appears to have overstepped older formations toward the east as though the Pedernal were rejuvenated slightly in early Laramide time.

TERTIARY

SIERRA BLANCA VOLCANICS

The Sierra Blanca volcanics crop out in an area of about zoo square miles in and around the Sierra Blanca Mountains (Thompson, 1966, fig.1). Thompson (1966, p.44) believed that the field may have originally covered an area as large as 750 square miles prior to intrusion by stocks and late Tertiary erosion.

During this study a new area of some 30 square miles of the formation was mapped that heretofore has not been shown on the State map. This area lies mostly along Indian Divide for 10 miles in R. 13 E. between U. S. Highway 38o and Bonito Creek.

The Sierra Blanca volcanics consist of massively bedded, somber, purplish-brown, andesitic breccias, flows, and tuffs, surmounted by trachyte breccias whose upper part has been removed by erosion. Thompson (1966, p. 22) has measured and described some 3,340 feet of section. A maximum of some 600 to 700 feet is present on Indian Divide in sec. 1, T. 9 S., R. 13 E.

West of Capitan the volcanics rest normally on Cub Mountain beds in several places, and this is generally the relationship in about the northern two-thirds of the volcanic field. In the northern part of T. II S. and generally south of Sierra Blanca Peak, the base of the volcanics steps down onto Mesaverde beds and Cub Mountain is absent to the south (Thompson, 1966, fig. I).

The base of the volcanics is generally horizontal although it is clearly unconformable on the underlying beds. Near

Ruidoso, Thompson (1966, p. 40) believed that the field relationships indicated some considerable filling of valleys that existed prior to the eruptions.

LATE TERTIARY

OGALLALA FORMATION

The Ogallala Formation (Darton, 1898, p. 732-742) is the only known late Tertiary in southeastern New Mexico. It is widespread east of longitude 104° west capping the High Plains. In 1949 Bretz and Horberg (p. 483-487) pointed out high gravel deposits west of the Pecos River that were correlated with the well recognized Pliocene Ogallala on the Llano Estacado. They located small gravel-capped pediments on the top of the Guadalupe Mountains and Guadalupe Ridge at altitudes ranging from 5,500 to 6,500 feet. The slope of the Ogallala on the High Plains east of Carlsbad is about 10 feet per mile. This slope projects from the Ogallala caprock edge to the top of the Guadalupe Mountains to an altitude of about 4,500 feet, about 2,000 feet lower than the present Guadalupe crest. The 2,000-foot difference is roughly the height of the Guadalupe fault scarp. Therefore, it is not unreasonable to assume that the Guadalupe gravel was once continuous with the Ogallala High Plains beds.

What bothered Bretz and Horberg, however, is the fact that similar gravel also occurred on the low surfaces in the Delaware basin at altitudes of 3,400 to 3,800 feet 15 to 20 miles west of the Pecos River and 500 to 900 feet higher than the river. These relationships led them to conclude that there had been an "ancestral" Pecos Valley which had been completely filled with early or pre-Ogallala sediment which thereby could account for Ogallala-type gravel at such different altitudes. However, before the tilting of the Guadalupe Mountains by the great faults along their western base the reef escarpment may have had little or no relief and the great Ogallala pediment gravel blanket may have spread across a pediment cut at essentially the same altitude across reef and basin evaporite beds alike. When the Guadalupe and Delaware Mountains were uplifted and tilted eastward, the great difference between the erosional resistance of the basin evaporites and the reef dolomites caused the escarpment to erode. During this time the Ogallala gravels would have been let down to their position in the present Gypsum Plain in the Delaware basin. By this explanation the siliceous gravel along the present Pecos Valley in terraces and other near-river positions would all be Quaternary and this may be said to be the present prevalent idea.

If, on the other hand, the Bretz-Horberg "ancestral" valley hypothesis is accepted, some of the gravel, especially the well-indurated gravel, could be Ogallala or pre-Ogallala in age, having been exhumed by re-excavation of the Pecos Valley. An interesting possibility which arises out of the Bretz-Horberg hypothesis is that the Gatuna Formation, which usually underlies the more prominent gravels of the valley, may also be Pliocene. It is so described below.

High-level pediment gravel that is very likely Ogallala equivalent is extensive in segmented mesas between Capitan and Ruidoso at altitudes of 6,800 to 7,400 feet. These high-level gravels are northeastwardly elongated, dendritic-shaped remnants that were controlled in their position and orientation by old fault-line valleys. In some places the gravel occupies a flat-topped ridge, no more than 200 to 300 feet wide aligned on or near a fault. From north to south the three principal faults related to the elongate mesa segment gravels are Champ, Airstrip, and Little Creek (pl. 1).

The even skyline of the Airstrip and Champ surfaces is strikingly evident from vantage points to the north and it is readily seen that, although they slope eastward from the base of the Sierra Blanca, their eastern lower ends are some zoo feet lower than Lincoln Ridge and the crest of Lincoln anticline of the Mescalero arch lying east of the gravel surfaces. The high-level drainage appears principally to have gone either to the east along a course paralleling Rio Bonito Canyon, or possibly along the Ruidoso below the Eagle Creek junction. There is also the possibility that drainage went through Capitan Gap between the east and west Capitans. This wind gap has an elevation of 7,452 or about 900 feet above the gravel remnants near Capitan. The gravel consists dominantly of fragments of igneous rocks from Sierra Blanca. Projection of these gravels to the Ogallala about too miles to the east near Caprock slopes about 13 feet per mile.

High-level gravel occurs on the wide plain north of the Capitan Mountains (pl. Ts. 5, 6 S., Rs. 14, 15 E.) at altitudes of 6,000 to 6,600 feet. These also project to the Ogallala rim east of the Pecos at about 13 feet per mile, although along the pediment they slope about 40 feet per mile. These gravel caps appear to be remnants of a widespread pediment that once covered most of the Hasparos embayment. These are not labelled "Ogallala" on the accompanying geologic maps owing to the uncertainty of an original continuity.

LATE TERTIARY OR PLEISTOCENE

GATUNA FORMATION

The Gatuna was named by Lang (1938, p. 84-85) for Gatuna Canyon. During the course of the present work the Gatuna, another valley-filling formation of supposed Pleistocene age, has been widely mapped in the Pecos Valley. As more and more of the unit was identified, its lithology and induration cast doubt on its Pleistocene age.

The Gatuna generally consists of sandstone, but locally contains mudstone, conglomerate, limestone, or, very locally, gypsum. The most typical color is orange red, a shade lighter in general than Dewey Lake sands. Gray, yellow, or purplish colors occur locally. Lang (op. cit.) reports as much as 300 feet in Cedar Canyon T. 24 S., R. 29 E. Along the Pecos River at Pierce Crossing 6 miles southeast of Malaga a partial section without exposure of bottom or top is exposed in an anticline striking about N. 30° E. The east limb exposure dipping ESE at 35 to 50 degrees measured about 300 feet thick. The section is dominantly friable reddish brown or tan-brown siltstone, fine sandstone, and claystone. The sandstone is typically clayey and the siltstone and clay-stone typically sandy. Several t-foot pebbly conglomerate or conglomeratic sandstone beds occur through the section. The pebbles consist of yellow, brown, black, and white chert, red and brown Santa Rosa sandstone and sparse rhyolite and limestone.

North of Hope in the Cottonwood drainage, exposures are about 150 feet thick. Overall, however, the thickness is quite variable, as though deposited on dissected terrain. In T. 16 S., R. 22 E. north of Hope, nearly horizontal Gatuna beds overlap the Fourmile Draw Member of San Andres and into the Bonney Canyon Member. The large area of Gatuna in the Cottonwood Creek area has been mapped as Artesia. In view of the red claystone and siltstone lithic fragments of Artesia sandstone and fresh-water limestone beds (secs. 27, 28, T. 15 S., R. 23 E.) overlap across the San Andres, and intertonguing with gravel at Arroyo Felix, it was decided that the Cottonwood outcrops are Gatuna. Nye (Fiedler and Nye, 1933, p. 46, 50-51) early identified these beds as Artesia (his Pecos) and described them in some detail including mention of the fresh-water limestone beds. Dane and Bachman (1965) also mapped the area as Artesia Group.

Along the north bank of Arroyo Felix in secs. 13-15, T. 14 S., R. 23 E. there are fine exposures of tilted red Gatuna beds with considerable conglomerate transitional upward out of red sandstones and mudstones. Sugary crystalline gray and reddish-gray limestone beds similar to those in the Cottonwood area occur locally in the middle part of the section. One bed in the lower part of the section contains numerous tiny gastropod shells, molds, and casts.

In the northern part of the area (pl. 2), Gatuna beds occur along the lower drainage of Cienega del Macho overlying Fourmile Draw beds and capped by terrace gravel. These outcrops, mapped formerly as Permian Artesia, are readily observed in the bluffs to the west where U. S. Highway 285 crosses Macho Creek 16 miles north of Roswell. About at the same latitude as the above occurrences but east of the Pecos a small remnant of Gatuna lies on Yates and slumped Santa Rosa Sandstone (T. 6 S., R. 26 E.). Here the outcrop is only about 200 feet above the Pecos and it is nearly 600 feet below the Ogallala some 6.5 miles to the east.

East of Hagerman in the Buffalo Valley area, Gatuna rests variously on Santa Rosa and Salado and on Yates and Seven Rivers in the bluffs along the river's edge. The lower occurrence is well exposed in the bluffs along State Road 31 four miles east of Hagerman. The outcrops resemble Artesia and have until now been mapped as such. In the small canyons of the bluff, exposures contain chunks of Permian rocks incorporated in the red sands which have festooned aeolian bedding, features foreign to the Permian.

East of Artesia in R. 28 E., Gatuna as much as 150 feet thick, occurs along the Crow Flats and Turkey Track collapse belt lying across Rustler, Triassic, and Salado outcrops. The Gatuna is locally considerably mixed with the older rocks by reason of collapse and small Salado generated piercements.

North and northeast of Avalon Lake on the Pecos there is a considerable area of Gatuna. It is mostly obscured by blow sand, caliche soil, and pediment gravel, but where exposed along Fadeaway Ridge it is typical. In this area (pl. 4) it rests mostly on Salado, but eastward, as in T. 19 S., R. 29 E., it rests on Rustler dolomite. In the southeastern corner of T. 20 S., R. 28 E. a core of much-disturbed Gatuna occurs in a low Salado generated sink and dome structure of the type described by Vine (1960).

Considerable Gatuna occurs northeast of Loving east of the Pecos, where it can be seen locally along the bluffs and in railroad cuts overlying Dewey Lake and underlying caliche and blow sand of the mesa rim. Southward from Loving, along the Pecos, numerous patches of Gatuna overlie upper Rustler beds. This, again, is an area of numerous sink and piercement domes and where the Gatuna is present it is commonly involved in the surficial structures (Reddy, 1961).

It is suggested under Ogallala Formation that the Gatuna may be older than Pleistocene and even pre-Ogallala. This relationship is possible with the Bretz-Horberg (1949) postulate of an "ancestral" Pecos valley. The gravel along the Pecos which they (op. cit., p. 485-487) thought could be Ogallala or pre-Ogallala is indurated more than overlying terrace gravel. Furthermore, these gravels overlie the Gatuna (Reddy, 1961, p. 43) and the Gatuna, although in places may have gravel in its lower part, does not overlie beds of gravel. The present mapping has shown the Gatuna to be more widespread than heretofore thought. It is fairly well consolidated in many occurrences. In places, such as in the Cottonwood drainage, it possesses several thin beds of freshwater limestone. The Gatuna is relatively fine grained, as Pecos Valley fill goes, and is thought to be a low-energy aggradation product that resulted from reversal of a down-cutting of the valley, whether Pleistocene or earlier. For these and less definable minor aspects, it is important to consider the likelihood of a Pliocene and pre-Ogallala age for the formation. The origin of both the Gatuna and the Ogallala and Ogallala-like gravels certainly needs further study in southeastern New Mexico.

QUATERNARY

The Quaternary rocks of the Pecos Valley and adjoining country are widespread and varied in type and conditions of origin. Pediment covers, terrace deposits, aeolian, and caliche soil covers are the most widespread. The map distinctions of types are not easy to make. Many combinations, overlays, and detailed mixing of types occur. Most of the areas mapped as pediments, soil cover, and blow sand lie east of the Pecos and above the river bluffs. Large areas along the Pecos Valley have been disturbed by slump, sliding, and collapse in marked-enough manner to allow their separate mapping.

PEDIMENT DEPOSITS

Most of the area east of the Pecos River to longitude 104° west is a gently westward-sloping surface lying 300 to 400 feet above the river. The area is referred to as the Mescalero Plain (Bretz & Horberg, 1949, fig. 1) in a broad sense, but it encompasses many low mesas, bluffs, and wide draws. The area is poorly drained, and in the northern part only short draws cut through the western bluffs up to parts of the surface. South of Roswell, on the other hand, several marked drainage lines flow southward or southwestward to the Pecos, such as Long Valley between Roswell and Hagerman, Bear Grass Draw east of Artesia, and Pamilla Draw northeast of Carlsbad. Numerous playa pans or smaller sinks are scattered across the plain and in general it is an arid sand-, caliche-, and gravel-covered area. The justification for terming the area a pediment lies in the long irregular mesas, along the edges of which caliche-cemented gravel and sand are exposed. These are usually no more than 5 to Io feet thick although locally they may be somewhat more. Gravel consisting of quartzite, chert, and other siliceous rock is widespread on the surface and has probably been derived by erosion of the Ogallala beds on the Llano Estacado to the east.

Horberg (1949, p. 465) correlated the surface of the Mescalero Plain with the Diamond A Plain along the western side of the Pecos Valley. At the latitude of T. 16 S. (Hope) the Mescalero Plain is at an altitude of about 3,600 feet and the Diamond A Plain is at 4,000 feet both at points about equal distance from the axis of the Pecos Valley. At T. 6 S. about 25 miles north of Roswell the altitude of the Mescalero Plain is about 4,000 feet and the Diamond A Plain only 4,110 feet even though the preserved remnant in R. 23 E. is about 7 miles farther from the axis of the valley. These data could be taken to indicate either some tilt of the Sacramento cuesta in post-Diamond A time or a steeper original gradient on the plain in the southern area. Both east and west surfaces should have slopes at least slightly toward the axis of the valley that existed at that time. The gravel in the Diamond A pediment remnants north of Hope is considerably coarser than that on the Mescalero Plain.

Another significant remnant of Diamond A gravel occurs along U. S. Highway 70 about 15 miles west of Roswell. These gravel deposits are coarse like the Hope deposits, but contain a high proportion of cobbles from the Sierra Blanca igneous rocks. The upper surface of the deposit lies at altitudes between about 4,200 and 4,300 feet.

TERRACE DEPOSITS

The Pecos Valley of New Mexico from about Roswell south consists of two broad alluvial plains or low terraces, one extending from about 15 miles north of Roswell to the Seven Rivers Hills, and the other from near Carlsbad to near Malaga. The northern valley is about 100 miles long, and at its middle near Artesia, about 28 miles wide. The southern alluvial valley is a somewhat equidimensional plain about 18 miles wide east to west, and 16 miles north to south. In both of these valleys the Pecos River follows closely along the eastern margins. The reason for this lies in the vastly greater input of alluvium from the much larger drainage area to the west.

The northern Roswell-Artesia valley terminates about at Macho Draw which is the farthest north of the long western tributaries to the Pecos that rise in high drainage areas to the west. On the south the alluvial valley terminates because of the transverse Seven Rivers monocline which brings the resistant Seven Rivers Azotea dolomite beds across the course of the Pecos. Nye (Fiedler and Nye, 1933, p. 10-13, pl.4) noticed the terraced nature of the Pecos Valley alluvium and mapped and named them in the following ascending order: Lakewood, Orchard Park, and Blackdom. The Lakewood is essentially the present alluvial bottom land of the Pecos and its major tributaries, except for the inner gully of the river which is only 10 to 30 feet deep. Deposits consist of sandy brown silt with lenses of gravel and some caliche locally in higher parts.

The Orchard Park terrace is the principal agricultural plain of the valley; it rises only 5 to 25 feet above the lower level, but due to the Lakewood erosion, the two surfaces merge into one another without a terrace over wide areas. Orchard Park deposits appear to be a thin veneer, as much as 20 feet thick, on older alluvium (Morgan, 1938, p. 14). It typically consists of silt and sand with some clay lenses and pebbly beds. Chalky caliche occurs commonly in the upper part.

The Blackdom terrace is a somewhat broader strip than the Orchard Park and is up to 100 feet above the Orchard Park in the Arroyo Felix area in R. 23 E. To the east, however, it is as little as 40 to 50 feet as in the western part of Artesia. Morgan (op. cit.) found the deposits of the pediment surface were less than 20 feet thick overlying older gravel. The lithology is similar to the Orchard Park though slightly coarser. Caliche is up to 3 or 4 feet thick and is usually denser by contrast with the more chalky caliche of the Orchard Park. Near the western margin, where the pediment material laps onto the San Andres, the caliche limestone closely resembles the Permian carbonates, especially in the weathered outcrops. In Ts. 12 to 14 S., Rs. 22, 23 E. the Blackdom caliche dips to the east at 4 to 5^0 more or less paralleling the bedrock dip. This is steeper than the regional bedrock dip and appears to be the result of general solution subsidence affecting the edge of the Blackdom terrace.

North of Roswell, Blackdom gravel caps the large mesa crossed by U. S. Highway 70 in T. 9 S., R. 24 E. (pl. 2) and this terrace can be traced up the river to T. 4 S., R. 25 E. East of this terrace and 50 to 70 feet lower, remnants of the Orchard Park are mapped, and the Lakewood forms the river fields (T. 6 S., R. 26 E.).

In the Carlsbad alluvial basin, Lakewood, Orchard Park, and Blackdom terraces have also been recognized (Horberg, 1949, fig. 3). This valley is bounded by Permian Artesia carbonates on the west and northwest, by Rustler .outcrops on the south, and by Pecos River bluffs of pediment gravels and Ochoan Permian outcrops along the northeast and east sides. The terrace alluvium opens out to the southwest along the base of the reef escarpment in a complex of dissected alluvial fans and valley alluvium of several levels. Carlsbad is on both Lakewood and Orchard Park deposits, but the large open valley to the south is almost entirely Orchard Park level. The highest level consists of dissected gravel mesa segments near the reef escarpment. Around White City these are correlated with the Blackdom of the Artesia-Roswell basin. Again, as in the northern valley, the Blackdom and Orchard Park deposits are considered to be a relatively thin pediment gravel lying on a surface eroded across older, locally deformed and thicker gravels (Horberg, 1949, p. 472). These older carbonate gravels, especially in exposures along the lower course of the Black River, contain abundant siliceous pebbles of quartz, chert, and quartzite, and minor granite, rhyolite, schist, and diorite (op. cit., p. 468).

The Carlsbad alluvial basin undoubtedly has some very important problems of origin, depth, and kinds of surficial fill. In order to understand these problems the Permian sub-crop needs to be known. As shown on Plate 4, two faults may cross all or parts of the valley. Additionally, there are some anomalies in the distribution of the Salado and Rustler outcrops on opposite sides of the valley south of Carlsbad that need more understanding.

In the large Roswell-Artesia alluvial valley the gravel is of uneven thickness and given as ranging up to almost 300 feet, but in a general way thinning to both margins. For the eastern margin this means that the thickness at the river or Lakewood level might be less than to the west. Morgan (1938, pl. 1) constructed a thickness map which shows a meandering, thicker isopach in the valley fill 1 to 5 miles west of the Pecos River. However, part of this may be due to the rise in the surface. For example, at Orchard Park in sec. 28, T. 12 S., R. 25 E., the altitude is about 130 feet higher than due east at the river. Along this line Morgan shows about the same difference in thickness. On the other hand, Morgan's map shows thick and thin bands not conforming to surface altitudes in the dissected areas of the Orchard Park and Blackdom pediments. There is no reason why the deepest excavation may not have been west of the present river position. If, following this excavation, the valley was aggraded to the Blackdom level, the river would have been crowded to the eastern bank. Such a position could have topped the bluffs east of the river where later incising of the valley would be expected to set the river course. This reasoning may be taken to indicate that the present depth of the valley to the base of the alluvial fill was eroded after the cutting of the Blackdom pediment.

The thickness of the valley alluvium is, however, not well enough known. Much of the evidence comes from drillers' logs, and churned bedrock cuttings; cavern fillings in bedrock may be mistaken for alluvium. Continued solution by ground-water and resulting lowering of the original position of the alluvium-bedrock contact may also confound the problem. Additionally, much more Gatuna appears to lie beneath the valley than has heretofore been thought, and it may be that some bedrock picks for Grayburg, or Queen red beds may be Gatuna instead. Indication that the valley has subsided by solution subtraction may be determined by projecting the Gatuna on Cottonwood Creek eastward at an inclination of 25 feet per mile, which is about the slope of the Orchard Park surface. It would come to the Pecos River 200 to 250 feet lower than the position of other Gatuna beds on the Mescalero Plain about 10 miles to the east of the river in T.15 S., R. 27 E.

AEOLIAN SAND

The Mescalero Plain is widely veneered with tan-brown sand. These aeolian sands with lesser quantities of soil and caliche were generally lumped by Darton (1928, p. 59) into the term "Mescalero sands." They occur mostly in the southern part of the plain especially to the east and northeast of Carlsbad. However, the sand is found extensively on the plain in local patches and even irregularly across Artesia beds to the west of the plain. Typically, the sands are associated with much mesquite, cactus, or buffalo grass which helps to hold and mound the sand. Where it is cut into white caliche, crusts occur in the base or lower part of the sand. Large dune forms are scarce, but areas of blow sand are distinct enough to allow mapping as shown on Plate 4.

LANDSLIDES AND SLUMP BLOCKS

Landslides of chaotic soil and larger blocks are abundant along the principal canyons of the Pecos slope where weak Yeso beds are overlain by more resistant San Andres beds. Locally, larger blocks slump into canyons as only slightly broken masses. There is, to some extent, a gradation between these two types. A few of the large slump blocks are mapped, but the many smaller landslide areas are not mapped because of the small scale and complicating cartographic problems that would result. Ruidoso, Rio Bonito, Hondo, James, Cox, and Penasco are the principal deep canyons whose sides are draped with San Andres that slid across the upper Yeso contact. This contact is extensively obscured because of the sliding.

Three large slump blocks are worthy of note. One of these is at Cloudcroft (pl. 3) where a block 1 to 2 miles long is slightly dropped into the head of Fresnal Canyon. The slide break curves through town just east of the junction of State Roads 83 and 24. The block appears to be old and rather well stabilized so that further sliding is unlikely. About 6 miles southeast of this block, near the junction of Russia and Cox Canyons, the side of a tributary canyon has slumped into Russia Canyon on a break 3 to 4 miles long.

The greatest slump masses in the area are along the Guadalupe fault escarpment in Ts. 21, 22 S., R. 18 E. In this area (pl. 3) the Guadalupe front appears to have flexed downward to the bounding fault along which the range was uplifted. Uplift brought the Yeso-San Andres contact well up into the scarp face, and on the steep slope blocks of the draped San Andres slid toward the valley more or less along the formation contact. Headley (1968, P. 43-46) has mapped and described this area in some detail.

LAKE DEPOSITS

The carbonate-evaporite terrain of this area is marked by countless holes, karst areas of collapse, and numerous sags up to several miles in width and length. Nearly all those that are not open at the bottom may have temporary small bodies of water in them after heavy rains. In a sense, the mud in their bottoms constitutes lake or playa deposits. If all were just ephemeral, the situation would hardly be worth mentioning, especially as most sags and sinks are small and no more than a few tens of feet in diameter. Several, however, are larger and have shoreline vestiges of longer-lasting bodies of water and preservation of some white calcareous lake clays. Sinks most worthy of note are as follows:

(1)	Canning	T. 7 S., R. 14, 15 E.
(2)	Elkins	T. 7 S., R. 28 E.
(3)	Cullins	T. 15 S., R. 28 E.
(4)	Nakee Ishee	T. 16 S., R. 28 E.
(5)	Crow Flats	T. 17 S., R. 28 E.
(6)	P.C.A.	T. 20 S., R. 30 E.

Cullins, Nakee Ishee, and P.C.A. sinks especially appear to have had persistent Pleistocene lake stands above their present floors and the thin lake deposits in them may possess a stratigraphy of significance.

CALCAREOUS TUFA

Numerous tufa and travertine banks along sides and bottoms of canyons occur in the area. Most, however, are too small to be mapped in this work. Small deposits have been noted in the following places.

(1)	Rocky Arroyo	Sec. 18, T. 21 S., R. 25 E.
(2)	Black River Valley	Secs. 23, 24, T. 24 S., R. 26 E.

(3)	Sitting Bull Falls	Sec. 9, T. 24 S., R. 22 E.
(4)	White Oaks Canyon	Sec. 5, T. 24 S., R. 22 E.
(5)	Russia Canyon	Sec. 21, T. 16 S., R. 12 E.

Commonly the more cavernous carbonate beds of the San Andres Formation are partly filled with travertine, and the bottoms of many small creeks are extensively armored with it.

VALLEY ALLUVIUM

Most of the early Holocene and Pleistocene alluvials of the Pecos Valley were described under "Terrace Deposits." In addition to these there are upland valley alluvial deposits which are extensive enough to be shown on the geologic maps. Many of these are extensions from Lakewood alluvium of the Pecos Valley. North of the Roswell basin, Lakewood or present alluvium extends for many miles up the Pecos River with bottomland widths of a few hundred feet to one mile or so. Significant valley-bottom alluvium is mapped along Salt, Eightmile, Blackwater, Hondo, and Felix creeks on Plate 2, and up Eagle, Periasco, Long, Gardner, and Segrest creeks on Plate 4, all leading from the Roswell-Artesia basin. Valley alluvial "strings" leading from the Carlsbad basin occur in Rocky, Last Chance, and Black Canyons.

Extensive open alluvial valleys that are quite remote or disconnected from the Pecos alluvials occur around the Capitan Mountains, northwest of the Capitans in areas underlain by Triassic and Cretaceous shale, in small upland valleys around Pajarito Mountain, and in large upland valleys around Dunken and Pirion (pl. 3). Alluvial fans occur along the western base of the Guadalupe Mountains fault scarp and in Dog Canyon and Shattuck Valley between the Guadalupe and the Brokeoff Mountains.

Perhaps the most interesting of the upland alluvials is the apron of alluvial fans, often much dissected, that surrounds the Capitan Mountains (pl. 1). This peripheral apron extends 1 to 4 miles outward from the bold igneous mountain and consists dominantly of igneous cobbles and boulders, but with occasional dolomite and sandstone fragments from beds in contact with the intrusion. Some of the boulders are as much as 25 feet in diameter near the mountains. They are larger on the north side especially around Pine Lodge. One of the remarkable features of the Capitan fans is the abundance of magnetite cobbles and boulders up to 2 or 3 feet in diameter. Some beds in the alluvium appear to be as much as 25 percent magnetite. The Capitan Mountains are just recently deroofed of their sedimentary country rock, and the contact zone in these sediments undoubtedly had enormous iron ore bodies.

DISTURBED ALLUVIUM

Disturbed alluvium is an unusual mapping division. In an area where there is so much subsurface subtraction of rock and so much consequent surface collapse, the mapping of the slumped, or otherwise disturbed gravel, has some meaning for the shallow unexposed lithology, and for the Quaternary erosional and tilting history.

