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Border Stratigraphy Symposium

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GeoScience Research is the Key to Industrial Development

Contents

Preface

This Border Stratigraphy Symposium was held at the University of Texas in El Paso, April 30, 1968, as part of the Forty-Fourth Annual Meeting of the Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science. Interest in the data presented, particularly by geologists unable to attend the symposium technical session, led to requests for publication of the papers.

Some of the material has been published in abstracts and in part in other journals, particularly McGlasson's, LeMone's, and Kottlowski's data. Compilation of descriptions of most of the rock units in the El Paso border region in a single volume should aid future geologic work in this area. Descriptions of the Cenozoic strata, the surface and near-surface rocks on which the cities of the border region are built, should be of much aid in the urban development of El Paso, Las Cruces, and Juarez.

The editors appreciate the full cooperation of the authors, particularly the extra efforts of John W. Hawley and William E. King. New Mexico Bureau of Mines and Mineral Resources staff members contributed greatly to the finished product; Teri Ray by editorial aid, William E. Arnold and Robert L. Price by drafting illustrations, and Juarine W. Wooldridge and Joyce M. Aguilar by preparing the page copy for final printing.

Basement Rocks in Far West Texas and South-Central New Mexico

by Rodger E. Denison and E. A. Hetherington, Jr.
Mobil Research and Development Corporation
Field Research Laboratory
Dallas, Texas

ABSTRACT

Far west Texas and south-central New Mexico contain eight areas of Precambrian exposure. Samples from twenty-five wells drilled to basement aid in the correlation of the outcropping units. Twenty-four new isotopic ages have been determined from outcrops and from subsurface samples. Four periods of activity can be defined on the basis of this and previous work. The oldest rocks exposed are in the San Andres Mountain trend. These largely granitic rocks are 1350 m.y. (million years) and older and represent the basic framework into or onto which younger rocks were intruded or deposited. The best age obtained for the Carrizo Mountain Group in the Van Horn area is 1240 m.y., based on a rather indistinct whole rock isochron from metarhyolites. These rocks were later metamorphosed at about 950 to 1000 m.y. The granite at Pajarito Peak, Otero County, New Mexico, yielded an age of 1170 m.y. and appears to be a restricted basement rock type. The Castner–Allamore carbonate rocks and the Hazel–Llanoria sandstones and shales, together with their subsurface equivalents, were deposited over a large area. This deposition was accompanied by basalts and diabase injection. Granite and rhyolite in the Franklin Mountain area and to the east were emplaced and injected essentially contemporaneously at 950 m.y. This igneous activity is the youngest recognized in the Precambrian of this area and caused the metamorphism of the slightly older clastic and carbonate sedimentary rocks where in contact.

INTRODUCTION

Far west Texas and south-central New Mexico contain eight areas of Precambrian exposure, ranging from the few acres at Bent Dome in Otero County, New Mexico, to more than one hundred square miles (260 square kilometers) around Van Horn, Texas. In addition, samples from twenty-five wells drilled in search of oil and gas are available for study in the area surrounding the outcrops. We have assembled information from the recent literature on these areas, determined an additional twenty-four isotopic ages both from surface and subsurface samples, and attempted to synthesize a workable geologic history and a basement geologic map of the area. Although certain parts of the history are imprecisely defined, a remarkably consistent evolution and correlation between outcrop and subsurface rocks can be made.

We first will describe each outcrop area and present the new isotopic ages; then we will examine the information from the subsurface, and finally we will use these data in formulating a geologic history.

FRANKLIN MOUNTAINS

The work of Harbour (1960) in the Franklin Mountains summarized previous studies as well as adding much significant original data. His work outlined four major stratigraphic units with an aggregated thickness in excess of 5000 feet (1520 meters). In addition, McAnulty (1967) studied the three lower units in considerable detail. Although the conclusions reached here do not wholly agree with McAnulty's his descriptions are the best to be found.

The lowermost unit is the Castner "Limestone." The base is not exposed, yet 1100 feet (335 meters) of marble, diabase, and related hornfels have been measured by Harbour in the Fusselman Canyon area. The term *limestone* does not seem appropriate for a rock characteristically carrying a variety of metamorphic minerals, including garnet, tremolite, diopside, and epidote. Therefore, we recommend changing the name to *Castner Marble.*

The lower part is characterized by white to gray or green carbonates showing delicately preserved structures including stromatozoan-like algal heads. These carbonates are interbedded with dark, fine-grained diabasic rocks and biotite argillites. The two are very difficult to distinguish in the field. The lower carbonate beds are dolomitic and in some instances almost pure dolomite. The basal unit must have contained only a little quartz; otherwise, the dolomite would have reacted with it to form more abundant diopside and tremolite.

The upper part was called a hornfels by Harbour. The carbonates were originally considerably less pure than in the lower intervals. The diversity of metamorphic minerals, including an abundance of garnet, is evidence of a substantial clay mineral content. Quartz grains as relicts are common, and the rock is considerably less dolomitic in general, as shown by analyses reported by Harbour. Edgewise conglomerates are common near the upper part, as are a wide variety of abundant microstructures. The uppermost part contains structures that are here interpreted as soft sediment deformation. The unit as a whole is lacking in any major schistose development. The sedimentary rock appears to have been converted to hornfels without attendant shearing.

The Mundy Breccia overlies the Castner Marble. It varies from 0 to 250 feet (76 meters) in thickness. Harbour interpreted this unit as basaltic fragments, in a "fine, dark-gray matrix resembling indurated mudstone." McAnulty interprets it as a basalt flow breccia. The petrography of this unit is not straightforward. The basaltic fragments are altered but only incipiently metamorphosed with a well-defined relict igneous texture. The matrix is not uniform but is composed mostly of altered feldspar, chlorite, actinolite, and lesser biotite and tourmaline. The suggestion is that the matrix is closely related to the basalt itself. Aside from blocks of Castner Marble in the lower part of the Mundy (reported by McAnulty), no material other than basalt has been found in the breccia. The matrix occupies only a small part of the total volume. We interpret the unit as a surface flow that extruded on a floor of soft Castner carbonates. Whether this was a surface or submarine flow breccia cannot be resolved with the available evidence. The soft sediment deformation in the Castner Marble is thus ascribed to differential loading by the basaltic debris. The appearance of the breccia has been altered by later metamorphism, by intrusive granite, and probably by trapped solutions from the Castner carbonates streaming along breccia zones.

Stratigraphically overlying the Mundy Breccia is the Llanoria Quartzite. The unit is composed of approximately 2600 feet (795 meters) of quartzite, siltstone, and shale. The lower part is mostly a rather pure quartzite containing only a minor amount of microcline. The upper part is separated from the lower by a granite sill. Harbour describes the upper part as "Sandstone, siltstone, and shale in thin beds which form brown-weathering slopes."

Overlying the Llanoria Quartzite is a sequence of as much as 1400 feet (425 meters) of rhyolite flows. This unit is here named the *Franklin Mountain Rhyolite* simply because this is what workers in the area call it.

The rhyolite generally carries sodic plagioclase and perthite phenocrysts in a groundmass of delicate devitrified quartz-feldspar. Quartz phenocrysts, where present, are abundant. Certain samples are poor in quartz and probably approach a trachytic composition. Locally, the rhyolite is converted to a hornfels by granite intrusion. This is particularly common in some areas on the western slopes.

Flow structures are difficult to find in place, although strongly banded types are easily found as boulders in stream beds. The general feeling, although difficult to demonstrate, is that the rhyolite is at least roughly conformable with the underlying sediments.

The Red Bluff Granite intrudes the entire Precambrian sequence. In addition, McAnulty reports an older microgranite porphyry in the Fusselman Canyon area. The microgranite is intrusive into the Precambrian sedimentary sequence, mostly as sills. The microgranite is in turn intruded by Red Bluff-type granite. The granites examined in this study were mostly medium- to fine-grained, characteristically carrying only perthite as the feldspar. Some are quartz poor and contain a pyroxene, but most are highly quartzose with less than five percent femic minerals, common hornblende, biotite, and riebeckite. Textures vary from porphyritic and micrographic to even-grained and hypidiomorphic. The granites have petrographic characteristics of epizone instrusions and were probably emplaced at depths of less than one mile.

Wasserburg et al. (1962) report K/Ar and Rb/Sr ages of 880 to 1030 m.y.* on a variety of granitic samples. Two zircon ages were determined with 1095 and 1080 m.y. being the Pb207/Pb206 ages. A whole rock age of 990 ± 50 m.y. was reported on a sample of metarhyolite by Muehlberger et al. (1966, p. 5415). We have determined ten Rb/Sr ages on whole rocks and feldspars from granites and rhyolites (table 1). We did not find any systematic difference in the ages of the granite and rhyolite and have grouped the two to obtain an isochron or "best" age. The determinations fall very closely along an isochron of 953 ± 13 m.y. with an initial ratio of 0.7081 ± 0.0010 (fig. 1). Two of the whole rock rhyolites fall below the line, but the other whole rocks and feldspars are close to the isochron age. The apparent low ages from the whole rocks are probably caused by minor alterations in the groundmass, because feldspars separated from the same specimens give higher ages.

We believe the sedimentary units were deposited in quick succession, soon became covered by rhyolite, and in the same time interval were intruded and metamorphosed by Red Bluff Granite. The granitic igneous activity took place at about 953 ± 13 m.y. The association of synchronous rhyolite-granite is common throughout the southern United States. Muehlberger, Denison, and Lidiak (1967, p. 2372-2373) drew attention to this relationship.

A succession of lower Paleozoic sedimentary rocks overlies both the granite and rhyolite. Although the structure is disrupted, the Paleozoic sequence appears to be only disconformable with the layered Precambrian rocks.

HUECO MOUNTAINS

Several small hills of red granite are exposed beneath Bliss Sandstone (Cambrian) near the south end of the Hueco Mountains (King, 1935). Wasserburg et al. report an Rb/Sr age of 990 ± 60 on feldspar from the granite. The rock is a partly micrographic perthite granite, petrographically indistinguishable from the Red Bluff Granite of the

*** The Rb/Sr ages reported by Wasserburg et al. have been recalculated using the 47 b.y. half-life, resulting in ages six percent lower than those using the 50 b.y. half-life.**

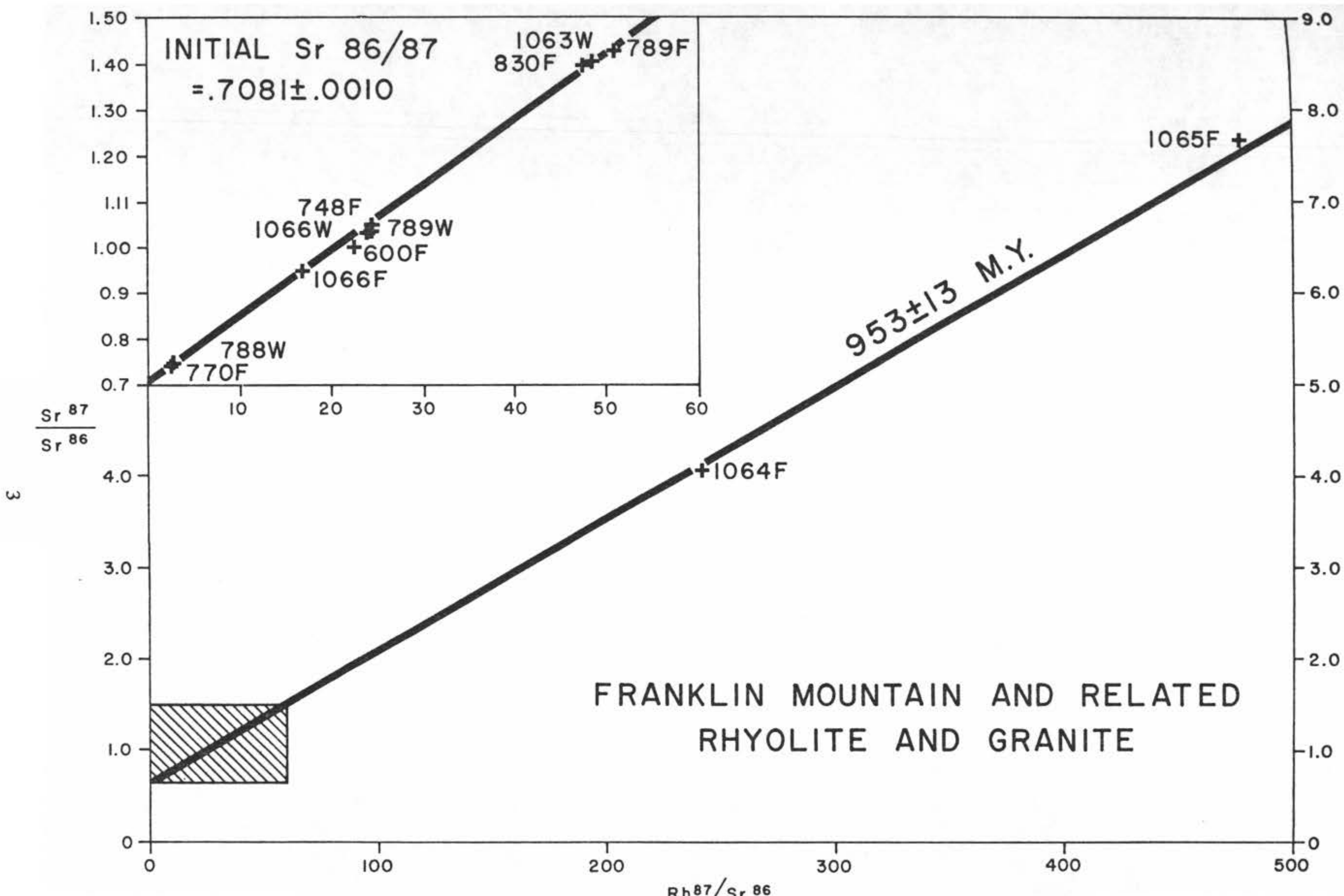


Figure 1

An Isochron Plot of Franklin Mountain and related rock determinations

Franklin Mountains. The determined age is close to the isochron age of the Franklin Mountains and related rocks. We conclude that the granite exposed in the Hueco Mountains is related both in petrographic character and age to that exposed in the Franklin Mountains.

PUMP STATION HILLS

Masson (1956) described the igneous rocks exposed in a group of low-lying knolls, the Pump Station Hills, in some detail. The dominant rock type is rhyolite porphyry, but some fine micrographic granite porphyry and other rock types are also present. Wasserburg et al. determined an Rb/Sr whole rock age of 960 ± 60 m.y. and a feldspar age of 1000 ± 40 m.y. on a rhyolite sample. These ages and the general petrographic character clearly relate these rocks to those in the Franklin and Hueco mountains.

BENT DOME

At a locality near Bent, Otero County, the Permian Abo Formation rests upon rocks of Precambrian age. Bachman (1960) named the structure the *Bent Dome* and described it in some detail as part of the Pedernal landmass.

A light-gray quartzite is the principal rock type. In the sample examined in this study, the quartzite contained almost no lithic or feldspathic debris. No metamorphic minerals were seen and shearing is lacking. The quartzite is apparently intruded (exposures are poor) by a deep-red micrographic granite porphyry. No samples fresh enough for dating could be collected, even though there are prospect pits in the granite. The quartzite is considered equivalent to the Llanoria in the Franklin Mountains. The micrographic granite, by analogy, is part of the 950 m.y. igneous activity common to the south. This is the most northerly encounter of rocks considered equivalent to the granite-rhyolite sequence.

Bachman reported cobbles of rhyolite, granite, and quartzite in the overlying Abo. This suggests that, at least locally, the Franklin Mountain Rhyolite was deposited this far north and was subsequently removed by erosion. An alternate but less likely explanation is that the rhyolite was derived from the Panhandle Volcanic Terrane in the 1100 to 1200 m.y. range.

PAJARITO PEAK

The age of the granitic rocks at Pajarito Peak has been the subject of some disagreement. Thompson (1942) thought them Precambrian as part of the Pedernal landmass. Lloyd (1949) and Motts and Gaal (1960) argued for a Tertiary age, and the outcrop is so shown on the State Geologic Map (Dane and Bachman, 1965).

Kelley (1968) recently described the geology of Pajarito Peak in detail. His conclusion is for a definitely Precambrian age, based on field relations. Our laboratory performed the isotopic ages reported by Kelley, which demonstrate a Precambrian age. Kelley generally described the alkaline rocks and no résumé is needed here. The samples we examined and dated from Pajarito Peak are of a riebeckite granite and associated syenite-quartz syenite pegmatite. The granite is composed, in volume percent, of 38.0 perthite, 25.8 quartz, 24.7 riebeckite, 4.7 aegirine, and 6.8 iron oxides and alteration material. The latter appears to replace a former femic mineral. The quartz is mostly in large, discrete, single crystals with local poikilitic inclusions of perthite and riebecktite. This texture gives the rock a porphyritic-like appearance. The syenite is fine-grained, actually a microsyenite, and is gradational with a quartz-bearing pegmatitic phase. The rock is composed of perthite and common hornblende with lesser riebeckite, pyroxene (?) alteration material, rutile, apatite, and iron oxides. Quartz occurs only in the pegmatitic phase.

At the suggestion of Frank E. Kottlowski, ages were determined on two samples from the controversial outcrop. Riebeckite from the granite yielded a K/Ar age of 1170 ± 25 m.y. and common hornblende from the pegmatitic phase an age of 1190 ± 25 m.y. An Rb/Sr age of 1135 ± 15 m.y. was obtained from feldspar from the granite.

Similar ages are not found elsewhere in this area. However, to the east, a large volume of granite and rhyolite was injected and extruded during the period 1100 to 1200 m.y. (the Panhandle igneous activity of Muehlberger et al.). The rocks at Pajarito Peak are interpreted as a local extension of this igneous activity.

The crystalline rocks are overlain by sedimentary rocks equivalent to the Permian Yeso and San Andres Formations (Kelley). Significantly, all Precambrian sedimentary rocks are absent, although they are demonstrably thick nearby. Either by nondeposition or later erosion, the thick sandstones and diabase-basalt of the DeBaca Terrane are missing. This suggests that Pajarito Peak is and has been a structural high and is part of the Pedernal landmass.

SACRAMENTO MOUNTAINS

Three small outcrops of Precambrian rocks are found south of Alamogordo, Otero County, at the base of the Sacramento Mountains escarpment. Pray (1961) described 80 feet (24 meters) of sedimentary section composed of quartzite, siltstone, and shales. These clastic rocks are cut by diabasic rocks, mostly as sills. The Precambrian sedimentary rocks have an angular discordance of about 10 degrees with the overlying Bliss Sandstone.