Subsiding and collapsing of surfaces is an old phenomenon in the area. It may well have been common in late Permian time and there are well-known examples of intra-Triassic collapse structures. However, the principal collapsing and slumping of surfaces and deposition of surficial debris probably began in late Tertiary and continued to the present.

The mapping of slumped alluvium was motivated by the finding of tilted gravel caps lying on Grayburg and Fourmile Draw beds along the western edge of the Pecos Valley plains above the level of the valley alluvium. In a north-south stretch in Ts. 10-15 S., Rs. 22-24 E. there are pediments and some caliche-capped surfaces which dip toward the valley at attitudes slightly in excess of the eastward-flowing stream courses. The dips range from about 1 to 5 degrees. These deposits were probably pediment blankets which have been warped down to the east in accompaniment with broad overall solution subsidence of the Pecos Valley. In places, as in T. 15 S., R. 24 E., the pediment gravel has flow ridges indicating a rather mobile bedrock base. These flow ridges show up in striking manner on aerial photographs and are shown on the geologic map with dotted lines which are at right angles to the direction of flow. The nature of these can be seen in a few exposures. They appear to be long, curving segments which have been tipped as they were slightly pulled apart during flow of the bedrock. On photographs these lines can be traced, in places, from gravel into thin caliche veneers, and into dolomite beds. In the dolomite the lines are found to be tension joints or narrow drape folds related to solution between joint blocks. From a geomorphic point of view the features need detailed study. They were given only cursory examination in this work when it was discovered that they were for the most part nontectonic.

Several large areas of disturbed gravel pediments are mapped west and north of Roswell. The large area mapped in T. 9 S., Rs. 23, 24 E. appears to be underlain by gypsum. The surface was originally a gravel terrace, but slumping has made the ground very hummocky, resembling a dump area. Another large area occurs in T. 11 S., Rs. 21, 22 E. The terrace gravel surface in this area, at about 4,350 feet elevation, has been described. Beneath the upper terrace of more or less undisturbed gravel, there are slumped gravel deposits all the way to the adjacent valley bottoms, a minimum thickness of about 300 feet. Unconformities between the slumped beds and the upper beds may be seen in roadcuts on U. S. Highway 70. All the gravel, including the slumped beds, contains Sierra Blanca igneous debris as well as Permian and other sediments. Similar gravel appears to lie beneath the surface in the Menecke sag valley through which the present Blackwater Draw passes. During Pleistocene time the area of the thick accumulation of slumped gravel and the area of the Menecke sag must have been a large, slowly subsiding catchment for one of the major drainage systems down the Pecos slope. Movement of the water to the east into the Pecos axial flow may have been only subsurface at times.

Igneous Intrusive Rocks

The northwestern part of the area includes a group of intrusions termed the Lincoln County porphyry belt (Kelley and Thompson, 1964, p. 114). The larger intrusions are either stocks or laccoliths. Numerous dikes and sills also occur in the area. A few sills occur as far east as the Pecos River and some dikes occur in the Delaware basin far from the main belt of igneous rocks. The distribution of the stocks, laccoliths, and some dikes is shown on Plate 4, but only those intrusives that lie wholly within the geologic maps, Plates 1 to 4, are described here.

The Capitan stock is the largest intrusive in the Lincoln County porphyry belt. It is roughly 21 miles long and 4 miles wide. For its size it is remarkably uniform in its overall composition and texture. It is medium- to fine-grained and only slightly porphyritic. Under the microscope the texture is allotriomorphic to hyidiomorphic and tends more to a seriate fabric, although equigranular and porphyritic samples are common. Phenocrysts are usually orthoclase or quartz, but locally biotite. Plagioclase (oligoclase) is almost entirely confined to groundmasses. Myrmekitic textures are fairly common in medium-grained groundmass textures.

The rock is strongly leucocratic. Biotite and muscovite are present only in accessory quantities, along with magnetite, sphene, chlorite, and apatite. The plagioclase appears to be oligoclase although a precise An-Ab ratio was not determined. Larger crystals of oligoclase commonly show Carlsbad as well as albite twinning. Thin sections from single hand specimens show considerable variation in proportions of orthoclase, plagioclase and quartz, and on microscope estimation of composition the rock could be said to range from granite to quartz monzonite, but syenite and syeno-monzonite are also apparent. The quartz-bearing aspect, however, is distinctive for the Capitan intrusive, as most Lincoln County intrusives are devoid, or nearly devoid, of quartz. Over-all the rock is perhaps best termed a fine-grained leucrocratic quartz syenite.

LINCOLN COUNTY PORPHYRIES

Name	*Form*	*Composition*	*Reference*
Tecolote	Laccoliths	Trachyte, rhyolite	Rawson, 1957
Jicarilla	Stocks, laccolith	Monzonite, diorite	Ryberg, 1968
Lone	Laccolith	Syenite	Smith, 1964
Patos	Laccolith	Rhyolite	Haines, 1968
Carrizo	Laccolith	Syenite	Kelley, in prep.
Vera Cruz	Stock	Monzonite	This report
Willow	Sill	Syenite	Thompson, 1966
Cub	Sill	Syenite	Thompson, 1966
Chaves	Sill	Syenite	Thompson, 1966
Rialto	Stock	Monzonite	Thompson, 1966
Bonito	Stock	Syenite	Thompson, 1966
Three Rivers	Stock	Syenite	Thompson, 1966
Black Peak	Stock	Syenite	Kelley, in prep.
Hollow Hill	Laccolith	Rhyolite	This report

Vera Cruz Mountain is a prominent rounded hill near the center of T. 8 S., R. 12 E. just north of U. S. Highway 380. In the upper center of the hill is a small stock of medium-grained granite consisting dominantly of allotriomorphic equigranular orthoclase and quartz. A low percentage of biotite, plagioclase, magnetite, and sphene are scattered in the otherwise leucocratic rock. A large aureole of bleached and slightly hornfelsed Mesaverde beds surrounds the intrusive. The Mesaverde beds dip principally southward and westward around the cross-cutting intrusive. Low on the southeast side of the mountain is the Vera Cruz mine which is located on a highly sericitized breccia pipe that was mined for gold.

To the north of Vera Cruz Mountain is a large elevated upland known as Tucson Mountain. The western side of Tucson Mountain consists of a monoclinal flexure which dips to the valley at 5 to 10 degrees. The slope is a dissected dip slope of Mesaverde sandstones, and especially along the lower part there are several sills. The most common is a white, fine-grained microsyenite. Under the microscope the rock is typically equigranular allotriomorphic orthoclase with minor quartz and few or no accessories beyond a sparse dusting of magnetite grains. Near the base of the hill there is a rather unusual light-gray, fine-grained sill consisting of lath-shaped, nearly idiomorphic orthoclase in a very felted fabric. The rock is nearly monomineralic; even quartz and plagioclase are essentially absent.

In the northwest corner of T. 10 S., R. 14 E. just north of Rio Bonito Canyon, in a rather remote location, there is a small rhyolite laccolith. The Hollow Hill laccolith, as it is termed, is circular and only about 0.5 mile in diameter. It is emplaced, with some discordance and marginal faults, near the top of the Mancos Shale and at the base of the Mesaverde Formation. The rhyolite is fine-grained, allotriomorphic, quite leucocratic, and considerably altered by sericite, kaolin, and pyrite.

A few miles to the north of the Hollow Hill laccolith there is a prominent butte-like peak known as Champ Hill. The upper part of Champ Hill is a sill, 50 to 100 feet thick, of augite diorite. The dark sill rock consists of medium-grained hyidiomorphic plagioclase and some orthoclase beset with phenocrysts of augite, some of which have well-developed hornblende aureoles.

Diabasic to monzonitic sills occur in many places along the Hondo drainage, commonly at the top of Yeso. As this contact is poorly exposed and not readily accessible, numerous occurrences of these sills have probably not been found. Similar sills also occur in the Rio Bonito Member as shown on Plate T in T. 11 S., Rs. 14, 15 E. and in T. 7 S., R. 18 E., northeast of the Capitan Mountains. Still another sill underlying nearly one-half of a township occurs close to the top of the Grayburg-Queen unit near and to the north of the northern boundary of the area (pl. 3) in T. 4 S., R. 23 E.

Dikes have great occurrences in the area in widely separated places. The best known are the long east-west dikes northeast of Roswell (Semmes, 1920, p. 420-425). The two principal dikes are Railroad and Camino del Diablo and are respectively about 31 and 25 miles long. The former is as much as 100 feet wide and consists of medium-grained olivine gabbro (op. cit., p. 421). Camino del Diablo reaches nearly 50 feet in width. It usually has a negative physiographic expression, in contrast to the ridge of Railroad dike. Semmes (op. cit., p. 425) found the Camino del Diablo rock to be a diabase of andesitic to basaltic in composition. Owing to deuteric and surficial alteration it is poorly exposed.

Both dikes cut bedrock as young as Triassic Santa Rosa Sandstone in the outcrop and are widely covered by thin veneers of gravel, caliche, and alluvium.

Castile rocks cut by dikes and possibly shallow sills, occur in the Delaware basin. Darton (1928, p. 61) noted these dikes and found them to be "lamprophyres of basaltic habit." Pratt (1954, p. 143-146) described and mapped the New Mexico occurrences and gave detailed petrographic descriptions of rocks identified as alkali trachytes, and in addition to oligoclase, anorthoclase, and albite as essential minerals, found them to also contain such accessories as ilmenite, magnetite, apatite, epidote, and chlorite.

The dikes occur along faults and trend east-northeastward in T. 26 S., R. 24 E. There has been much alteration and shearing of the dikes. The occurrences are irregularly present on the fissures, and widths are usually only a few feet. During this work, float from either a dike or sill was found strewn over several acres (sec. 31, T. 26 S., R. 25 E.). The rock is almost black and very fine grained; probably basalt. As Pratt noted, the rocks are commonly vesicular, and at this locality, pencil-size tube vesicles extend completely through samples and appear to have been six inches or more in length.

Dikes occur in swarms arranged roughly radially with respect to the Sierra Blanca stocks and in a great swarm some 7 miles wide and 22 miles long trending north-northeastward from Ruidoso to east of Patos Mountain. The main axis more or less coincides with the crest of Indian Divide. In the heart of the dike swarm the host rocks are mostly Cub Mountain and Sierra Blanca volcanics, but they are still numerous in the southwestern part of Tucson Mountain in the Mesaverde, especially the shaly intervals. Likewise they are very abundant in the Mesaverde between Bonito and Eagle Creeks. In places associated sills make a sort of "crating" structure of the country rock. Most dikes are not traceable for more than a mile, but one, east of Capitan, has a length of more than 5 miles. The dikes are steep to vertical with east dips about twice as common as west dips. Thickness ranges from a foot or two to 60 to 70 feet, with the thick dikes being concentrated along the middle of the swarm. In the central one-half or so of the swarm they are spaced 10 to 20 per mile, but many dikes are composite. Probably if exposures were complete nearly 200 dikes could be counted across the swarm. With an average width of 15 feet it would represent a total cross-section emplacement of more than 0.5 mile. Elston and Snider (1964, p. 140) described seven petrographic types, four of which were diabasic, two latitic or monzonitic, and one rhyolite. In the southern part of the swarm Thompson (op. cit., p. 60) noted some syenite porphyry dikes which may be offshoots from the Sierra Blanca stocks, but otherwise the dikes show somewhat of a compositional divergence from the major intrusions, especially in the basic category which make up 60 to 70 percent of the dikes by volume.

Dikes were not included on the geologic map owing to cartographic limitations. Further consideration of the disposition of some of the intrusives is given under Structure.

Structure

REGIONAL SETTING

The area of this study lies between the late Tertiary Basin and Range structure to the west and the vast, relatively undeformed plains structure to the east (fig. 12). It embraces an array of episodes of deformation from Tertiary to Permian, but perhaps the most significant picture of its setting lies in the late Pennsylvanian-Permian paleotectonic elements which underlie the area. Thus, the large, high western strip of the area lies across the buried ancient Pedernal landmass,

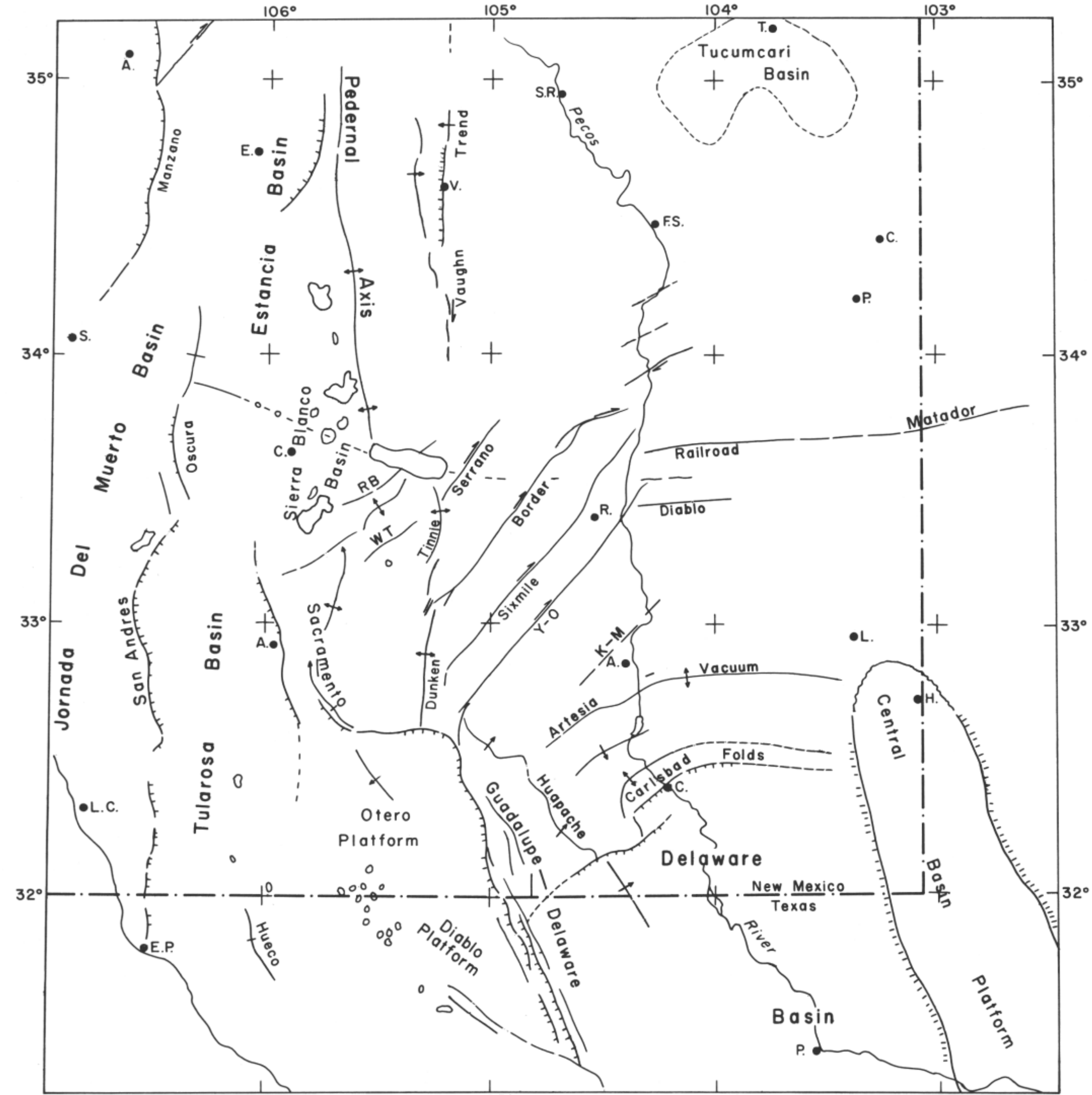

Figure 12

TECTONIC MAP OF SOUTHEASTERN NEW MEXICO

whereas the rest of the area lies in the Permian basin. Most of the eastern and southern part of the area is the Northwest shelf of Permian reef paleogeography. The major part of the late Permian Delaware basin adjoins the area on the south and east, but with a small but significant corner extending into the southeastern corner of the area.

The large Lincoln County porphyry belt borders the area along the northwest side in the Laramide Sierra Blanca basin, and the large Tularosa Valley graben adjoins the area on the west.

MESCALERO ARCH

Mescalero arch is a term introduced by Kelley and Thompson (1964, p. 110) for the broad structural divide which separates the long regional inclination into the Pecos country from the westward declevity into the Sierra Blanca basin and its extension northward through the Claunch sag. The axis begins about 10 miles south of Cloudcroft, near the top of the Sacramento uplift, and plunges northward to Ruidoso Creek near Green Tree. North of Ruidoso Creek the axis and the crest of the arch swing northeastward along what is termed the Lincoln Ridge anticline, to a termination against the Capitan uplift in R. 16 E. (pl. 5). The axis is offset to the west about 10 miles north of the Capitan uplift, and the position is obscure in T. 7 S., R. 15 E. and in the Patos graben. However, it must swing northwestward near the Jicarilla intrusions into R. 12 E. where it trends again northward for many miles to a coincidence with the Pedernal uplift in Torrance County. Although the existence of the axis is certain in the region to the west of the Hasparos embayment its position is obscured by faulting, solution collapse, and laccolithic intrusions (see Kelley and Thompson, 1964, tectonic map). In a general way it appears that the Mescalero arch coincides with the buried late Paleozoic Pedernal uplift and mountains.

PECOS SLOPE

The term Pecos slope was applied by Kelley and Thompson (1964, p. 110-111) for the broad, very gentle, over-all eastward regional dip west of the Pecos Valley. The slope and its variety of folds and faults dominate the tectonics of the area.

The western limit of the slope is the structural divide formed, in order from north to south, by the Mescalero arch and the crests of the Sacramento and Guadalupe uplifts. To the west of this structural divide the descent is into inter-montane basins of a Basin and Range, late Cenozoic type. The Pecos slope, on the other hand, is a structural descent into extramontane basins such as the Delaware and Midland. From the crest of the Sacramento uplift to the eastern margin of the area, a distance of about 100 miles, the structural fall is nearly 10,000 feet or an over-all regional dip of 100 feet (1°) per mile. In other places the over-all dip is only about one-half as great. As shown on the tectonic map (pl. 5) of the region, the Pecos slope is far from a simple homocline, as it is modified by a considerable variety of folds and faults. Some of the large faults, herein termed buckles, are very long wrench types. Folds include long open anticlines and synclines, basins, monoclines, circular domes, and even some local folds which may be closed, overturned, or fan. This study has concentrated on the slope, and perhaps the major structural contribution has been the detailing of the second-or third-order structures which modify it to a greater extent than has heretofore been generally realized.

SACRAMENTO UPLIFT

South of the Mescalero arch, uplifting takes the form of an eastward-tilted fault block known as the Sacramento uplift. The dominant mechanism of rise is a large fault which lies at the western base of the uplift, in the Tularosa basin. However, east of this fault there is a broad gentle anticline (Pray, 1961, pl. 3) in places which suggests that the uplift is a broken anticline, and that this anticline, a part of the Mescalero arch, probably extended the full length of what is now the Sacramento uplift. The Sacramento uplift extends roughly for about 45 miles through Ts. 13-20 S. The northern end plunges in part into the Sierra Blanca basin (Kelley and Thompson, 1964, p. 114), and the southern end descends through several southeastward-plunging monoclines into the Otero platform.

The eastern boundary of the uplift is taken here as the Dunken uplift in R. 16 E. and the Elk basin trough is essentially the base of the uplift. One of the most striking aspects of the east flank of the uplift is its simple undeformed dip of 100 to 140 feet per mile. This contrast's on Plate 5 markedly with the west side of the uplift as well as the surrounding area to the east and north.

GUADALUPE UPLIFT

The Guadalupe uplift has been studied principally by King (1948), Hayes (1964), and Boyd (1958). It is part of a longer gently eastward tilted block, which extends north-northwestward for some 110 miles from the southern end of the Delaware Mountains, northeast of Van Horn, Texas, to the northern end east of Pilion, New Mexico, in T. 19 S., R. 18 E. In New Mexico the western boundary is a great fault scarp along which the uplift ranges from 2,000 to 4,000 feet. The eastern margin is formed largely by erosional conformance to the Huapache monocline. Using the Huapache monocline as the east boundary, the uplift is about 11 miles wide in the southern part, but tapers northward to about 3 miles. In T. 21 S., the Huapache monocline is essentially nonexistent for a stretch of about 8 miles and here the structure as well as the surface descends rather evenly from the high Buckhorn escarpment eastward for about 40 miles to the Pecos Valley.

On the south, the Guadalupe uplift is terminated by the east-northeast-trending reef monocline (Bone Springs in Texas). The uplift is largely a late Tertiary Basin and Range tilted fault block, but a small Holocene fan scarp (fig. 13) along its northeastern base in T. 20 S., R. 17 E. was noted during the present work.

SIERRA BLANCA BASIN

The Sierra Blanca basin has been known for a long time and it was mapped or outlined by Wegemann (1914, pl. 27) by a ring of "coal outcrops" around Sierra Blanca and out-

Figure 13

FAN SCARP NEAR THE NORTHERN END OF GUADALUPE MOUNTAINS

The base of the San Andres Formation is just below the two sunlit spurs in the upper right. The lower one-half of the escarpment to the
fan is Yeso Formation. The light-colored outcrops are gypsum capped by a thin limestone unit (dark).

lying mountains. A more specific form of the basin was given by Kelley and Thompson (1964, p.111, and tectonic map), and Thompson (1966, figs. 1, 10). Only a portion of the eastern flank is included in the present area, but the structure and formational make-up of this part is quite new and different from what has been published. The trough of the basin is thought by Thompson (1966, fig. 10) to lie about 5 to 6 miles west of Sierra Blanca Peak where the top of the San Andres Formation would lie at about 2,000 feet. It is at about 6,600 feet, along the axis of the Mescalero arch 25 miles to the east, an over-all dip of about 200 feet per mile. However, several folds and faults modify the limb in the Sierra Blanca region.

The principal structure is a set of east-northeastward-trending faults which roughly parallel the large buckle faults and the Lincoln anticline. A lesser set of faults trends northward along Indian Divide west of Capitan (pl. 1).

DELAWARE BASIN

Only a minor northwestern part of the large Delaware basin is included within the area of mapping. However, this small part of the basin has very significant exposures bearing on the structural and stratigraphic relationships of late Permian and modern basin. The basin in this area has a fairly regular over-all regional dip toward the east of about 80 feet per mile at the top of the Bell Canyon (pl. 5).

Along the northwestern side of the basin the northerly strike of the basin swings around toward the northeast, to almost parallel the margin, and seemingly merges with the shelf along the forereef downflex.

The northern boundary of the basin is usually taken at the shelf front at least as far as Guadalupian levels are concerned, but for older Permian levels it is commonly taken to the Abo reef trend or about to the Artesia-Vacuum trend (pl. 5) which is some 25 miles farther north. From a late Permian point of view it is the part that was occupied by the Castile and bounded on the north by the Capitan reef. The relief along the northern side is difficult to determine because of lack of complete agreement on projection from the basin to the shelf through the Capitan facies. In general, however, the structural relief ranges between 1,000 and 2,000 feet (fig. 9). It appears to reach greatest prominence, abruptness, or height in the stretch of some 27 miles from near McKittrick Canyon to the Frontier Hills monocline at the Cueva reentrant (Lang, 1939, p. 839). To the west of McKittrick the structural rise is less abrupt. Northeast of the Cueva reentrant the over-all structural leveling effect of the Carlsbad domes on the shelf decreases the structural relief into the basin in the vicinity of Carlsbad from 1,000 to 1,500 feet.

GUADALUPE RIDGE FOLDS

Guadalupe Ridge is a northeastward-trending spur from the Guadalupe Mountains. It results in part from resistance of the reef as compared to the weaker basin rocks on the south side and the weaker back-reef facies on the north. Two anticlines and an intervening syncline parallel the ridge and determine something of the form of the ridge as now eroded. The principal fold, Guadalupe Ridge anticline, is on the north; the rather subdued Reef anticline is on the south at the brow of the escarpment, and the Walnut syncline is in the middle. These folds plunge too to 150 feet per mile to the east-northeast and are about 25 miles in length. In the high western part of the belt the Walnut syncline passes into synclinal bend and only a terrace intervenes between the Guadalupe Ridge anticline and the forereef monocline (pl. 5, T. 26 S., R. 22 E.). On the southwest the folds die out before reaching the crest of the Guadalupe Range, and on the east the folds terminate at the head of the Frontier Hills monocline.

The origin of these folds is puzzling. Hayes (1964, p. 44) reasoned that the ridge folds and at least part of the forereef monocline was Laramide. To date there is no evidence that the folds extend into the pre-Artesia rocks, although admittedly not enough subsurface data exist. If they do not extend to depth, they may be related to something in the progression of the reef growth in early Capitan time over which later compaction folds would form.

HUAPACHE MONOCLINE

The Huapache monocline trends north-northwestward along the eastern flank of the Guadalupe uplift. Because of its physiographic expression, it is commonly taken as the eastern boundary of the uplift and the western side of the Seven Rivers embayment. The principal and best-known part of the monocline lies between the Guadalupe Ridge anticline on the south and Texas Hill (T. 22 S., R. 21 E.) on the north. North of the Texas Hill dome the monocline possesses only slight expression for about six miles. In the southeastern part of T. 19 S., R. 20 E. the monocline becomes pronounced again as it swings westerly and then northwesterly to its termination at the northern end of the Guadalupe uplift, in T. 19 S., R. 18 E., against the northward-trending Lewis buckle.

The width of the monocline is 0.5 to 2.5 miles, and the structural rise or relief ranges from 300 to 400 feet in the northern part, to as much as 900 to 1,000 feet in the southern part north of Guadalupe Ridge. Although complicated by crossing folds in the reef area the relief is about the same as to the north. In the Delaware basin the structural relief on the monocline is 300 to 600 feet.

Maximum dip along the monocline in its typical development at the mouth of Last Chance Canyon does not exceed 15 degrees, and maximum dip in the northern part is 13 degrees. Above and below the monocline dips range from 3 to 5 degrees. As is common of most monoclines the bottom or synclinal bend is sharper than the upper anticlinal bend. The Huapache monocline crosses the folds of the shelf margin with a left shift and comes to the reef escarpment between Rattlesnake and Slaughter Canyons in the northwestern part of T. 25 S., R. 24 E. where it appears to be offset left again to the same or a similar monocline in the Delaware basin.

Drilling along the Huapache monocline has clearly indicated that it is a drape reflection of older underlying structure. Hayes (1964, pl.1) shows a thrust fault of Pennsylvanian or post-Pennsylvanian age beneath the Huapache mono-cline. Meyer (1966, p. 67-85) shows repeated evidence of activity along the Huapache during at least Late Pennsylvanian time, with much thicker Pennsylvanian to east of the old fault. In most places he shows no Pennsylvanian on the western upthrown side, and in effect, he implies that the Huapache marks the eastern boundary of the Pedernal-positive area. It also appears that the fault was active during (op. cit., p. 28, 77) and after (op. cit., p. 85) Wolfcampian time, before being buried in Leonardian time. The Huapache is one of the few structures in the area which has been shown to specifically reflect earlier orogenic events.

DUNKEN UPLIFT

The Dunken uplift is the largest, most prominent structural feature on the Pecos slope between the Guadalupe uplift and the Capitan stock. It is expressed physiographically by a high ridge west of Dunken that may be seen for many miles to the east and from vantage points from the west, as for example, midway between Pilion and Weed along State Road 24. The Dunken uplift is 35 miles long and 5 to 10 miles wide. It extends from the transverse Stevenson fault scarp on the south in T. 19 S., Rs. 16, 17 E. to a narrow termination against the Border Hills buckle on the north. It is bounded on the east by the Dunken syncline, and on the west by the Elk syncline.

The uplift is somewhat like a block with steepest dips bordering the adjacent synclines, whereas the central part consists of open folds with only gentle limbs. The southern part of the uplift is dominated by the Watts Ranch anticline along the western side with lesser folds in the southeastern part, termed the Couhape bench. The central part of the uplift is the boldest, arid is dominated by the Clemente and Bluewater anticlines. The Clemente anticline rises 1,100 feet from the Dunken syncline to the east, and the Blue-water rises 400 to 600 feet from the Elk syncline on the west (fig. 14). The shallow Pefiasco syncline and several lesser echelon folds and faults intervene locally between the two anticlines. The northern part of the uplift is dominated by Manning anticline which appears to consist of a near convergence of the Clemente and Bluewater axis.

The eastern boundary of the uplift is most significant in relating the uplift to the great buckles. This is especially true for the part near the junction with the Six Mile buckle. At this point the bounding Dunken syncline turns north-northeastward and appears to be accompanied by an offset of the Dunken uplift to the right. There is a broadening of the west limb of the Dunken syncline that creates a reentrant into the uplift. The Clemente anticline, that is so much a part of the

Figure 14

AIR VIEW NORTH ALONG THE DUNKEN UPLIFT

Dog Canyon in foreground and Capitan Mountains on skyline.

Dunken uplift to the north, plunges to an abrupt termination against the northern edge of the reentrant. As a result the uplift appears to be offset by movement on the Six Mile buckle.

TINNIE FOLD BELT

The Tinnie fold belt lies in R. 17 E. and extends about 20 miles north to south through Ts. 9-12 S. It is 1.5 to 3.5 miles wide and slightly arcuate to the east. It consists of closely spaced, long, narrow anticlines and synclines with moderately to steeply dipping limbs (fig. 15). In the northern part there are 12 anticlines and synclines in a width of three miles; 8 or 9 crossing Hondo Canyon in a width of 2 miles; and 5 near the southern end. Anticlines from crest to crest are typically 0.35 to 0.5 mile wide. Structural relief on the tighter, larger folds may be as much as 1,000 feet (fig. 16), but this is not shown on the structure contour map (pl. 5) owing to scale limitations and lack of dip attitudes in all necessary places.

About 5 miles north of Tinnie, the Tinnie anticline becomes isoclinal, and for a short stretch, both limbs are overturned to form a fan fold. Locally, folding is isoclinal and overturning of folds may be either east or west. Overall the belt is a low anticlinorium.

As may be noted on the geologic and structure maps there are other folds east and west of the Tinnie anticlinorium, but these are wider and more gentle. The anticlinorium is bounded structurally along its middle part by the Hondo basin on the west and the Talley basin on the east. The southern part of the belt appears to plunge very slightly north and the northern part plunges south. Hondo Canyon is about the lowest part across the belt and this may actually have accounted for the location of the Rio Hondo. The northern part plunges quite noticeably, and its over-all structural, as well as physiographic relief, may be viewed from proper vantage points south of Hondo Canyon. Chavez and Goat anticlines form the central, generally highest, and most continuous axes in the anticlinorium (fig. 15) although the Tinnie anticline is also major in the northern part of the belt.

CAPITAN UPLIFT

The Capitan intrusive has been thought to have the form of either a laccolith or a stock. If it is a laccolith it may be

Figure 15

AM VIEW NORTH OF THE TINNIE FOLD BELT

Only the central highest part of the anticlinorium is shown in the picture.

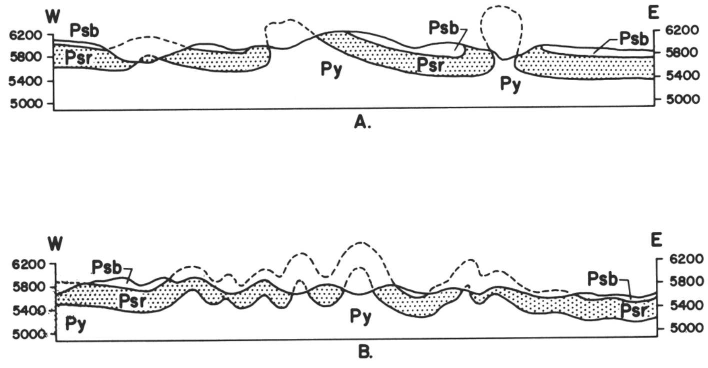

Figure 16

Structure sections of the Tinnie fold belt

multiple in the vertical, consisting perhaps, of two or three laccolithic sheets or wedges extending bilaterally from a central feeder dike. If a stock, its contacts could be expected to dip outward slightly beneath the surface but constrict to a dike in the Precambrian. Its western end has a roof of Rio Bonito beds which dip west, and outliers of the roof are present on the top of the mountain. The eastern end is steeper and more rugged, and Yeso beds stand almost vertical near the contact. The flank contacts are only exposed locally, and in these places the dips are also away from the intrusive.

The intrusive is 21 miles long in outcrop and ranges from about 3.5 to 5 miles wide. However, its width is rather regular, averaging about 4.5 miles. Beneath the extensive flanking aprons of alluvium, Yeso is probably in contact with the intrusive everywhere but at the western end. There is, however, considerable difference in the stratigraphic position, and also some considerable structural discordance.

Viewed from the east in the vicinity of Roswell the mountain has a rather symmetrical triangular profile, and viewed from north or south it has a bold mountain range appearance, albeit with a remarkably even skyline. Actually its boldness is illusory as its over-all slopes from base to summit areas range in several profiles from 12 to 15 degrees on the south to 11 to 15 degrees on the north. The over-all cross-sectional area, to exposed mountain bases is about 1.2 square miles disregarding, of course, the dissection by the numerous flanking canyons. The above ground volume is roughly 20 cubic miles.

The question of whether the intrusion is a laccolith or

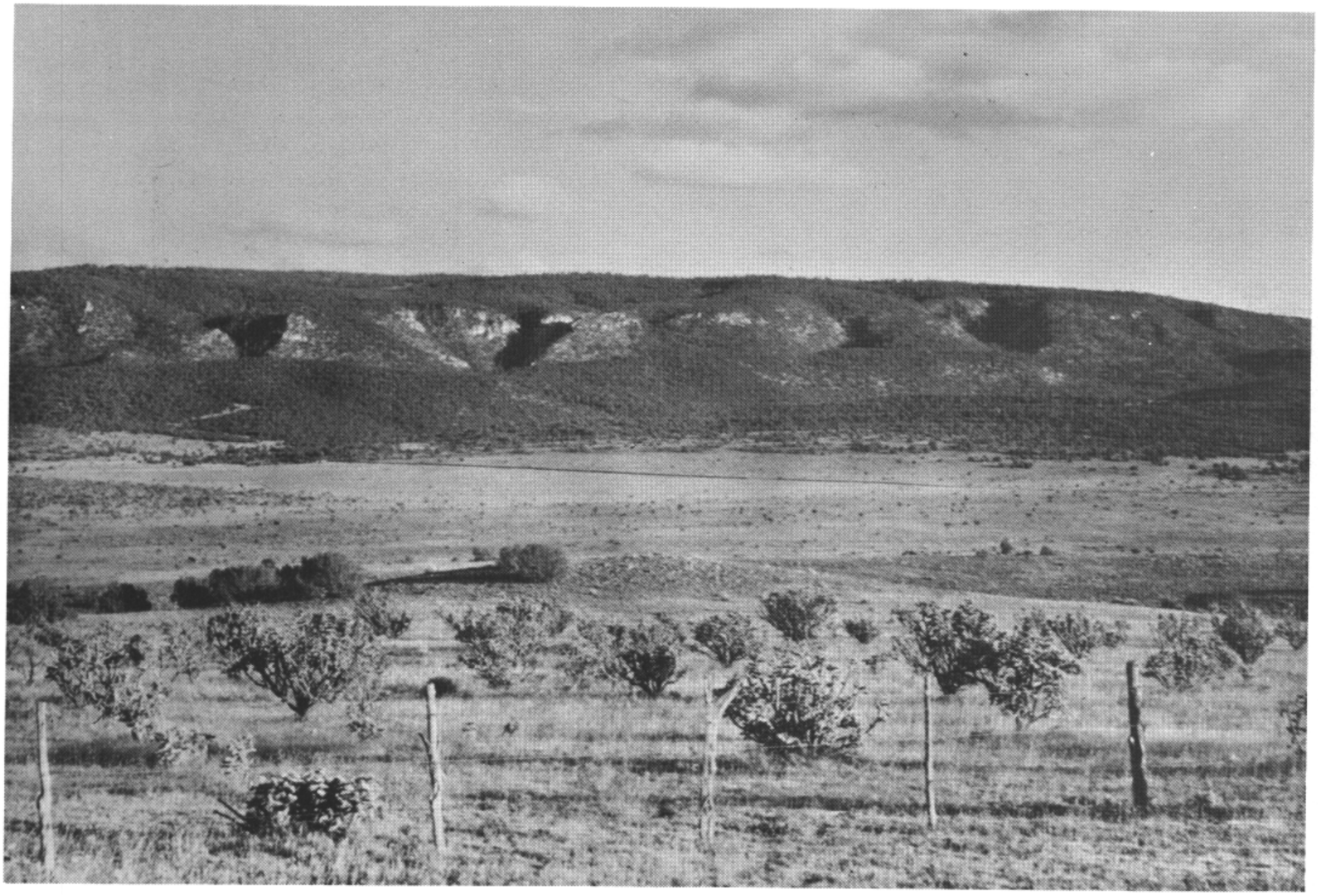

Figure 17
VIEW SOUTH OF THE FAULT IN THE NORTHWESTERN END OF THE CAPITAN UPLIFT
Heavily wooded ridge along base of the mountain is dropped with reference to the dissected face rising to the capped top of the intrusive.

stock is largely indeterminable. The structural and stratigraphic discordances favor the stock, and if a laccolith, it would be one of most unusual shape. Uplifting as expressed by structure contours north and south of the intrusion appears to affect as much as 2 to 3 miles on either side. Structural nosing is evident as much as 9 miles beyond the western end of the intrusion, and 15 miles to the east. These effects are more than would be expected of a laccolith. On the other hand, the evidence of a concordant roof along most of the summit favors a laccolith.

The intrusion is cut by several faults, and vertical offsets can be deciphered for several of those in the western part where there is a sedimentary cap present. One north-south fault along the Rs. 14-15 E. boundary drops the west side 400 to 500 feet (fig. 17). Others in the eastern part (T. 8 S., R. 17 E.) offset the side contacts. Near the western end there are flanking faults of similar magnitude, and some possibility exists, on physiographic as well as structural grounds, that such faults may follow the north and south contacts of the intrusion for most of its length. If so, some of the displacement could be deep-seated as with the Capitan fault, but some may result from a sort of downbuilding action betweenthe compactible and soluble sedimentary units and the rigid intrusive.

The regional evidence is strong that the intrusion follows a lineament of fracturing in the basement that was probably formed as early as Permian (Kelley and Thompson, 1964, p. 520). Petrography of the Capitans is given above under Igneous Intrusive Rocks.

HASPAROS EMBAYMENT

Both the geologic and structure-contour maps accompanying this report show a marked embayment into the Pecos slope north of the Capitan uplift. The major east-west down-warping of the embayment lies in Ts. 4-6 S., and is much nearer to the bench structure southeast of Corona than to the Capitan uplift. The southern side of the embayment is made irregular by northeastward nosing in connection with the Serrano and Purcella buckles, by the Downing buckle, the Encinoso anticline, and the Patos graben.

At the southwest corner of the embayment only a low narrow structural divide separates the embayment from the Sierra Blanca basin. At the San Andres horizon the divide is about 1,000 feet lower than across the Mescalero arch south of the Capitan uplift.

FOURMILE EMBAYMENT

The northwest-trending Huapache monocline and buried fault, together with the northward-trending Dunken uplift and the northeastward-striking Y-0 and Six Mile buckles result in a triangular reentrant into the Pecos slope. Its form is roughly expressed by the outcrop pattern of the Bonney Canyon-Fourmile Draw contact in southern Chaves County (pl. 4). The apex of the embayment is adjacent to the Dunken basin and the reentrant into the Dunken uplift in Ts. 17, 18 S., R. 17 E. To the north, structure contours swing slightly east of north and to the south they swing southeasterly. The apex is also roughly coincident with the structural channel between the Sacramento and Guadalupe uplifts.

SEVEN RIVERS EMBAYMENT

The Seven Rivers embayment lies between the Huapache monocline on the west and the Waterhole anticlinorium (pl. 5) on the east. On the south it is bounded by the Guadalupe Ridge anticline, and to the north the embayment opens out to the slope and the Fourmile embayment. The central part of the embayment is nearly flat and in Ts. 22, 23 S., R. 24 E. a slight closing anticline may be a partial surface expression of some of the Indian Basin field in the Pennsylvanian at depth.

The boundary of the Seven Rivers embayment on the east by the Waterhole anticlinorium is an important departure from the generally used physiographic boundary formed by the Seven Rivers, Azotea, and Hess Hills. The structural boundary proposed here lies 4 to 5 miles to the east or southeast of the physiographic boundary.

BUCKLES AND NORTHEASTWARD-TRENDING FAULTS

Perhaps the most distinctive structures of the Pecos slope are the long buckles and faults that occur at almost regular intervals across a great portion of the slope. Most of the major ones are remarkably straight and are exposed for distances of 35 to 80 miles. They are spaced at distances of 8 to 20 miles. Merritt (1920, p. 55-56) named the well-known Y-0, Six Mile, and Border structures. Other similar features such as the Serrano, White Tail, and Bonito were mapped and named during this work. Renick (1926, p. 123) referred to the Y-0 as an overthrust. Nye (Fiedler and Nye, 1933, p. 77-81) appears to have had a better understanding of the nature of these structures than many later workers. He referred to them as faults and noted correctly that the up-thrown block changed sides commonly along strike.

The term buckle is used here owing to the fact that their surface expressions are in some places folds, elsewhere faults or combinations of the two. Furthermore, there is much evidence that they have experienced strike movement. Both sides are generally turned up sharply in a zone that may range from a few tens of feet to 4,000 feet wide. In many places there is wider uplifting outside a narrow zone of intense deformation. This is the case along the Six Mile buckle west of Roswell where the anticline may be as much as 4 miles wide. The buckles plunge northeastward diagonally across the easterly regional dip. As a result of this relationship there generally is a plunging syncline on the northwest side of the fault or buckle and a synclinal bend on the southeast side, and these axes are mapped. Where the buckle is a fault one buckled-up limb may have a bed separation in the vertical of as much as 500 feet without the beds outside the buckled zone being measurably up or down with respect to each other. Elsewhere, however, key beds away from the buckle are observed to be lowered or raised relatively by 50 to l00 feet.

Along the strike of a buckle the nature of a deformation may change markedly in a short distance. This is strikingly demonstrated by comparing the cross section of the Border buckle in the north wall of Hondo Canyon with roadcut exposure 3 miles to the northeast on U. S. Highway 70 (fig. 18). Only a small quantity of breccia is present in the fine exposures on the Hondo. However, the great quantity and chaotic disturbance revealed in the highway cut is not believed to be too unusual.

The evidence for wrenching action along the faults falls into two principal categories (i) steeply plunging drag folds and left-branching spur faults along the axis or fault, and (2) echelon diagonal folds of some length between the buckles.

Y-0 BUCKLE

The known length of the Y-0 buckle is about 72 miles, although through about one half its length it is beneath Pecos Valley fill. It is slightly curved, striking N. 40 to 43 E. Its northernmost exposure is in poorly exposed folds about 18 miles west of Hagerman. As projected northeastward beneath the Pecos Valley, it crosses U. S. Highway 285 about six miles southeast of Roswell, and the Pecos River and U. S. Highway 380 six miles east of Roswell. North of U. S. Highway 380 the buckle is followed by the Pecos River until it ascends the bluffs along a canyon in the northeast corner of T. 10 S., R. 25 E. Northeastward, it is lost on the covered surface. Southwestward, it extends in T. 18 S., R. 18 E. where it dies out in two splay faults about 2 miles north of the northern end of the synclinal bend of the Huapache mono-dine. The severely compressed part of the buckle is typically only about 500 to 800 feet wide. It is quite disharmonic as a fold and this is well shown in the north bank of the Rio Penasco where at creek level the core is severely compressed compared to beds above (fig. 20). Along the southwestern part, the southeastern block appears lowered in places to as much as 100 feet with respect to the northwest. To the northeast, especially in T. 16 S., R. 20 E., the northwestern side is down on the order of 50 feet locally. However, the buckle follows an older line of deformation, and in Paleozoic time the southeast side appears to have subsided generally. Furthermore, there is subsurface evidence that in the northern part of the fault the southeastern side may have subsided as much as several hundred feet at the end of Permian time (Havenor, 1968, p. 17, and pl. 5).

Small drag folds occur in several places on either limb of the buckle. Their axes strike typically N. 15 to 25 E. They are acutely left-branching and indicate right shift

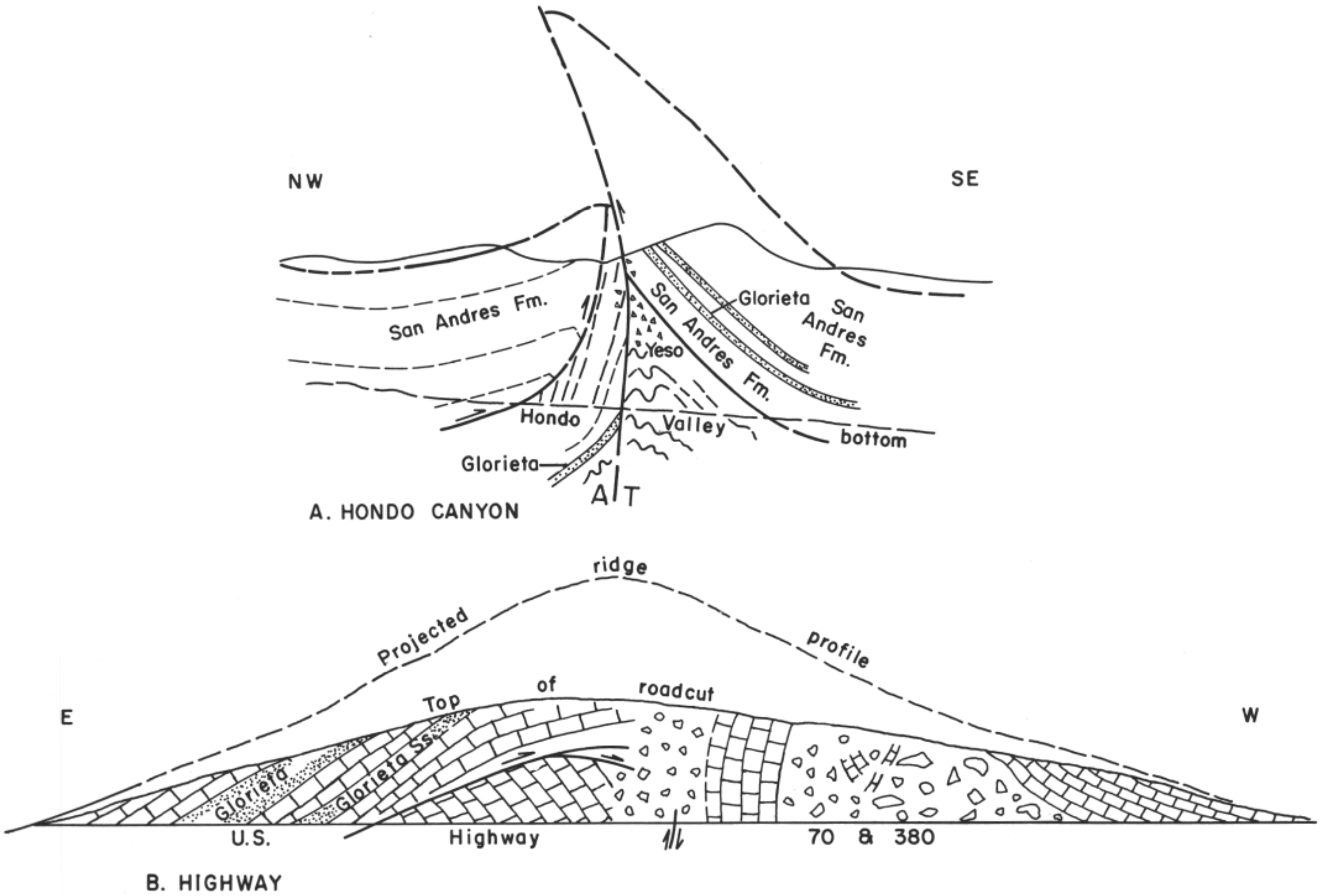

Figure 18

STRUCTURE SECTION SKETCHES OF BORDER BUCKLE OF HONDO CANYON (A), U. S. HIGHWAY 70 AND 380 (B), AND DOWNING BUCKLE (C) IN T. 6 S., R. 18 E.

along the buckle, i.e. the northwest side moved northeast (fig. 19). If the shift were left, the strike of drag folds would be N. 65 to 75 E., and would be right-branching. Plunges are typically away from the buckle, but occasionally they plunge toward it. Drag folds of this nature occur in secs. 2 and 31, T. 17 S., R. 19 E. In T. 18 S., R. 18 E., just south of the Y-0 terminations, there is a fault which is subparallel, but not connected, to the Y-0 buckle. It has similar small drag folds on its north side indicating right movement. This fault essentially merges with the north end of the Lewis buckle, which to the south dies out on the western escarpment of the Guadalupe uplift. However, the Y-0 buckle does not connect in the outcrop to the Lewis buckle or the northern end of the Guadalupe fault. In this part of the map it may be seen that the Huapache synclinal bend axis is terminated against the Lewis buckle fault. To the north of the buckle, however, there is another synclinal bend associated with a short, closely folded and faulted belt. The geometric relationships at this intersection suggest that the Lewis faulted buckle offsets and is younger than the Huapache monocline (pl. 5). On the other hand, a right offset of the synclinal bend axis by the splay of the Y-0 buckle is about 1,800 feet, and this furnishes some evidence of the possible magnitude of strike-slip movement along the Y-0 buckle.

Six MILE BUCKLE

The Six Mile buckle has an exposed or traceable length of about 80 miles from exposures near the Pecos River, about 25 miles northeast of Roswell to a junction with the Dunken syncline in T. 17 S., R. 17 E. The trend is slightly undulated along its over-all strike of N. 41 E. Buckling along the fault is not as evident nor as wide as along the Border and Y-0. In a stretch of more than 20 miles between Monument and Butte Creeks (pl. 2) there is essentially no buckling and very little drag, except for a stretch of 3 or 4 miles in T. 15 S., R. 20 E., where thin weak beds high in the Bonney Canyon Member abut the fault. To the north of Butte Canyon, and on through the Fourmile Draw outcrops, buckling is again evident. Buckling along the fault is also common through Ts. 16, 17 S. In the north wall of the Rio Felix there is buckling in the high beds, but not in those in the lower part of the canyon wall (fig. 9). A similar situation is evident in the north side of the Rio Penasco canyon (fig.

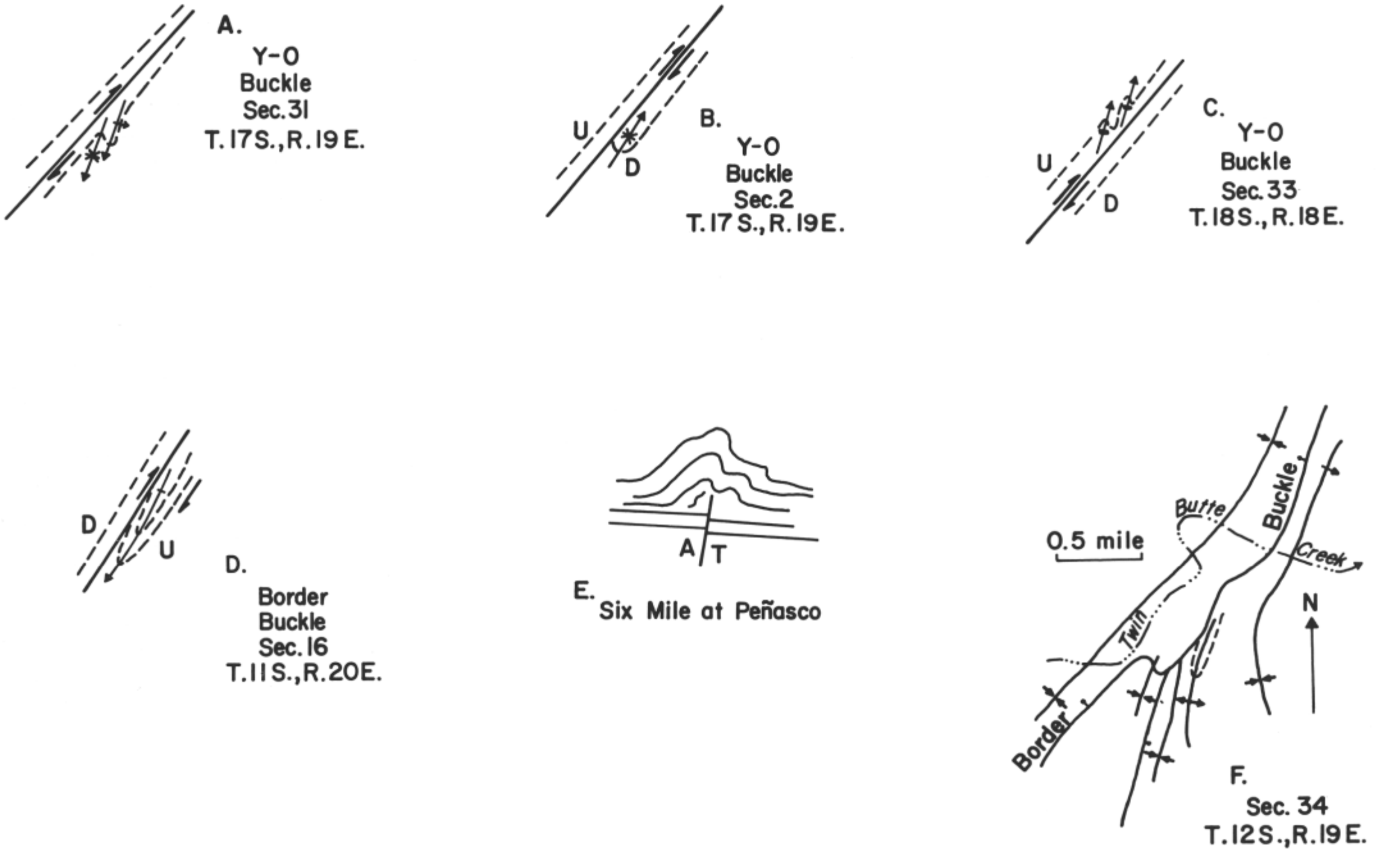

Figure 19

DRAG FOLDS AND LEFT BRANCHING FOLDS AND FAULTS ASSOCIATED WITH BUCKLES

18). The upper beds are strongly buckled and the lower ones have no buckling and little or no throw. Strike slip may produce this effect where contrasts of strength exist in successions of beds.