These rocks are similar to others found in a large north-south band in south-central New Mexico (Muehlberger and Denison, 1964; Muehlberger, Denison, and Lidiak), the DeBaca Terrane.

SAN ANDRES MOUNTAINS

The San Andres Mountains expose Precambrian rocks along an 85-mile (137- kilometer) north-south length. The sequence is complex and diverse. Kottlowski (1959) reports

> Red to gray granites, including roof-pendants of various schists and gneisses, and cut by pegmatite and diabase dikes, occur in the northern and southern parts of the mountains. From Sulphur Canyon to south of Hembrillo Canyon a thick series of metamorphic rocks is exposed including mica and quartz-feldspar schists, quartzites, amphibolites, phyllites, talc schist, talc, and dolomite, intruded by diabase and aplite dikes and by small masses of granite. Foliation of the metamorphic rocks along Hembrillo Canyon strikes N. 30-45 °W. and dips steeply westward. In places, this metamorphic series is truncated by a light-gray quartzite with bedding almost parallel to that of the overlying Bliss sandstone; however, the quartzite is cut by pale-pink aplite dikes that are truncated by basal beds of the Bliss Sandstone.

Kottlowski also notes the similarity of the quartzite to the Precambrian sedimentary rocks in the Sacramento Mountains and to samples from a well near Cloudcroft, Otero County.

Four ages have been reported from the length of the San Andres Mountain trend (Muehlberger et al.). Potassium-argon ages from micas range from 1350 to 1400 m.y., and one Rb/Sr determination on a whole rock yielded an age of 1300 ± 70 m.y. In addition, two ages were determined on a core from the Sun No. 1 Bingham (Socorro County) oil test a few miles north of the north end of the Precambrian outcrops along the San Andres trend. This granite gneiss (described by Muehlberger and Denison) gave an Rb/Sr age of 1570 ± 100 m.y. on microcline and a K/Ar age of 1350 m.y. on biotite.

Clearly, this is a different type of Precambrian complex from that exposed to the south in the Franklin Mountains. It is older and composed of a massive igneous-metamorphic complex. The igneous rock composition is dioritic to granitic, considerably more diverse than the granite of the 950-m.y. activity.

VAN HORN AREA

The rocks in the Van Horn area have been the object of excellent studies by King and Flawn (1953) and King (1965). Our dating has substantiated their field interpretation and the following is taken largely from their work. We do differ in the interpretation of the origin of some of the metamorphic rocks. What Flawn called meta-arkose is interpreted here mainly as metarhyolite.

The area may be divided into two segments. The older is exposed in the Eagle, Wylie, Van Horn, and Carrizo mountains and the southern end of the Diablo platform. The Carrizo Mountain Group is composed of quartzite, schist, phyllite, and marble overlain and intruded by metarhyolite and amphibolite. The exposed thickness in the Carrizo Mountains is reported to be as much as 19,000 feet (5800 meters) and does not appear to be repeated. In the Van Horn Mountains, the entire sequence is intruded by abundant pegmatite and is a higher metamorphic grade than the rocks to the north. The rocks of the Carrizo Mountain Group are separated from the younger rocks cropping out on the Diablo platform by the Steeruwitz overthrust.

On the Diablo platform, the lowest unit is the Allamore Formation, composed of very thick marbles with interbedded phyllite, chert, and pyroclastic volcanic rocks. The Allamore is overlain by another thick but very different unit, the Hazel Formation, which is made up of coarse-grained conglomerate and sandstone. The Van Horn Sandstone rests with angular unconformity on these older metasedimentary units and is of probable Late Precambrian age. Bliss(?) Sandstone overlies parts of these units in the Diablo platform area, but the Carrizo Mountain Group is overlain by Hueco Limestone (Permian).

Wasserburg et al. determined a number of ages on rocks and minerals from the Van Horn area. There is considerable variation in the apparent ages, but the oldest center around 1000 m.y. We interpret this to be near the time of metamorphism. We have determined seven whole rock ages on the metarhyolites. Only one of these (No. 759) falls into the 1000-m.y. range; the others are distinctly older. The youngest sample is very muscovitic. The muscovite was formed during metamorphism and indicates that during the addition of water to form muscovite, a closed system was not maintained. A least-squares cubic fit of an isochron using the six older ages yields a best age of 1238 ± 65 m.y. with an initial ratio of 0.7002 ± 0.0058. The error is high and the scatter considerable (fig. 2). We are not confident that the determined age is actually the age of formation because of the scatter; however, it is clear the metarhyolites have an age of formation substantially older than similar rocks in the Franklin Mountains.

A feldspar was separated from a rhyolite dike (?) that cuts the Allamore. This rock is unmetamorphosed and distinctly different from other rhyolitic rocks in this area. The determined age is 950 ± 14 m.y., identical to the Franklin Mountain rhyolites.

Thus, the rhyolites of the Carrizo Mountain Group were formed at about 1250 m.y. and metamorphosed about 1000 m.y. The faulting and deformation that thrust the Carrizo Mountain Group over the Allamore–Hazel sequence is probably contemporaneous with the metamorphism. A postmetamorphic dike (?) rock yields an age of 950 m.y.

Granite and rhyolite boulders reported in the Hazel Formation (King *in* King and Flawn, p. 84) have not been dated. These cannot be derived from the Pump Station Hills–Hueco Mountains, as suggested by King, because this terrane is too young. However, these granitic rocks could be

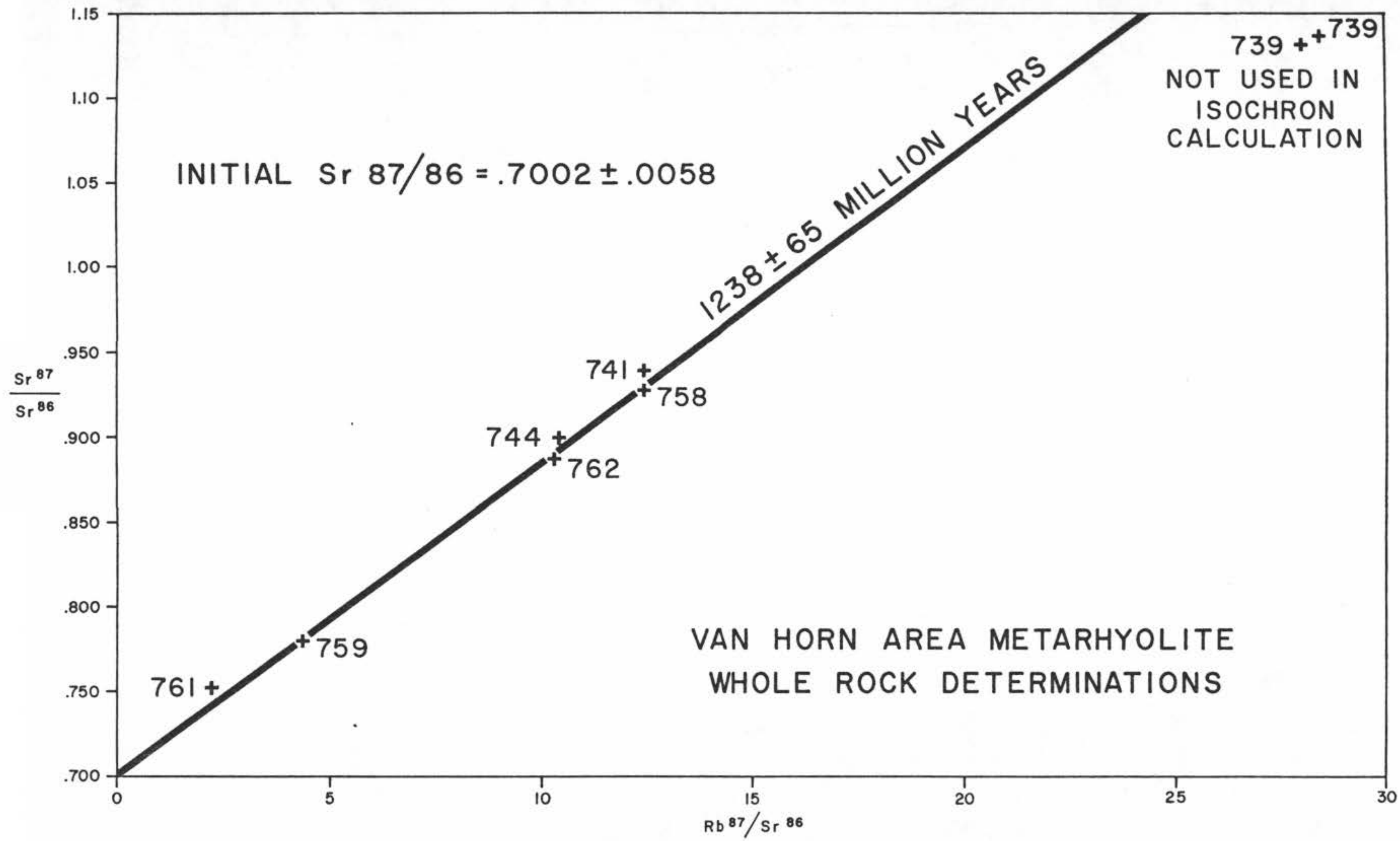


Figure 2

AN ISOCHRON PLOT OF WHOLE ROCK DETERMINATIONS FROM THE METARHYOLITE IN THE CARRIZO MOUNTAIN GROUP derived from the *1100* to *1200* m.y. terrane reported by Muehlberger et al. (p. 5422). The actual spread of ages in the volcanic rocks in this 1100 to 1200 m.y. terrane does not preclude the possibility that the Carrizo Mountain metarhyolite is related to some of those in the Panhandle area.

Unresolved problems remain in the Van Horn area. Perhaps the most puzzling is the difference in general strike of units in the Carrizo Mountain Group and those of the Hazel–Allamore sequence. This is best shown on King's (1965) map of the Sierra Diablo region. The dominant strike direction north of the Steeruwitz Fault is nearly east-west; south of the fault it is about N. 60° E. There is an interval covered by Van Horn and younger units, and there could be a general wrapping around of units beneath the two to three miles of cover. The lineations in the metarhyolite appear to be closer to the structural direction found to the north of the Steeruwitz Fault. In any event, the suggestion is that the Carrizo Mountain Group has undergone more than one period of major deformation. The area has been used as an example of major left lateral (Moody and Hill, 1956) and right lateral (Muehlberger, 1965) fault. The arguments are based on geometry, and specific support for the contentions is sparse.

SUBSURFACE

Scattered wells drilled to basement lie within the study area. Basement rocks from some of these wells have been described (Flawn, 1956; Foster, 1959; Muehlberger and Denison). Several basement rock units have been discussed and named by Muehlberger, Denison, and Lidiak. Much of the discussion to follow is taken from these works, particularly Muehlberger and Denison.

The oldest rocks in the subsurface are believed to be equivalent, in part, to those in the San Andres Mountains. Muehlberger, Denison, and Lidiak named these rocks the *Chaves Granitic Terrane.* The rocks penetrated are granitic in composition but diverse in petrography. Granites and granodiorites, some with a well-defined gneissic fabric, are the most common rock types. The only age determined on basement rocks of this terrane was from a biotite granite from the Humble No. 1 Huapache Unit oil test in sec. 35, T. 23 S., R. 22 E., Eddy County. The biotite yielded an age of 1310 ± 20 m.y. and the feldspar 1350 ±m, 20 m.y. This compares favorably with the outcrop ages from the San Andres Mountains. It is believed that some of the gneisses may be substantially older (possibly 1600 m.y.), becoming metamorphosed at about 1350 m.y. This unit is the basic framework rock, into which and onto which younger units were deposited or intruded, for much of southeast New Mexico.

The granite and related pegmatite dated at Pajarito Peak represent a basement rock unit that has not been drilled in the study area. However, numerous basement wells have penetrated petrologically related rock with the same ages in southeastern New Mexico, mainly in eastern Chaves and Eddy counties and Lea County. The unit is not yet named.

The vast majority of the map area shown in Figure 3 is underlain by rocks of the DeBaca Terrane. In the north, the rocks are argillites and feldspathic quartzites with interbedded basalts and are intruded by diabase. However, beginning with a line running east-west through central Otero County, carbonate rocks become a commonly drilled rock type.

The Turner No. 1 State in sec. 36, T. 25 S., R. 16 E., Otero County, drilled 2135 feet (651 meters) of altered diabase, talc-tremolite marble, quartz syenite, and micrographic granite porphyry. Nineteen intervals were examined petrographically in the drilled sequence. The similiarity between this and the section exposed in the Franklin Mountains is remarkable. In the LeFores No. 1 Federal oil test, sec. 22, T. 21 S., R. 16 E., wollastonite marble has been described by Muehlberger and Denison.

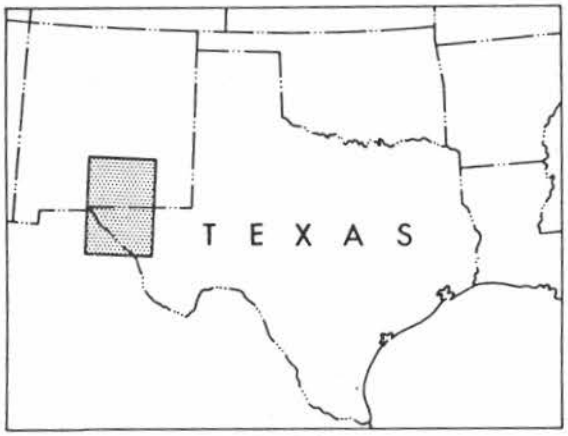
In southern Otero County and in Texas, the majority of wells penetrated rhyolite or micrographic granite. The only age determined from these rocks is on feldspar from the Gulf No. 1 Burner State in Hudspeth County. This fraction from a micrographic granite porphyry yielded an age of 890 ± 20 m.y. The age is younger than expected and may be due to alteration in the feldspar. In any event, we interpret these granites and rhyolites as equivalent to those cropping out in the Franklin and Hueco mountains and Pump Station Hills.

PRECAMBRIAN HISTORY

The oldest rocks exposed in this area are in the San Andres Mountains where micas from igneous rocks yield ages of 1350 to 1400 m.y. A suggestion of relict older ages of about 1600 m.y. is present, but how extensive these older rocks (later metamorphosed at 1350 to 1400 m.y.) are is not known. The metasedimentary rocks in this linear outcrop belt are not recognized in any of the wells penetrating basement in this area. These older layered rocks may be equivalent to the sequence found in the Los Pinos–Manzano mountains. The gneisses form the framework for all younger Precambrian units. These younger rocks are a veneer of sediments with locally significant intrusions.

To the south in Hudspeth and Culberson counties, the Carrizo Mountain Group was deposited and extruded. The exact time interval this took place is not so straightforward as might be hoped. Our best age of 1240 ± 65 m.y. on the age of extrusion of the rhyolite overlying sedimentary rocks shows they are significantly older than a comparable sequence in the Franklin Mountains. The former extent of this sedimentation and volcanic activity is not known, but it certainly extended considerably to the north of the present limited outcrop area. The inexactness of a best age for the rhyolite extrusion opens the door for speculation of its possible "real" age. The only other thick metasedimentary sequence fairly close at hand is that in the San Andres Mountains; this would require the rhyolite age to be lowered very significantly, probably ten or fifteen percent

BASEMENT GEOLOGIC MAP OF FAR WEST TEXAS AND SOUTH CENTRAL NEW MEXICO



INDEX MAP

EXPLANATION

950 M.Y.	(diagonal hatch)	FRANKLIN MTN. IGNEOUS ROCKS
950-1000 M.Y.	(stipple)	DEBACA TERRANE
1150 M.Y.	(vertical lines)	GRANITE AND SYENITE
~1250 M.Y.	(horizontal lines)	CARRIZO MOUNTAIN GROUP
1350 M.Y. & OLDER	(dark)	CHAVES GRANITIC TERRANE
	o²	WELL REACHING BASEMENT SEE APPENDIX 2

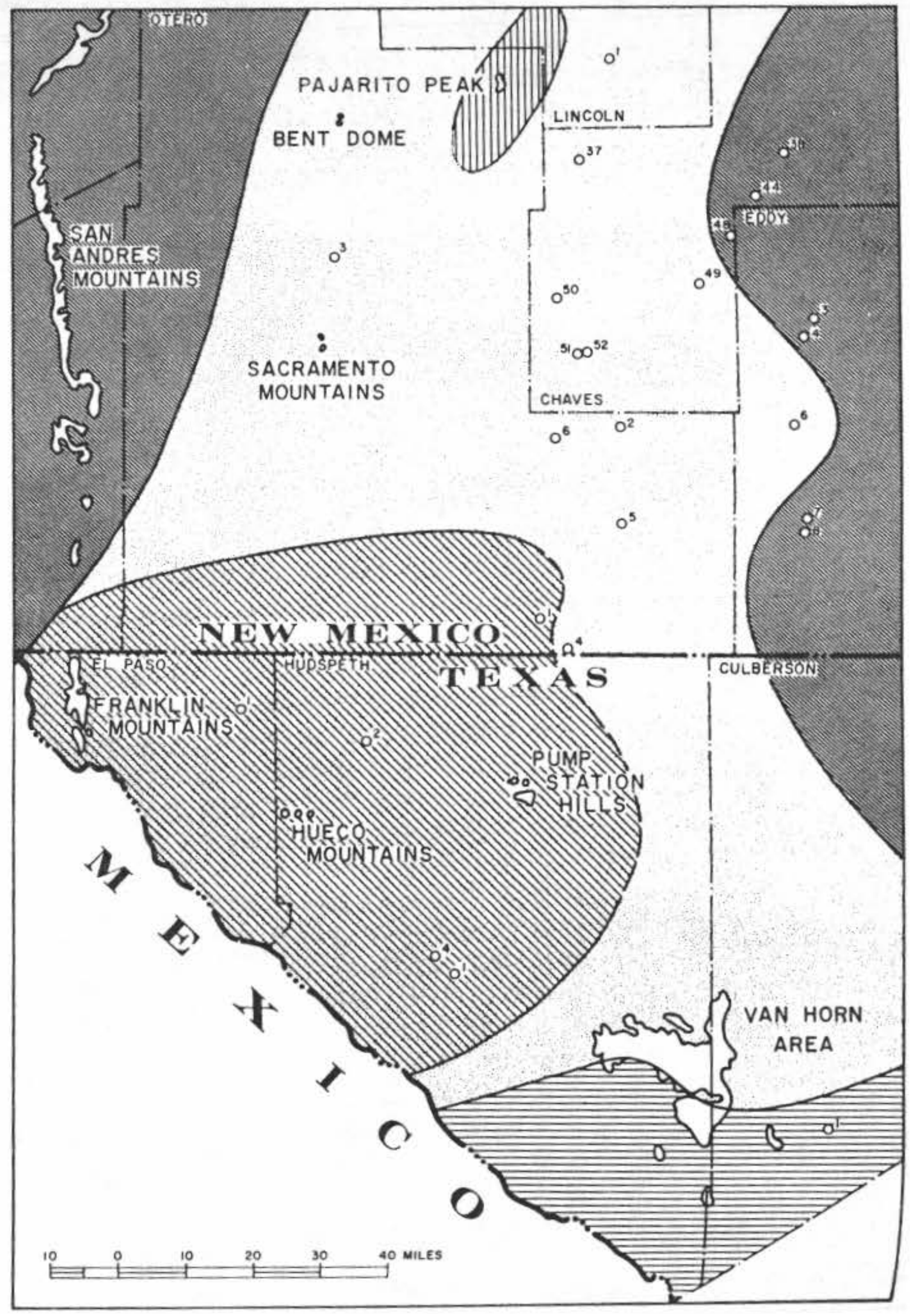


FIGURE 3

at the least. On the basis of our experience and considering the data, we believe this unlikely.