BORDER BUCKLE

The Border buckle has an exposed length of about 60 miles and extends from a splayed termination at the northern end of the Dunken uplift into the eastward turned Five Mile Draw buckle in T. 7 S., R. 23 E. It is a stronger zone of buckling than any of the other similar features. The buckle is prominently expressed by a long series of ridges known as the Border Hills (fig. 21). The hills rise in places 200 to 300 feet above the adjacent plains or mesas. The strike of the buckle is slightly more irregular than those of the Six Mile and Y-0, and ranges from N. 34 to 53 E. around an over-all principal trend of N. 40 E. The width of the steep part of the buckle is generally 1,200 to 1,600 feet in the middle part of its exposed length through T. 10 to 12 S., but in T. 13 S. it narrows to 500 feet or less. The over-all width including all flaring away from the regional dip reaches nearly one mile in places. The southeast limb overrides along the entire length south of U. S. Highway 70 (fig. 20), but in a 7-mile stretch from the highway north the overriding side changes four times.

The finest exposure of any of the buckles is in the north wall where the Border buckle crosses Hondo Canyon (fig. 18A). Here the east side, which is down regional dip, overrides the western side although there is practically no up-throw or downthrow of the beds outside the buckled-up area which here is about three-quarters of a mile wide. The canyon depth on either side of the ridge is about 300 feet. Glorieta and Yeso beds are present on the east side, but neither is in view above the valley bottom on the west side. An auxiliary fault adds to the complication on the west side, where it separates a steep wedge in the core area from gently inclined beds. Three miles to the north the highway cut (fig. 18B) reveals considerable complication involving breccia, some fragments of which are about 10 feet in diameter. The surface expression, the turning up of the limbs, and the Glorieta exposure on the east side are similar to the Hondo section. However, the "chaos" in the core area is quite different, and it is difficult to locate the fault precisely in the cut section. It should be at the breccia and the steep beds in the center of the section.

It was noted by Nye (Fiedler and Nye, 1933, p. 78) that the overriding limb was steep and the under limb was usually flat. This is more apparent than real in that the under limb is usually less well exposed. At the classical exposure along the Hondo, however, the under limb is steeper, and locally, about one mile south of the Hondo, the under limb appears steep beneath a nearly flat upper limb (fig. 22).

In some short stretches, both limbs, although separated by

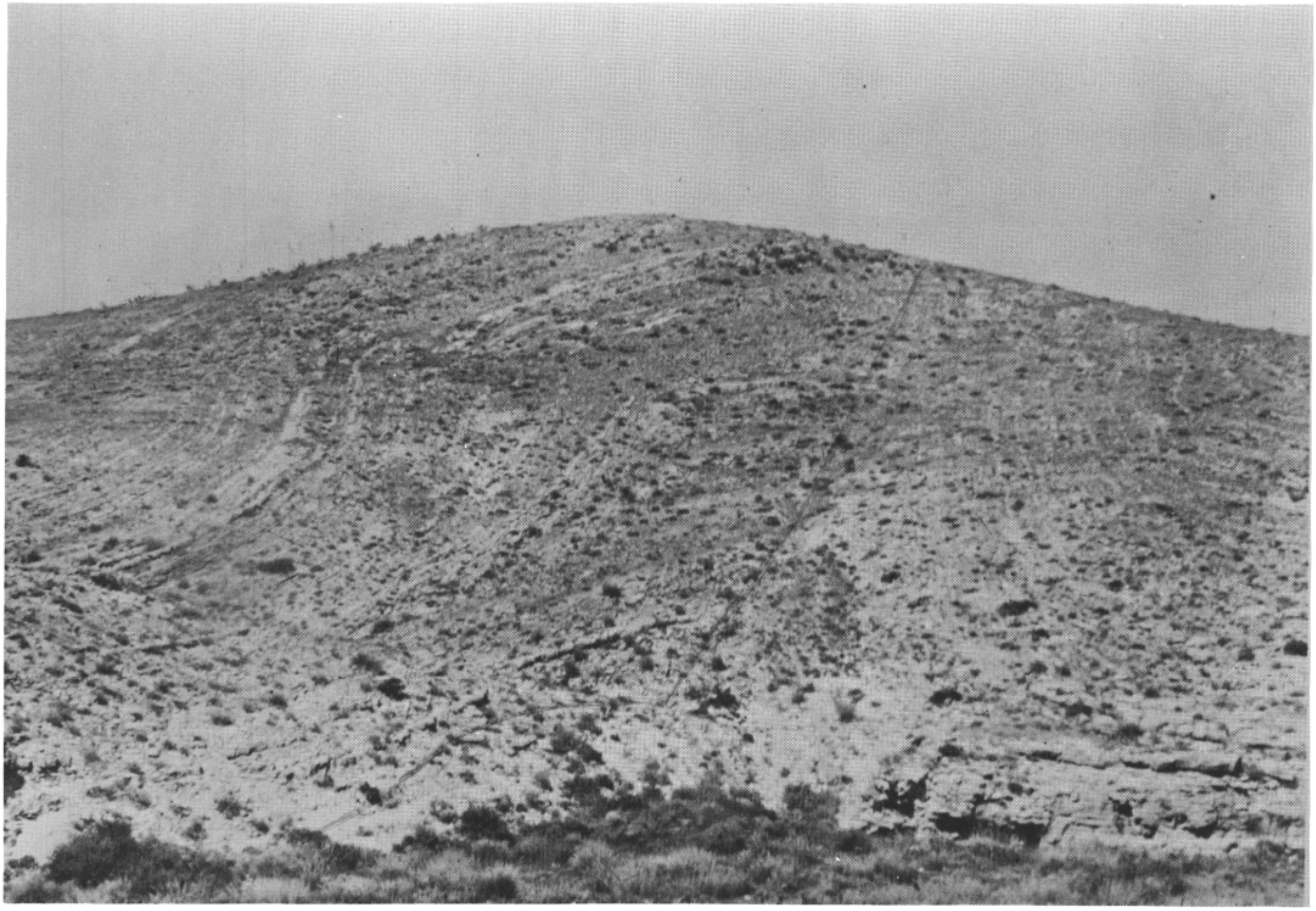

Figure 20

VIEW OF THE Y-0 BUCKLE ALONG THE NORTH SIDE OF RIO PESTASCO CANYON

The fold is disharmonic with the fault following close to the steeper right limb. The core of the buckle at the valley bottom is sharply broken.

the medial fault, are equally turned up, and this situation is found where the overriding switches sides. At two or three of the stretches, where the overriding changes sides, there is a swing to the right as one observes along the buckle trend.

At the south end of the buckle the western strand is the main fault, and the other two are small left splits into the south block. At the northern end of the exposed buckle its identity is almost lost among a set of small auxiliary folds in the incompetent upper part of the Fourmile Draw Member. However, it can be traced to a termination or merger with the Five Mile Draw buckle (pl. 2).

Drag folds again indicate a right movement along the fault. A notable example is present in the overriding wall about one mile south of U. S. Highway 7o. A left-branching shear (sec. 23, T. 12 S., R. 19 E.) corroborates the right shift also. In section 34 of the same township, just south of Twin Butte Canyon crossing, there is a rolling over of the buckle which forms a small right offset (fig. 17). At this point a left shear and three folds branch southward from the buckle. These folds, together with four others to the east toward the Six Mile buckle, form a fine series of left diagonals with respect to the two buckles. Shorter left diagonals lie to the west of the Border buckle, and short left diagonals arepresent south of the buckle in the northern end of the Dunken uplift in T. 14 S., R. 18 E.

Evidence for the wrench character of the buckles, and that right movement occurred on them, is supported by (i) great length coupled by small throw, (2) drag folds, (3) left-branching folds and short faults, and (4) long left diagonal folds in the blocks between the buckles. The lack of right splits, right diagonals, and left drag makes the right-wrenching interpretation convincing.

WHITE TAIL FAULT

The White Tail fault extends from the southwest corner of T. ro S., R. 17 E. southwestward for about 21 miles to a termination near' the Indian village of White Tail in T. 12 S., R. 14 E. It is fairly straight except at its northern end where it curves northward as it crosses Ruidoso Canyon. The strike through most of its course curves from N. 49 E. in the southern part to N. 61 E. in its northern part. It has little or no buckling associated with it, but instead appears to have a zone of shearing and local parallel folds in either wall. The fault is downthrown on the southeast through most of its length, but at the southwest end it is

Figure 21

VERTICAL AIR PHOTO OF THE BORDER BUCKLE

Incised, meandering Hondo Canyon is at the bottom and U. S. Highway 285 is near the center. See Plate 1 for details of surface geology.

downthrown on the northwest. In the northern few miles and in Ruidoso Canyon downthrow of the southeast is as much as 600 feet. Drag folds have not been found along the fault, but judging from a few obtusely diagonal folds both north and south of the fault, there probably has been some right movement.

SERRANO BUCKLE

The Serrano buckle is about 26 miles in length and strikes N. 37 E. overall. It extends out of the northern end of the Tinnie anticline (pl. 5) and here for several miles beds are buckled and turned from their northerly strikes to the northeasterly strike of the Serrano buckle. Except for the first five miles of the southern end, where it is obliquely transverse to several fold axes, the surface expression of the buckle through the rest of its course is weak. It exhibits anticlinal buckling in a narrow zone of generally less than 300 feet and the buckling up is alternately greater from side to side. Short left-branching spur folds and short shears together with offsetting and terminating folds and faults around thehead of Blackwater Canyon all attest to right movement along the Serrano buckle. Study of some of the offsets lead to an estimate of about 500 feet of horizontal shift along the southern five miles or so. To the northeast this may diminish considerably.

BONITO FAULT

The Bonito fault follows Bonito Creek from the Bonito Lake stock in Sierra Blanca to a few miles west of Lincoln where it runs up Salazar Canyon and under the alluvial apron south of the Capitan stock (pl. 1). Although the fault may end at the stock, it is to be noted that the fault along Peachtree Creek north of the stock could be a continuation. There is no strong indication of a fault in the intrusive except for some alignment of canyons and saddles. The western end of the fault appears to terminate at the contact of the Bonito Lake stock, although Thompson (1966, fig. 1) found some short faults, on trend, in the volcanic breccias to the west of the stock.

Including a possible extension north of the Capitans, the fault is about 36 miles long. The trace of the fault is much more curved than the others of the northeasterly group. Exclusive of the turn to the west, at the western end the overall strike of the fault is N. 54 E. The apparent right offset of a north-south fault in T. so S., R. 13 E. and a sill in the Mancos in T. 10 S., R. 14 E., and one or two left-branching short folds and faults all indicate a right movement at least in the western part of the fault.

K-M FAULT

Between Artesia and Lake Arthur, subsurface structure contouring strongly suggests another northeast-trending fault which may be a part of this group. It is referred to as the K-M fault (Roswell Geol. Soc., 1968) taking its name from E. E. Kinney and G. E. Maddox who early identified with the existence of the fault. As plotted from subsurface structure contouring in this work it is about 3o miles long and appears to drop the southeast side as much as zoo feet. Surface support for the existence of this break in the bedrock beneath the Pecos Valley fill lies mostly with a pronounced southwest swing of the Pecos River for about 6 miles east of Lake Arthur. However, just northwest of the river east of Lake Arthur a low inlier escarpment of Queen rocks in valley fill parallels the trace of the fault as projected (pl. 2).

BARRERA FAULT

The Barrera fault lies along the base of the Capitan reef escarpment and it is traceable in outcrop expression for 18 miles. It is projected as a possible buried feature beneath alluvial outwash 5 to 6 miles to the southwest along the base of the escarpment to about R. 22 E. It is extended also to the northeast for 7 to 8 miles, past the turn of the reef monocline into the Frontier Hills monocline, beneath alluvium and at the southern base of a small hill of Rustler. The fault is expressed at the surface by small scarps and a line of bushes. It is shown strikingly on air photos by a smooth well-defined line (fig. 23). The fault surface

Figure 22

LOW OBLIQUE AIR VIEW NORTH ALONG THE BORDER BUCKLE

Butte Canyon crossed the buckle at the upper right. At the abrupt turn in the buckle south of the canyon the east limb appears to override the west limb.

has been found in two places, at the mouth of Rattlesnake Canyon in the west bank of the arroyo, where the dip is 65°S. on a carbonate footwall. The other exposure is near U. S. Highway 62, 2.4 miles east of White City where the dip is about 80°S. Highway 62 crosses the fault diagonally on the east bank of Jurnigan Draw just west of State Road. Here the northwest-side roadcut is in Tansill and the southeast in gravel. The next gully west of this point is where the above steep fault surface is exposed and here at least 20 feet of pediment gravel is downthrown opposite the Tansill near the fault.

At the surface between Jurnigan and Chinaberry Draws (pl. 4) the Salado contact is displaced to the right about two miles and on the basis of meager exposures it is estimated that the stratigraphic throw may be 200 to 400 feet. In this same area uppermost Castile beds are in mapping juxtaposition with nearly the top of the Tansill, a position that could agree with filling to the top of a preexisting constructional or depositional monocline.

In summary, the evidence for the fault includes exposure of its surface, scarps, a well-marked trace, offset of bedrock, and displacement of pediment gravel.

Hayes (1964, personal communication) was aware of the straightness of the contact of the limestone at the base of the reef escarpment, but did not believe that a fault was present. A contact between the Artesia or Capitan carbonates and the Castile gypsum of the valley is not exposed even though they are in juxtaposition with only a few tens of feet of soil or colluvium intervening along a few arroyo banks. Hayes (1964) and many others believe that the Castile is simply deposited as a whole unit filling up on or against the preexisting Guadalupian carbonate rocks. No one has ever described or seen, to my knowledge, debris that was washed from the reef into Castile beds. The reef is thought to have been submerged in deep water, but certainly by the time the upper beds were lapping onto the reef some debris from waves and currents should have been added to the Castile. The smoothness or straightness of the contact line between the reef rocks and the Castile is difficult to reconcile with onlapping of a reef front with its inherent irregularities.

If the escarpment conformed to a forereef depositional slope then onlap might be smooth. If the depositional beds were later flexed up on the synclinal bend at the base of the monocline, then the course of onlapping might be smooth.

Figure 23

VERTICAL AIR PHOTO OF THE CAPITAN REEF ESCARPMENT AND THE BARRERA FAULT NEAR WHITE CITY

Walnut Canyon cuts through the escarpment at White City. The fault trace shows clearly north of U. S. Highway 180.

A subsequent fault in homology with the flexure would also produce a smooth boundary at the contact with the displaced basin beds.

In a cross section constructed with the help of wells straddling the fault in the western part of T. 24 S., R. 26 E., it was determined that the top of the Delaware was less than 100 feet lower south of the fault than north. At depths of 4,500 to 4,600 feet, the top of the third Bone Springs sandstone shows essentially no vertical separation across the fault. The presence of throw at the surface and none at depth might be explained by flattening of the fault toward the basin where it would die out in bed distortion. Thus, the fault might be an expression of slumping, partly initiated by solution, into the basin and the slump surface might base on the top of the Bell Canyon. It is also possible that the fault roots at depth and that the movement is primarily strike slip, thereby yielding little stratigraphic displacement. With only small vertical displacement it could locate the position of the Capitan reef buildup.

CARLSBAD FAULT

The Carlsbad fault is expressed in outcrop from about 2 miles north of the entrance to Dark Canyon for 5 miles northeasterly toward Carlsbad. Where well exposed in sec. 6., T. 23 S., R. 26 E., it strikes N. 56°E. and dips 60°S. Its expression on air photos is sharp and straight (fig. 23). At the surface red mudstone and gypsum of the Salado Formation is clearly dropped against Tansill dolomite which dips south toward the fault at 5 degrees.

Stratigraphic separation across the Carlsbad fault can be calculated roughly by comparing the estimated top of the surface top of the Tansill with what can be picked as the same top in the Jefferson Lake Sulfur Company 27-I Windham Ranch. From a lithologic log of chip samples supplied by A. R. Smith, a top was picked of the Tansill or Capitan, a depth of 750 feet at a point about 1,000 feet south of the fault. The top in the well is about 950 feet lower than the estimated top north of the fault. If there were no fault between the two tops the average dip between the two points would have to be 14 degrees. Dip in the Tansill to the fault is 5 degrees, and on this basis, dip south of the fault to the well top would have to be about 35 degrees. Motts (1962) estimated dip in the interval to be 10 to 15 degrees, judging from his structural contour line spacing. About one mile to the south of the well surface Rustler beds are nearly flat. Although these data do not furnish conclusive evidence of downfaulting they suggest that vertical separation of several hundred feet is quite possible. As with the Barrera fault there is no evidence of much vertical separation at depth along the trend of the fault.

Extension of the Carlsbad fault northeastward beneath the Pecos Valley is suggested on Plates 4 and 5 along a course about coinciding with U. S. Highway 180. Short northeast-trending folds are present in the Rustler diagonally across the projection of the Carlsbad fault.

OTHER FAULTS

Between Capitan and Ruidoso, there are four other faults of the northeast-trending category. These are, from south to north, Ruidoso, Little Creek, Airstrip, and Champ. There is no evidence of horizontal movement on the Champ or Ruidoso faults, but the Little Creek and Airstrip faults each show right offsets, which for the Dakota outcrop amounts to about 2 miles.

A short buckle, termed Purcella, occurs northeast of the Capitan Mountains. It is similar in development to Serrano buckle. It turns southward at its south end to parallel the Arabela fault. Left anticlinal spurs again indicate right movement.

WATERHOLE ANTICLINORIUM

The Waterhole anticlinorium is an arcuate fold belt about o to 12 miles west of Carlsbad (pl. 5). It is about 20 miles long and 1 to 2 miles wide. It generally consists of three synclines alternating with three anticlines, all closely spaced and narrow. They culminate near the middle of the arc in several short doubly plunging folds, and the belt plunges toward both ends but more so to the northeast. Structural relief across the belt and on individual folds is only 200 to 400 feet. The axes of the anticlines are sharper than those of the synclines and the anticline axial planes appear to be faults at least locally.

The belt forms a boundary between the little deformed Seven Rivers embayment on the west and the Carlsbad belt of domical folds to the east. From a study of the tectonic map, Plate 5, there appears to be some sort of geometric and mechanical relationship between the belt, the Carlsbad folds, and the Frontier Hills monocline. It further appears that the arcuate curvature of the Waterhole belt could be a drag effect along the Seven Rivers monocline, or the postulated Major Johnson fault of the subsurface, which is more or less coincident with the monocline (Roswell Geol. Soc., 1968, fig. 18).

CARLSBAD FOLDS

The term "Carlsbad folds" is employed here for the belt of domical uplifts which lies just back of the so-called front of the Capitan reef. It is 6 to 9 miles wide and extends from the Waterhole anticlinorium to the Central Basin platform (Stipp and Haigler, 1956), a distance of about 65 miles. On Plate 5, only the western 28 miles of this belt is shown. The belt is mostly covered at the surface and it is only in the 11 to 14 miles west of Carlsbad that the folds are seen in the outcrop.

In outcrops of the Carlsbad Hills the structures are strikingly exposed by considerable coincidence between the surface and the top of the Tansill Formation (fig. 24). Tracy, Hackberry, and McGruder anticlines especially typify the folds. "Top of Yates" dome apexes range from 3,600 feet west of Carlsbad to near sea level at the eastern end of the belt where the depth below the surface is about 3,200 feet. The individual domes of the belt are circular to elliptical with average dimensions of 1.5 by 3 miles. Although orientation of the major axes is of several directions, it appears that the prevalent orientation is normal to the trend of the belt.

Figure 24

VERTICAL AIR PHOTO OF CARLSBAD FOLDS AND FAULT

The trace of the fault shows best in the lower corner where Sheep Draw enters the Tansill bedrock. At this point on the north bank of the draw the fault is exposed, dipping 6o degrees toward the gravel valley floor. Dark Canyon wash is lower right in the picture. In the upper left corner is the McGruder dome, marked by radial canyons cut into a surfacing Tansill outcrop.

It does not appear that the folds extend below the Artesia Group. Motts (1962) concluded that the domes are biohermal mounds and that the normal orientation of the major fold axes result from currents flowing across the reef to the shelf, and perhaps the local hydration of gypsum, probably of the Seven Rivers Formation. However, this does not appear too likely, as the domes are restricted to the shelf margin, and are absent in the Guadalupe Ridge part of the reef. The western termination of the domes at the Waterhole anticlinorium, and apparent offset of the reef front at the Cueva reentrant and Frontier Hills monocline appears to call for some other possibility than buried bioherms. It may be significant that the belt of domes takes up where the tectonic front is shifted northward over an area of known evaporites beneath them at no great depth. If the swing to the north on the Frontier Hills monocline is tectonic, as believed here, then the reef or bank front boundary with the basin may continue on line with the Barrera fault, rather than curving over near Carlsbad. Exposures at the entrance to Dark Canyon are not entirely structureless reef material. Could it be that large sink holes in overlying beds such as the Castile triggered salt or gypsum rise into the mass deficient column in a style explained by Vine (1963, p. 40-41) for the young domes in the Rustler and younger beds?

ARTESIA-VACUUM ARCH

The Artesia-Vacuum arch is a long nose which extends from beneath the Pecos Valley fill through Ts. 17-19 S., to R. 35 E., in Lea County, a distance of about 75 miles. It roughly parallels the Carlsbad folds described above. The arch is almost completely covered by post-Permian beds, except for a short stretch of 4 to 5 miles near Chalk Bluff Draw where the plunging south limb in Yates and Tansill may be seen dipping S. 47 E. at about 4 degrees.

The arch to the west beneath the valley fill was projected from subsurface data furnished by Pubco Petroleum Corporation. The arch reflects the Abo reef trend of the subsurface.

LOCAL STRUCTURES

Numerous small folds, faults, grabens, basins, and solution-collapse structures occur within the area. Brief descriptions and discussions of a number of these are given here, partly for better information on the details of the region and because many of them have some bearing on regional interpretation and understanding. Plate 5 shows or indexes all these features and more and they are treated here mostly in order north to south.

BOGLE ANTICLINE

The Bogle anticline is a short northwest-trending structure lying across the boundary between R. 14 E. and R. 15 E., T. 4 S. It lies in the Hasparos embayment (pl.1). Yeso is believed to be exposed in one place along Hasparos Creek in the center of the anticline. Bonney Canyon and Glorieta beds constitute the principal part of the anticline and they are in-hers to the surrounding Fourmile Draw beds.

PATOS GRABEN

The feature referred to as the Patos graben occupies about 30 square miles in Ts. 5, 6 S., Rs. 14, 15 E. It consists of a rectangular area of Triassic rocks surrounded on the north, east, and south by Grayburg and Fourmile Draw beds. The whole thing is considerably covered by terrace and valley alluvium. The structure may be only a large area of solution collapse, but field relations indicate fault boundaries on the south and in the few exposed parts along the eastern side. There is considerable contorting of Grayburg beds beneath the Triassic along the northern side, and a suballuvial continuation of the fault south of the Jicarilla Mountains in T. 6 S., Rs. 13, 14 E. is presumed to bound the graben on the north. It is to be noted that the north-trending prominent Dakota ledge terminates in the north-central part of T. 6 S., R. 16 E. and a north-side terminating fault would appear essential to complete this structural situation.

DOWNING BUCKLE

The Downing buckle is north of the Capitan Mountains in T. 6 S., R. 16 E. and T. 7 S., R. 18 E. Its principal strike is N. 31 W., except for a short job to the right in the southern part. The buckle is 9 miles long. It is unusual in consisting of two anticlines separated by a medial syncline or fault. Furthermore, in a sense it consists of two acutely left-echeloned buckles, owing to the fact that the western anticline of the southern part becomes the eastern anticline in the northern part, and it is common to the full length. The three fold axes making up the structures are closely spaced, and the full width of 2,200 to 2,300 feet for the buckle is rather uniform, except at the interval of echelon where it is about 1,500 feet.

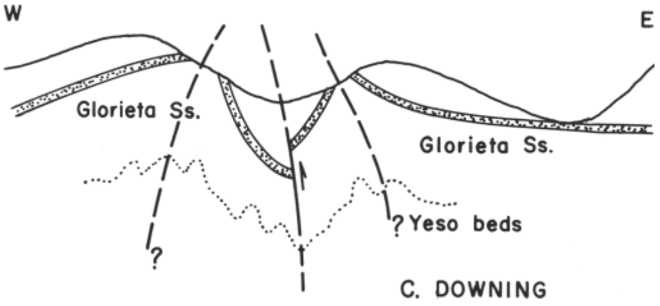

Figure 25

STRUCTURE SECTION SKETCH OF DOWNING BUCKLE

The syncline dominates the structure and the topography. In the southern part the structure is crossed by the canyon of Middle Arroyo, and the northern part is well sectioned along the south side of Cienaga del Macho. In this exposure (fig. 17), a Glorieta sandstone tongue serves as a structural connecting marker in all limbs. It may be observed that both anticlinal buckles are asymmetrical toward the syncline. A supposed fault along the axial surface of the syncline is not exposed, but the thickness of the exposed limb on the west between the sandstone and the axis is considerably greater than on the east, and therefore, geometrically demands a fault. In the northern part, exposures along the syncline limbs are good and they are very near to 60 degrees.

ENCINOSO ANTICLINE

Encinoso anticline lies north of the Capitan Mountains in T. 7 S., R. 15, 16 E. The crestal position of the fold is much obliterated by the large Canning sink. The sink is in Yeso but contains some blocks of San Andres which have collapsed onto the Yeso. Exposures in Yeso south of the sink are generally not good enough to determine the completeness of the reversal on the south, beyond the obvious westward plunging for a short distance at the western end of the structure and the curving northeasterly plunging nose.

ARABELA FAULT

The Arabela fault lies about 2 miles east of the Capitan Mountains. It strikes north and is about 6 miles long. It is downthrown on the east, and in the middle part a narrow band of steeply dipping Rio Bonito beds is downthrown against Yeso. On the south it terminates on the Serrano buckle, and the northern end dies out in an anticline which although not quite connected to the Purcella buckle appears mechanically related to it.

TITSWORTH FOLDS

North of Capitan there is a set of folds consisting of two anticlines and two synclines that generally plunge westerly. The northern anticline has a nearly circular domelike closure on the eastern end that has been termed the Titsworth dome (Allen and Jones, 1951, p. 4). It is ringed by hogbacks of Dakota Sandstone, and Triassic Santa Rosa conglomerate surfaces the center of the dome that has been drilled and found dry. The presence and orientation of the folds suggest some right shift on the Capitan fault which bounds the south side of the Capitan nose and follows the valley just north of the Titsworth anticline.

WINKLER ANTICLINE

The Winkler anticline and related syncline trend northward through the eastern part of Ts. 8, 9 S., R. 19 E. The structure crosses and is a part of the nose extending eastward from the Capitan Mountains. The axes are about 8 miles long, and the critical west limb of the anticline is only about 1 mile wide. Closure might be around 100 feet. It has not been drilled.

HONDO-SAN PATRICIO BASINS

These two basins lying mostly athwart the Rio Hondo drainage around the junction of the Ruidoso and Bonito Creeks are essentially one large downwarp. They are divided by the White Tail fault and a small anticline. The combined basin covers considerable area and is structurally a sort of counterpart to the uplift in the Tinnie anticlinorium to the east.

GLENCOE BASIN

Glencoe basin is a small feature around Glencoe on Ruidoso Creek. Its long axis follows the stream, but its existence is mostly the result of the Glencoe fault which drops the western side by 200 to 300 feet. (pl. 5).