The isotopic ages determined on the rocks at Pajarito Peak in Otero County are interpreted to separate these rocks from those surrounding them. No trace of the 1140 to 1180 m.y. age or rock type can be found in the subsurface surrounding the Peak. The age is common to the east in eastern Eddy, Chaves, and Lea counties. We interpret this outcrop to be the westernmost known occurrence of this rock age in southern New Mexico. The outcrop is also significant because all the younger Precambrian sediments of the DeBaca Terrane are absent, whereas they are demonstrably thick nearby. Thus, by nondeposition or, more likely, by erosion during the lower Paleozoic, these sediments are no longer present from this structural high. Probably part of the Pedernal uplift affected sedimentation during Late Paleozoic time.

The period of 950 to 1000 m.y. saw the last major Precambrian activity. This is manifested in a variety of ways. The lowest stratigraphic unit that can be demonstrated is a carbonate rock sequence, the Castner–Allamore Marble. What these marbles rest upon or are underlain by is not known, for the base is nowhere exposed. This thick carbonate rock deposition was accompanied locally by diabase intrusions and basic volcanic rocks. The carbonate rocks were followed by a thick clastic sequence of variable composition. Pure sandstones, arkoses, shales, and conglomerates are found in the subsurface DeBaca Terrane, Hazel Formation, and Llanoria Quartzite. Diabases and basalts are common in the subsurface DeBaca Terrane but are not found on the outcrop in the Hazel–Llanoria. Movement had already begun in Hazel time, as evidenced by the abundant clasts of Allamore in the conglomerates of the Hazel Formation. This movement culminated with essentially synchronous igneous intrusions with pegmatite formation. The movement led to the Steeruwitz thrust with the older Carrizo Mountain Group rocks and associated younger intrusions being ramped over the Hazel–Allamore sequence.

To the west in the Franklin Mountains, activity was far less intense. Conglomerates present in the Llanoria are relatively minor. Widespread rhyolites were extruded, probably many of which were welded tuffs. The rhyolites provided a cover for the intrusion of comagmatic granites. This igneous activity was passive and relatively dry, as talc is sparse or absent in the Castner but diopside is common. A significant shearing component is not reflected in the metasedimentary sequence; the rocks are simply converted to hornfels.

To the north, the rocks of the DeBaca Terrane were being deposited. These were mostly impure sandstones and shales with abundant diabase and basalt. Limestones are not penetrated north of a line through central Otero County, probably through nondeposition. North of this arbitrary line, the rocks are characteristically unmetamorphosed. This reflects the absence of major igneous activity equivalent to that in the Franklin Mountains. The exception is at Bent Dome where a quartzite similar to the Llanoria is intruded by a finely micrographic granite. However, intrusions do not appear to be common, and the rocks of the DeBaca Terrane are only locally converted to hornfels but not regionally metamorphosed. The Franklin Mountain granite-rhyolite sequence is easily separated from the other rock units on the basis of petrography and age; however, it is difficult to define in terms of areal distribution. It is shown on the basement rock map as a distinct area, but one should recongize that this represents only that part of Texas and New Mexico where the granite-rhyolite sequence is most likely to occur. Areas outside that shown may be covered by rhyolite or have breached granite intrusions on the basement surface that are Franklin Mountain equivalents. Conversely, areas within the mapped area may have Van Horn Sandstone covering the rhyolite or granite, or the rhyolite may be removed by erosion to expose the underlying DeBaca Terrane.

The period between 950 m.y. and the Cambrian was marked by some differential movement and erosion that exposed the more deeply emplaced granites. The amount of uplift, folding, and faulting during this period is relatively small, as evidenced by the roughly conformable or mildly disconformable relationship between lower Paleozoic and the Precambrian layered sequences in the Franklin, Sacramento, and San Andres mountains.

CONCLUSION

This area, about 180 miles (290 kilometers) long and 130 miles (210 kilometers) wide, is one of the best in the United States to show very close correspondence between scattered Precambrian outcrops and intervening basement control from drill holes. The basement evolution can be developed using petrography and geochronology, though not so precisely as might be hoped in every instance. We believe any vagueness can be resolved by further, detailed work. The two main problems not resolved to our satisfaction are the possible "real" age of extrusion-deposition of the Carrizo Mountain Group and the complex San Andres Mountain Precambrian sequence, about which very little is known.

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TABLE 1. Rb/Sr AGES FOR SAMPLES IN FAR WEST TEXAS AND SOUTH-CENTRAL NEW MEXICO (cont)

NO. FRAC-TION	Rb (ppm)	Sr (ppm)	Rb/87 Sr 86	Sr87 Sr86	AGE	ROCK TYPE AND LOCATION
*770F	118.5	127.6	2.68	0.7475	990±50	Quartz syenite, pyroxene bearing. Dam spillway at base of Fusselman Canyon
788W	126.1	145.77	2.50	0.7420	915±50	Rhyolite porphyry. Middle part of the Franklin Mountain Rhyolite in Fusselman Canyon
789W	179.4	21.5	24.1	1.032	905±20	Rhyolite porphyry. Upper part of the Franklin Mountain Rhyolite on western dip slope opposite Fusselman Canyon
789F	375.7	21.2	51.2	1.430	950±15	
1064F	929.1	11.1	241.4	4.060	935±15	Granite. East of Tom Mayes Park at prospect pit in narrow part of Canyon
1063W	263.7	15.7	48.5	1.407	970±20	Metarhyolite porphyry. East of Tom Mayes Park east of sample 1064
1065F	442.3	2.67	477.5	7.378	980±15	Granite. McKelligon Canyon about 1000 m from end of road on southwest side of road
1066W	216.5	26.1	23.9	1.030	910±20	Metarhyolite porphyry. McKelligon Canyon near the end of the road at head of canyon
1066F	323.5	55.1	16.9	0.9452	940±15	
830F	446.5	27.1	47.6	1.394	970±15	Granite. Tin Mine locality about 2 miles north of North Franklin Mountain
					VAN HORN AREA	
739W	22.4	22.9	28.0	1.132	1040±40	Metarhyolite porphyry. Carrizo Mountains 3800′ N 30° 02′30″ N
	218.7	22.3	28.4	1.137	1040±40	5500′W of 105°55′W. The sample is highly muscovitic
741W	157.5	36.8	12.4	0.9381	1290±60	Metarhyolite porphyry. Carrizo Mountains, 4100′ N 31° 82′ 30″ N, 7200′W of 105° 55′ W
744W	178.1	49.7	10.4	0.8997	1290±80	Metarhyolite porphyry. Carrizo Mountains, Gifford-Hill Quarry 8500′N 30° 02′ 30″N, 1000′ W 105° 57′ 30″
748F	326.0	38.5	24.4	1.051	950±15	Rhyolite porphyry. Sierra Diablo, 10080′N 30° 5′, 3800′E 105° 2′30″ W. The sample is related to Franklin Mountain samples and is a dike in the Allamore Formation
758W	168.3	39.3	12.4	0.9275	1240±60	Metarhyolite porphyry. Carrizo Mountains, 900′N 31° 2′30″ 5300′ W 104° 57′ 30″
759W	122.3	80.8	4.36	0.7793	1220±200	Metarhyolite porphyry. Carrizo Mountains same location as 758

TABLE 1. Rb/Sr AGES FOR SAMPLES IN FAR WEST TEXAS AND SOUTH-CENTRAL NEW MEXICO (cont)

NO. FRAC-TION	Rb (ppm)	Sr (ppm)	Rb/87 Sr 86	Sr87 Sr86	AGE	ROCK TYPE AND LOCATION
761W	33.4	43.3	2.23	0.7520	1640±450	Metarhyolite porphyry. Wylie Mountains, location C-5 on the map of Flawn (in King and Flawn, 1953)
762W	137.7	38.6	10.3	0.8753	1140±100	Metarhyolite porphyry. Wylie Mountains, same as 761
				PAJARITO PEAK		
723F	1381.	9.96	400.3	7.472	1135±15	Riebeckite granite. Pajarito Peak, on boundary of sections 25 and 26 12S-15E, Otero County, New Mexico
				SUBSURFACE		
600F	372.7	44.3	24.3	1.008	840±15	Micrographic granite. Gulf No. 1 Burner State, Hudspeth County, Sec. 14. Blk. 19, PCL Sur., core at 9222′
607F	263.2	249.6	3.04	0.7674	1350±30	Granite. Humble No. 1 Huapache, Eddy
607B	634.8	11.7	156.7	3.767	1310±20	County, 35-235-22E. Core at 12616′

*F = feldspar

TABLE 2. K/Ar AGES FROM AMPHIBOLES AT PAJARITO PEAK, OTERO COUNTY, NEW MEXICO

SAMPLE NO.	SAMPLE WT (gms)	PERCENT K	Ar 40* MOLES X10-9	Ar 40* Ar 40 TOTAL	AGE	ROCK TYPE
723	0.158	1.391	0.631	0.97	11.70 25	Riebeckite granite
724	0.167	1.297	0.641	0.95	1190 25	Syenite pegmatite

TABLE 3. ROCKS OF THE FRANKLIN MOUNTAINS AND VAN HORN AREA

AGE (m.y.)	FRANKLIN MOUNTAINS	VAN HORN AREA	SUBSURFACE LITHOLOGY
–950	----	VAN HORN SANDSTONE	----
	GRANITE	GRANITE AND PEGMATITE	GRANITE
	RHYOLITE	RHYOLITE INTRUSIVES	RHYOLITE
	LLANORIA QUARTZITE	HAZEL FORMATION	QUARTZITE
950-1000		POSSIBLY REPRESENTED BY	
	MUNDY BRECCIA	BASIC VOLCANIC ROCK	DIABASE
		IN THE ALLAMORE	
	CASTNER MARBLE	ALLAMORE	MARBLE
1250	----	CARRIZO MOUNTAIN GROUP	SCHIST

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APPENDIX A

ANALYTICAL PROCEDURES

The strontium measurements were determined on a 13-inch radius, 60-degree magnetic sector, 15.8-inch radius, 91-degree electric sector, second order double-focusing mass spectrometer.

The rubidium measurements were made on a symmetric 6-inch, 60-degree, single-focusing Nier-type mass spectrometer. Separate strontium measurements were made on spiked and unspiked aliquots. The unspiked strontium 87/86 measurements were normalized to Nier's value of $Sr^{86}/Sr^{88} = 0.1194$. Separations were made on an ion-exchange column and identified by using Sr^{85} and Rb^{83} tracers. The analytical precision based on replicate analysis is estimated to be ± 0.2 percent for isotope ratio measurements and ± 1 percent for both Rb and Sr concentrations. Our results compare favorably with published standards (*see* Lanphere and Dalrymple, 1967).

The argon measurements were made on a 4.5-inch Reynolds-type mass spectrometer. The samples were fused by induction coil heating in tungsten or columbium crucibles and purified through (1) dry ice, (2) copper oxide at 600°C. (3) liquid nitrogen, and (4) calcium at 900°C and then absorbed on charcoal at liquid-nitrogen temperature in a break seal. A typical blank is about 10^{-11} moles of atmospheric argon; the best are about 4×10^{-12} moles.

The constants used to compute the ages are

$$Rb^{87} \ \lambda_{\beta} = 1.47 \times 10^{-11}/\text{yrs}$$
$$Rb^{87} = 0.283 \text{ gm/gm Rb}$$
$$K^{40} \ \lambda_{\varepsilon} = 0.585 \times 10^{-10}/\text{yrs}$$
$$\lambda_{\beta} = 4.72 \times 10^{-10}/\text{yrs}$$
$$K^{40} = 1.22 \times 10^{-4} \text{ gm/gm K.}$$

APPENDIX B

The following are brief summaries of samples drilled to basement in the areas shown in Figure 1. The wells are numbered within each county. The numbers in New Mexico are the same as those used by Foster and Stipp (1961). The Texas numbers follow Flawn with additions for newer wells.

CULBERSON 1

Cosden No. 1 Cockrell, sec. 7, blk. 80, PSL Survey. Cuttings at 3210 to 3356 ft. The rock is fine-grained biotite granite gneiss, most of which is composed of microcline, plagioclase, and quartz in a granoblastic mosaic varying in grain size. Fresh olive-green biotite books show a high degree of preferred orientation parallel to grain size banding. It is interpreted as a metaigneous rock of granitic composition. Possibly, it is equivalent to the metarhyolites of the Carrizo Mountain Group, but petrographic evidence is unclear. In any event, the rock is interpreted as being related to the Carrizo Mountain sequence.

EL PASO 1*

Jones No. 1 Sorely, sec. 17, blk. 5, PSL Survey. Flawn (p. 155) reported a quartz diorite in cuttings from 2213-20 ft. The descriptions suggest a rock similar to some found as intrusions within the Castner Marble, but certain differences are apparent and no definite correlation can be made.

HUDSPETH 1*

American Land No. 1 Roseborough, sec. 7, blk. 21, Tws 6, PSL. Flawn (p.167) examined cuttings from two intervals, 1600-10 ft. and 1625-1787 ft., and described a rhyolite porphyry. The rhyolite is interpreted here as being equivalent to the Franklin Mountain Rhyolite.

HUDSPETH 2*

California No. 1 Theison, sec. 19, blk. E. Univ. Lands. Flawn (p. 169) described a micrographic granite in cuttings from 4844-48 ft. The well was drilled about 20 miles north of granite cropping out in the Hueco Mountains. The granite described in the well is interpreted as equivalent to that in the Hueco and Franklin mountains.

HUDSPETH 4

Gulf No. 1 Burner State, sec. 14, blk. 19, PSL. A core taken at 9222 ft. is a micrographic granite porphyry. The feldspar yielded an age of 840 ± 15 m.y., which is below the age of granites of the Red Bluff type. However, petrographic similarity prompts us to consider it equivalent to the granite in the Hueco and Franklin mountains. The age is possible too low because of alteration in the feldspar.

CHAVES 3‡

Humble No. 1 State N, 35-14S-17E. Muehlberger and Denison described five intervals from 2610 to 4010 ft. The well penetrated a sequence of quartzite, arkose, and olivine basalt, which comprise part of the DeBaca Terrane.

CHAVES 38‡

Magnolia No. 1 Turney, 23-14S-22E. Four intervals from 4920 to 5340 ft. were described by Muehlberger and Denison. The well penetrated diabase and a gneissic granitic rock. The petrography is not clear-cut, but the granitic rock is probably part of the Chaves Granitic Terrane and the diabase probably equivalent in age to those in the DeBaca Terrane.

CHAVES 44 ‡

Humble No. 1 Gorman, 30-15S-22E. An interval at 5805-25 ft. is in a banded granitic gneiss, part of the Chaves Granitic Terrane.

CHAVES 48 ‡

Black No. 1 Shildneck, 24-16S-20E. Four intervals from 6740 to 6990 ft. were examined. The upper interval penetrated a granite gneiss, the lower three were in diabase. The gneiss is part of the Chaves Granitic Terrane; the lower diabase is probably equivalent to those in the DeBaca Terrane.

CHAVES 49 ‡

Magnolia No. 1 Black Hills Unit, 31-17S-20E. Three intervals from 5915 to 6085 ft. penetrated quartzitic and arkosic sandstones and argillaceous siltstones of the DeBaca Terrane.

CHAVES 40‡

Gulf No. 1 Chaves "U", 10-18S-16E. One core interval at ±

* Described by Flawn, but the interpretation here does not necessarily agree.

† Described by Muehlberger and Denison.

‡ Described by Flawn and by Muehlberger and Denison. Those not marked are described here for the first time.

3100 ft. was interpreted as an enigmatic, slightly metamorphosed rock of clastic sedimentary origin by Muehlberger and Denison. In this interpretation, the rock would be related to those in the DeBaca Terrane.

CHAVES 51‡

Sun No. 1 Pinon Unit, 19-19S-17E. Four intervals from 1732 to 1911 ft. all penetrated altered albite andesite porphyry. The rock is probably related to those in the DeBaca Terrane.

CHAVES 52‡

Sun No. 2 Pinon Unit, 20-19S-17E. One interval at 1650-59 ft. was in a meta-albite andesite. The rock is similar to that in Chaves 51 and is related to those in the DeBaca Terrane.

EDDY 3*

Southern Union No. 1 Elliot, 24-18S-23E. One core interval at 9886-87 ft. was in a foliated granite. The rock may be simply a granite gneiss. The well penetrated part of the Chaves Granitic Terrane.

EDDY 4†

Magnolia No. 1, Tres Rancho Unit, 10-19S-23E. The only interval examined, 10,000 to 10,010 ft., was interpreted as a banded granite gneiss related to the Chaves Granitic Terrane.

EDDY 6‡

Magnolia No. 1, State "W", 16-21S-22E. Three intervals from 11230 to 11312 ft. were interpreted as a quartzite intruded by an albite diabase later metamorphosed to lower greenschist facies or hydrothermally altered. The rocks are part of the DeBaca Terrane.

EDDY 7

Humble No. 2, Huapache, 23-23S-22E. A biotite granodiorite was penetrated from 12570 to 12580 ft. The rock is petrographically very similar to Eddy 8, although somewhat different in bulk composition. The rock is part of the Chaves Granitic Terrane.

EDDY 8

Humble No. 1 Huapache, 35-23S-22E. A core taken at 12629 ft. was a biotite granite. The biotite yielded an Rb/Sr age of 1310 ± 20 m.y. and the feldspar an age of 1350 ± 30 m.y. The granite is part of the Chaves Granitic Terrane.

LINCOLN 1†

Stanolind No. 1 Picacho, 10-12S-18E. Two intervals from 2538 to 2759 ft. penetrated a feldspathic sandstone. The rock is part of the DeBaca Terrane.

OTERO 1*

Hunt No. 1 McMillan–Turner, 5-26S-16E. Two intervals from 1887 to 2060 ft. were diabase, two lower intervals from 2860 to 2170 ft. were in rhyolite porphyry. The rhyolite is probably related to the Franklin Mountain Rhyolite and the diabse to that in the DeBaca Terrane. The petrographic-geometric relationship suggests that the diabase is younger than the rhyolite, but this is not unequivocal.

OTERO 2‡

Standard of Texas No. 1 Scarp, 18-21S-18E. Diabase was penetrated in two examined intervals from 2630-2660 ft. The rock is related to the DeBaca Terrane.

OTERO 3†

Southern Union No. 1 Cloudcroft, 5-17S-12E. Fourteen thinsections were examined in the interval from 4520 to 4702 ft. These showed a quartzite and argillaceous quartzite cut by diabase dikes. The rocks are part of the DeBaca Terrane.

OTERO 4

Turner No. 1 State, 36-25S-16E. Nineteen thinsections were examined from 3115 to 5195 ft. The sequence was diabase with alternate talc-tremolite marble intruded by a sill of granite. The well was abandoned in micrographic granite porphyry at 5195 ft. The sequence is a remarkable parallel to the lower part of the section in the Franklin Mountains.

OTERO 5

Coral No. 1 Warren, 19-23S-18E. Cuttings taken at 2300 to 2330 ft. show an olivine diabase. The rock is probably related to those of the DeBaca Terrane.

OTERO 6†

LeFores No. 1 Federal, 22-21S-16E. The well penetrated diverse metamorphic rocks. In the interval from 2230 to 2250 ft., four thinsections showed a marble with wollastonite, garnet, tremolite, and calcite. The origin of the rock is contact metamorphism of an impure limestone. The rock is probably related to the Allamore–Castner sequence.

Cambrian–Ordovician in El Paso Border Region

by David V. LeMone
University of Texas at El Paso

ABSTRACT

The Cambrian–Ordovician of El Paso border region is represented by two basic rock units. The lower unit (Late Cambrian(?)–Early Ordovician) consists of Bliss Sandstone and El Paso Group and is time-transgressive; it is older in the west and younger in the east. Detailed stratigraphic and paleontological studies reveal a complex series of transgressions and regressions rather than a simple west-to-east transgression.

The lower unit is thickest in the south; it thins to a feather edge in central New Mexico.

The upper unit (Montoya Group–Upper Ordovician) is separated from the lower by a profound regional angular unconformity. The Montoya Group consists of four basic units that have been correlated by Flower from El Paso area to northern Greenland. These include an unnamed, sporadically occurring sandstone (Harding–Winnipeg erosion remnants); the Upham Formation, including the basal, locally developed Cable Canyon Sandstone (Red River); the Aleman Formation (Lower Richmond); and the Cutter Formation (Upper Richmond). All four units are separated by regional disconformities.

ROCK SEQUENCES

The Cambrian and Ordovician rocks of the El Paso border region are divided into two major lithologic units, a lower sequence consisting of the Bliss Sandstone and the El Paso Group, and an upper sequence consisting of the Montoya Group. The two sequences are divided into twelve formations that are present in the southern Franklin Mountains (from oldest to youngest): Bliss Sandstone; El Paso Group (Sierrite Formation, Cooks Formation, Victorio Hills Formation, José Formation, McKelligon Canyon Formation, Scenic Drive Formation, and the Florida Mountains Formation); and the Montoya Group ("Harding–Winnipeg" Sand, Upham Formation (including a basal Cable Canyon Sandstone equivalent), Aleman Formation, and Cutter Formation).

BLISS SANDSTONE

The Bliss Sandstone (Richardson, 1909; 1904) rests with apparent nonconformity on a Precambrian surface of low to considerable relief. Richardson (1909, p. 3, 7) reported that the contact between the Bliss and the underlying granite is intrusive and post-Carboniferous in age. Further work is in progress (E.M.P. Lovejoy, personal communication, 1968) to determine the relationship between the Bliss and the underlying Precambrian (?), particularly the Red Bluff Granite, which Nelson (1940, p. 160) designated as Precambrian in age. A low Precambrian mountain of rhyolite, lithologically similar to the types discussed by Harbour in the Fusselman Canyon area (1960, p. 1785-1792), exposed on the western slope of South Mount Franklin, protruded above the sea floor and influenced sedimentation until Early Ordovician time (LeMone, Foster, and Kottlowski, 1967). Balk (1958) reported burial of a Precambrian surface of relief varying from 50 to 100 feet (15 to 30 meters) in the Capital Dome area in the Florida Mountains, New Mexico.

The Bliss Sandstone in the Franklin Mountains, 225 to 250 feet (69 to 77 meter) thick, has been divided into two members (LeMone, 1966a). In the southern Franklin Mountains, the lower member is quartzitic, contains a few shaly partings, and is a coarse- to fine-sand-size quartzite that weathers dark red. It is overlain by the glauconitic member, which is composed of glauconitic-hematitic, cross-bedded quartzite that weathers to a dark reddish green. Brachiopod fragments have been observed along the planes of the cross-bedding in this member; they are too poorly preserved to be recovered. The glauconite probably formed from fecal pellets in much the same manner as suggested by Lewis (1962, p. 26-27).

The age of the Bliss Sandstone is not clearly established in the Franklin Mountains. *Lingulepsis* aff. *walcotti* Resser has been collected from approximately 80 feet (24 meters) below the top of the Bliss Sandstone by Cloud and Barnes (1958, p. 369). *Lingulepsis* aff. *walcotti* has been found in the Bliss Sandstone at Beach Mountain in Culberson County, Texas, in association with Ordovician cephalopods and gastropods (Cloud and Barnes, p. 369). Richardson (1909) recovered *Lingulepsis acuminata* from the Bliss Sandstone, and, on the basis of this inarticulate brachiopod, assigned a Cambrian age to the Bliss Sandstone.

Brachiopods are sporadically distributed in lenses in the Bliss Sandstone. The recoverable brachiopods are inarticulates that are generally lingulepisoid.

Several zones of gastropods are present in the southern

Franklin Mountains sequence. Those in the Bliss Sandstone have "*Sinuopea*-like" characteristics that would associate them with strata of Canadian age.

Fucoids in the Bliss Sandstone are formed in eleven beds in the McKelligon Canyon Park area in the southern Franklin Mountains. Vertical (*Scolithus* and *Sabellariflex*-like forms), straight, angular (45°), and horizontal tubes are observed in El Paso section.

Trilobites, which are sporadic in their distribution in the Bliss Sandstone of New Mexico and west Texas, have not been found in the Franklin Mountains. Several spinelike fossils of uncertain affinity have been collected from a zone about 21 feet (6 meters) above the base of the Bliss Sandstone. Similar undescribed fossils occur in rocks of both Trempealeau and Gasconade age (Flower, personal communication, 1966).

EL PASO GROUP

The type El Paso Limestone as defined by Richardson (1904) includes all the limestone of Ordovician age exposed in the Franklin Mountains. Richardson (1909) divided El Paso Limestone into two formations: El Paso Formation, which includes only rocks of Lower Ordovician, and Montoya Formation, overlying Ordovician sediments.

Kelley and Silver (1952, p. 41) raised El Paso Formation to group status and subdivided it in New Mexico into two formations: the lower Sierrite Limestone and the upper Bat Cave Formation. These units cannot be recognized in the southern Franklin Mountains for several paleontological and lithologic reasons (Flower, 1964, p. 148).

Kelley and Silver (p. 52) recognized the north-south regional angular unconformity between the El Paso and Montoya Groups. In general, it may be stated that in far west Texas and southern New Mexico, there exists a general and progressive thinning of El Paso Group from south to north as the result of erosion of the upper part. In central New Mexico, El Paso Group is absent because of erosion (Kottlowski, 1963, p. 15). Examination of the northern eroded edge of El Paso Group indicated that the shoreline was farther to the north.

El Paso Group is time-transgressive from west to east. Kelley and Silver (p. 55) recognized this general west-to-east transgression of the Cordilleran geosynclinal sea during deposition of the Cambrian and Lower Ordovician sedimentary units in Arizona and New Mexico. This transgression can be demonstrated as far east as the Van Horn area in west Texas (Cloud and Barnes, p. 352-360). Sabins (1957, p. 471) presented a simplified diagram of the time-transgressive nature of the Cambrian and Ordovician units in Arizona, New Mexico, and west Texas. Subsequent detailed examination of the sequences by Flower and others indicates, however, that this relationship is a complex one of transgression and regression rather than simple, single transgression.

At the type section in the southeastern Franklin Mountains, El Paso Group represents probably the most nearly complete Canadian section exposed in the northern Chihuahua, New Mexico, and west Texas area.

Flower (1957, p. 17-19) proposed major divisions of the Canadian series into four stages utilizing, in part, New Mexico units with the Ozark standard stages (Twenhofel et al., 1954, Plate 1; table 1, p. 5 this volume, col. 1 and 2). These stage names are (1) Gasconadian–Lower Canadian; (2) Demingian–Middle Canadian; (3) Jeffersonian–Early Upper Canadian; and (4) Cassinian–Late Upper Canadian.

Flower (1964, p. 148-149) designated ten formation names that are well suited for substage designations, as they represent not only distinct rock stratigraphic units on a regional basis but also distinct sequential biostratigraphic-paleontological units (table 1, col. 3). El Paso Group in the southern Franklin Mountains includes seven of these formations (table 1, col. 6).

SIERRITE FORMATION GASCONADE, EARLY CANADIAN LYTOSPIRA–SYMPHYSURINA BREVISPICATA ZONE

The basal unit of El Paso Group is the Sierrite Formation. Flower (1964, p. 146, 148) restricted the Sierrite Formation to the lower thin-bedded limestone with wavy bedding of early Canadian age of the type Sierrite Formation, as originally designated by Kelley and Silver (p. 259). The type section is on the southwestern side of Cable Canyon in the Caballo Mountains, Sierra County, New Mexico (sec. 10, T. 16 S., R . 4 W.).

The Sierrite Formation in the southern Franklin Mountains (121 feet–37 meters-thick) has been divided into two members (LeMone, 1967a). The Transition Zone member, 20 feet (6 meters) thick, rests on the quartzite of the Bliss Sandstone and consists of a cross-bedded, dolomitic sandstone that weathers in bas relief; there are three zones of granitic and quartzitic pebbles and cobbles (up to 3 inches-8 centimeters–in diameter). The upper 4 feet (1.2 meters) of this member develops two distinct edgewise conglomerates, each overlain by a layer of graniticlike pebbles.

The overlying Wavy Bedded member of the Sierrite, 101 feet (31 meter) thick, is composed largely of silt and fine sand with calcarenitic to calcilutitic dolomite. The peculiar wavy bedding observed is probably due to differential solution, compaction, or both. Two relatively pure dolomite units separated by a sandy dolomite, 93 to 98 feet (28 to 30 meters) above the Bliss Sandstone, contain flow cast structure.

Fossils include fucoids, gastropods (five zones, mostly of *Ophileta* or *Ozarkospira persuasion),* and a brachiopod fauna *(Apheroorthis finkelnburgia).* El Paso Group fauna will not be discussed in detail here, because Flower (1969) has already described El Paso Group guide fossils. Fauna and lithology indicate an intertidal to supratidal environment. The Sierrite Formation is equivalent to Cloud and Barnes' Unit A, beds 25-27 (p. 368).

CANADIAN	OZARK STANDARD G.S.A. (1954)	NEW MEXICO-WEST TEXAS STANDARD FLOWER (1957)	NEW MEXICO-WEST TEXAS SUBSTAGE FLOWER (1964)	NEW MEXICO-WEST TEXAS FAUNAL ZONES	COMPOSITE GARDEN CITY-IBEX AREAS UTAH WESTERN U.S. STANDARD HINTZE (1951, 1952), ROSS (1951): ZONE	FAUNA	EUROPEAN STANDARD
LATE UPPER	Odenville-Black Rock	Cassinian	Florida Mountains	Buttsoceras	K (?) J	Hespernomiella minor Pseudocybele nasuta	ARENIG
LATE UPPER	Smithville Powell Cotter	Cassinian	Scenic	Curtoceras	I	Paranileus ibexensis	ARENIG
			Drive	Ceratopea buttsi-hami Ceratopea ankylosa	H	Trigonocerca typica	ARENIG
EARLY UPPER	Jefferson City	Jeffersonian	Mc Kelligon Canyon	Third Piloceroid Second Piloceroid	G-2	Protopliomerops contracta	ARENIG
				McQueenoceras	G-1(?)	Protopliomerops celsaora	ARENIG
MIDDLE	No Apparent Equivalent	Demingian	Snake Hills	Leiostegium-Paranileus	G-1(?)	P. celsaora	ARENIG
			Mud Springs Mountain	Bridgeites	G-1(?) F (?)	P. celsaora P. superciliosa	ARENIG
			José	Bridgeina-Aulacoparia	F E	P. superciliosa Tesselacauda	ARENIG
	Roubidoux		Victorio Hills	First Piloceroid	E	Tesselacauda	ARENIG ?
			Cooks	First Endoceroid	D-2	Leiostegium-Kainella	TREMADOC
	No Apparent Equivalent		Big Hatchet	Leiostegium-Kainella	D-1	Leiostegium-Kainella	TREMADOC
LOWER	Gasconade	Gasconadian	Sierrite (restricted)	Lytospira-Symphysurina brevispicata	C (?) B	Paraplethopeltis Symphysurina	TREMADOC
LOWER	Van Buren	Gasconadian	Bliss	Apheoorthis melita	A(?)	Nanorthis-Bellefontia	TREMADOC

	SOUTHERN FRANKLIN MOUNTAINS EL PASO COUNTY TEXAS	SOUTHERN FRANKLIN MOUNTAINS CLOUD AND BARNES (1948): BEDS	UNITS	APPROXIMATE CENTRAL TEXAS EQUV.
	Florida Mountains Formation	1-6	C	Odenville - Black Rock
EL PASO GROUP	Scenic Drive Formation: Nameless Canyon Member; Black Band Member	7-10	B2b	Post-Honeycut- Pre-Black Rock
EL PASO GROUP	Mc Kelligon Canyon Formation	11-14	B2a	
EL PASO GROUP	Mc Kelligon Canyon Formation	15	B1	Honeycut
EL PASO GROUP	Pistol Range Member	16 and upper 17	B1	Honeycut
EL PASO GROUP	Missing			
EL PASO GROUP	José Formation	lower 17 and 18	B1	Honeycut (?)
EL PASO GROUP	Victorio Hills Formation	19-22	A	Gorman
EL PASO GROUP	Cooks Formation	23-24	A	Gorman
EL PASO GROUP	Missing (?)			
EL PASO GROUP	Sierrite Formation (restricted)	25-27	A	Gorman Tanyard (?)
	Bliss Sandstone	Tanyard		

Table 1
LOWER ORDOVICIAN CORRELATION

BIG HATCHET FORMATION DEMINGIAN, MIDDLE CANADIAN LEIOSTEGIUM–KAINELLA ZONE

The Big Hatchet Formation was named by Flower (1964, p. 148) for a massive dolomite and interbedded shales sequence in the Big Hatchet Mountains. This formation is not recognizable in the Franklin Mountains. Either it is represented by another facies or it may be absent because of nondeposition or erosion or both. The type section is on the northwestern side of Mescal Canyon in the northern Big Hatchet Mountains, Hidalgo County, New Mexico (SW¼ sec. 29, T. 30 S., R. 15 W.). The stratigraphy has been described by Zeller (1965, pl. 1, 2; p. 17, 79).

The Big Hatchet Formation may be equivalent to the *Apheoorthis finkelnburgia* Zone (discussion in Flower, 1969). The Big Hatchet Formation has been recognized only in the Big Hatchet Mountains and the Victorio Mountains in southwestern New Mexico.

COOKS FORMATION DEMINGIAN, MIDDLE CANADIAN FIRST ENDOCEROID ZONE

The Cooks Formation was named by Flower (1964, p. 148) for the ghost town of Cooks, 12 miles (19 kilometers) north of Deming. The type section is on the northern end of the Cooks Range in Luna County, New Mexico (sec. 11, T. 20 S., R. 9 W.). Kuellmer's (1956) Hillsboro quadrangle map and Jicha's (1954) study of the Lake Valley quadrangle give the general geologic setting of the type section area.

The Cooks Formation in the Franklin Mountains is 109 feet (33 meters) thick and thus thicker than the carbonate rock sections in New Mexico, which do not exceed 80 feet (24 meters) (Flower, 1969). In the southern Franklin Mountains the basal unit contains a pebble conglomerate of rock fragments and black pebbles in a dolomitic matrix. However, the formation consists largely of calcarenitic dolomites. A large fauna of nautiloids has been collected from this formation. Nautiloids, pelmatozoan fragments, brachiopods, and gastropods are the main faunal elements of the Cooks Formation.

Three supratidal to intertidal algal stromatolites are developed in this section. Paleoecological studies of the uppermost stromatolite have revealed eighteen demonstratable disconformities in 20 feet (6 meters) of section (LeMone, 1967a). The Cooks Formation represents an intertidal to very shallow subtidal environment and is equivalent to Unit A, beds 23 and 24, of Cloud and Barnes (p. 367-368).

VICTORIO HILLS FORMATION DEMINGIAN, MIDDLE CANADIAN FIRST PILOCEROID ZONE

The name *Victorio Hills Formation* replaces *Victorio Formation* (Flower, 1964) because of pre-emption of the name *Victorio* (G. V. Cohee, personal communication, 1968). The Victorio Hills Formation was designated by Flower (1964, p. 148) for a well-exposed and thick section in the Victorio Mountains, approximately 3 miles (5 kilometers) south of Gage, New Mexico. The type section is in the East Hills of the Victorio Mountains, Luna County, New Mexico (SE¼NE¼ sec. 28, T. 24 S., R. 12 W.). A detailed geologic map of the Victorio Mountains was made by Kottlowski (Griswold, 1961, pl. 3).