TALLEY BASIN

Talley basin is an elongate downwarp lying between the Tinnie anticlinorium on the west and the McKnight buckle and Picacho anticline on the east. The trough of the basin crosses U. S. Highway 70 about 1.8 miles east of Tinnie. The Talley syncline axis parallels the McKnight buckle a short distance to the west. It is sharp, and in fact, an integral part of the buckle. North of the buckle, the Talley syncline axis is the trough of the Talley basin. The syncline is 25 miles long. It appears to terminate on the Serrano buckle, but the syncline just west of the Arabela fault may be an offset continuation northward.

PICACHO ANTICLINE

Picacho is a well known anticline whose curving axis extends northward for 14 miles through Ts. 10, 12 S., R. 18 E. It is about two miles wide from syncline to syncline axes where it crosses Hondo Canyon. The crest of the anticline lies about two miles west of the village of Picacho. It has been drilled twice, once in the Hondo Valley in sec. 21, T. 11 S., R. 18 E. to Precambrian in 2,191 feet and once in sec. 10, T. 12 S., R. 18 E. to Precambrian in 2,843 feet, and both were found dry.

MCKNIGHT BUCKLE

The McKnight buckle extends northward from the eastern part of T. 13 S., R. 17 E. in a zig-zag course to the south side of the Hondo Canyon in the west-central part of T. it S., R. 18 E. The north and south ends both die out as short anticlines, but along most of its 14-mile length it is a faulted buckle along which the western side uprides the depressed eastern limb. The overriding limb forms a prominent low ridge along its course across the gently rolling uplands. Strong shearing and local crumpling accompanies the buckle in many places. It is similar in some respects to the Arabela fault.

PAJARITO DOME

Pajarito dome lies in the southeastern part of the Mescalero Indian Reservation, mostly in T. 12 S., Rs. 15, 16 E. but extending in a minor way into T. 13 S. The structure has a curving trend from northerly in the southern part to north-northwesterly in the northern part. It is doubly plunging, about 6 miles long, and 2 miles wide. It is slightly asymmetrical to the east with the western limb dipping less than o degrees and the eastern limb 10 to 20 degrees. Its Precambrian core and overlying beds are described under Yeso Formation. The western limb is marked about midway by Pajarito Mountain which rises some 1,300 feet above the country to the east. It is one of the principal landmarks in the region (Kelley, 1968).

TURKEY CREEK FAULT ZONE

In the area south of Ruidoso there are a number of northwest-trending faults which diagonally cross the north-northeast plunging end of the Sacramento uplift (pl. 1). The largest of these within the mapped area is the Turkey Creek fault zone. It trends in a N. 33° W. direction from the Elk Creek fault in T. 15 S., R. 15 E. northwesterly for 20 miles to Dark Canyon, a south fork of Ruidoso Canyon.

The fault zone consists of several splits and nearly parallel members with diverse effects along the trend. Near the northwestern end along the road to White Tail the zone is a narrow graben in gently dipping Rio Bonito beds into which is dropped a narrow zone of tilted higher San Andres as well as a small block of Bonney Canyon and Grayburg red beds (T. 12 S., R. 13 E.). Southward only the eastern fault continues through. Near the junction of Ranges 13 and 14 the fault pivots to downthrow on the east. In splitting step faults the southwest block is uptilted and elevated by as much as 400 feet. Yeso is brought up in outcrops along the uplifted block. Southeastward of the Yeso exposures, the fault extends through high forested San Andres outcrops with downthrows continuing mostly on the east to a junction with the Elk Creek fault.

CAMP DOME

Camp dome is a small, rather anomalous feature in sec. 25, T. 13 S., R. 15 E. It rises with some physiographic prominence along the northern side of the north fork of Indian Creek. Although nearly circular, it does have a northwestward-trending axis that is terminated by short northeastward-trending faults. Its proximity to Pajarito dome is suggestive of a similar shallow buried peak in the Precambrian.

INDIAN CREEK ANTICLINE

Indian Creek anticline lies mostly in the eastern part of T. 14 S., R. 16, 17 E. in the southeastern corner of Otero County and adjoining Chaves County. It trends N. 20° W., is about 8 miles long and 2 miles wide. It is broad, topped with steeper dips up to 10 degrees along the north or east sides. The plunge is more gradual to the south as the structure narrows and dies out. To the west, the limb is short and of quite low dip, so that closure is small (pl. 5).

GOODRUM ANTICLINE

The Goodrum anticline is a long narrow structure running northerly through T. 12, 14 S., R. 20 E. It is about ten miles long, and its west-dipping short limb is 1.5 to 2 miles wide. It appears to have closure of possibly 50 to 100 feet. It is surfaced by Bonney Canyon except for small inliers of Rio Bonito along crossing canyons. It is doubtful that there would be much section below the Permian.

ELK BASIN

Elk Basin is a large downwarp which adjoins the prominent Dunken uplift on the west. Its lowest part is near Elk along a sharp north turn in the Rio Penasco. On the north, the basin ends against the broad south plunge of the Indian Creek anticline and in a narrow syncline constriction between the Indian Creek and Dunken uplifts. To the south, the Elk Basin synclinal axis extends to near Pinon, paralleling the Dunken uplift to its southern termination at the Stevenson ranch fault. In the basin's principal development it is about 5 miles wide, 16 miles long and 600 feet deep, making it the largest basin on the Pecos slope.

BELL RANCH ANTICLINE

The Bell ranch structure is a narrow isolated anticline in the lower southeastern part of the Sacramento uplift. It is doubly plunging, 1.5 miles wide, and 7 miles long. It is asymmetrical to the short western limb which dips 15 degrees at its maximum. Relief is nearly 200 feet.

MEADOW HILL ANTICLINE

Meadow Hill anticline lies along the northwest side of the Y-0 buckle in secs. 9 and 22, T. 18 S., R. 18 E. It occupies 2 to 3 square miles between the Y-0 and a short diagonal fault on the north. The axis trends about N. 20° W. and limbs up 5 to 6 degrees. It has not been drilled.

BLACK HILLS DOME

This is a small structure with prominent physiographic expression centered at the southwestern corner of T. 17 S., R. 20 E., about 12 miles west of Hope. It covers 6 to 7 square miles and is nearly circular in a central part (sec. 31) of about 2 to 3 square miles. Dips reach 5 to 6 degrees along the short northern flank. It has been drilled and found dry.

LEWIS BUCKLE

The Lewis buckle is in the northern end of the Guadalupe uplift. It is a north-trending fault with buckle aspects similar to the northeast-trending buckles described above. It is about 10 miles long and only 600 to 700 feet wide. In the narrow zone of buckling the beds are turned up steeply to vertical in many exposures. Mapping indicates that the east side is downthrown. The buckle dies out on the south in the high part of the Guadalupe escarpment near the frontal fault. Near the northern end the fault is offset by an auxiliary fault of the Y-0 buckle, and in this area the Huapache monocline merges with the Lewis buckle.

SALADO-RUSTLER PIERCEMENTS

In the southeastern part of the area, and especially along the Pecos River south of Loving, there are hundreds of small collapse features and associated piercements. Vine (196o, 1963) and Reddy (1961, fig. 2) have mapped and described these features in considerable detail. They are surficial structures related to the salt in the Salado at rather shallow depth, and to sink-hole collapse in near-surface evaporitic beds. The distribution of many of these features is shown on Plate 4 by small circles and ellipses. Others exist east of the mapped area and south in Texas along the Pecos. The circles shown on the map include sink holes as well as piercements and there appears to be every gradation in kind and stage of development.

Vine (1960, p. 1910-1911) showed that the decrease of mass caused by solution and accompanying collapse triggered the rise of salt from below. The doming which resulted from the salt rise occurred in and around the sinks. A unique aspect of many of these is the existence of Triassic block collapsed into Rustler with the two domed into Dewey Lake, Gatuna, and Quaternary caliche. Reddy (op. cit.) shows map detail of many of the single circles of Plate 4 southeast of Malaga, consisting of annular outcrops from Salado through Rustler, Gatuna, and Quaternary siliceous gravel. However, not all domes are so ringed, and outcrop structures of individual domes may consist wholly of either caliche, gravel, Gatuna, Dewey Lake or Rustler.

RED LAKE-TURKEY TRACK SINKS

These unusual features run northerly through R. 28 E. from U. S. Highway 83 for a distance of about 15 miles (pl. 4). The sinks form two parallel graben-like features which are mostly floored by thin alluvium and blow sand. They are 70 to 170 feet in physiographic relief, each about one mile wide and 15 miles long. Red Lake sink is on the west and Turkey Track on the east.

The sides of the depressions are mostly Gatuna, but considerable stretches consist of Rustler or Santa Rosa beds. Locally the sides consist of all three in order: capped gravel, caliche, or blow sand. The floors of the sinks show through the alluvium in scattered small exposures and consist of Rustler, Gatuna, local pediment gravel, or small piercement knobs of Rustler gypsum. In secs. 23, 26, T. 16 S., R. 28 E., pediment gravel overlying Gatuna beds is warped down from the west side into the floor of the Turkey Track sink. Considerable disturbance occurs along some of the walls in the form of slumped blocks, monoclinal flexing, and small domes of piercement which bring up Rustler dolomite and gypsum.

Localization and trend of these depressions appears most likely related to the Salado wedge edge of salt at shallow depth.

DELAWARE BASIN FAULTS AND FOLDS

The Delaware basin is marked in its western part by a large set of fractures trending N. 75 to 80° E. almost parallel to the regional direction of dip into the basin. Part of the belts extends into New Mexico. Where studied they appear to be small faults with throws of only a few tens of feet downthrown either north or south. The blocks between these faults commonly possess marked photo linears parallel to the faults. On the ground these appear, at least in some places, to be small incompetent folds whose axes also parallel the fault trends. Near the Texas line in Rs. 24, 25 E. there is an anticline-syncline pair which is also parallel to the regional fault grain. The relief on the anticline is about 50 feet and it plunges abruptly west at its western termination.

Olive (1957, p. 356) studied these features in some detail in Texas and concluded that their marked surface expression was due to solution channels along a joint set of the same direction, but like King (1948, p. 90) ventured no idea as to the origin of the fractures. Even though it is thought they are confined to the Castile they could be tectonic, arid the accompanying folds and displacements as seen in the northern area supports such an origin.

FOLDS OF THE YESO FORMATION

Folds of an incompetent nature occur widely in the Yeso of New Mexico, and they are unusually developed in this area. They are especially well exhibited in Rio Bonito Canyon near Lincoln, and from detailed studies in this canyon and surrounding areas Craddock (1964, p.122-133) termed them "the Lincoln fold system."Craddock included many folds not in the Yeso such as the Border Hills, Tinnie, Serrano, and Downing which lack cohesive relationships with the formational Yeso folds of the Lincoln area.

For the region as a whole, there is considerable variation in trend of the folds, and individual folds commonly curve considerably in short distances. Some of those seen in the canyon wall near Lincoln curve from north-northeasterly to north behind the cross-section exposures in the lower canyon side. They are generally not continuous on strike beyond a few hundred to 1,000 feet. Their heights range up to several hundred feet as do their widths. It is also important to note that there are considerable areas of no folding in the Yeso as in the Tularosa Canyon country west of Bent and in the Guadalupe escarpment.

Some of the folds are undoubtedly related to the larger tectonic features of the area; some are due to surficial slump; some are caused by intrusions of sills or dikes; some to solution collapse; some to volume changes accompanying hydration; and some to gravity tectonics arising out of regional tilt. Above all else they are to be classed as incompetent folds by their abundant confinement to the Yeso or a small part of it. They are erratic in form and distribution and clearly could have formed at almost anytime from shortly after Yeso deposition to the present.

ORIGIN

The structure of the Pecos country is dominated by the Pecos slope which is largely due to the late Tertiary rise of the Sacramento and Guadalupe uplifts. Prior to these uplifts the area was probably no more than a broad low arch. How much, if any, of the structure that exists on the slope at present was there before the rise of the uplifts is unknown. Were the structures such as the buckles, Dunken uplift, and Tinnie fold belt present, or were they formed concurrently with the Sacramento and Guadalupe uplifts?

There is abundant and long known surface and subsurface evidence that the large primary features, such as the Delaware basin and the Pedernal landmass were in existence in Permian time. It is also known that secondary structures such as the buried Huapache fault and the Artesia-Vacuum arch were initiated in Permian or older times. Thompson (1966) has also shown that the Sierra Blanca basin is at least pre-volcanics or early Tertiary in age. Less clear as to age and relative time or times of formation are the buckles, Dunken uplift, Tinnie fold belt, Huapache monocline, Guadalupe Ridge folds and other similar second or third magnitude structures. The ages and mechanics of origin of many of these cannot be known directly or rigorously for lack of adequate field relationships. Nevertheless, some indirect evidence and local geometric sequential relationships are suggestive as to likely origins.

The question as to what structures pre-dated the Basin-

Range uplifts and what the broad early structure was like may be answered by examining the country to the north of these uplifts. North of the Capitan uplift, and especially north of the intrusive complications in the Jicarilla Mountains (Kelley and Thompson, 1964, tectonic map), the Mescalero arch is broad and low with a crest at the San Andres level at about 5,500 to 6,400 feet. In the Claunch sag, a northern extension of the Tularosa basin, downwarping with respect to the Mescalero arch is no more than a few hundred feet. The structural relief in the Sacramento-Guadalupe country was probably similar prior to the late block-fault uplifting.

South of the Capitan intrusive in the Ruidoso-Capitan country, the structural development is intermediate to the northern and southern parts of the Mescalero arch. It is the best area for analysis of the pre-block-fault post-Permian tectonic events because of the preservation of formations ranging from Permian to Tertiary in the mutual flank of the Sierra Blanca basin and the Mescalero arch. Tectonic disturbances are recapitulated as follows:

(1) In post-San Andres time east-west faulting or monoclinal downflexing to the north along the Capitan intrusive trend caused the Fourmile Draw member to be removed to the south along the crest of the Pedernal (Mescalero) arch where Grayburg rests directly on Bonney Canyon.

(2) Uplift and erosion in late Permian (probably pre- and post-Salado time) caused further stripping on the arch as shown by late Triassic stepping down westward from late Artesia or Rustler east of the Pecos to Gray-burg along the Pedernal crest.

(3) Renewed arching with northward tilt and long erosion occurred during Jurassic and Early Cretaceous times as shown by Cretaceous beds stepping down from Triassic through Grayburg and onto San Andres.

(4) Renewed arching in early Laramide time as shown by early Tertiary Cub Mountain stepping down toward the Pedernal-Mescalero arch from high to low Mesaverde.

(5) Renewed arching and/or subsidence of the Sierra Blanca basin in middle Tertiary as shown by truncation wedging of the Cub Mountain toward the arch by plicating Sierra Blanca volcanics.

The repeated disturbances strongly suggest that deformation occurred in the Mescalero arch country prior to the Sacramento-Guadalupe late Tertiary uplifting. However, it is not possible to determine precisely the time of formation of features such as the northeast-trending faults in Ruidoso-Capitan country, the Arabela fault, or the Tinnie folds. That some at least are Laramide or older is shown by the termination of faults in the Ruidoso area at the base of the Sierra Blanca volcanics.

A number of evidences of probable relative ages of more important features on the slope can be pointed out and discussed profitably. Considerable differences in styles and orientations of structures are to be noted from place to place on the slope, and as these are better understood, origins and times of deformation may be better inferred.

The largest of the elements is the little deformed part of the slope east of the Dunken-Tinnie trend. It is little deformed except for the long diagonal buckles, and it dips eastward only 60 to 80 feet per mile. The part north of a line from the Capitans to Railroad dike dips very gently eastward out of the Hasparos embayment at an over-all rate of only 50 feet per mile. This northern part is almost devoid of structure, but in the part north of the Capitans the northwestward-trending Downing-Bogle fold alignment contrasts with the northeasterly buckles of the large southern part. The little deformed eastern part of the slope probably continued southward through the present Guadalupe uplift prior to its rise in late Tertiary time.

The western boundary of the above gentle slope is formed by the north-trending Dunken-Tinnie belt. Deformation to the west of this belt contrasts strongly between north and south. In the south, west of the Dunken uplift, deformation is slight in the broad eastward-tilted back of the Sacramento uplift. In the northern part, especially west of the Tinnie folds, deformation is greater than to the east of the fold belt. This is the area of the Lincoln anticline which forms the structured divide into the Sierra Blanca basin. It includes the Hondo-San Patricio basin, the Glencoe half basin, Pajarito dome, Indian Creek anticlines, Camp dome, the Turkey Creek and other northwestward-trending faults in addition to members of the northeast-trending buckle group. In general, it extends southward from the Capitan uplift in T. 15 S., where the southern undeformed back of the Sacramento uplift begins.

All this area west of the Dunken-Tinnie trend lies nearly astride the buried Pedernal landmass. At one time it was thought that the domes and basin might reflect ridges and valleys on the Pedernal. However, such an explanation would imply that the Pedernal surface was "smooth" beneath the Sacramento uplift. Two other explanations may be better. One, the extra deformation, over and above the northeast trends, was caused by the Sierra Blanca basin subsidence which exerted a crowding effect on the area east of the Lincoln anticline (Kelley and Thompson, 1964, p. 119); two, the deformed northern part may have only Yeso or thin Abo lying on Precambrian, making it relatively less competent than in the Sacramento area where more Abo might intervene.

The Tinnie area is especially important because of the meeting of the Capitan intrusive, the fold belt, and the White Tail-Serrano faults. The alignment of White Tail and Serrano suggest a single deep-seated controlling fracture, but because of the separation of the two by the Tinnie fold belt, the latter was probably formed first. The Tinnie folds terminate at the Capitan but they probably formed after the stock, as partly indicated by their curving eastward from the intrusive and partly because the eastern end of the stock is horsted slightly in conformance with the anticlinorium rise. Finally, the Arabela fault which appears to be a part of up-faulting of the eastern end of the stock, is offset by the Serrano fault. Thus, oldest to youngest are the Capitan stock, Tinnie folds, and the White Tail-Serrano faults. However, since the northeast-trending buckles are also considered to have Precambrian and Paleozoic ancestry, this simply means that their activity has been repetitive or that some, such as Serrano are younger. As the Tinnie folds probably die out at no great depth, the White Tail and Serrano faults may connect beneath them.

The Dunken-Tinnie belt of deformation appears to have some possibility of coinciding with a wedge edge of Wolfcampian beds, especially the Abo Formation. This line of deformation may reflect a buried flex or fault along which the Pedernal was uplifted and eroded in late Wolfcampian time. If so there may be little or no Abo west of this belt.

The southern end of the Dunken uplift is abruptly terminated by the Stevenson fault, a late Tertiary break related to the Guadalupe uplift. As a result of this chronological relationship, one may reason that the Dunken uplift may be Laramide. There are no field relationships between the great buckle faults of the region and the Basin-Range-type faults along which the Sacramento and Guadalupe uplifts rose. The four great buckles, Serrano, Border, Six Mile, and Y-0 all impinge on the north-south Dunken-Tinnie belt and in various ways appears to deflect or offset the folds or faults of this belt (pl. 5). Even though evidence exists for the buckles displacing the Tinnie and Dunken folds they do not cross them. Instead, the buckles appear to merge with or split from the north-south belt.

Another field relationship suggesting some tectonic-igneous chronology exists where the Bonito fault appears to cross the Capitan uplift and possibly cut the Bonito Lake stock (pl. 5). This relationship does not preclude the likelihood based on other lines of evidence that the Bonito fault is older than the Capitan intrusive but has been reactivated by post-intrusion movement. The crossing of the intrusive by the fault is somewhat obscure although suggested by physiographic features.

A final set of field relationships is in the Capitan Reef area. The Huapache monocline appears to be crossed by the Guadalupe Ridge anticline, the Reef monocline, and the Barrera fault. The Guadalupe Ridge folds are terminated to the east by the Frontier monocline in a manner which suggests that the monocline is older, and if the Reef and Frontier monoclines are of the same age, then the Guadalupe Ridge folds are the youngest of all except for some very late, possibly Quaternary, movement on the Barrera fault.

The discovery in this work that the long, northeast-trending buckle faults are right wrenches raises questions as to the regional significance and relationships of this kind of strain and deformation. The regional major structural features to which they must be related, if we are to understand the tectonic and especially paleotectonic origin, are the Pedernal landmass, the Huapache monocline with its deep-seated fault, the Precambrian trends, and principal Paleozoic depositional hinge-lines.

Recently Meyer (1966) published many small-scale subsurface paleogeologic and structure maps of the late Paleozoic buried features in southeastern New Mexico. These maps are very useful, and from them and other data including the new material of the present work some interesting analyses may be ventured concerning the paleotectonics and many of the surface structures. Many of the Meyer paleogeologic and facies maps (op. cit., figs. 35, 48, 49) show a curious hourglass pattern with regard to the ancient Pedernal and certain Pennsylvanian and earlier sedimentary wedge-edge hinge lines. These maps resemble the diagrammatic principal shears illustrated in Figure 26.

The region is conceived to be divided into four large segments on the basis of what may be two complementary hinged shears of possible Precambrian derivation. The orientation and position of the great shears are determined primarily by two surface- or near-surface structures, the Six Mile buckle and the Huapache monocline and fault. The northwesterly trending Huapache is continued north of the Six Mile shear on the basis of an inferred subsurface hinge line or wedge edge at the Pennsylvanian-Mississippian pinchout against the Pedernal. This northeasterly trend is also thought by some (West Texas Geological Society, 1958, p. 5) to be coincident with an Ellenburger wedge edge. The projection of the Six Mile shear zone in its southwestern part is based on a similar wedge-out line of the Pennsylvanian (Meyer, 1966, p. 68). The Six Mile shear line could be placed southeast of the Six Mile buckle, or possibly at or near the Y-0 buckle, as far as the validity of the postulate. It is placed on the Six Mile rather than add another line so close in the figure. These postulated complementary shears very neatly bound major subsurface sedimentary basin wedges and positive elements. The shear zones could be Precambrian ones that have been extended upward into the overlying sedimentary rocks.

Four segments, Pedernal, Fourmile, Guadalupe, and Sacramento are formed by the two principal shears. The opposite Sacramento and Fourmile segments are low and contain large thicknesses of pre-Permian strata. The Pedernal and Guadalupe segments were high in pre-Wolfcampian time. The two shears are pivotal in their motion, Six Mile clockwise, and Huapache, counterclockwise. If these shears are complementary and an east-west principal stress is envisioned (fig. 26), then the Huapache shear should move left and the Six Mile right. It has been shown above in some detail that shifting on the Six Mile has indeed been right. The evidence for left shift on the buried Huapache fault is indirect and the form of the bowings on the monocline gives but slight evidence of such movement. Fortunately, however, subsurface data show left offsets of the Abo trend (fig. 26), and Pennsylvanian subcrop edges (Podpechan, 1960, p. xxii).

MAJOR GRAVITY ANOMALIES

Bouger relative gravity anomalies show variable relationships to the principal structural features of the region. The large Pedernal and Central Basin buried late Paleozoic demonstrate this in particular. The Central Basin platform has a strong positive anomaly of 60 to 100 milligals and the faulted west side into the Delaware basin is especially reflected in the regional gravity map (Woollard and Joesting, 1964). By contrast the Pedernal buried landmass shows no reflection in the regional gravity data.

The Delaware basin is well defined by a large negative gravity anomaly of 50 to 100 milligals. Between Carlsbad and Roswell there is a northeast-trending gravity high of about 20 to 30 milligals that parallels the belt of northeast-trending buckles and in part is coincident with Y-0 and K-M buckles, with the Six Mile buckle closely following the northwest side of the gravity high belt. The Artesia-Vacuum arch follows part of this high and shows a remarkable coincidence with a

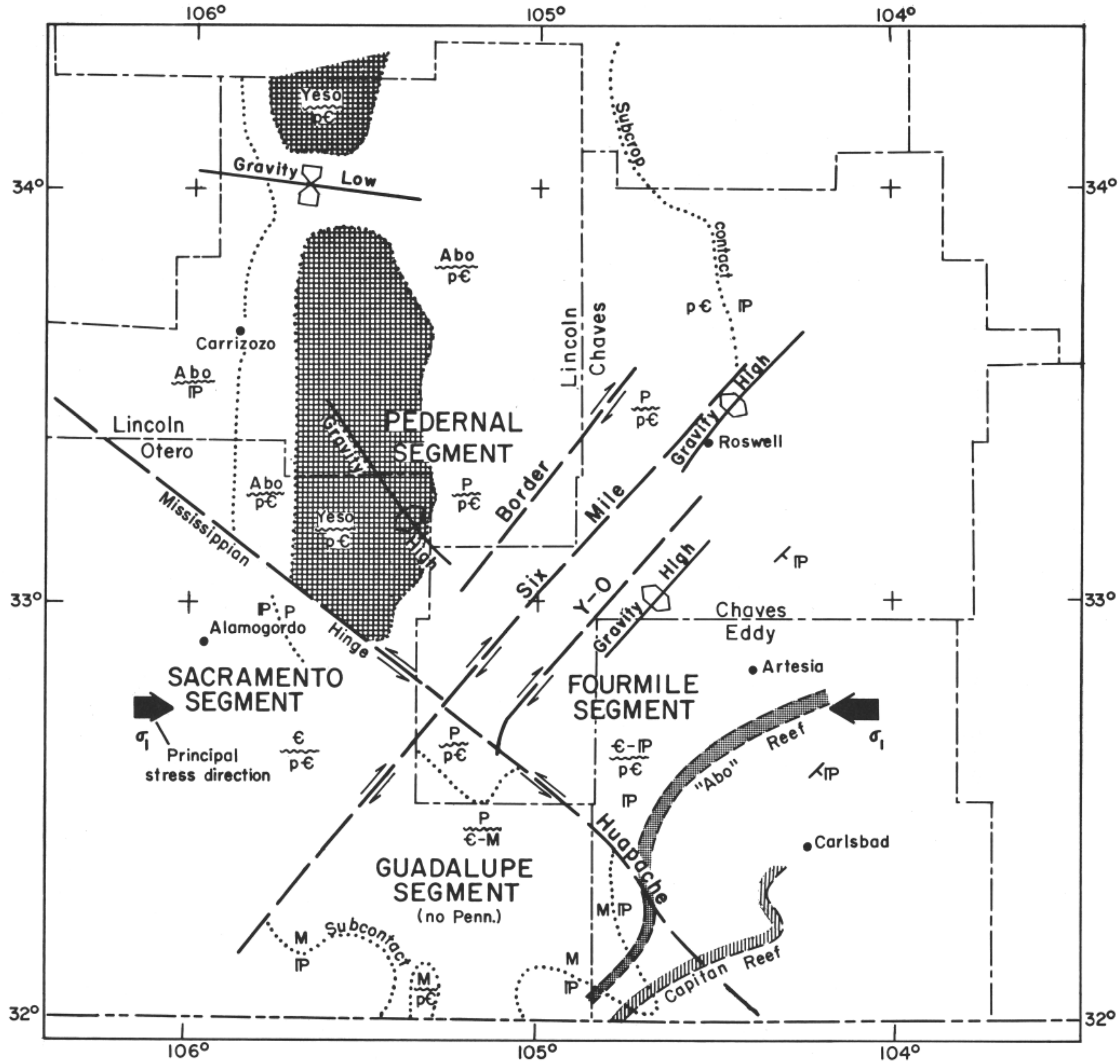

Figure 26

MAP OF POSSIBLE DEEP-SEATED SHEAR ZONES IN RELATIONSHIP TO CERTAIN SUBSURFACE AND SURFACE FEATURES

$\frac{P}{M}$ Permian rests on Mississippian;- $\frac{Є=ℙ}{pЄ}$ Cambrian to Pennsylvanian rests on Precambrian, etc.

northwest-plunging positive gravity nose from the Central Basin platform.