In the Franklin Mountains, the Victorio Hills Formation is about 290 feet (88 meters) thick, which is considerable more than in the New Mexico sections where it is usually less than 100 feet (30 meters) thick (Flower, 1969). The Victorio Hills Formation consists largely of fossiliferous, nearshore carbonate rocks. In the southern Franklin Mountains, the base of the formation is the first limestone developed up from the base of El Paso Group.

The main elements of the fauna of the Victorio Hills Formation are gastropods, pelmatozoan fragments, brachiopods, and nautiloids. The oldest piloceroid in El Paso section has been recovered from the basal portion of the formation.

The Victorio Hills Formation is predominantly a shallow-water marine deposit of greater depth than the underlying nearshore to supratidal Cooks Formation. The Victorio Hills Formation is the approximate equivalent of Unit A, beds 19-22 of Cloud and Barnes (p. 366-367).

JOSÉ FORMATION DEMINGIAN, MIDDLE CANADIAN BRIDGEINA–AULACOPARIA ZONE

The José Formation was named for the José mining district in the Cooks Range (Flower, 1964, p. 148). The type section is located in sec. 11, T. 20 S., R. 9 W., Luna County, New Mexico (Kuellmer). The José Formation forms a distinct dark oolitic band in the gray to light-gray rocks of El Paso Group.

In the southern Franklins, the José Formation is 72 feet (22 meters) thick and is divided into two members (LeMone, 1968). The lower Cyclic member, which is 54 feet (16 meters) thick, disconformably overlies the Victorio Hills Formation. It reflects an intertidal environment (digitate algae) alternating with sand. Seventeen cycles are recognizable in this member, with each cycle consisting of a basal sand, cross-bedded in part and overlying digitate stromatolites with associated fossiliferous arenaceous surge channel deposits. The digitate algae are similar to those reported by W. B. Howe (1966) from southeastern Missouri Ordovician. The upper Barren member is 18 feet (5.5 meters) thick and consists of cross-bedded sand with lutitic stringers. Howe's (1966) interpretation of the paleocology of the digitate algae seems to be reasonably consistent with the evidence preserved in the José Formation in the Franklin Mountains. The José Formation indicates repeated shifting of shallow-water environments across wide areas. The lateral largely oolitic character of the formation indicates slightly deeper but still very shallow water conditions. Rocks in this formation have a strong fetid odor.

Silicified gastropods, brachiopods, pelmatozoan fragments, and slender nautiloid siphuncles occur in the arenaceous surge channels. The José Formation is approximately equivalent to Unit A, bed 18 and subunit B_1, lower bed 17 of Cloud and Barnes (p. 366).

MUD SPRINGS MOUNTAIN FORMATION DEMINGIAN, MIDDLE CANADIAN BRIDGEITES REEF ZONE

The Mud Springs Mountain Formation is not recognized in the southern Franklins, where it is believed to be absent because of either nondeposition or erosion. Flower (1964, p. 148) named the formation for its exceptional exposure and development on the southwestern flank of Mud Springs Mountain, Sierra County, New Mexico (sec. 25, T. 13 S., R. 2 W.). Kelley and Silver (p. 251, pl. I) showed the location and gave the general lithology of the section, which is located north and west of Truth or Consequences, New Mexico. The formation consists of 20 to 30 feet (6 to 9 meters) of cherty, cliff-forming, stromatolitic limestone that generally weathers to a light color (Flower, 1969). The only common fossil is a large flat gastropod 2.5 to 4 centimeters across.

SNAKE HILLS FORMATION DEMINGIAN, MIDDLE CANADIAN LEIOSTEGIUM–PARANILEUS ZONE

The Snake Hills Formation is not recognized in the Franklin Mountains, where it is believed to be absent because of either nondeposition or erosion. The formation was named by Flower (1964, p. 148) for the largely thin-bedded calcilutites that overlie the cliff-forming Mud Springs Mountain Formation. Gastropods, locally abundant and small, are not readily extracted in identifiable condition. Trilobites are rare. The type section is exposed in the Snake Hills about 10 miles (16 kilometers) southwest of Deming and 4 miles (6 kilometers) south of Red Mountain in Luna County, New Mexico(sec. 33, T. 24 S., R. 10 W.). The observed maximum thickness of this formation is 60 feet (18 meters) in the Cooks Range (Flower, 1969).

MCKELLIGON CANYON FORMATION JEFFERSON CITY, EARLY UPPER CANADIAN MCQUEENOCERAS-SECOND PILOCEROID ZONE THIRD PILOCEROID ZONE

The McKelligon Canyon Formation is about 675 feet (205 meters) thick and was named by Flower (1964, p. 148). It is exposed in dip slopes on the east side of McKelligon Canyon, but the type locality of the formation is to the south and west of McKelligon Canyon above the Scenic Drive in El Paso. The base of the McKelligon Canyon Formation type section is 1 mile (1.6 kilometers) west and 1500 feet (460 meters) south of the intersection of longitude 106° 27′ 30″ and latitude 31° 47′ 30″ (El Paso, Texas, 7.5-minute quadrangle, 1955). It is most easily reached by driving west on Scenic Drive and stopping at the first canyon south and west of the quarry in which the Police Academy is located.

The lower 70 or 80 feet (21-24 meters) are designated the Pistol Range member. This member has a distinctive basal sand that varies from 2 to 5 feet (0.6 to 1.5 meters) in thickness. It is principally intertidal to supratidal in origin and contains several stromatolitic units. A detailed paleoecological study of a part of the Pistol Range member, about 70 feet (21 meters) above the base, has revealed five depositional phases in a 2-foot (0.6 meters) vertical exposure, including two periods of stromatolitic growth and four phases of subaerial and/or subaqueous erosion (LeMone, 1967b). The Pistol Range member probably is equivalent to subunit B_1, upper part of bed 17 and bed 16 of Cloud and Barnes (p. 366).

Above the Pistol Range member, the McKelligon Canyon Formation is largely a carbonate rock sequence containing numerous *Pulchrilamina* mounds. The fauna and paleoecology of these stromatolitic-like mounds and similar mounds in southern Oklahoma have been described in considerable detail by Toomey and Ham (1967) from exposures in the Franklin Mountains and the Wichita and Arbuckle mountains. The mounds were wave-resistant structures with surge channels submerged in very shallow water.

Nautiloids, sponges, especially *Archaeosouphia* and *Calathium* (Toomey, 1964), gastropods, trilobite fragments, pelmatozoan fragments, and brachiopods are the most common faunal elements observed in association with the *Pulchrilamina* in the mounds. That part of the McKelligon Canyon Formation above the Pistol Range member is equivalent to subunit B_1, beds 15 and 16 and all of subunit B_2a, beds 11 through 14 of Cloud and Barnes (p. 365-366).

SCENIC DRIVE FORMATION CASSINIAN, LATE UPPER CANADIAN CERATOPEA ZONES–CURTOCERAS ZONE

The Scenic Drive Formation was named by Flower (1964, p. 149) for a sandy dolomite, dolomite, and limestone sequence that is equivalent to subunit B_2b, beds 7 through 10 of Cloud and Barnes (p. 365-366). The type locality of this formation is directly above the type section of the McKelligon Canyon Formation. The base of the section can be seen in an arroyo north of Scenic Drive about 1000 feet (305 meters) northeast along the Drive from the bench mark at Scenic Point.

The Scenic Drive Formation, which is 288 feet (88 meters) thick, is divided into the Black Band Dolomite member and the overlying Nameless Canyon member. The Black Band Dolomite rests disconformably on the McKelligon Canyon Formation.

The basal part of the Scenic Drive Formation is composed of very coarse-grained, slightly dolomitic sandstone, which represents the first major sand unit above the base of the McKelligon Canyon Formation, more than 600 feet (180 meters) lower stratigraphically, in El Paso Group. The Black Band Dolomite member about 60 feet (18 meters) thick, contains several dark bands within the dolomite. This member has two well-developed faunal zones, a lower

Ceratopea aynklosa Zone and an upper *Ceratopea buttsi* and *hami* Zone.

The Nameless Canyon *(Curtoceras* Zone) member is largely made up of calcilutitic limestones. Chert in the upper part of the member weathers orange and, on the dip slope, it is difficult to distinguish from overlying units of the Florida Mountains Formation.

Silicified brachiopods and gastropods, including operculi *(Ceratopea),* have been recovered from the formation. Trilobites, nearly always fragmental, pelmatozoan fragments, gastropods, nautiloids, and sponges make up the remainder of the main faunal elements.

FLORIDA MOUNTAINS FORMATION CASSINIAN, LATE UPPER CANADIAN BUTTSOCERAS ZONE

The name *Florida Mountains Formation* replaces *Florida Formation* because the name *Florida* has been pre-empted (G.V. Cohee, personal communication, 1968). The Florida Mountains Formation was named by Flower (1964, p. 149) for rocks exposed in the (type locality) east-central part of the Florida Mountains, Luna County, New Mexico (sec. 6, T. 26 S., R. 7 W.). The formation is about 36 feet (11 meters) thick both in the southern Franklin Mountains (Scenic Point area and east entrance to McKelligon Canyon) and in the east-central Florida Mountains. In the Franklin Mountains, the formation contains a 6.5-foot (2 meters) orange-weathering, resistant key bed, 10 feet (3 meters) below the top of the formation.

The Florida Mountains Formation contains an abundant fauna, including nautiloids, brachiopods, cystoid plates, pelmatozoan fragments, trilobites, gastropods, and sponges (LeMone, 1966b, p. 121). The Florida Mountains Formation is equivalent to Unit C, beds 1 through 6 of Cloud and Barnes (p. 362-363).

In summary, El Paso Group in the southern Franklin Mountains is divided into seven lithologic units utilizing the formation nomenclature of Flower (1964, p. 148, 149). A distinct sedimentological break is present at the base of each unit. El Paso Group section represents one of the best examples of nearshore to supratidal shelf Canadian rocks.

The paleontological divisions of El Paso Group are well established on the base of nautiloids and other faunal groups.

The formations of El Paso Group have been tentatively correlated with the deeper water, miogeosynclinal, western standard section (table 1, col. 5, this volume) Hintze, 1951, 1952; Ross 1951.

MONTOYA GROUP

The name *Montoya* was first used by Richardson (1908) in the El Paso area; Entwistle (1944, p. 16-19) subdivided the Montoya into three members, the Second Value, Par Value, and Raven. Kelley and Silver (p. 57), in view of the difficulty of stratigraphic continuity, alteration, and accessibility presented by Entwistle's members, decided to propose new names in the Caballo Mountains, an area that offers continuous and easily accessible exposures. The type locality of the Montoya Group is in Cable Canyon opposite the Sierrite mine, Caballo Mountains, Sierra County, New Mexico (NW¼ sec. 10, T. 16 S., R. 4 W.). The formations, named for stations along the Santa Fe Railway, are the Cable Canyon Sandstone, the Upham Dolomite, the Aleman Formation, and the Cutter Formation (Kelley and Silver, p. 58, 59, 60, 62). Flower (1957, p. 20) pointed out the presence of an unnamed sporadic basal sand, which he referred to as the Harding–Winnipeg equivalent. Pray (1953, p. 1906-1911) named a light-gray, thin- to medium-bedded, sublithographic dolomite unit the *Valmont Dolomite,* which is apparently equivalent to the Raven member and the Cutter Formation.

The stratigraphy of the Montoya Group has been studied in some detail by Richardson (1908, 1909), Nelson (1940), Pray (1958), and Howe (1959). The most exhaustive work on the El Paso section was done by Howe, who measured ten sections in the Franklin Mountains of Texas and New Mexico.

Paleontological studies date back to Ulrich's identification of fossils collected by Richardson (1909). Ulrich equated the faunas to the Galena and the Richmond; the Richmond fauna was interpreted to have a Fernvale aspect. Howe wrote a series of papers on the details of the brachiopod faunas of the Montoya Group (1965a; 1965b; 1966, p. 241-247; and 1967, p. 845-860). Flower has written a series of papers discussing the Montoya Group nautiloids *(see* especially Flower, 1957). Flower (1961) also described the coelenterate fauna and attached organisms. Hill (1959) described some of the Montoya coral fauna. Flower (1961, p. 122-126) correlated the Middle and Late Ordovician fauna of west-central North America from the New Mexico–Texas region with that of Greenland and demonstrated that equivalents of the four units of the post-Canadian Ordovician occur in Colorado, the Big Horn Mountains, Winnipeg, and Hudson Bay.

RIO MIMBRES SANDSTONE BED
(previously an unnamed sandstone)
Mohawk–Porterfield
Harding–Winnipeg Equivalent

Flower (1957, p. 20-21) described a basal remnant of sandstone of extremely local nature that seldom exceeds a few feet (0.6 meters) in thickness. He reported (1961, p. 126) presence of this sequence at the following southern New Mexico localities: Mimbres Valley, Grant County; Hembrillo Canyon, San Andres Mountains, Dona Ana and Sierra Counties; Lone Mountain, Grant County; Big Hatchet Mountains, Hidalgo County; and the Cooks Range, Luna and Grant counties, New Mexico. This unit was apparently deposited on an uneven El Paso Group surface and subsequently eroded to a remnant. The age of the beds is based *solely* on stratigraphic position. Howe (1959) reported the presence of a thin basal sandstone (6 to 12 inches–15 to 30 centimeters–thick) between the Upham Dolomite and El Paso Group in the Hueco Mountains and southern Franklin Mountains.

It is proposed that, until such time as the age and relationship for the unnamed sandstone are resolved, the name *Rio Mimbres Sandstone Bed* be adopted for this unit. Flower (1961, p. 126) described the Harding–Winnipeg equivalents at Mimbres Valley as being 2 to 3 feet (0.6 to 0.9 meters) of white sandstone that sharply contrasts with the overlying darker, coarser grained Cable Canyon Sandstone. Flower also indicated the facies relationships in the aforementioned localities that range from siltstone to dolomitic sandstone. The type section is located on the west side of the Mimbres Valley (sec. 26, T. 17 S., R. 11 W., Grant County, New Mexico), which leads westward to Santa Rita (Flower, 1961, p. 10).

CABLE CANYON SANDSTONE
Mohawkian–Cincinnatian, Coburg–Eden
Red River Equivalent

The Cable Canyon Sandstone was named by Kelley and Silver (p. 58-59). It is a massive, ledge-forming sandstone (35 feet–11 meters–thick) that occurs as the base of the Montoya Group. The type locality is near the Sierrite mine at the head of Cable Canyon, Caballo Mountains, Sierra County, New Mexico (sec. 10, T. 16 S., R. 4 W.).

Kottlowski (163, p. 18-20) noted that the Cable Canyon Sandstone appears to thicken significantly toward a possible source area located in the vicinity of of southeastern Catron County. The Cable Canyon shows great lateral variation and normally grades vertically into the overlying Upham Dolomite (Kottlowski, 1963, p. 18). It appears that this sandstone is a distinct unit at its type locality in the Caballo Mountains, but it may be simply a basal arenaceous phase of the Upham Dolomite.

Kottlowski (1963, p. 20) suggested that the Cable Canyon Sandstone and the arenaceous beds of the Upham Dolomite are marine clastics deposited and reworked from a low positive area to the north in the Catron County region.

UPHAM DOLOMITE
Mohawkian–Cincinnatian, Coburg–Eden
Red River Equivalent

The Upham Dolomite was named by Kelley and Silver (p. 59-60) for the cliff-forming, massive, medium-gray to brown-gray dolomite, 78 feet (24 meters) thick, that conformably overlies the Cable Canyon Sandstone at the type locality in Cable Canyon, Caballo Mountains, Sierra County, New Mexico (sec. 10, T. 16 S., R. 4 W.). The Cable Canyon Sandstone and the Upham Dolomite are equivalent to Entwistle's Second Value Member (p. 16-19). Flower (1957, p. 20-21) raised the Second Value to formational rank.

Howe (1959, p. 2301), on the basis of eight sections measured throughout the Franklin Mountains, stated that the thickness ranged from 98.5 to 102.8 feet (30-31 meters). Howe (1959) noted very abrupt changes in dolomitization in sections in the Franklin and Hueco mountains, Texas. His key section at the north end of the Franklins clearly shows this relationship. Pray (1958) measured 104 feet (32 meters) of Upham Dolomite in the northern Franklin Mountains (1.1 miles south of the intersection of 32° N and 106° 30′ W, Canutillo 7.5-minute quadrangle). He subdivided the Upham into three major units of carbonate rocks with a basal foot (0.3 meters) bed of sandstone and limestone. Decreasing minor amounts of arenaceous sand in the carbonate rocks are observed up to 26 feet (8 meters) above the base of the unit.

The abundant Red River Fauna includes brachiopods, four genera (expanded by Howe), trilobites, gastropods (particularly large *Maclurina* and *Hormotoma),* the questionable sponge *Receptaculites oweni,* eight genera of coelenterata (Flower, 1961, p. 124), and at least fourteen genera of nautiloids. Fauna of this age are very similar from northern Greenland to west Texas.

ALEMAN FORMATION
Cincinnatian–Lower Richmond

The Aleman Formation was named by Kelley and Silver (p. 60-62). It is a distinct banded chert and dolomite section, 107 feet (33 meters) thick. The type locality is in Cable Canyon, Caballo Mountains, Sierra County, New Mexico (sec. 10, T. 16 S., R. 4 W.). It is equivalent to the Par Value member of Entwistle (p. 16-19).

Howe (1959) listed five measured sections in the northern Franklin Mountains ranging from 166 to 177 feet (50 to 54 meters) in thickness and two sections in the southern Franklin Mountains, 151 and 152 feet (46 meters) thick. Pray (1958) reported 163 feet (50 meters) of Aleman, which he subdivided into ten units composed of limestone and dolomite with considerable chert. The Aleman rests disconformably on the Upham Dolomite.

The fauna of the Aleman Formation is abundant and varied. Howe (1959) listed six genera of corals, thirteen genera of brachiopods, bryozoans, and trilobites. He also defined five faunal zones (older to younger): Zone A, *Lepidocyclus–Thaerodonta–Onniella;* Zone B, *Hebertella;* Zone C, *Lepidocyclus–Thaerodonta;* Zone D, *Paleophyllum;* and Zone E, *Hypiptycha.* Flower (1957, p. 20) listed four zones for the same interval in the San Andres Mountains (older to younger): *Zygospira; Rafinesquina; Rhynchotrema capax;* and the "megaripple".

CUTTER FORMATION
Cincinnatian–Upper Richmond

The Cutter Formation was named by Kelley and Silver (p. 62-64). It is a light- to medium-gray, thin- to medium-bedded dolomite sequence, 129 feet (39 meters) thick. The type section is in Cable Canyon in the Caballo Mountains, Sierra County, New Mexico (sec. 10, T. 16 S., R. 4 W.). It is equivalent to the Valmont Dolomite of Pray (1953, p. 1906-1911) and to the Raven member of Entwistle (p. 16-19).

Flower (1957, p. 22) reported a minor disconformity separating the Aleman and Cutter Formations. Howe (1959) described five measured sections in the northern Franklin Mountains ranging in thickness from 148.5 to 166.5 feet (45 to 51 meters) and two sections in the southern Franklin Mountains of 145 and 149 feet (44 and 45 meters). In the northern Franklin Mountains, Pray (1958) subdivided the Cutter Formation, 182 feet (49 meters) thick, into eleven units.

Howe (1959) recognized two zones in the Franklin Mountains, *Hebertella* and *Diceromyonia*.

Flower (1961) stated that the upper beds are largely barren but may contain from one to three horizons of silicified corals, mainly *Paleofavosites* with rare stromatoporoids.

In the Franklin Mountains, the Montoya Group is overlain by the massive, very light-gray to brownish orange Fusselman Dolomite.

In summary, the Montoya Group appears to consist of four sedimentary units deposited with intervening erosional periods, oldest to youngest: Harding–Winnipeg equivalents (Rio Mimbres Sandstone Bed), Cable Canyon Sandstone–Upham Dolomite, Aleman Formation, and Cutter Formation. Flower (1965, p. 124) correlated the Montoya Group from Texas to Greenland across western North America.

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Siluro–Devonian of West Texas and Southeastern New Mexico

by Ed H. McGlasson
Mobil Oil Corp., Midland, Texas

Rocks of Silurian and Devonian age are known in three areas in west Texas, as shown in Figure 1. These are the Marathon and Solitario uplifts, the subsurface Tobosa basin, and the outcrops in the Franklin, Hueco, and Sierra Diablo mountains. The names and correlation of the rock units of these three areas are shown in Figure 2. The rocks were deposited in an Early and Middle Paleozoic depositional basin called the Tobosa basin (Galley, 1958) and in the adjoining Marathon–Ouachita geosyncline. Four columnar sections, shown in Figure 3, are typical of the four areas in which they are located. Correlation between these areas has been difficult, but detailed studies have shown that they contain different facies of equivalent rock units.

MARATHON AREA

The Caballos Novaculite crops out in the Marathon and Solitario uplifts of southwest Texas. 200 to 600 feet (61 to 183 meters) thick in the area of outcrop, it is composed of chert and novaculite with a few beds of siliceous shale and limestone. The Caballos is overlain by the Tesnus Formation of Mississippian and Pennsylvanian age and underlian by the Maravillas Formation of Upper Ordovician age. Both the upper and lower contacts have been described as unconformable, but now they are considered conformable contacts. Fossils are rare in the Caballos, but conodonts and radiolaria from the upper part of the formation have been dated as Upper Devonian and correlative with the Woodford Formation of west Texas and Oklahoma (Graves, 1952; Aberdeen, 1940). Radiolaria and sponge spicules can be seen in the chert and novaculite, and linguloid brachiopods have been reported from the formation. Although the Caballos has been called Late Devonian and possibly Early Mississippian in age, the current interpretation is that it represents continuous deep-water deposition from Early Silurian to Early or Middle Mississippian time (Thomson, 1964). Deep subsidence began in the Ouachita–Marathon geosyncline in Late Ordovician time, but the basin received very little sediment until Mississippian time. The Caballos represents a very slow accumulation of siliceous ooze throughout Silurian and Devonian times. The rocks of the Marathon facies have been thrust northweastward over rocks of the Tobosa basin facies, and the original depositional site of the Caballos is not known.

SUBSURFACE OF WEST TEXAS AND SOUTHEAST NEW MEXICO

Four rock units of Silurian and Devonian age are recognized in the subsurface of west Texas as shown in Figures 2 and 3. The Fusselman Formation and the "Upper Silurian" rock unit are Silurian in age, and the "Devonian" rock unit and the Woodford Shale are Devonian in age. "Upper Silurian" and "Devonian" are ill-chosen names for rock units, but these units have never been formally named and represent the only terms widely used by geologists in west Texas; therefore, they will be set off in quotation marks to distinguish them as informal rock units rather than time or time-rock terms. These rocks represent a major transgression and regression of the sea and the beginning of a second transgression that continued into Mississippian time. A basin facies and a shelf facies have been recognized (fig. 4).

FUSSELMAN FORMATION

The Fussleman Formation rests unconformably on the Montoya Formation of Late Ordovician age. It is recognized as far east as central Sterling County, Texas, north as far as northern Cochran County, Texas, and west almost to Arizona. It varies in thickness from 0 to about 1000 feet (305 meters), as shown in Figure 5. The Fusselman consists of a limestone facies toward the southeast and a thicker dolomite facies toward the north and west (fig. 6). Both facies are composed of clean, light-colored carbonates and contain a shallow-water fauna that includes crinoids, tabulate corals, brachiopods, trilobites, bryozoa, and stromatoporoids. The Fusselman is Early and Middle Silurian in age, and it is probably correlative with the Chimneyhill Formation of Oklahoma.

"UPPER SILURIAN" ROCK UNIT

The Fusselman Formation is overlain by the "Upper Silurian" rock unit. The "Upper Silurian" consists of a shaly facies toward the southeast grading into a much thicker carbonate facies toward the north and west as shown in Figures 7 and 8. The "Upper Silurian" is more restricted areally than the underlying Fusselman. It has also