One of the most interesting small coincidences between gravity and surface geology is at Pajarito Mountain. A small sharp gravity positive of about 20 milligals trends northwestward through Pajarito Mountain in near coincidence with the northeasterly buried ridge of Precambrian mafic rocks that can be seen in the surface structure. The Pajarito gravity high axis diagonally crosses the Mescalero arch and the tip of the Pedernal landmass. The Hasparos embayment north of the Capitan Mountains is reflected in part by a gravity low. West of Roswell and roughly between the Six Mile buckle and Tinnie fold belt there is a minor north-trending gravity low that lends some support to the thesis that the Dunken-Tinnie belt may reflect a principal eastern border to the Pedernal uplift.

In summary, the regional gravity picture principally reflects the Delaware basin. Elsewhere the structures and buried Precambrian terrain variations are not great enough to strongly reflect the principal tectonic features. The picture tends to show that the Pedernal is not a buried uplift of sharp orogenic aspect and that it is not closely bordered by thick sedimentary basins.

Geologic History

In the area of this work it suffices to begin the geologic history with the Permian, and in particular with the development of the ancient buried Pedernal landmass. This feature, together with the development of the Permian basin strongly influenced much of the later depositional and structural patterns.

The Leonardian Yeso is the oldest rock that crops out in the area, and in no more than small parts of the western one-half of the area are there more than a few hundred feet of pre-Yeso Leonardian and Wolfcampian rocks intervening between the Yeso and the Precambrian. In the southeastern part of the area, mostly in Eddy County, the picture is quite different and there are several thousands of feet of pre-Permian rocks and nearly 13,000 feet of Permian, a thickness that is five or six times that near or on the buried Pedernal.

The Pedernal began its rise in late Pennsylvanian time as is indicated by influxes of clastics into sediments of that age. Continuation and acceleration of rise through Wolfcampian time resulted in denudation of the Pedernal well into the Precambrian. The outline and structure of the Pedernal is not well known, but it appears that it may have been a broad upwarp in some places and fault-bounded blocks in others. It was probably sharpest on the west with the possible exception of the southeastern edge along the buried Huapache zone. Judging from the proportion of clastics and the volume and coarseness of conglomerate, the maximum relief and vigor of erosion came in late Pennsylvanian time. Arkosic sandstone and conglomerate are common in the basal parts of the Abo, Yeso, and locally in the San Andres where these beds lap onto or are in proximity to Precambrian exposures. The most illuminating exposures in this regard are those in the northwestern part of the Sacramento Mountains (Bachman, 1960, p. 239-241; Otte, 1959, p. 60-62), Gallinas Mountains (Kelley, 1949, p. 141, 171, fig. 33) and at Pajarito Mountain (Kelley, 1968, p. 1571). Records of conglomerate, granite wash, or arkose exist in well logs as in the Elliott o Federal (sec. 0, T. 5 S., R. 16 E.), Boyle Steward-Federal (sec., T. 9 S., R. 20 E.), and others. During Wolfcampian (Abo) time, a large eastern part between Roswell and the present Dunken-Tinnie belt was lapped onto by several hundred feet of sediment. The Delaware basin had its beginnings at this time with the development of the Abo reef (pl. 5) and the creation of backreef lagoons in which muds and carbonates accumulated. The entire area including the Pedernal gradually was lapped, and by latest Leonardian time all but a few highest Precambrian peaks was buried. Along the highest part of the Pedernal, the Yeso sediment consisted of red and yellow muds and sand, but little or no gypsum and minor limestone was evident. Away from the Pedernal, west as well as east, gypsum and dolomite or limestone were precipitated in saline lagoons and in occasional regular marine water. Thus, the Pedernal had a mild expression during Yeso time even though shelf waters may have completely covered it.

To the southeast along the early Delaware basin, lowering of sea level or a broad gradual rise of the shelf caused regression of the basin margin as bank and reef deposits built upward and southward across earlier basin deposits (Silver and Todd, 1969, p. 2235). During Yeso time, gypsum, mud, and sand accumulated in the broad lagoonal shelf while the banks of gray carbonate (Victorio Peak) formed along the basin edge, and black limestone (Bone Spring) formed in the basin.

During early Guadalupe (San Andres) time, the Pedernal was completely covered by marine waters through Bonney Canyon deposition. Fourmile Draw deposition of late San Andres time may or may not have covered the Pedernal area. In the Capitan-Ruidoso area Artesia beds rest on Bonney Canyon beds. The absence of Fourmile Draw beds suggests either (1) arching of the Pedernal during Fourmile time to prevent deposition, or (2) uplift after Fourmile time and stripping prior to overlap by Artesia red beds. Probably some of both actions were involved. In any event limited evaporitic conditions prevailed during Fourmile Draw time in both basins flanking the Pedernal arch.

To the south in San Andres time, carbonate banks encroached on the basin while within the basin, sand, some dark muds, and limestone of the Brushy Canyon and lower Cherry Canyon accumulated to considerable thickness in the subsiding Delaware basin. Locally, there was marked flexing (Bone Spring) that resulted in some erosion along the margin where Leonardian Bone Spring beds were arched and eroded during part of Brushy Canyon-San Andres time.

In upper Guadalupian (Artesia) time, the shelf region reverted to an evaporitic environment as gypsum, dolomite, mud, and sand were deposited while the whole area gradually subsided. To the south in the Delaware basin, subsidence was even greater, and along the margin carbonate banks and reefs built up at a rapid pace in Goat Seep and Capitan times. Within the basin, typical dark lime muds and fine sands accumulated during Cherry Canyon and Bell Canyon times alongside the shelf margin. Some (Silver and Todd, 1969, p. 2247-2248) believe that sea level subsided, especially in middle Guadalupian (Manzanita) time. As the shelf edge built forward to the basin, Bell Canyon deposits built up apace although at a depositional level a few hundred feet lower than on the reef and shelf. These conditions changed either at the end of Seven Rivers time or at the end of Tansill time when the bottom waters of the Delaware basin turned saline. The basin may have subsided, and its connections with the ocean and other entrances may have been shut off or restricted. Whatever the causes may have been, evaporites began to form in a rather still and nonturbid environment which eventually killed the marine reef by overtopping it with evaporites and muds of high Castile or Salado.

In the Pedernal country some broad arching and erosion had taken place before the lowest Artesia (Grayburg?) red beds unconformably overstepped the low arch as seen in the Capitan-Ruidoso country. How far upper Artesia beds overlapped the Pedernal is not known. Perhaps some or all covered it and were removed in post-Guadalupian time, or perhaps arching occurred early so that the Queen and younger beds did not cover the arch. High beds do not occur in the Tularosa side of the arch where Triassic rests widely on Grayburg. In the Pecos country, basin or shelf filling continued through Rustler time. However, post-Artesia rise of the Pedernal arch is shown in the southeast where Salado steps down to the west in the Delaware basin to midway in the Castile. Similar rise of the Pedernal during and following Salado deposition is shown by Rustler stepping down onto Tansill beds east of Artesia. Toward the end of Ochoan time there was some freshening of the salt basins as Rustler dolomitic muds, salt, and gypsum formed the last residues before the red terriginous Dewey Lake sands and silts covered the great Permian basin.

Latest Permian and early Triassic was a time erosion in nearly all the area, but by late Triassic the area must have been reduced to a great peneplain that probably included the Pedernal as well. Upon this surface, perhaps due to strong development of source areas to the north, sands, muds, and gravel of the Upper Triassic Dockum group were spread. Its subcrop ranged from highest Permian Dewey Lake beds in the southeast to Yates in the northeast, and Grayburg along the top of the Pedernal, as in the Capitan-Ruidoso area and on to the west and northwest.

Evidence of renewed rise of the Pedernal in post-Triassic to pre-Dakota time is shown by the configuration of the wedge-edge line of the Triassic beneath Dakota Sandstone. South and southwest of Sierra Blanca, the edge appears to be in T. 13 S., whereas, at Ruidoso nearly on the crest of the buried Pedernal, the pinch-out of Triassic beneath the Dakota is in the middle of T. 11 S. In the Pecos Valley it swings far to the south again, and into Texas southwest of Carlsbad.

There are no Jurassic rocks and hence no direct record of events. However, the gradual overstepping of the Cretaceous Dakota beds across a Jurassic wedge somewhere in T. 8 N., down through Triassic and Artesia beds, onto San Andres beds in T. 14 S., indicates an expansive, slight tilt to the north during late Jurassic to early Cretaceous time, accompanied by widespread stripping (see Dakota Sandstone). Elsewhere in New Mexico, evidence indicates that this event took place after Morrison time and probably mostly during early Cretaceous.

Subsidence of the area marked Cretaceous time and the surface was probably near sea level in shallow marine and floodplain environment. This condition prevailed into Montanan time, but as indicated by Kelley and Silver (1952, p. 137) and Bushnell (1955, p. 86-87), Laramide disturbances began in this region in late Montanan time. This condition is represented by the unconformity between the Mesaverde and Cub Mountain Formations. Although the unconformity is not noticeably angular, the base of the Cub Mountain, which is Late Cretaceous to Paleocene in age, rests in the Sierra Blanca basin area on beds ranging from Mancos to high Mesaverde. At Ruidoso the Cub Mountain is on Mancos; southwest of Sierra Blanca and west of Capitan, on low Mesaverde; and south and east of Carrizozo on high Mesaverde. Thus, there is some truncation downward to the east. One may take this to indicate an early Laramide reactivation of the Pedernal or the beginning of the Sierra Blanca basin subsidence, which is essentially the same thing. However, the strike-line of overstepping appears to be northeast at slight divergence to the nearly north over-all trend of the Pedernal.

The Cub Mountain beds contain conglomerate reminiscent of the Triassic, and the mudstone and sandstone are also Triassic in aspect, and in marked contrast with the less colorful underlying Mesaverde. The difference reflects a change from paludal floodplain environment to perhaps drier and yet more vigorous conditions of contemporary uplift, erosion, and deposition.

The principal formation of the Sierra Blanca basin came after the Cub Mountain deposition and before the eruption and building of the great Sierra Blanca volcanic field (Kelley and Thompson, 1964, p. 118, and Thompson, 1966, p. 81). A considerable period of erosion must have intervened between the subsidence of the basin and the eruption of the volcanics, as the latter lies across both Cub Mountain and Mesaverde beds. Because the stocks which intrude the volcanics are late Oligocene (Thompson, 1966, p. 47) and the volcanics may be Oligocene or late Eocene, the formation of the basin was probably late Laramide. As the subsidence of the basin determined the west limb (Permian to Paleocene beds) of the Mescalero arch to a great extent, it appears that the arch as seen today is largely a late Laramide feature. This applies also to much of the faulting along the east flank of the basin, but not to all of it; some faults dislocate the Sierra Blanca volcanics and the porphyry intrusives. Although the stocks intrude the volcanics at Sierra Blanca, it is important to note that Smith and Budding (1959) found Sierra Blanca type volcanics resting on the porphyry laccolith at Lone Mountain, northwest of White Oaks. Thus, two ages of porphyry intrusion are indicated; the White Oaks one being late Laramide, and the later ones as at Sierra Blanca being middle Tertiary. Furthermore, some of the disarray of faults east and southeast of the Sierra Blanca intrusives and volcanics may be a part of accompanying disturbances. The northeast-trending Rio Bonito fault offsets the volcanics in T. 10 S., R. 13 E., and although it may have originated in late Laramide time it appears to have suffered middle Tertiary movement also.

The important tectonic point reached here is that, owing to the involvement of the Paleocene or Eocene Cub Mountain beds and the noninvolvement of the Oligocene volcanic breccias in the western limb of the Mescalero arch, the arch and the Pecos slope are probably Laramide. During Laramide time the arch axis may have extended southwestward from the Ruidoso country about through the back slope of the Sacramento uplift toward Piiion. Late Tertiary Basin-Range doming and faulting may have shifted the Laramide arch westward to the present position of the Mescalero arch, to the crest of the Sacramento uplift.

In addition to the structural and physiographic evidence of the youthful age of the Sacramento uplift there is the evidence, first noted by Kelley and Thompson (1964,p.118), that the Sierra Blanca volcanics have, along their southwestern border, a northward dip in conformance with the northern plunge of the Sacramento uplift. Probably also of late Tertiary age are the great faults forming the western escarpment of the Guadalupe uplift and the east-west related Stevenson fault in T. 19 S., R. 16, 17 E. During the present work, a small scarp in the alluvial fans along the northern end of the Guadalupe fault scarp was found indicating some slight Holocene uplift.

There is little tectonic structure across the Mescalero arch north of the Sacramento uplift that can be identified as late Tertiary. Pliocene time, especially, was one of the expansive erosion with Ogallala deposits extending headward into and across the high structural divide especially in the Sierra Blanca area. Solution collapse, slumping, and draping accompanied the surface stripping of the slope and erosion of the Pecos Valley.

(Appendix follows)

Appendix

Several sections of Rio Bonito and Bonney Canyon Members, one of the Bonney Canyon, and one of the Fourmile Draw were measured, sampled, described megascopically, and chemically analyzed. Data on these are tabulated here. The northernmost principal section, designated Cooper ranch, is in T. 9 S., R. 18 E., and the southernmost, near the northern end of the Guadalupe Mountains, is in sec. 18, T. 20 S., R. 18 E. and designated Lewis. The spread from north to south is about 65 miles.

Tabular presentation is used in preference to a conventional descriptive form with the hope that vertical changes of significance would be more readily discovered. Dolomite and limestone were first identified by rate of effervescence in dilute acid and confirmed or changed after chemical analysis. Field identifications had to be changed in about 15 percent of the cases. Double X's in the bed thickness columns indicate a range of thickness for the interval. Double X's in the color column indicate different colors, mottling, or gradational colors. Double X's in the fabric column indicate both variations in a single sample and among beds of the interval.

The column under "Depositional Fabric" follows Dunham (1962, p. 117) in carbonate classification in which mudstone is less than .02 mm; wackestone consists of more than io percent grains "floating" in mudstone; packstone consists dominantly of grains, all touching, but with minor mud ((cement"; and grainstone lacks mud. Most of the samples appear to be grained, but insofar as recognition of the fabric as being depositional is rather uncertain, the checking in the columns is questionable.

II. SUNSET (S) SECTION (SW¼ SEC. 20, T. 11 S., R. 19 E.) OF RIO BONITO AND BONNEY CANYON MEMBERS. SEVERAL TENS OF FEET OF TOP OF BONNEY CANYON MAY BE ERODED.

	NUMBER	ROCK NAME	BED THICKNESS (FEET)				COLOR							GRAIN SIZE MILLIMETER					CHEM COMP		DEPOSITIONAL FABRIC					MgO: CaO RATIO	THICKNESS FEET		FOSSILS, ETC.						
			< 1	1-3	3-6	> 6	White	Gray	Black	Yellow	Brown	Green	Red	< .06	.06-.25	.25-.50	.5-2.0	> 2.0	CaO	MgO	Mudstone	Wakestone	Packstone	Grainstone	CRYSTALS		Unit	Cumulative	Frag.	Whole	Micro.	Pellet	Oolite	Chert	
	31	Limestone	x	x				x			x				x				52.5	2.1				x		.040	22	163	x	x					
	30	Limestone		x				x			x			x					52.9	1.7			x		x	.032	30	141	x	x	x				
	29	Dolomite		x				x							x				33.2	18.0				x		.543	5	111							
	28	Limestone		x	x			x							x				44.8	7.7				x		.171	11	106							
	27	Limestone	x					x			x			x					38.5	9.9		x				.203	12	95	x		x				
	26	Limestone		x	x			x						x	x				50.6	4.0				x		.080	25	83							
	25	Dolomite	x					x			x			x	x				30.4	19.2				x	x	.631	18	58							
Psb	24	Dolomite			x						x				x				30.6	20.5				x		.669	40	40	x						Psb
Psr	23	Dolomite		x	x						x			x	x				31.5	19.6				x	x	.622	21	269							Psr
	22	Dolomite			x						x				x				36.9	15.2				x	x	.412	14	248	x						
	21	Dolomite	x	x							x			x					35.7	15.5				x	x	.434	6	234							
	20	Dolomite		x			x							x					38.1	14.7		x		x	x	.370	3	228							
	19	Dolomite	x								x			x					35.6	16.3				x		.457	7	225	x						
	18	Dolomite				x		x			x				x				30.1	19.5				x		.633	20	218	x	x	x				
	17	Dolomite				x		x			x				x				31.3	19.6				x		.626	23	198							
	16	Dolomite				x		x			x			x					31.8	19.7				x		.618	16	175							
	15	Limestone		x				x							x	x			53.4	1.4				x	x	.027	5	159					x		
	14	Dolomite	x	x							x			x					30.4	20.6				x		.679	9	154							
	13	Dolomite			x			x						x					33.4	17.0				x	x	.509	6	145							
	12	Sandstone	x	x	x		x									x								x			58	139							
	11	Dolomite	x					x						x					32.4	17.4				x	x	.538	4	81							
	10	Dolomite sandy			x			x						x					32.7	16.9		x			x	.517	5	77	x						
	9	Dolomite sandy	x		x			x							x				30.2	18.3				x	x	.606	10	72	x	x					
	8	Dolomite sandy			x			x			x				x				30.8	18.1				x		.590	4	62							
	7	Dolomite			x	x		x						x					31.4	19.8				x	x	.630	17	58							
	6	Dolomite			x		x	x						x					30.3	19.1			x	x		.632	7	41							
	5	Dolomite			x		x	x						x					31.9	18.2			x			.572	7	34							
	4	Dolomite			x			x							x				28.7	18.9				x		.660	8	27	x						
	3	Dolomite	x					x			x			x					30.3	20.6			x			.680	4	19							
	2	Dolomite		x				x			x				x				29.7	19.8				x		.672	4	15							
	1	Sandstone			x		x			x					x	x			42.8	0.7				x			11	11							

I. COOPER RANCH (C) SECTION N½ SEC. 25, T. 9 S., R. 18 E., OF RIO BONITO AND BONNEY CANYON MEMBERS. NOT MORE THAN 10-15 FEET OF THE TOP OF THE BONNEY CANYON ERODED.

	NUMBER	ROCK NAME	BED THICKNESS (FEET)				COLOR							GRAIN SIZE MILLIMETER					CHEM COMP CaO	MgO	DEPOSITIONAL FABRIC					MgO: CaO RATIO	THICKNESS FEET		FOSSILS, ETC.						
			< 1	1-3	3-6	> 6	White	Gray	Black	Yellow	Brown	Green	Red	< .06	.06-.25	.25-.50	.5-2.0	> 2.0	CaO	MgO	Mudstone	Wakestone	Packstone	Grainstone	CRYSTALS		Unit	Cumulative	Frag.	Whole	Micro.	Pellet	Oolite	Chert	
	41	Dolomite	x	x							x			x					28.9	19.1			x			.662	12	156							
	40	Dolomite	x					x							x				32.0	19.2				x		.602	22	144	x	x					
	39	Dolomite	x					x						x					31.3	19.3			x			.619	28	122							
	38	Dolomite	x					x			x			x					34.2	17.7			x		x	.517	7	94							
	37	Dolomite	x					x			x			x	x				40.3	11.3			x	x	x	.279	15	87	x	x				x	
	36	Dolomite	x						x		x			x					33.8	15.6			x			.462	12	72	x	x					
	35	Limestone	x					x	x		x			x					54.1	0.6				x	x	.001	13	60	x	x			x		
	34	Dolomite		x			x	x						x	x	x			37.8	13.6			x			.366	14	47					x		
	33	Caliche																									3	33							
	32	Dolomite		x	x						x			x					31.4	19.8			x			.629	16	30							
	31	Limestone	x								x			x	x				55.3	7.3			x		x	.132	6	14							
Psb	30	Dolomite			x						x				x				33.8	18.2					x	.539	8	8							Psb
Psr	29	Dolomite			x						x				x	x			33.5	18.6				x	x	.556	16	282	x						Psr
	28	Dolomite			x	x		x			x			x	x				30.8	19.8				x		.643	18	266		x					
	27	Caliche																						x	x		6	248							
	26	Limestone	x					x			x				x	x			54.2	0.6				x		.011	14	242							
	25	Dolomite			x			x			x			x					30.9	19.2			x			.622	9	228							
	24	Dolomite		x	x			x	x		x			x					30.1	19.7				x		.657	11	219							
	23	Dolomite		x				x	x		x			x	x				27.6	17.6				x		.637	9	208	x						
	22	Dolomite		x				x							x				35.2	16.1				x		.457	8	199							
	21	Dolomite		x				x			x				x				31.8	18.8				x		.592	5	191	x						
	20	Dolomite			x			x			x			x	x	x			32.0	17.8			x	x		.555	7	186	x	x					
	19	Dolomite	x	x				x	x					x					30.5	15.0			x			.493	11	179							
	18	Limestone	x					x			x				x	x			52.3	1.7			x			.032	3	168					x		
	17	Dolomite	x					x						x	x				32.5	18.5				x		.568	6	165							
	16	Dolomite	x	x				x			x				x				33.2	17.8			x			.537	7	159							
	15	Dolomite			x			x			x			x	x	x			36.0	16.5			x			.458	10	152					x		
	14	Limestone	x					x			x			x	x				44.8	9.0			x		x	.200	6	142							
	13	Sandstone		x		x	x			x						x								x			59	136							
	12	Dolomite			x		x	x						x	x				32.2	18.9			x			.587	8	77	x						
	11	Caliche		x				x		x					x	x									x		5	69							
	10	Dolomite		x				x			x				x	x			33.7	14.8					x	.393	5	64							
	9	Dolomite			x			x						x	x				31.1	20.0			x			.643	6	59							
	8	Dolomite			x			x			x				x				41.3	12.1				x		.292	6	53							
	7	Dolomite	x					x							x				34.0	16.7			x	x		.491	5	47							
	6	Dolomite		x				x			x				x				32.3	18.0			x			.557	10	42						x	
	5	Dolomite		x				x						x					28.0	14.8		x			x	.529	6	32						x	
	4	Dolomite		x				x						x					27.9	17.0				x		.608	4	26						x	
	3	Dolomite		x				x			x			x					29.8	20.0				x		.672	4	22							
	2	Dolomite		x				x						x					29.7	16.7		x			x	.563	3	18							
	1	Sandstone		x			x			x						x								x			15	15							
		Yeso																																	

III. WHITE RANCH (W) SECTION (NW¼ SEC. 24, T. 11 S., R. 20 E.) OF BONNEY CANYON MEMBER. NOT MORE THAN 10-15 FEET OF TOP OF MEMBER ERODED.

	NUMBER	ROCK NAME	BED THICKNESS (FEET)				COLOR							GRAIN SIZE MILLIMETER					CHEM COMP		DEPOSITIONAL FABRIC				CRYSTALS	MgO: CaO RATIO	THICKNESS FEET		FOSSILS, ETC.					
			< 1	1-3	3-6	> 6	White	Gray	Black	Yellow	Brown	Green	Red	< .06	.06-.25	.25-.50	.5-2.0	> 2.0	CaO	MgO	Mudstone	Wakestone	Packstone	Grainstone			Unit	Cumulative	Frag.	Whole	Micro.	Pellet	Oolite	Chert
	8	Dolomite	x	x				x						x					30.2	20.2		x				.668	6	151						
	7	Limestone	x					x							x				44.2	8.4				x		.190	13	145						
	6	Dolomite	x				x	x							x	x			31.6	19.7				x		.624	18	132						
	5	Dolomite		x				x			x					x			31.2	19.3				x		.618	28	114					x	x
	4	Dolomite	x					x						x	x				37.2	14.8			x	x		.398	24	86						
	3	Dolomite	x					x			x				x				30.5	20.1				x		.660	11	62						
	2	Dolomite	x					x			x			x	x				31.2	19.7			x	x		.632	19	51						
Psb	1	Dolomite		x	x			x			x			x					30.0	20.5				x		.683	32	32						
Psr		Rio Bonito Member																																

IV. MANNING (M) ANTICLINE SECTION (N½ SEC. 1, T. 15 S., R. 17 E.) OF RIO BONITO AND BONNEY CANYON MEMBERS. LESS THAN 50 FEET OF TOP OF BONNEY CANYON ERODED.

	NUMBER	ROCK NAME	BED THICKNESS (FEET)				COLOR							GRAIN SIZE MILLIMETER					CHEM COMP CaO	MgO	DEPOSITIONAL FABRIC				CRYSTALS	MgO: CaO RATIO	THICKNESS FEET		FOSSILS, ETC.						
			< 1	1-3	3-6	> 6	White	Gray	Black	Yellow	Brown	Green	Red	< .06	.06-.25	.25-.50	.5-2.0	> 2.0			Mudstone	Wakestone	Packstone	Grainstone			Unit	Cumulative	Frag.	Whole	Micro.	Pellet	Oolite	Chert	
	43	Dolomite	x				x	x			x			x					30.3	20.4		x			x	.673	36	609							
	42	Dolomite	x					x							x				32.0	18.1			x		x	.565	7	573							
	41	Dolomite			x			x							x	x			31.1	18.2			x			.584	12	566					x		
	40	Dolomite	x					x			x			x	x				31.1	19.3			x	x		.622	25	554							
	39	Dolomite		x	x			x			x			x					30.3	19.5			x		x	.643	24	529							
	38	Dolomite			x						x				x				30.7	20.3				x		.661	13	505	x						
	37	Limestone			x			x			x			x	x				54.4	0.3			x	x	x	.005	25	492	x						
	36	Limestone			x			x							x				54.3	1.2			x		x	.022	20	467							
	35	Dolomite		x				x						x					39.3	12.1			x			.308	18	447							
	34	No sample																									22	429							
	33	Dolomite	x	x				x							x				38.8	13.4			x			.351	20	407	x						
	32	Dolomite			x			x			x			x					34.6	17.4			x			.503	17	387							
	31	Dolomite		x	x			x						x	x			x	33.7	15.7			x			.464	18	370							
	30	Limestone lam.	x					x			x			x					45.0	7.6		x				.169	6	352							
	29	Dolomite				x					x				x				29.9	17.4				x		.579	11	346							
	28	Dolomite				x					x				x				37.3	13.8			x		x	.370	13	335							
Psb	27	Dolomite				x					x				x	x			38.5	13.6				x		.353	16	322	x						Psb
Psr	26	Dolomite	x	x							x				x				33.4	16.9				x	x	.505	16	306	x						Psr
	25	Dolomite	x	x				x			x								37.0	14.9						.403	5	290							
	24	Dolomite	x	x			x								x				34.9	16.2				x	x	.465	23	285							
	23	Dolomite		x	x						x			x					36.6	13.2		x				.361	17	262							
	22	Dolomite			x						x				x				34.5	15.4					x	.448	7	245							
	21	Dolomite	x	x							x			x					36.3	13.1				x		.361	7	238							
	20	Dolomite			x						x			x					38.5	12.9			x		x	.336	6	231							
	19	Limestone			x						x				x				40.8	10.5			x		x	.257	15	225	x						
	18	Limestone				x					x			x					55.1	0.2			x		x	.005	22	210							
	17	Limestone		x	x						x			x					54.4	0.7			x		x	.013	19	188							
	16	Dolomite		x				x			x			x	x				33.3	18.0			x			.541	10	169	x						
	15	Dolomite				x		x			x				x				30.3	18.8			x			.619	13	159	x						
	14	Dolomite				x					x			x					30.4	18.8			x			.618	12	146							
	13	Dolomite	x					x						x					29.9	19.4			x			.651	6	134							
	12	Sandstone		x			x									x											18	128							
	11	Dolomite	x				x	x						x					36.7	17.1			x			.466	5	110							
	10	Sandstone		x	x		x									x			17.6	0.1						.007	16	105							
	9	Dolomite	x	x			x	x							x	x			38.2	11.6			x		x	.304	11	89	x						
	8	No Sample																									16	78							
	7	Dolomite				x		x			x			x					29.8	18.4		x				.617	12	62							
	6	Limestone				x					x			x					49.0	0.9			x		x	.018	11	50							
	5	Dolomite lam.	x								x			x					36.2	12.3		x				.334	1	39							
	4	Limestone			x						x			x					53.6	0.9		x			x	.017	4	38						x	
	3	Limestone lam.	x								x			x					44.1	7.5		x				.169	1	34							
	2	Limestone		x	x						x			x					38.1	11.7			x			.037	17	33							
	1	Dolomite				x		x			x			x					31.1	18.8			x			.602	16	16							
		Yeso																										619							

V. STEVENSON (X) RANCH SECTION (NE¼ SEC. 23, T. 19 S., R. 16 E.) OF RIO BONITO AND BONNEY CANYON MEMBERS. LESS THAN 50 FEET OF BONNEY CANYON ERODED.

	NUMBER	ROCK NAME	BED THICKNESS (FEET)				COLOR							GRAIN SIZE MILLIMETER					CHEM COMP		DEPOSITIONAL FABRIC				CRYSTALS	MgO: CaO RATIO	THICKNESS FEET		FOSSILS, ETC.						
			< 1	1-3	3-6	> 6	White	Gray	Black	Yellow	Brown	Green	Red	< .06	.06-.25	.25-.50	.5-2.0	> 2.0	CaO	MgO	Mudstone	Wakestone	Packstone	Grainstone			Unit	Cumulative	Frag.	Whole	Micro.	Pellet	Oolite	Chert	
	32	Limestone	x		x						x			x					52.7	0.8			x			.016	30	265	x	x					
	31	Limestone		x							x				x				52.5	1.8			x	x	x	.034	16	235	x	x					
	30	Limestone	x	x							x	x		x					53.4	0.7			x		x	.013	17	219	x	x					
	29	Limestone		x				x			x				x				42.6	10.1			x		x	.236	33	202	x	x					
	28	Limestone		x							x			x					53.2	0.8			x			.015	18	169		x					
	27	Limestone	x					x			x			x					54.0	0.8			x			.015	19	151	x						
	26	Limestone	x	x							x			x					52.7	0.6		x	x		x	.011	21	132	x						
	25	Limestone	x								x			x	x				52.7	0.9			x			.017	15	111	x	x					
	24	Limestone brach	x	x							x			x	x	x			53.7	0.8		x				.014	16	96	x	x					
	23	Limestone	x	x							x			x	x				52.6	1.0		x			x	.020	24	80	x	x					
	22	Limestone	x								x			x	x				51.5	2.0		x	x		x	.039	24	56	x	x					
	21	Limestone	x								x			x					53.9	0.8		x				.015	12	32	x	x					
	20	Limestone	x	x							x			x					53.8	0.9		x			x	.017	12	20	x	x					
Psb	19	Limestone	x	x							x			x					53.4	0.5		x	x		x	.009	8	8	x	x					Psb
Psr	18	Limestone			x						x			x	x				52.8	1.5			x			.029	13	288	x	x					Psr
	17	Limestone		x	x						x			x	x				52.9	0.6			x		x	.011	17	275	x	x					
	16	Limestone	x								x			x	x				53.6	1.2			x		x	.022	11	258	x	x					
	15	Limestone		x	x						x			x	x				53.7	1.0			x		x	.018	10	247	x	x					
	14	Limestone		x							x			x					52.9	0.8		x				.016	18	237							
	13	Limestone	x	x							x			x					53.9	0.8		x			x	.016	15	219	x	x					
	12	Dolomite	x	x	x			x			x			x					32.5	18.8		x			x	.579	16	204							
	11	Dolomote		x	x			x						x					33.1	17.8		x			x	.538	18	188	x						
	10	Dolomite				x		x						x					30.7	19.1		x				.623	17	170							
	9	Dolo. & Limestone				x		x			x			x	x				35.6	13.2		x			x	.371	20	153							
	8	Limestone			x	x					x			x					51.5	0.6		x				.011	28	133							
	7	Dolomite			x	x		x						x					30.6	17.5		x				.573	12	103							
	6	Limestone lam.	x	x				x			x			x					52.2	0.6			x			.011	6	91							
	5	Limestone		x							x				x				45.7	0.7			x			.016	6	85							
	4	Dolomite	x		x			x						x	x				32.8	16.4			x			.499	13	79							
	3	Sandstone			x		x								x												16	66							
	2	Dolomite	x					x			x			x					36.7	15.7		x	x		x	.426	20	50							
	1	Dolomite		x	x			x						x					32.7	19.0		x				.581	30	30							

VI. LEWIS SECTION (SE¼ SEC. 18, T. 20 S., R. 18 E.) OF RIO BONITO AND BONNEY CANYON MEMBERS. TOP OF BONNEY CANYON ERODED.

NUMBER	ROCK NAME	BED THICKNESS (FEET)				COLOR							GRAIN SIZE MILLIMETER					CHEM COMP		DEPOSITIONAL FABRIC				CRYSTALS	MgO: CaO RATIO	THICKNESS FEET		FOSSILS, ETC.						
		< 1	1-3	3-6	> 6	White	Gray	Black	Yellow	Brown	Green	Red	< .06	.06-.25	.25-.50	.5-2.0	> 2.0	CaO	MgO	Mudstone	Wakestone	Packstone	Grainstone			Unit	Cumulative	Frag.	Whole	Micro.	Pellet	Oolite	Chert	
43	Dolomite		x							x				x	x			29.9	21.9				x		.731	27	138						x	
42	Dolomite		x							x				x	x			30.7	21.1				x		.688	15	111							
41	Dolomite		x							x				x				31.0	20.9			x			.676	19	96							↑
40	Limestone		x							x			x	x				43.2	10.5			x		x	.253	18	77							
39	Limestone		x							x				x	x			54.3	0.7			x			.013	20	59							
38	Dolomite			x						x				x				38.0	14.2			x		x	.373	39	39	x		x				Psb
37	Limestone			x						x				x	x			54.3	1.1			x		x	.020	28	663	x		x				Psy
36	Limestone			x						x				x				55.1	0.5			x		x	.009	38	635							
35	Limestone			x						x								52.9	1.9		x				.036	26	597		x	Brach				
34	Limestone			x						x				x				55.1	0.4			x		x	.007	46	571							
33	Limestone		x							x			x					51.2	3.2		x				.063	18	525							↓
32	Limestone		x							x				x				46.5	5.0			x		x	.108	30	507	x						
31	Limestone		x							x			x	x				54.6	0.4		x			x	.007	29	477							
30	Limestone				x					x				x				52.6	0.2			x		x	.004	18	448	x						
29	Limestone				x					x				x				51.8	0.8			x			.016	6	430	x	x	Ammon				
28	Limestone						x			x				x	x			54.2	0.6				x	x	.011	7	424	x						
27	Limestone									x				x				51.1	2.8		x			x	.055	8	417	x		Brach				
26	Limestone	x								x				x				54.6	0.5			x			.009	18	409	x	x	x				
25	Limestone		x				x			x				x				54.1	0.7		x	x		x	.013	30	391	x	x					
24	Limestone	x	x							x				x				54.9	0.6			x		x	.011	25	361							
23	Limestone	x	x							x				x	x			54.8	0.7			x		x	.013	30	336	x	x					
22	Limestone		x	x						x			x	x				54.3	0.5			x		x	.009	18	306	x	x					
21	Limestone		x	x						x				x				54.8	0.6			x		x	.011	19	288	x	x	x				
20	Limestone			x						x				x				54.1	1.1			x		x	.020	20	269							
19	Limestone		x	x						x			x	x				51.8	0.6		x			x	.012	11	249							
18	Limestone		x	x						x				x	x			52.8	0.6			x		x	.011	12	238							
17	Limestone		x	x			x			x			x		x			54.7	0.6		x			x	.011	12	226	x		x		x		
16	Limestone		x	x						x				x				55.2	0.5		x			x	.009	13	214							
15	Limestone				x					x				x				55.1	0.5		x			x	.009	9	201						x	
14	Limestone				x					x				x				55.0	0.4			x		x	.007	18	192							
13	Limestone				x					x				x				55.2	0.5		x				.009	18	174	x	x					
12	Limestone				x					x			x					52.9	0.6		x				.011	29	156							
11	Limestone				x					x					x	x		54.5	0.5				x		.011	35	127						x	
10	Dolomite				x		x		x					x				32.9	19.0			x			.578	11	92							
9	Sandstone		x			x			x						x											3	81							
8	Limestone	x	x							x				x	x			52.7	0.6			x		x	.011	12	78							
7	Dolomite	x	x				x			x				x				35.7	16.9			x			.473	12	66							
6	Dolomite			x			x						x	x				32.8	18.3		x		x		.542	13	54							
5	Dolomite			x			x		x					x				31.4	20.5			x			.653	14	41	x						
4	Limestone			x		x	x							x	x			54.8	0.8				x		.015	9	27							
3	Limestone		x	x			x		x					x				49.6	4.6			x			.093	8	18							
2	Sandstone		x			x			x						x											3	10							
1	Sandstone	x	x				x		x					x				31.5	18.0			x			.572	7	7							

VII. ROCKY ARROYO (R) SECTION (NW¼ SEC. 1, T. 23 S., R. 21 E.) OF FOURMILE DRAW MEMBER.

	NUMBER	ROCK NAME	BED THICKNESS (FEET)				COLOR							GRAIN SIZE MILLIMETER					CHEM COMP CaO	MgO	DEPOSITIONAL FABRIC				CRYSTALS	MgO: CaO RATIO	THICKNESS FEET		FOSSILS, ETC.						
			< 1	1-3	3-6	> 6	White	Gray	Black	Yellow	Brown	Green	Red	< .06	.06-.25	.25-.50	.5-2.0	> 2.0			Mudstone	Wakestone	Packstone	Grainstone			Unit	Cumulative	Frag.	Whole	Micro.	Pellet	Oolite	Chert	
Pag	23	Sandstone oil st	x						x	x			x		x	x			28.3	18.1				x		.640	10	10							Pag
Psf	22	Dolomite	x					x						x					30.8	20.6		x		x		.669	6	387	x						Psf
	21	Dolomite	x				x	x						x					27.7	20.0	x					.722	3	381							
	20	Dolomite	x				x	x						x					30.3	20.9	x		x	x		.690	6	378							
	19	Dolomite	x					x						x					29.4	21.0	x					.716	12	372							
	18	Dolomite	x				x	x						x					29.3	20.4	x				x	.693	7	360							
	17	Dolomite	x				x	x							x				29.1	20.1		x		x		.691	22	353					x		
	16	Dolomite		x	x			x						x					29.8	20.9				x		.701	18	331	x						
	15	Dolomite		x	x			x							x				28.8	21.0				x		.729	20	313							
	14	Dolomite sandy		x			x								x				14.7	7.5			x			.510	4	293							
	13	Dolomite	x	x				x						x					28.3	19.3			x			.683	18	289							
	12	Dolomite	x	x			x	x						x					29.2	20.5	x			x		.702	26	271					x		
	11	Dolomite		x	x			x						x					29.6	21.5				x		.726	24	245							
	10	Dolomite		x	x			x						x					29.4	21.1				x	x	.718	32	221							
	9	Dolomite banded	x		x			x						x					28.9	19.9				x		.687	10	189							
	8	Dolomite				x		x						x			x		28.6	19.9		x		x		.698	15	179					x		
	7	Dolomite			x			x							x				29.0	20.3				x		.703	16	164							
	6	Dolomite				x		x						x					29.2	20.1				x	x	.689	39	148		x fus					
	5	Dolomite			x			x						x	x				33.2	18.3			x	x		.552	23	109		x fus					
	4	Dolomite				x		x							x				33.8	17.4				x		.514	15	86		fus					
	3	Dolomite			x	x		x			x			x	x				31.2	18.5				x	x	.593	25	71							
	2	Dolomite		x				x						x	x				29.5	18.3				x		.620	22	46		x fus					
	1	Dolomite			x	x		x						x					29.4	19.5				x		.663	24	24		x fus					
Psb	0	Dolomite	x					x						x										x						x fus				x	Psb

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Index

Numbers in **boldface** indicate main sections

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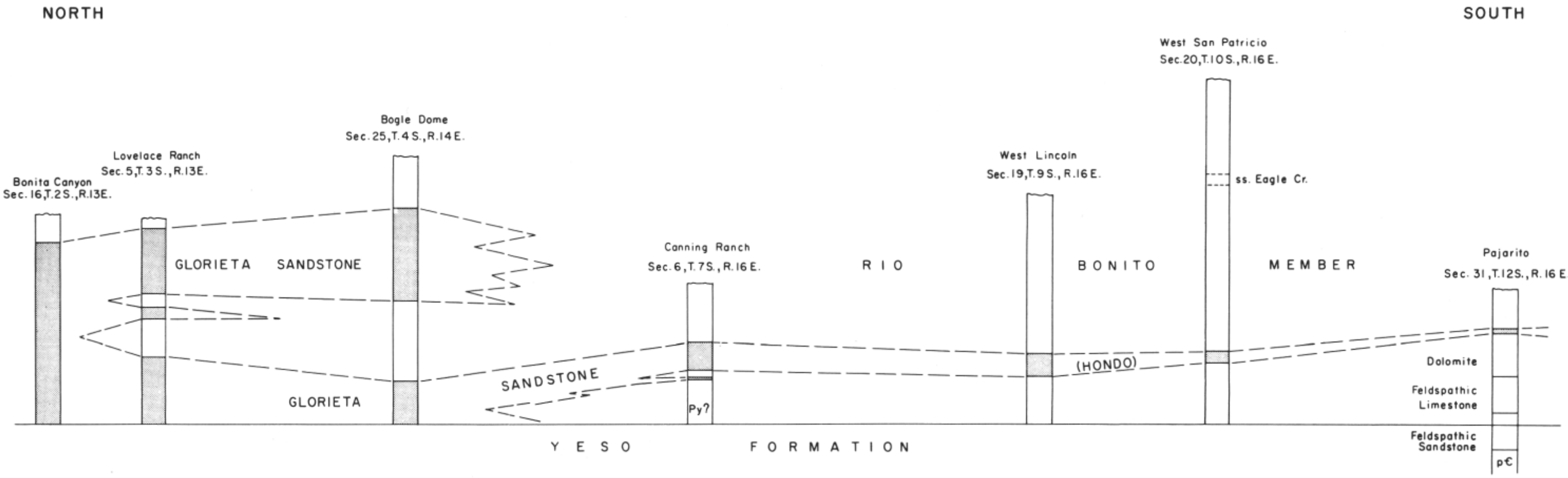
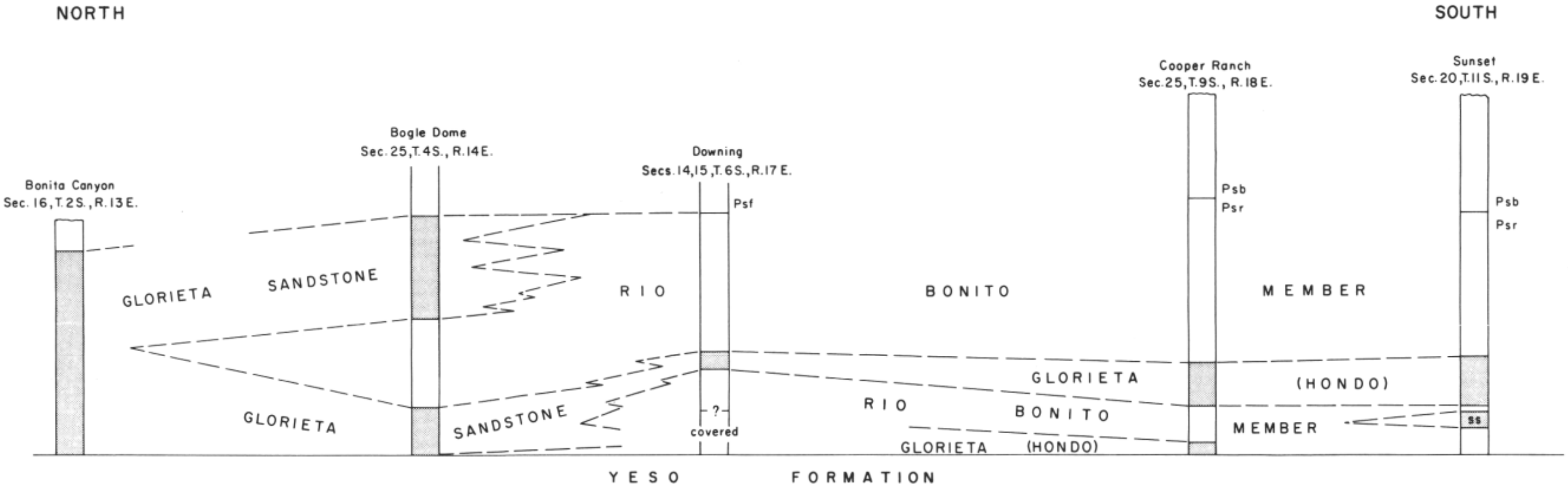
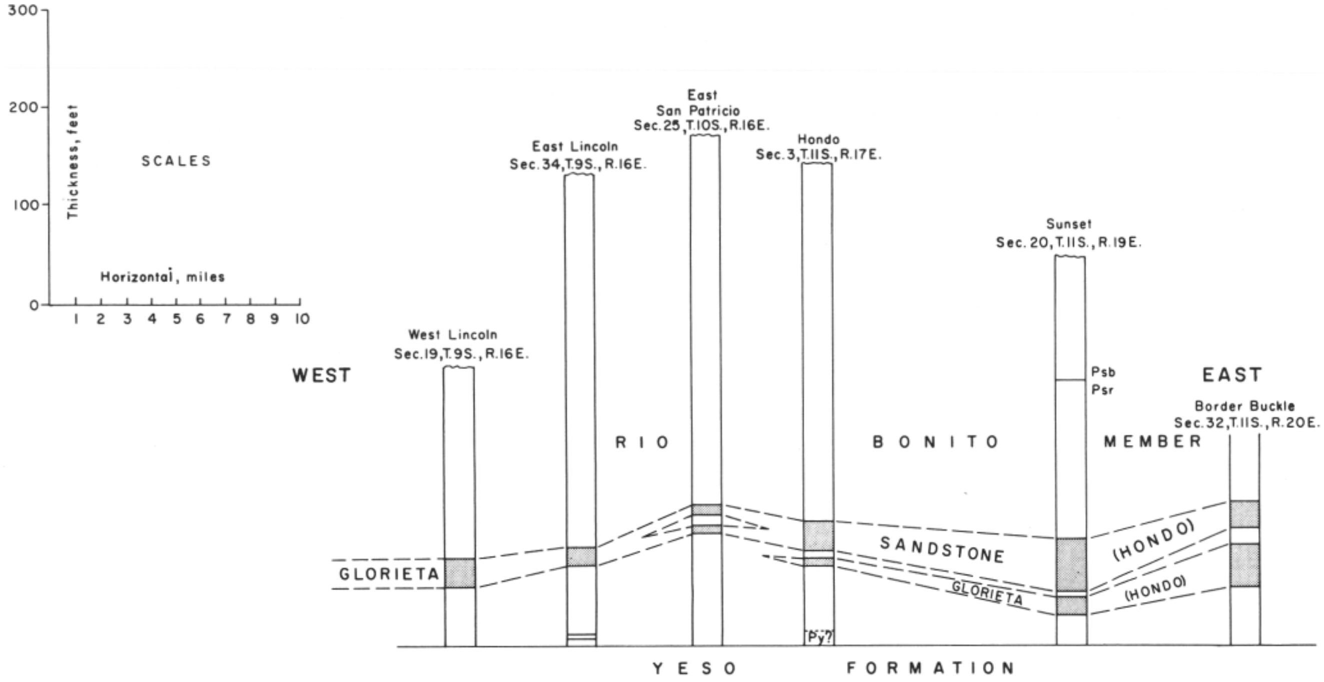


A. North–south panel around the west end of the Capitan Mountains



B. North-south panel around the east end of the Capitan Mountains



C. East-west panel along the Hondo drainage system

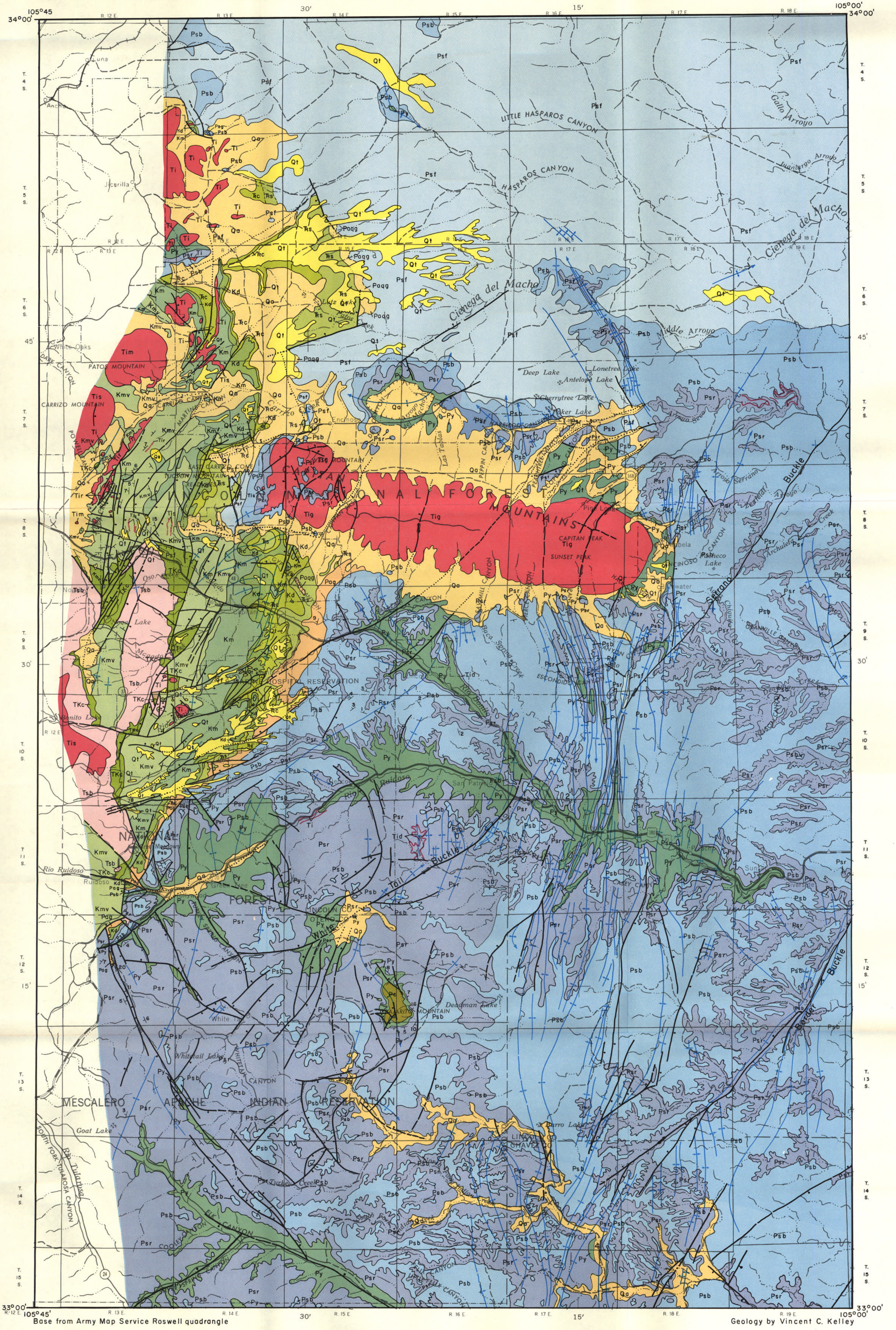
PLATE 7-MEASURED SECTIONS OF SAN ANDRES FORMATION, SHOWING DISTRIBUTION OF GLORIETA SANDSTONE TONGUES.