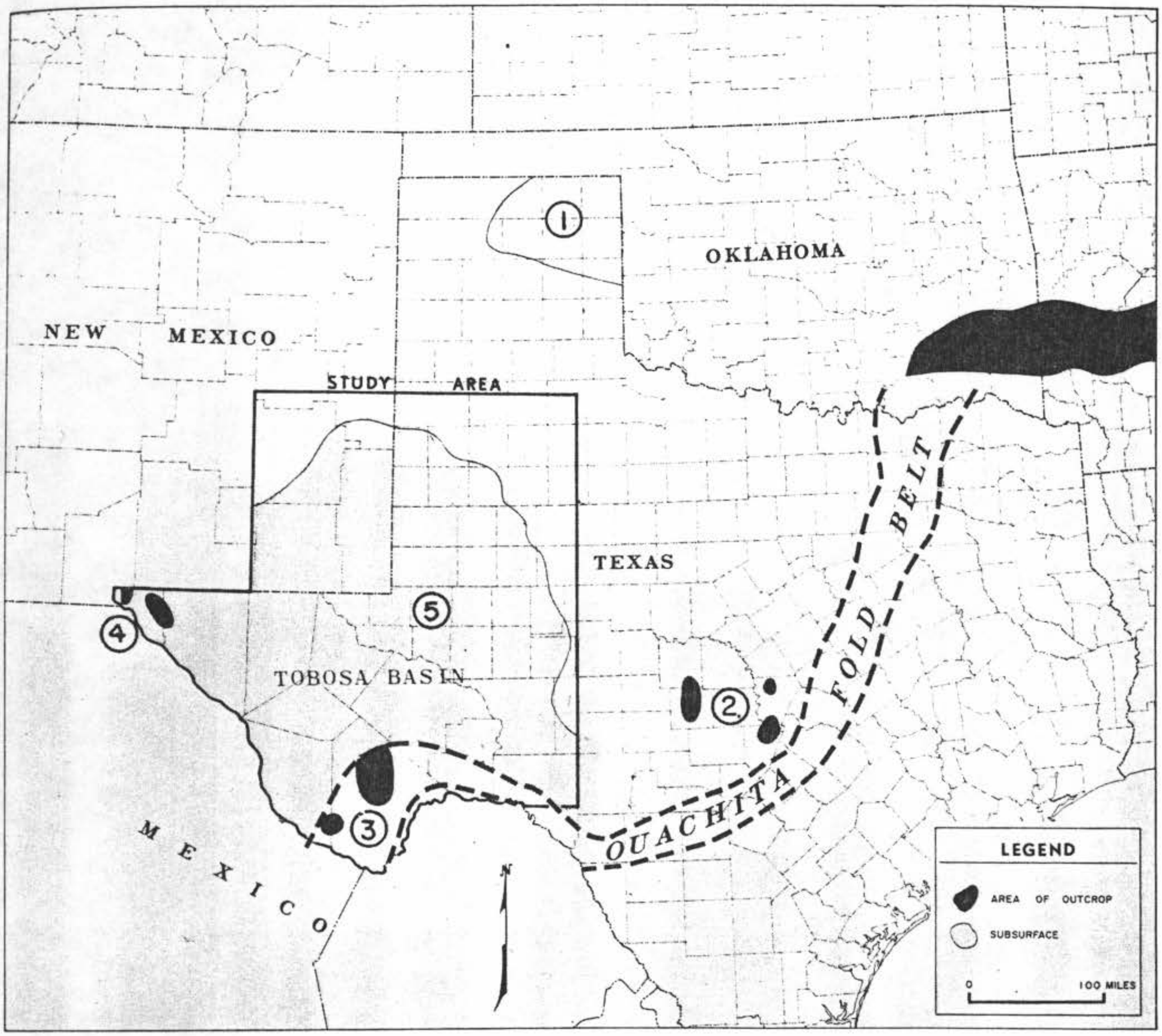

Figure 1

INDEX MAP SHOWING AREAS OF SILURIAN AND DEVONIAN ROCKS IN TEXAS AND THE AREA DISCUSSED IN THIS PAPER

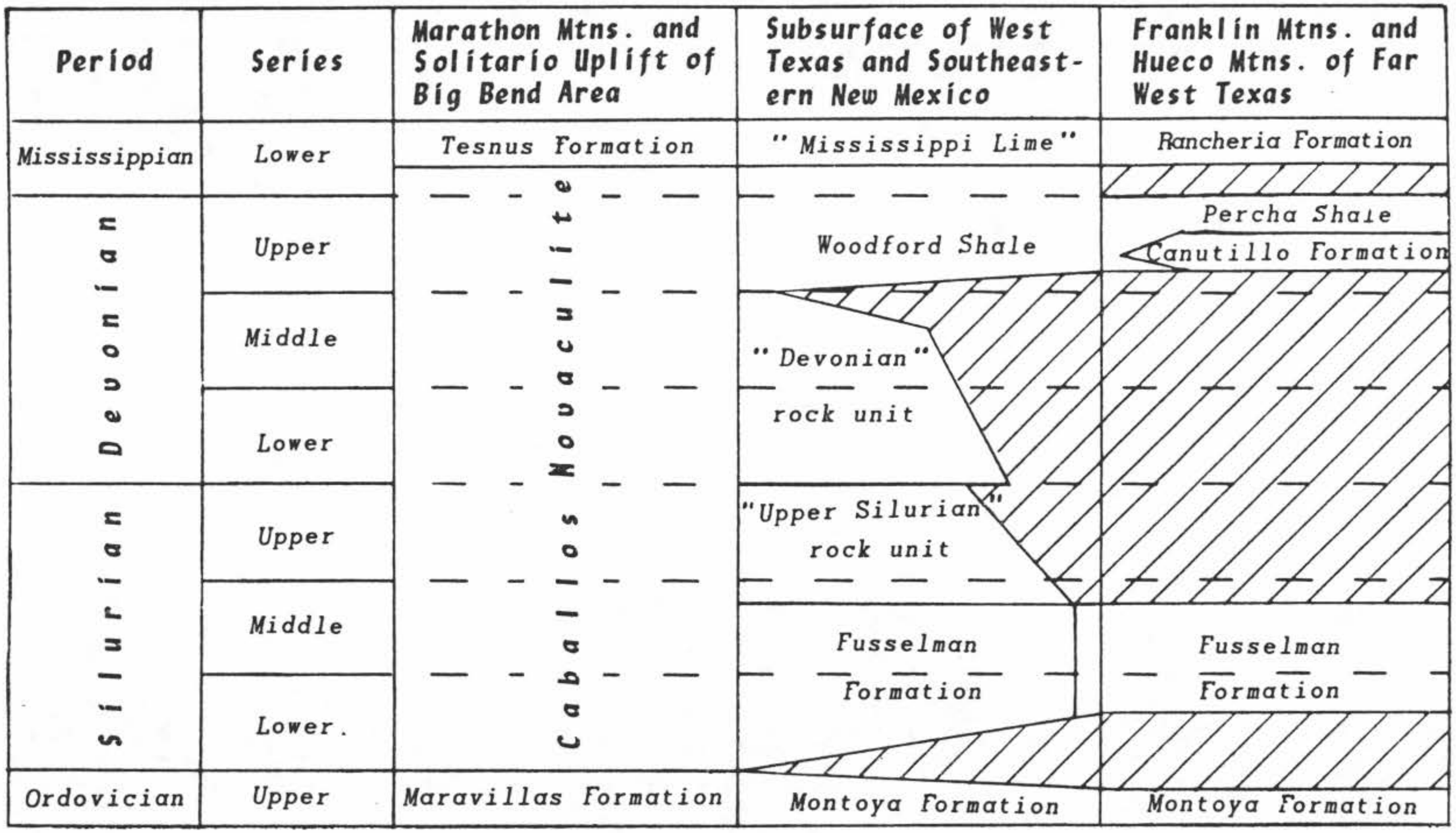

Figure 2
SILURO-DEVONIAN CORRELATION CHART FOR WEST TEXAS

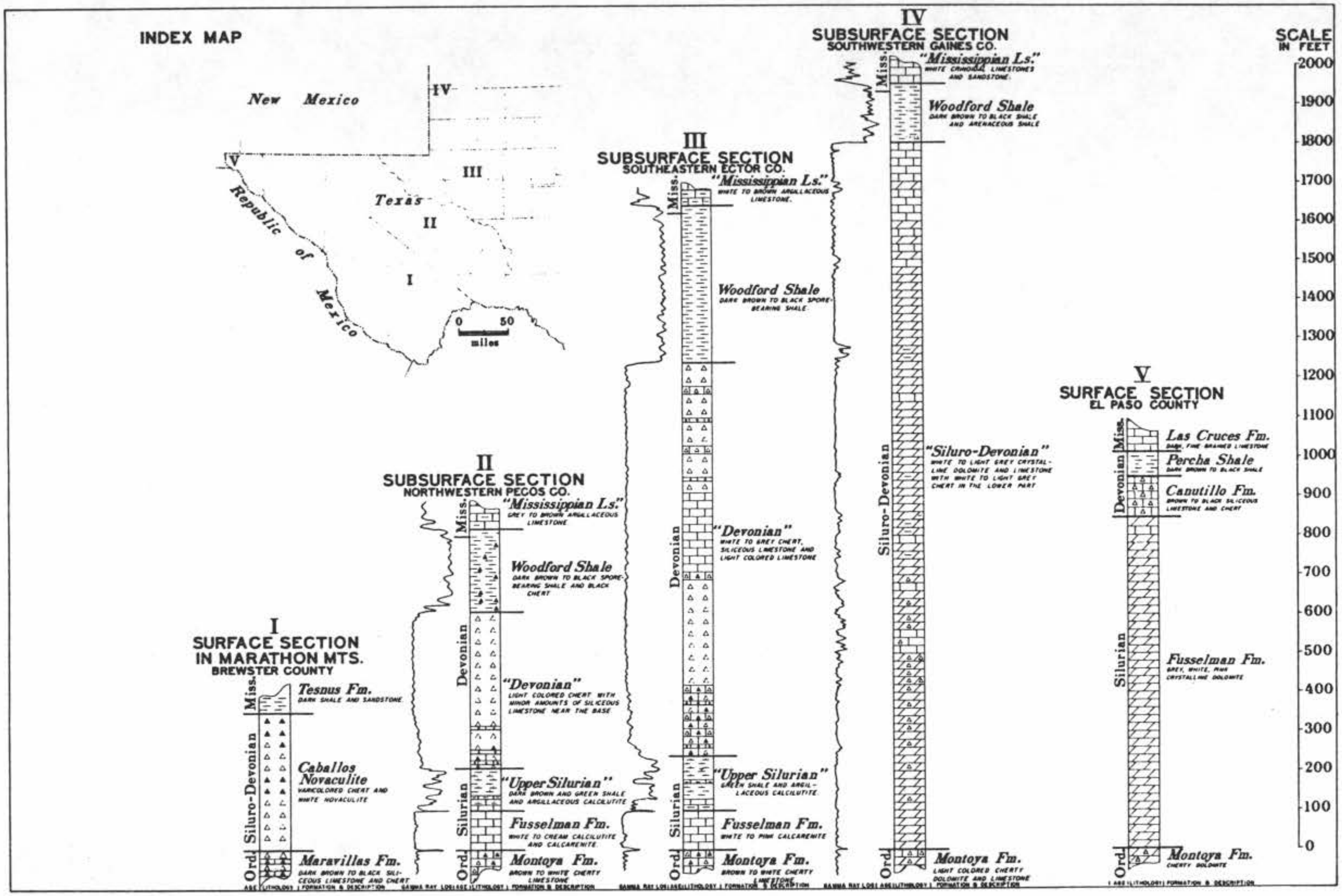

Figure 3

COLUMNAR SECTIONS OF THE SILURO-DEVONIAN IN WEST TEXAS AND SOUTHEASTERN NEW MEXICO

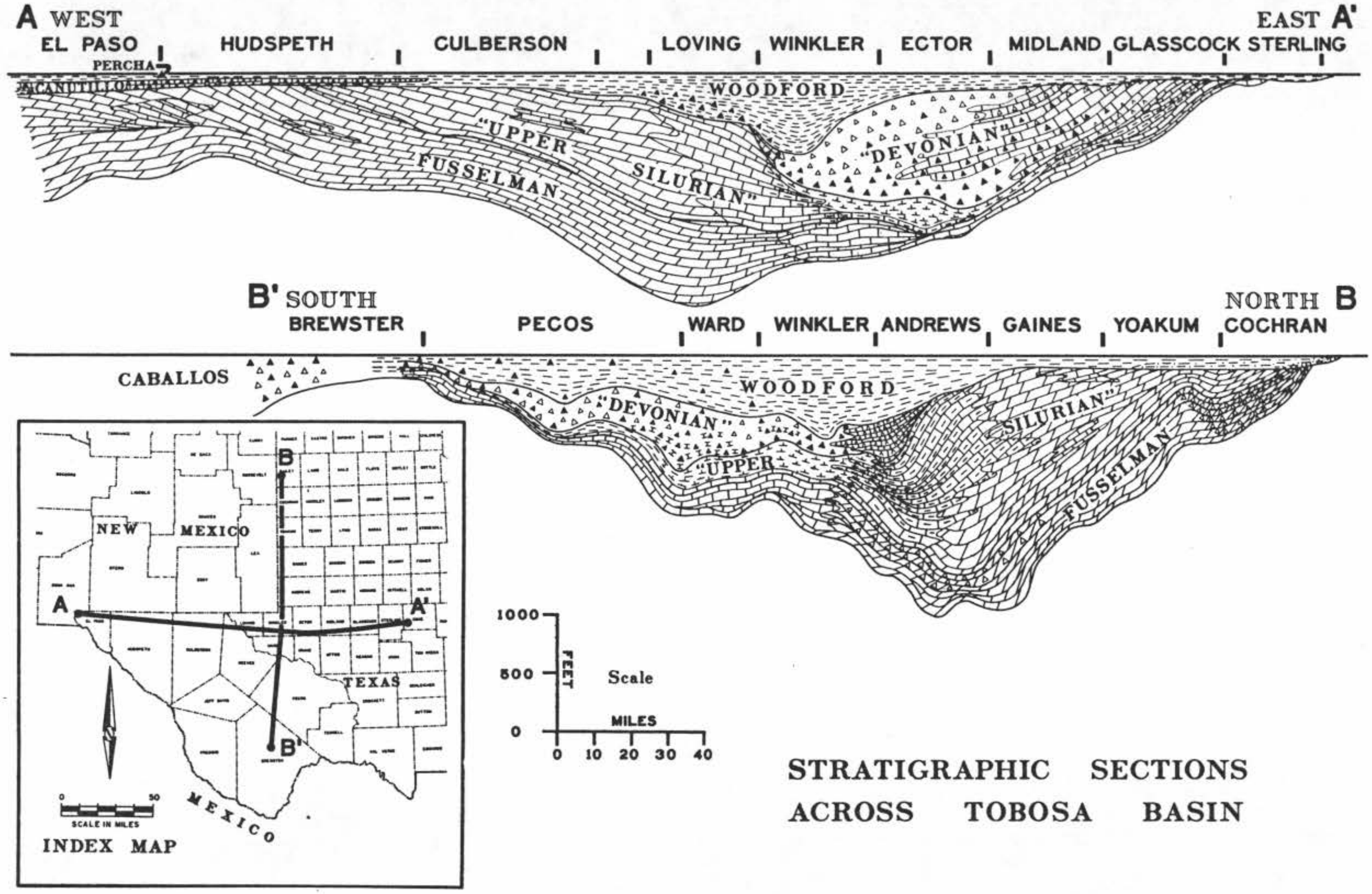

Figure 4

STRATIGRAPHIC SECTIONS ACROSS TOBOSA BASIN

The datum is the top of the Woodford and correlative horizons. A-A′ extends from El Paso eastward to the stratigraphic pinchout in eastern Coke County. Silurian shelf deposits extend from El Paso to Winkler County. "Upper Silurian" shales and "Devonian" cherts were deposited in the deepest part of the basin. B-B′ extends from the stratigraphic pinchout in northern Cockran County southward to the deep, starved Marathon geosyncline in Brewster County. The edge of the Siluran shelf is in central Andrews County.

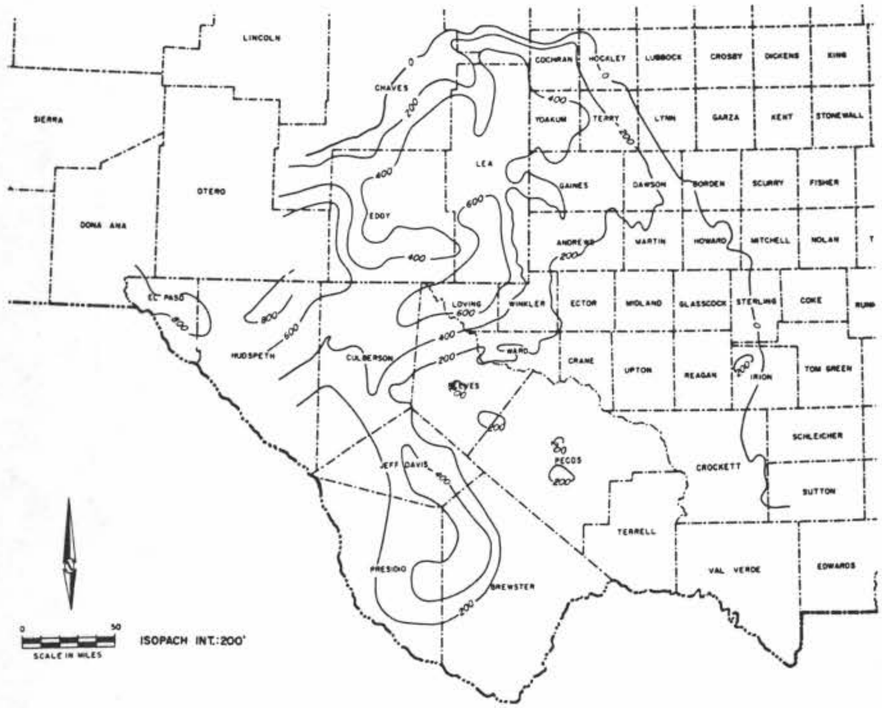

Figure 5
FUSSELMAN FORMATION
Isopach Map. Thickness restored where eroded

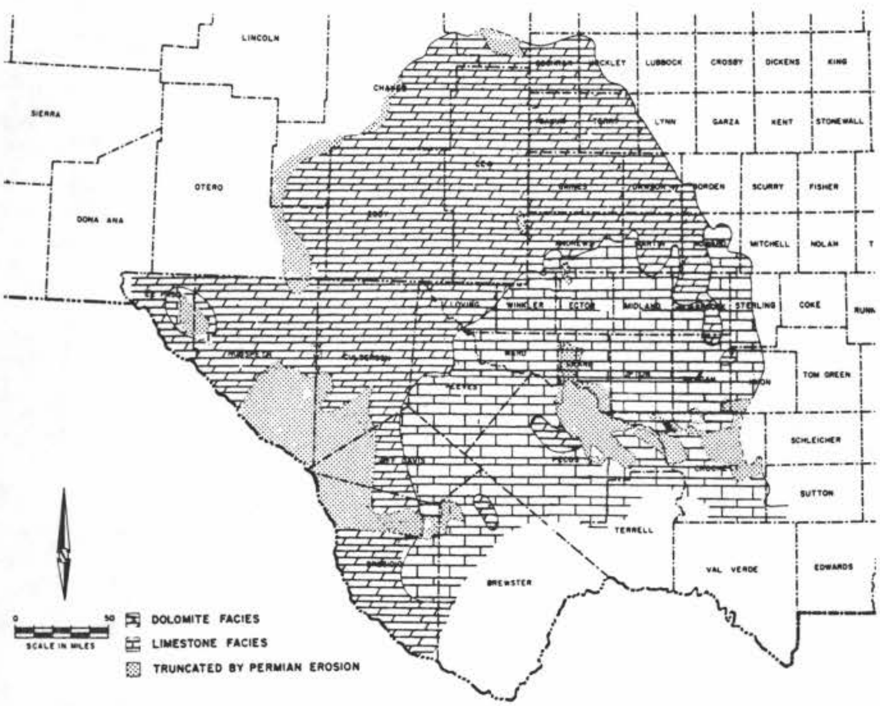

Figure 6
FUSSELMAN FORMATION
Lithofacies Map

been subjected to pre-Woodford erosion; however, this erosion was probably minor. The shaly facies is composed of green and dark brown shales and white to brown calcilutite. It ranges from 0 to about 300 feet (91 meters) in thickness. Ostracods are the most abundant fossils, but graptolites, arenaceous foraminifera, and crinoid fragments are also present. The upper part of the unit is more shaly than the lower part.

The carbonate facies includes limestone and dolomite and ranges from 0 to more than 1500 feet (460 meters) in thickness. Most of the fossils have been destroyed by recrystallization and dolomitization, but a shallow-water fauna present includes fragments of crinoids, tabulate corals, brachiopods, trilobites, and stromatoporoids. The carbonate facies is very similar to the underlying Fusselman, and the boundary between them is often difficult to establish.

The shaly facies was deposited in a subsiding, sediment-starved basin. The carbonate facies was deposited on a shallow shelf where deposition kept pace with subsidence. The "Upper Silurian" is Middle and Late Silurian in age and is probably correlative with the Henryhouse Formation of Oklahoma.

"DEVONIAN" ROCK UNIT

The "Upper Silurian" is overlain by the "Devonian" rock unit. The "Devonian" ranges from 0 to 1000 feet (305 meters) in thickness as shown in Figure 9. The "Devonian" is predominantly chert in the southwest, and it grades northeastward into dark, nonfossiliferous, siliceous micrite and light-colored calcarenite, as shown in Figure 10. The Devonian has undergone considerable diagenetic alteration and is petrographically complex in most places. Fossils are generally rare over most of its extent and consist mainly of radiolaria and spicules in the cherts and ostracods in the siliceous micrites. Calcarenites are present in the upper part of the unit in the northern and eastern parts of the basin with a more abundant fauna including brachiopods, tetracorals, tabulate corals, and trilobites indicating an Early and Middle Devonian age (Wilson and Majewski, 1960). Conodont studies indicate a similar age for the unit. The "Devonian" is probably correlative with the Haragan and Bois D'Arc Formations of Oklahoma. The "Devonian" is much more restricted in area than the "Upper Silurian" unit. It was exposed to erosion during Middle Devonian time, but this erosion was probably minor.

WOODFORD SHALE

The Woodford Shale (fig. 11) is composed of dark-brown to black, fissle, bituminous, spore-bearing shale that becomes arenaceous northward and contains black chert in the south and west as shown in Figure 12. It ranges in thickness from 0 to about 700 feet (210 meters). The Woodford overlaps the "Devonian," "Upper Silurain," Fusselman, and Montoya and is a transgressive unit. It has an unconformable lower contact and is conformably overlain by Early Mississippian limestones, sandstones, and shales. The Woodford contains linguloid brachiopods, conodonts, and large spores of which the principal genus is *Tasmanites*. The Woodford is Late Devonian in age and is correlative with the Woodford of Oklahoma.

OUTCROPS OF FAR WEST TEXAS

The Fusselman Formation was named by Richardson (1909) for outcrops in the Franklin Mountains near El Paso. It crops out in the Franklin Mountains, the Hueco Mountains, and the Sierra Diablo. In each of these outcrops, the formation is composed of dolomite with some limestone, and it bears a shelf fauna consisting predominately of crinoid fragments, pentamerid brachiopods, *Favosites, Halysites,* and sponges. The formation has been dated as Early and Middle Silurian in the west Texas outcrops and in outcrops in the mountains of southern New Mexico (Pray, 1958).

The Fusselman is unconformably overlain in the Franklin Mountains by the Canutillo Formation. The Canutillo consists of thick-bedded, dark-brown to black siliceous, micritic limestone and black chert in the lower part. This is overlain by dark, fissle shale with a thin bed of brachiopod-bearing limestone above it and a bed of black siltstone at the top. The entire sequence was named the Canutillo Formation by Darton (1929). Brachiopods from the top of the Canutillo have been dated as Middle or Late Devonian (Jones, 1953), and conodonts from the Canutillo are Late Devonian according to Ellison (Wilson and Majewske).

The Canutillo is overlain by the Percha Shale, consisting of dark-gray, fissle shale. The Percha is lithologically similar to the subsurface Woodford and is the same age. The Percha is unconformably overlain by the Helms Formation of Mississippian age.

In the Hueco Mountains east of El Paso, the Fusselman is unconformably overlain by thin-bedded, light-colored shale. Upward, the shale is interbedded with thin, resistant beds of siliceous claystone and siltstone. These beds become thicker and more numerous upward and finally grade into a massive, light-colored, siliceous unit. The massive unit consists of chert and silicified dolomitic claystone and siltstone. It is overlain by the Percha Shale, which is light tan on outcrop because of weathering. The interval between the Fusselman and the Percha has been called Canutillo by King, King, and Knight (1945). The rock is marine and bears ostracods, but no dates have been established. East of the Hueco Mountains in the subsurface the Canutillo is black chert and black limestone, usually with a dark shale interval at the base. Farther east, the Canutillo becomes argillaceous and finally appears to grade into the lower part of the Percha or Woodford. The Canutillo is probably a siliceous facies of the lower part of the Percha Shale. It grades into Percha, and individual beds are probably not correlative over any large area.