MAPS

(in pocket)

NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

MEMOIR 24 PLATE I



Base from Army Map Service Roswell quadrangle

Geology by Vincent C. Kelley

EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY

Qa Qs Qe Ql Qd Qtr Qt Qp Qc

Surficial Deposits

Qa, alluvium of stream and valley bottoms; Qs, caliche soil; Qe, blow sand and dunes; Ql, landslides; Qd, disturbed gravel, etc. affected by collapse; Qtr, travertine spring deposits; Qt, terrace gravel; Qp, pediment gravel; Qc, caliche

TERTIARY

QTg

Gatuna Formation

Red, tan, and buff sand, gravel, and mudstone

TKc

Cub Mountain Formation

Purplish mudstone and buff, conglomeratic sandstone

CRETACEOUS

Kmv

Mesaverde Group

Olive-drab to black shale, grayish sandstone, and coal

Km

Mancos Shale

Black shale, local sandstone, and limestone

Kd

Dakota Sandstone

Gray to white sandstone, local shale, and conglomerate

TRIASSIC

TRc

Chinle Formation

Reddish-brown mudstone

TRs

Santa Rosa Formation

Brown, buff, and red sandstone; local conglomerate

PERMIAN

Pd

Dewey Lake Formation

Tan-brown, clean sandstone

Pr Pru Prl

Rustler Formation

Dolomite, gypsum, and reddish sandstone; Pru, upper member; Prl, lower member

Psl

Salado Formation

Gypsum, dolomite, mudstone, and orange-red, collapsed, recrystallized, residual breccia

Pc Pcu Pcl

Castile Formation

Gypsum, anhydrite and limestone; Pcu, upper member; Pcl, lower member

Artesia Group

Pat

Tansill Formation

Dolomite intertonguing northward into gypsum

Pay Paye

Yates Formation

Pay, limestone, sandstone, and dolomite southward
Paye, gypsum, dolomite, and siltstone northward

Pas Pase

Seven Rivers Formation

Pas, limestone and dolomite southward
Pase, gypsum, mudstone and then dolomite northward

Paq Pag Paqg

Queen and Grayburg Formations

Paq, Queen Formation; dolomite and sandstone southward; gypsum and mudstone northward
Pag, Grayburg Formation; sandstone and dolomite southward; gypsum, red sandstone, and local dolomite northward
Paqg, Queen and Grayburg Formations undivided in north and locally elsewhere

Pac

Capitan Limestone

Pbc

Bell Canyon Formation

Basin-facies limestone and sandstone

Pgs

Goat Seep Formation

Massive dolomite

Psf Psb Psr Psbr Psg

San Andres Formation

Psf, Fourmile Draw Member; Psb, Bonney Canyon Member; Psr, Rio Bonito Member; Psg, Glorieta Sandstone

Py

Yeso Formation

Tan, yellow and rusty sandstone, red mudstone, dolomite, and gypsum

PRECAMBRIAN

P€

Precambrian rocks, undivided

Granite, syenite, and gneiss

IGNEOUS ROCKS

TERTIARY

Tsb

Sierra Blanca Volcanic Group

Andesitic to rhyolitic breccia, tuff, and flows

Ti Tis Tig Tir Tim Tid

Dikes, sills, stocks, and laccoliths

Ti, not identified; Tis, syenite or latite; Tig, granite or aplite; Tir, rhyolite; Tim, monzonite; Tid, diorite or diabase

Contact

Dashed where approximately located; dotted where concealed

kdo

Key bed or zone within a formation

High-angle fault

Dot on downthrown side; arrows show apparent or inferred lateral shift; dashed where approximately located; dotted where concealed

Anticline

Showing trace of axial plane

Syncline

Showing trace of axial plane

A S

Traces of anticlinal and synclinal bends

15

horizontal *vertical* *inclined*

Attitude of beds

5

Line of measured section

Tie leader

Connects outcrops of equivalent rocks

Lines of slump

In gravel, caliche, evaporites, or other rocks due to flowage or collapse

Small salt piercements and related sinks

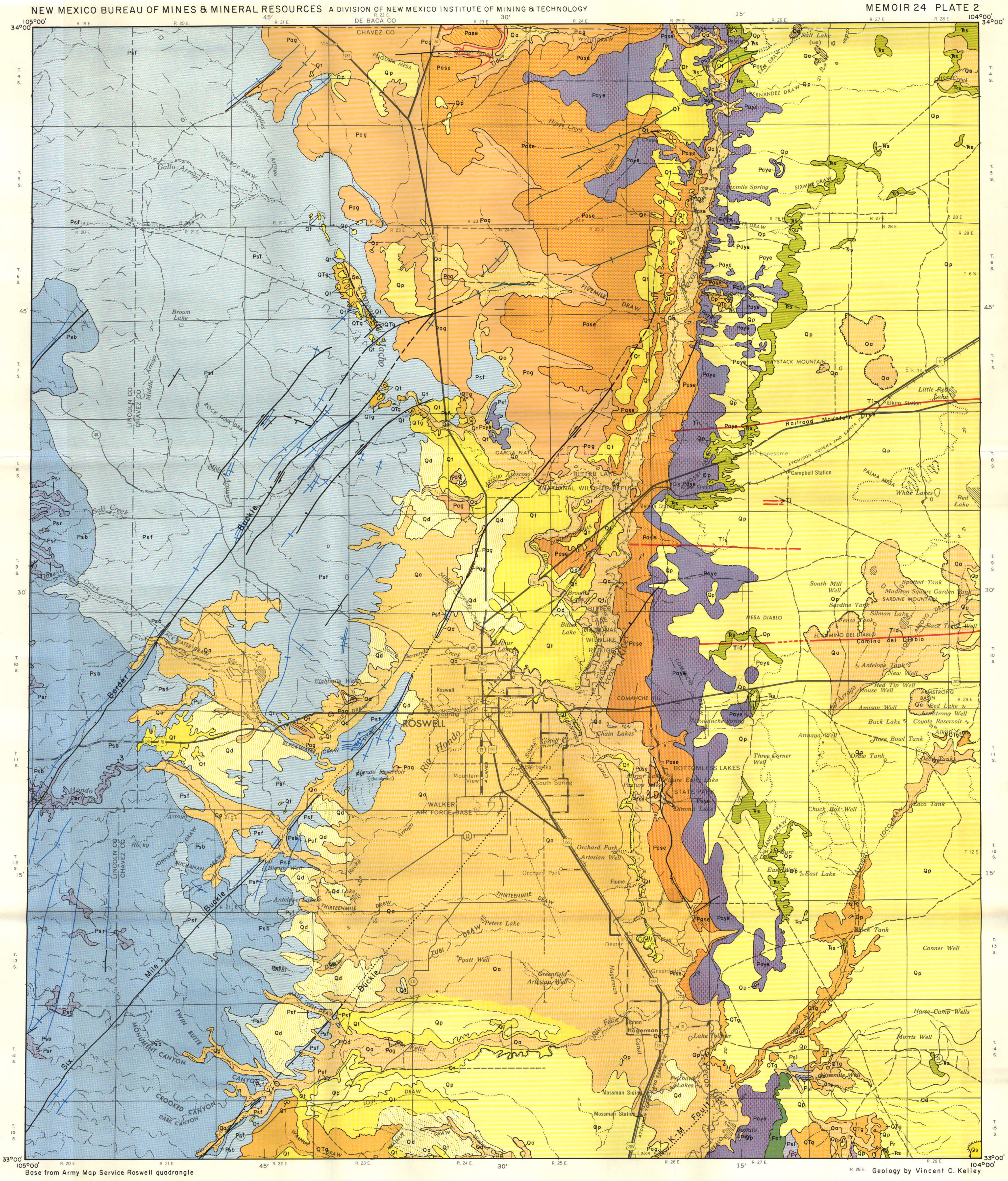
Contain cores of Triassic, Dewey Lake, Rustler, or San Andres Formations which are not shown

INDEX MAP OF NEW MEXICO

GEOLOGY OF THE CAPITAN-RUIDOSO REGION

by Vincent C. Kelley, 1971

5 0 5 10 15 20 Miles



Base from Army Map Service Roswell quadrangle

Geology by Vincent C. Kelley

EXPLANATION

SEDIMENTARY ROCKS

Qa Qs Qe Ql Qd Qtr Qt Qp Qc

Surficial Deposits
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QTg

Gatuna Formation
Red, tan, and buff sand, gravel, and mudstone

TERTIARY QUATERNARY

TKc

Cub Mountain Formation
Purplish mudstone and buff, conglomeratic sandstone

Kmv

Mesaverde Group
Olive-drab to black shale, grayish sandstone, and coal

Km

Mancos Shale
Black shale, local sandstone, and limestone

Kd

Dakota Sandstone
Gray to white sandstone, local shale, and conglomerate

CRETACEOUS

Ꞧc

Chinle Formation
Reddish-brown mudstone

Ꞧs

Santa Rosa Formation
Brown, buff, and red sandstone; local conglomerate

TRIASSIC

Pd

Dewey Lake Formation
Tan-brown, clean sandstone

Pr Pru Prl

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Dolomite, gypsum, and reddish sandstone; Pru, upper member; Prl, lower member

Psl

Salado Formation
Gypsum, dolomite, mudstone, and orange-red, collapsed, recrystallized, residual breccia

Pc Pcu Pcl

Castile Formation
Gypsum, anhydrite and limestone; Pcu, upper member; Pcl, lower member

Artesia Group

Pat

Tansill Formation
Dolomite intertonguing northward into gypsum

Pay Paye

Yates Formation
Pay, limestone, sandstone, and dolomite southward
Paye, gypsum, dolomite, and siltstone northward

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Seven Rivers Formation
Pas, limestone and dolomite southward
Pase, gypsum, mudstone and then dolomite northward

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Queen and Grayburg Formations
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Basin-facies limestone and sandstone

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Goat Seep Formation
Massive dolomite

Psf Psb Psr Psbr Psg

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Psf, Fourmile Draw Member; Psb, Bonney Canyon Member; Psr, Rio Bonito Member; Psg, Glorieta Sandstone

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Yeso Formation
Tan, yellow and rusty sandstone, red mudstone, dolomite, and gypsum

PERMIAN

p€

Precambrian rocks, undivided
Granite, syenite, and gneiss

PRECAMBRIAN

IGNEOUS ROCKS

Tsb

Sierra Blanca Volcanic Group
Andesitic to rhyolitic breccia, tuff, and flows

Ti Tis Tig Tir Tim Tid

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TERTIARY

Contact
Dashed where approximately located; dotted where concealed

kdo

Key bed or zone within a formation

High-angle fault
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Anticline
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Syncline
Showing trace of axial plane

A S

Traces of anticlinal and synclinal bends

⊕ horizontal ┼ vertical ⊥ 15 inclined

Attitude of beds

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Line of measured section

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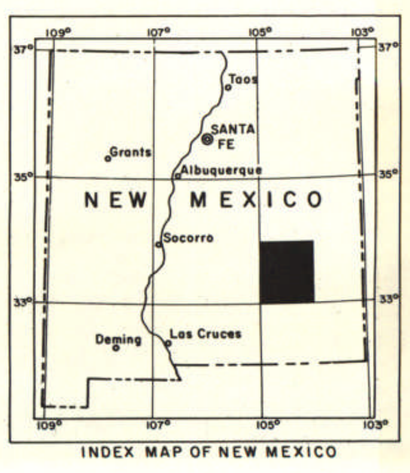
Connects outcrops of equivalent rocks

Lines of slump
In gravel, caliche, evaporites, or other rocks due to flowage or collapse

Small salt piercements and related sinks
Contain cores of Triassic, Dewey Lake, Rustler, or San Andres Formations which are not shown



INDEX MAP OF NEW MEXICO

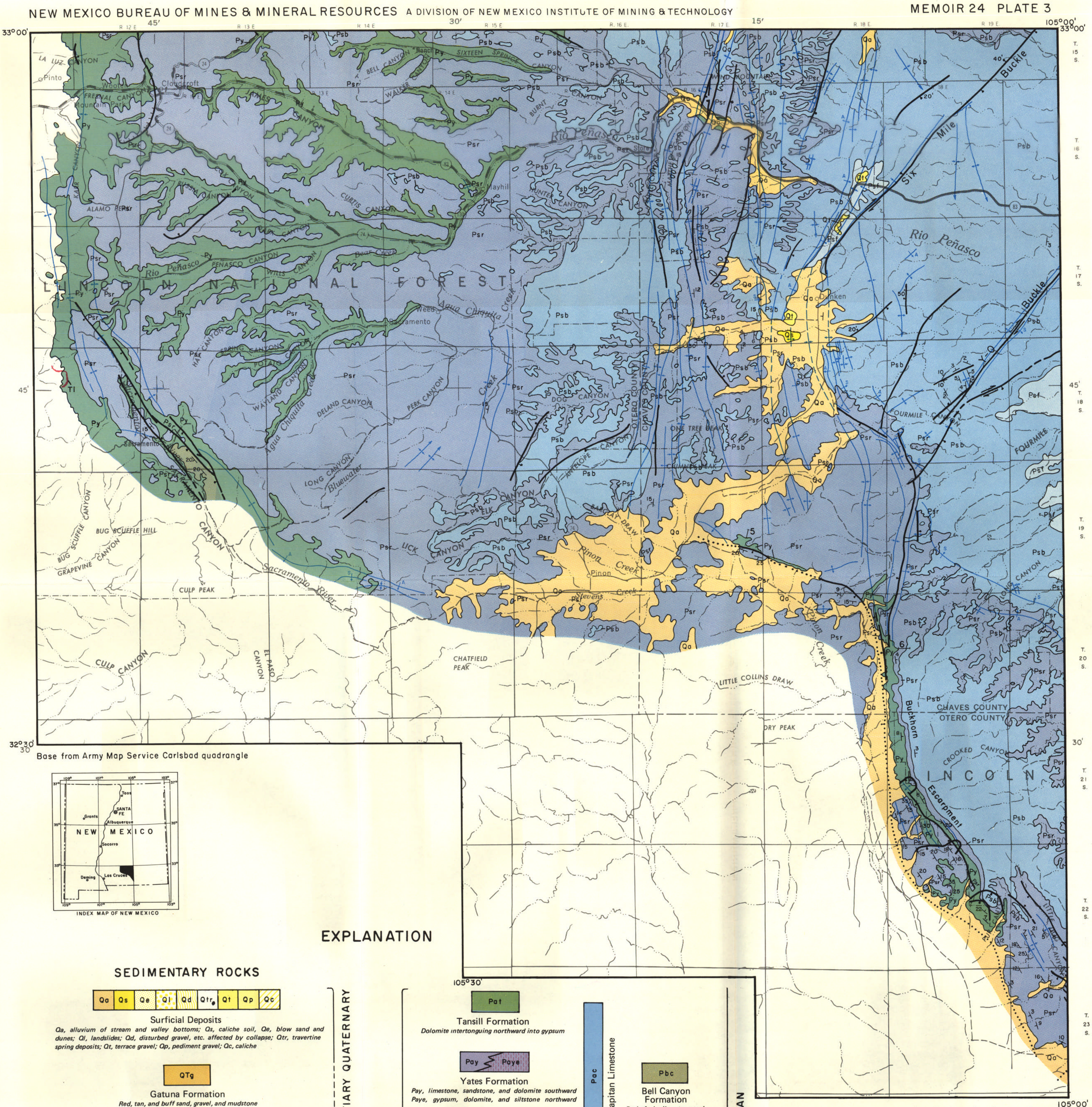
GEOLOGY OF THE ROSWELL REGION

by Vincent C. Kelley 1971

5 0 5 10 15 20 Miles

NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

MEMOIR 24 PLATE 3



Base from Army Map Service Carlsbad quadrangle

Geology by Vincent C. Kelley

EXPLANATION

SEDIMENTARY ROCKS

TERTIARY QUATERNARY

Qa **Qs** **Qe** **Ql** **Qd** **Qtr** **Qt** **Qp** **Qc**

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Kd

Dakota Sandstone

Gray to white sandstone, local shale, and conglomerate

TRIASSIC

₮c

Chinle Formation

Reddish-brown mudstone

₮s

Santa Rosa Formation

Brown, buff, and red sandstone; local conglomerate

PERMIAN

Pd

Dewey Lake Formation

Tan-brown, clean sandstone

Pr **Pru** **Prl**

Rustler Formation

Dolomite, gypsum, and reddish sandstone; Pru, upper member; Pri, lower member

Psl

Salado Formation

Gypsum, dolomite, mudstone, and orange-red, collapsed, recrystallized, residual breccia

Pc **Pcu** **Pcl**

Castile Formation

Gypsum, anhydrite and limestone; Pcu, upper member; Pcl, lower member

Artesia Group

Pat

Tansill Formation

Dolomite intertonguing northward into gypsum

Pay **Paye**

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Pay, limestone, sandstone, and dolomite southward
Paye, gypsum, dolomite, and siltstone northward

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Seven Rivers Formation

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Bell Canyon Formation

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PRECAMBRIAN

p€

Precambrian rocks, undivided

Granite, syenite, and gneiss

IGNEOUS ROCKS

TERTIARY

Tsb

Sierra Blanca Volcanic Group

Andesitic to rhyolitic breccia, tuff, and flows

Ti **Tis** **Tig** **Tir** **Tim** **Tid**

Dikes, sills, stocks, and laccoliths

Ti, not identified; Tis, syenite or latite; Tig, granite or aplite; Tir, rhyolite; Tim, monzonite; Tid, diorite or diabase

Contact

Dashed where approximately located; dotted where concealed

kdo

Key bed or zone within a formation

High-angle fault

Dot on downthrown side; arrows show apparent or inferred lateral shift; dashed where approximately located; dotted where concealed

Anticline

Showing trace of axial plane

Syncline

Showing trace of axial plane

A S

Traces of anticlinal and synclinal bends

⊕ *horizontal* *vertical* 15 *inclined*

Attitude of beds

5

Line of measured section

Tie leader

Connects outcrops of equivalent rocks

Lines of slump

In gravel, caliche, evaporites, or other rocks due to flowage or collapse

○ ○ ○ ○ ○ ○ ○

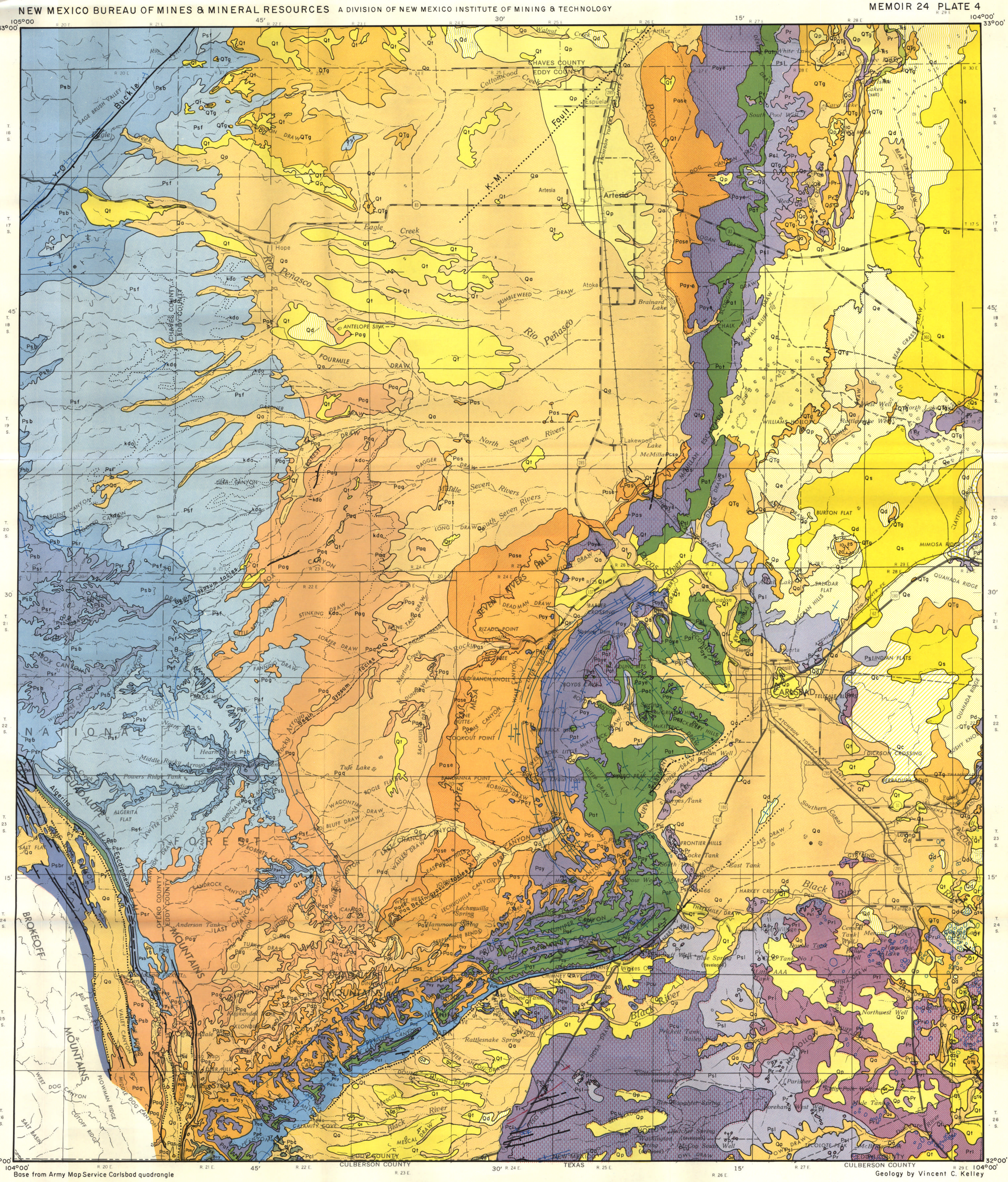
Small salt piercements and related sinks

Contain cores of Triassic, Dewey Lake, Rustler, or San Andres Formations which are not shown

GEOLOGY OF THE SACRAMENTO MOUNTAINS-DUNKEN REGION

by Vincent C. Kelley, 1971

5 0 5 10 15 20 Miles



Base from Army Map Service Carlsbad quadrangle

Geology by Vincent C. Kelley

EXPLANATION

SEDIMENTARY ROCKS

Qa Qs Qe Ql Qd Qtr Qt Qp Qc

Surficial Deposits

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TERTIARY QUATERNARY

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Km

Mancos Shale

Black shale, local sandstone, and limestone

Kd

Dakota Sandstone

Gray to white sandstone, local shale, and conglomerate

CRETACEOUS

₮c

Chinle Formation

Reddish-brown mudstone

₮s

Santa Rosa Formation

Brown, buff, and red sandstone; local conglomerate

TRIASSIC

Pd

Dewey Lake Formation

Tan-brown, clean sandstone

Pr Pru Prl

Rustler Formation

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Pac Capitan Limestone

Pbc

Bell Canyon Formation

Basin-facies limestone and sandstone

Pgs

Goat Seep Formation

Massive dolomite

Psf Psb Psr Psbr Psg

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Psf, Fourmile Draw Member; Psb, Bonney Canyon Member; Psr, Rio Bonito Member; Psg, Glorieta Sandstone

Py

Yeso Formation

Tan, yellow and rusty sandstone, red mudstone, dolomite, and gypsum

PERMIAN

p€

Precambrian rocks, undivided

Granite, syenite, and gneiss

PRECAMBRIAN

IGNEOUS ROCKS

Tsb

Sierra Blanca Volcanic Group

Andesitic to rhyolitic breccia, tuff, and flows

Ti Tis Tig Tir Tim Tid

Dikes, sills, stocks, and laccoliths

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TERTIARY

Contact

Dashed where approximately located; dotted where concealed

kdo

Key bed or zone within a formation

High-angle fault

Dot on downthrown side; arrows show apparent or inferred lateral shift; dashed where approximately located; dotted where concealed

Anticline

Showing trace of axial plane

Syncline

Showing trace of axial plane

A S

Traces of anticlinal and synclinal bends

⊕ *horizontal* ┼ *vertical* ⊥ 15 *inclined*

Attitude of beds

5

Line of measured section

Tie leader

Connects outcrops of equivalent rocks

Lines of slump

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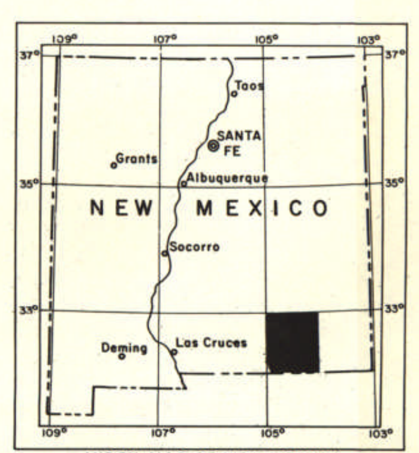
Small salt piercements and related sinks

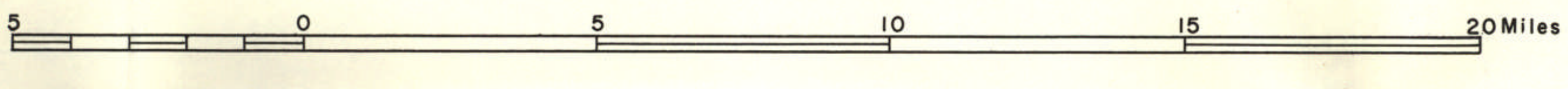
Contain cores of Triassic, Dewey Lake, Rustler, or San Andres Formations which are not shown



INDEX MAP OF NEW MEXICO

GEOLOGY OF THE GUADALUPE MOUNTAINS-CARLSBAD REGION

by Vincent C. Kelley, 1971



NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

MEMOIR 24 PLATE 5N

TECTONIC MAP OF THE PECOS COUNTRY, NORTH HALF

by Vincent C. Kelley

5 0 5 10 15 20 MILES

Explanation is on south half

NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

MEMOIR 24 PLATE 5S

EXPLANATION

Fault with dot on downthrown side; dashed where approximately located; dotted where concealed. Arrows show lateral movement.

Axis of anticline

Axis of syncline

Axis of anticlinal (A) and synclinal (S) bends.

5600 3600
5800 3400
6000 3200

Structure contours; Interval; 200 feet. Drawn on top of the Bell Canyon Formation in the Delaware Basin, on top of the Yates Formation in the Capitan Reef area, and on top of the Rio Bonita member of the San Andres Formation elsewhere.

Igneous intrusions
(Sills and abundant dikes of Sierra Blanca region not shown)

	Name	Tp	Rge
1.	Walker Ranch anticline	3	14-15
2.	Ancho anticline	4	11
3.	Cowboy anticline	4	21
4.	Igneo fault	4	23
5.	Salt Draw anticline	4	26
6.	Horse Creek anticline	5	24
7.	Higgins Creek anticline	5	24
8.	White Oaks fault	6	13
9.	Robinson fault	6	14
10.	Five-Mile draw buckle	6	24-25
11.	Encinoso anticline	7	15-16
12.	Purcella buckle	7-8	18-19
13.	Irvin Corn fault	7	22
14.	Indian Divide fault	8	13
15.	Titsworth dome	8	14
16.	Border Buckle splays	8	22
17.	Keith fault	9	13-14
18.	Champ fault	8-9	13
19.	Chavez anticline	9	17
20.	Winkler anticline	8-9	19
21.	Hollow Hill laccolith	10	14
22.	San Patricio syncline	10	16
23.	Alamo anticline	10-11	17
24.	Meneke sag and anticline	10	22
25.	Eight-Mile syncline	10	23
26.	Godfrey Hills fault	11	9
27.	Ruidoso fault	11	14
28.	Green Tree fault	11	14
29.	Casey anticline	9-11	17
30.	Tinnie anticline	10-14	17
31.	Picacho anticline	11	18
32.	Black Mountains fault	12	10
33.	Rinconada fault	12	10-11
34.	Dry Canyon fault	12	11
35.	Four-Mile fault	12	12
36.	Apache fault	12	13
37.	Turkey Spring fault	12	14
38.	Jouce syncline	12-13	17
39.	Bottomless Lakes fault	11-12	26
40.	Soldier Tank fault	13	14
41.	Summit fault	13	13
42.	Camp dome	13	15
43.	Treat syncline	13	19
44.	Turkey Creek fault zone	13	14
45.	South Fork graben	14	11-12
46.	Elk Creek fault	14	14
47.	Indian Creek anticline	14	16
48.	Funk anticline	14-16	17
49.	Vandewart anticline	14-15	17
50.	Manning anticline	14-15	17
51.	Thimble Canyon faults	15-16	18
52.	La Luz anticline	16	10
53.	Fresnal Canyon fault	16	11
54.	Caballero anticline	16-17	11
55.	Karr syncline	15-18	11
56.	Penasco syncline	16	16
57.	Salt Hill syncline	16	17
58.	Mule Peak anticline	17	10
59.	Alamo fault	17	10
60.	Gobbler anticline	17	11
61.	Dry Canyon syncline	17	11
62.	Watts Ranch anticline	16-19	16
63.	Dunken syncline	16-19	17
64.	Meadow Hill anticline	17	18
65.	Johnson syncline	18	10
66.	Ridge fault	18	11
67.	McAfee anticline	18	11
68.	Bell Ranch anticline	18	14
69.	Couhape syncline	17-19	17
70.	Dunken dome	18	18
71.	Red Lake-Turkey Track sinks	18	28-29
72.	Table Top syncline	19	11
73.	Bug Scuffle anticline and fault	19	11
74.	Sacramento River fault	18-19	12
75.	Sacramento River monocline	19	12-13
76.	Stevenson Ranch fault	19	16-17
77.	Couhape anticline	19	17
78.	Lewis buckle	19-20	18
79.	Seven River monocline	20	26
80.	Russell dome	20	28
81.	Gatuna dome	20	28
82.	Getty dome	20	29
83.	Spencer basin	21	25
84.	Tracy dome	21	26
85.	Avalon anticline	21	26
86.	Cedar Hill anticline	21	26
87.	Waterhole anticlinorium	21-23	24-25
88.	McKittrick Hill anticline	22	24
89.	Boyd Canyon dome	22	25
90.	McGruder dome	22	25
91.	Hackberry anticline	22	25
92.	Little McKittrick syncline	22	25-26
93.	Hackberry Draw syncline	21-22	26
94.	Carnero Peak dome	22	25
95.	Frontier Hills monocline	23-24	25-26
96.	Huapache monocline (basin)	25-26	24-25
97.	C-P Ranch faults	26	24-25

Base from Army Map Service Fort Sumner,
Roswell, and Carlsbad quadrangles

TECTONIC MAP OF THE PECOS COUNTRY, SOUTH HALF

by Vincent C. Kelley

5 0 5 10 15 20 MILES