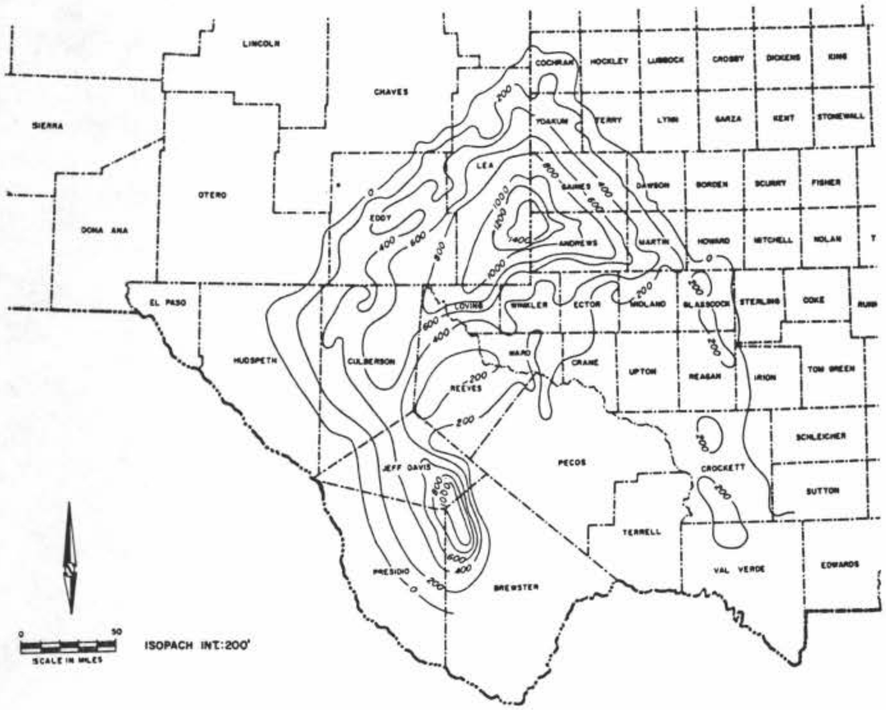

Figure 7
"UPPER SILURIAN" ROCK UNIT
Isopach Map. Thickness restored where eroded

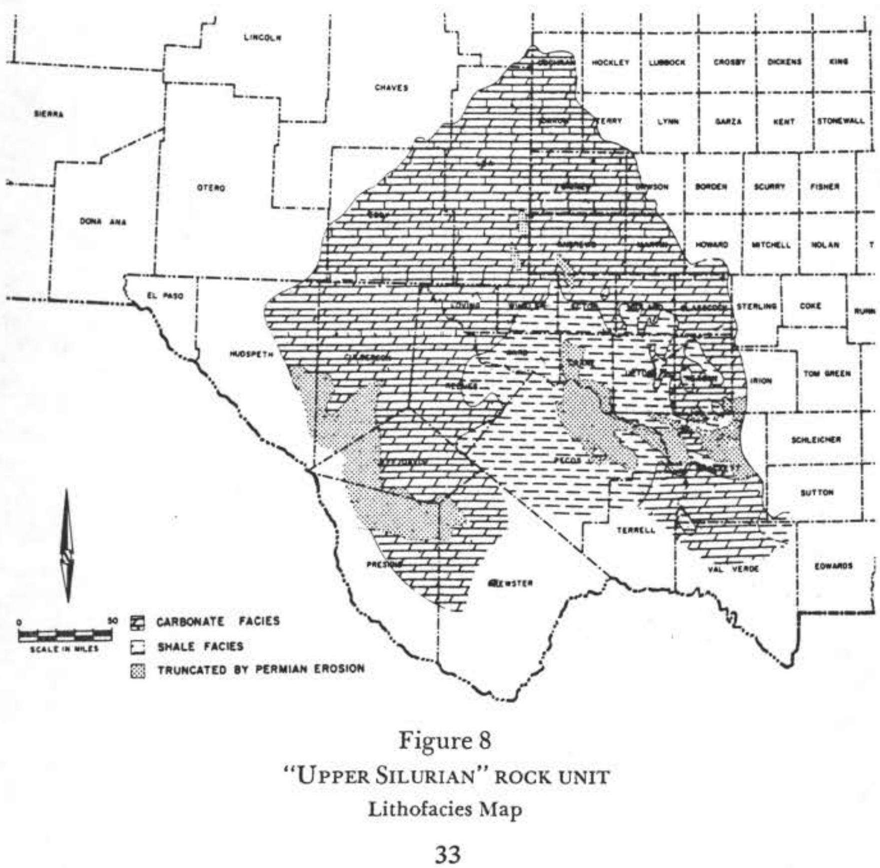

Figure 8
"UPPER SILURIAN" ROCK UNIT
Lithofacies Map

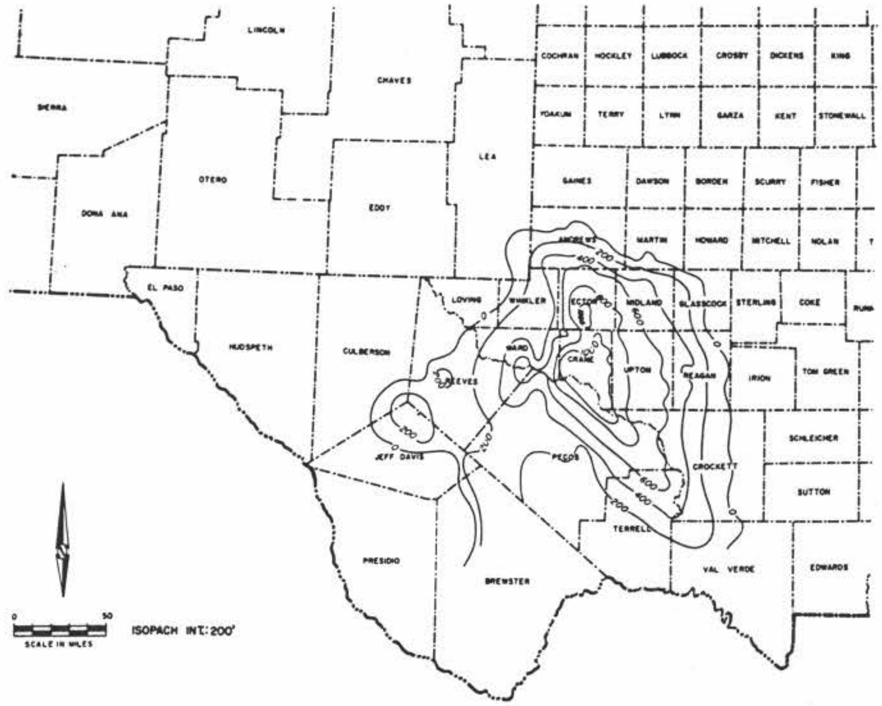

Figure 9
"DEVONIAN" ROCK UNIT
Isopach Map. Thickness restored where eroded

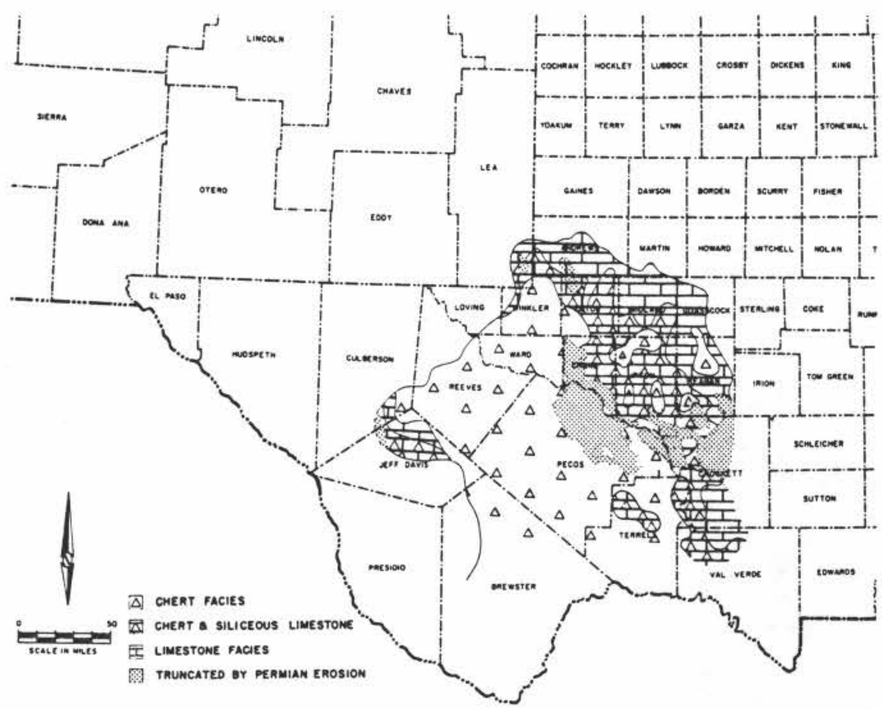

Figure 10
"DEVONIAN" ROCK UNIT
Lithofacies Map

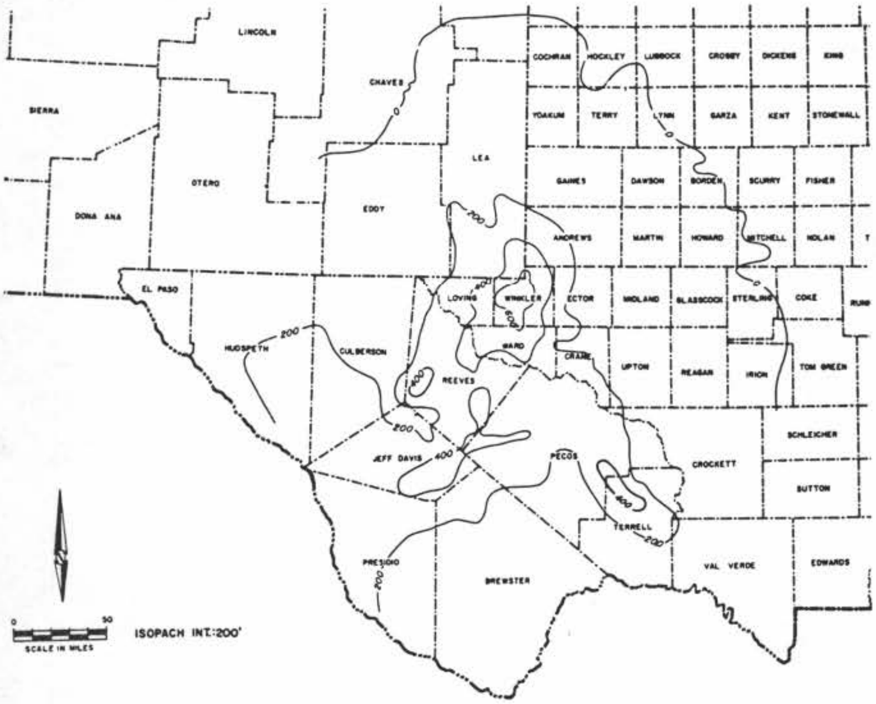

Figure 11
WOODFORD, PERCHA, AND CANUTILLO
Isopach Map. Thickness restored where eroded

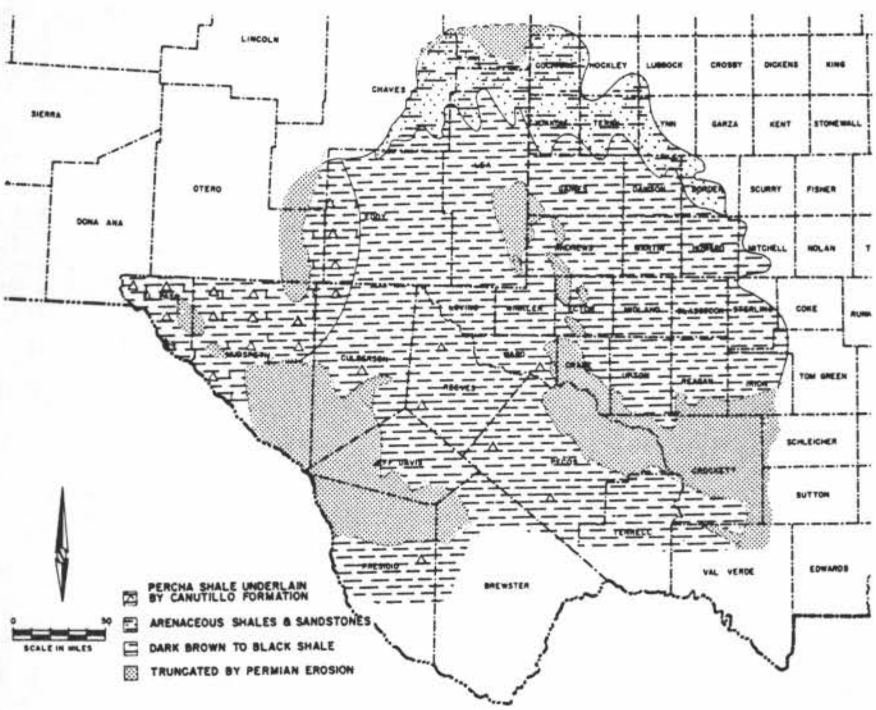

Figure 12
WOODFORD, PERCHA, AND CANUTILLO
Lithofacies Map

SUMMARY OF SILURIAN AND DEVONIAN GEOLOGIC HISTORY

Figure 13 summarizes the interpretation of the history of the Tobosa basin during the Silurian and Devonian periods and the inferred environments of deposition.

During Silurian and Devonian time, west Texas was the site of a depositional basin called the Tobosa basin (Galley). It was bounded on the east and northeast by the Texas peninsula and on the north by a land area in central and northern New Mexico. Both of these land areas were of low relief, and very little terrigenous clastic sediment was deposited. Toward the south, the Tobosa basin bordered the Marathon–Ouachita geosyncline. This geosyncline began subsiding in Late Ordovician time and may have reached bathyal or abyssal depths during the Silurian and Devonian Periods when the Caballos Novaculite was being deposited. The Caballos is interpreted as a deep-water leptogeosynclinal deposit representing continuous deposition throughout the Silurian and Devonian Periods (Dally, 1964). During this time, the Tobosa basin also subsided and received a limited supply of clastic sediments. Deepening water is indicated by the sequence of sediments in the deeper parts of the basin, beginning with exposure at the end of Ordovician time followed by the deposition of shelf calcarenites in Early and Middle Silurian time, calciluties and shales in Late Silurian time, and bedded chert in Lower Devonian time. As the basin subsided, a broad carbonate shelf developed around the northern and western margins, as shown by the thick carbonate facies of the "Upper Silurian." Deposition kept pace with subsidence on the shelf and minor fluctuations of sea level exposed or inundated large areas. The self edge became more prominent during Late Silurian time, and the shore line was regressive (fig. 13C). By Early Devonian time, only the deeper part of the basin was submerged, and most of the wide Silurian shelf was emergent but very near sea level. The basin was asymmetrical, with the deepest water near the western shelf edge. Deep-water-bedded chert was deposited in the deeper waters on the western side of the basin, grading to dark siliceous micrite toward the east. As the basin filled with sediment during Early Devonian time, a carbonate shelf developed on the eastern and northern sides, but the shelf was never so extensive as the Silurian shelves (fig. 13D). Epeirogenic uplift in Middle Devonian time exposed most of the Tobosa basin to erosion (fig. 13E). The basin was depressed again in Late Devonian time and invaded by the sea, and the Woodford Shale was deposited, overlapping all the earlier Devonian and Silurian rocks (fig. 13F).

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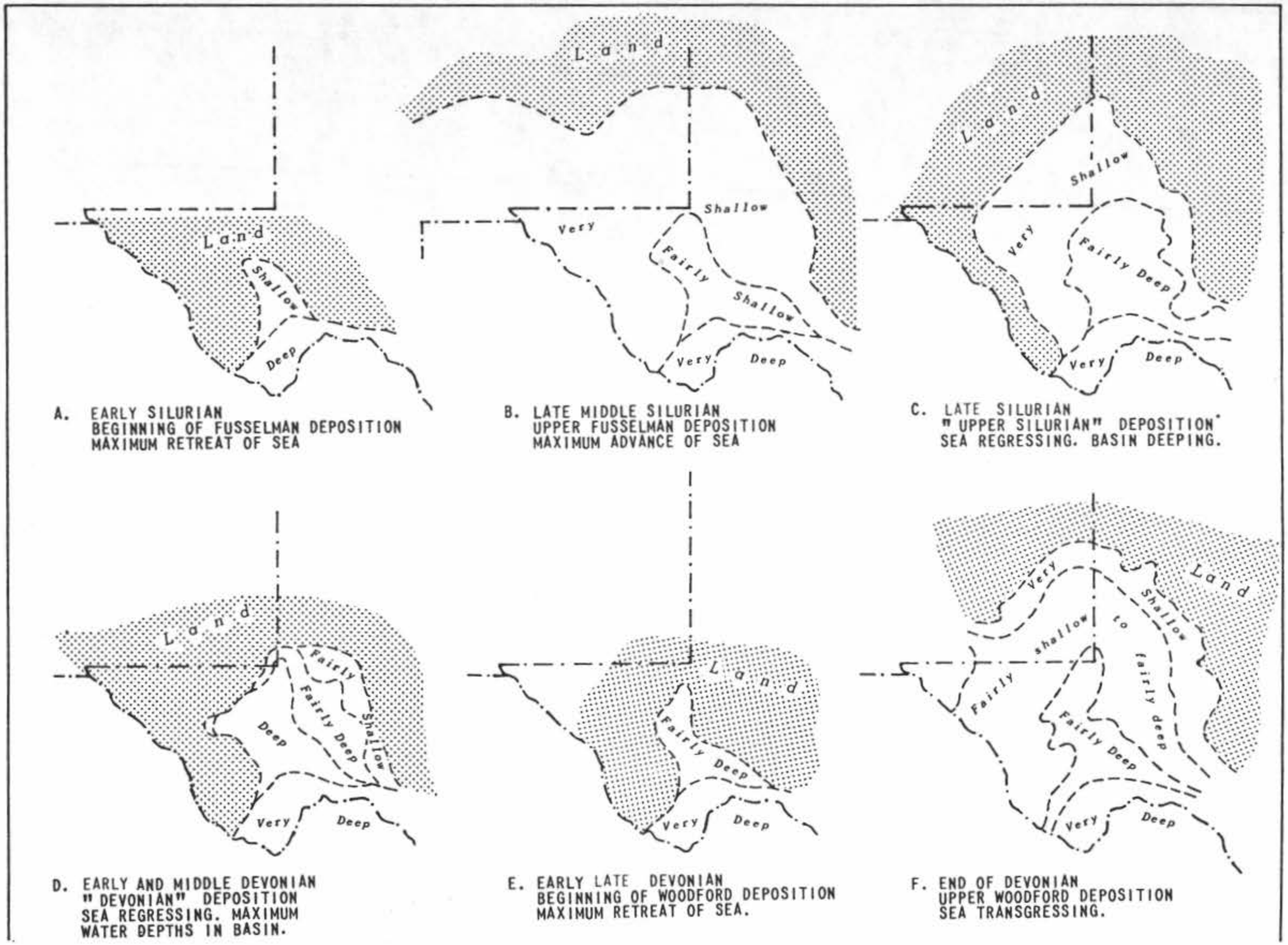

Figure 13

POSTULATED RELATIVE WATER DEPTHS IN THE TOBOSA BASIN DURING THE SILURIAN AND DEVONIAN PERIODS

"Very Shallow," "Shallow," and "Fairly Shallow" are successively deeper shelf environments. "Very Shallow" is characterized by widespread littoral and supratidal environments with the depositional interface near sea level. "Shallow" means a normal shelf environment with the depositional interface near wave base. "Fairly Shallow" means the depositional interface was generally well below wave base. "Fairly Deep," "Deep," and "Very Deep" are successively deeper basinal environments. "Fairly Deep" means water depths of several hundred feet. "Deep" means epibathyal depths or a deep intracratonic basin. "Very Deep" means water depths of several thousand feet.

Summary of Late Paleozoic in El Paso Border Region

by Frank E. Kottlowski
New Mexico Bureau of Mines and Mineral Resources

ABSTRACT

Basal Mississippian strata overlie the Late Devonian black shales in southern New Mexico and west Texas but older cherty Devonian limestone near Chihuahua City. Mississippian rocks, mainly crinoidal limestones, thicken southwestward to more than 1200 feet (365 meters) in the Pedregosa basin and southeast to about 800 feet (245 meters) in the Delaware basin. The Chesterian nearshore beds occur mainly south of the thirty-third parallel.

Total thickness of the Pennsylvanian is more than 3000 feet (910 meters) in the Delaware basin at the southeast, perhaps 4500 feet (1370 meters) in Orogrande basin northeast of El Paso, and more than 2400 feet (730 meters) in the Pedrogosa basin to the southwest. Wolfcampian strata, Abo redbeds to the north, Hueco Formation to the south and southeast, and Earp to the southwest are 3000 to 4000 feet (910 to 1220 meters) thick in the Delaware and Orogrande basins. The marine limestone and shale of the Hueco grade laterally northward into terrestrial Abo red beds. Leonardian strata, as much as 4000 feet (1220 meters) thick in the southeast, thin northward and westward, being removed by erosion during early Mesozoic time over the Burro uplift.

Guadalupian strata, as much as 5500 feet (1670 meters) thick in the Delaware basin, thin to an eroded edge westward. Ochoan rocks mainly anhydrite and halite, are concentrated in the Permian Basin area with about 5000 feet (1670 meters) present in the Delaware basin part.

INTRODUCTION

El Paso in Late Paleozoic time, from the Mississippian until the Ochoan seas vanished, was near a number of significant geologic features. During the Devonian and Mississippian, it was the site of southern seas, with a low platform to the north, and far to the south, the almost mythical landmass of Llanoria. Pennsylvanian time saw the rise of nearby islands to the northwest, the Florida Islands, and the uplift of a mountain range to the east and northeast, the Pedernal Mountains. During the Wolfcampian, the Diablo platform rose to the southeast, to be covered by later Wolfcampian seas; and finally, as the Permian seas withdrew into their restricted basin of Ochoan time, El Paso region was exposed to the harsh air and remained an erosional target until the Early Cretaceous.

DEVONIAN STRATA

The Devonian isopach map (fig. 1) is similar to McGlasson's (this volume) except that it also covers southwest New Mexico and northern Chihuahua. Unfortunately, most of Chihuahua's Paleozoic rocks are buried by vast amounts of Mesozoic marine strata and Cenozoic volcanic and terrestrial deposits. The only two fairly complete sections of Late Paleozoic rocks lie northeast of Chihuahua City in the Placer de Guadalupe region and about 60 miles (97 kilometers) west of El Paso in Sierra de Palomas (Diaz and Navarro, 1964). One of the interesting geologic features of northern Chihuahua is the possible southwest extension of the Diablo platform, as deduced by Bridges (1964) and others, a boomerang-shaped area believed to have been an upland in early Wofcampian time.

This Devonian isopach map shows the rocks on which the late Paleozoic strata of the Mississippian were deposited. These are mainly the Percha and Woodford black shale facies of late Devonian age in the north, north of El Paso. Near El Paso, the thin late Devonian is underlain by the cherty Canutillo limestone of late middle Devonian age. The thick sections far to the south near Chihuahua City in Placer de Guadalupe appear to be entirely of late Middle Devonian cherty limestone.

MISSISSIPPIAN STRATA

The isopach map of the Mississippian (fig. 2) shows thicknesses due to both deposition and erosion. The more than 1200 feet (365 meters) of Mississippian to the southwest in the Big Hatchet Mountains and Sierra de Palomas comprise an almost complete Mississippian section, whereas the thin section to the north near Socorro is a mere erosional remnant. Near Chihuahua City, only local remnants remain, because of later erosion that probably took place during early Pennsylvanian time.

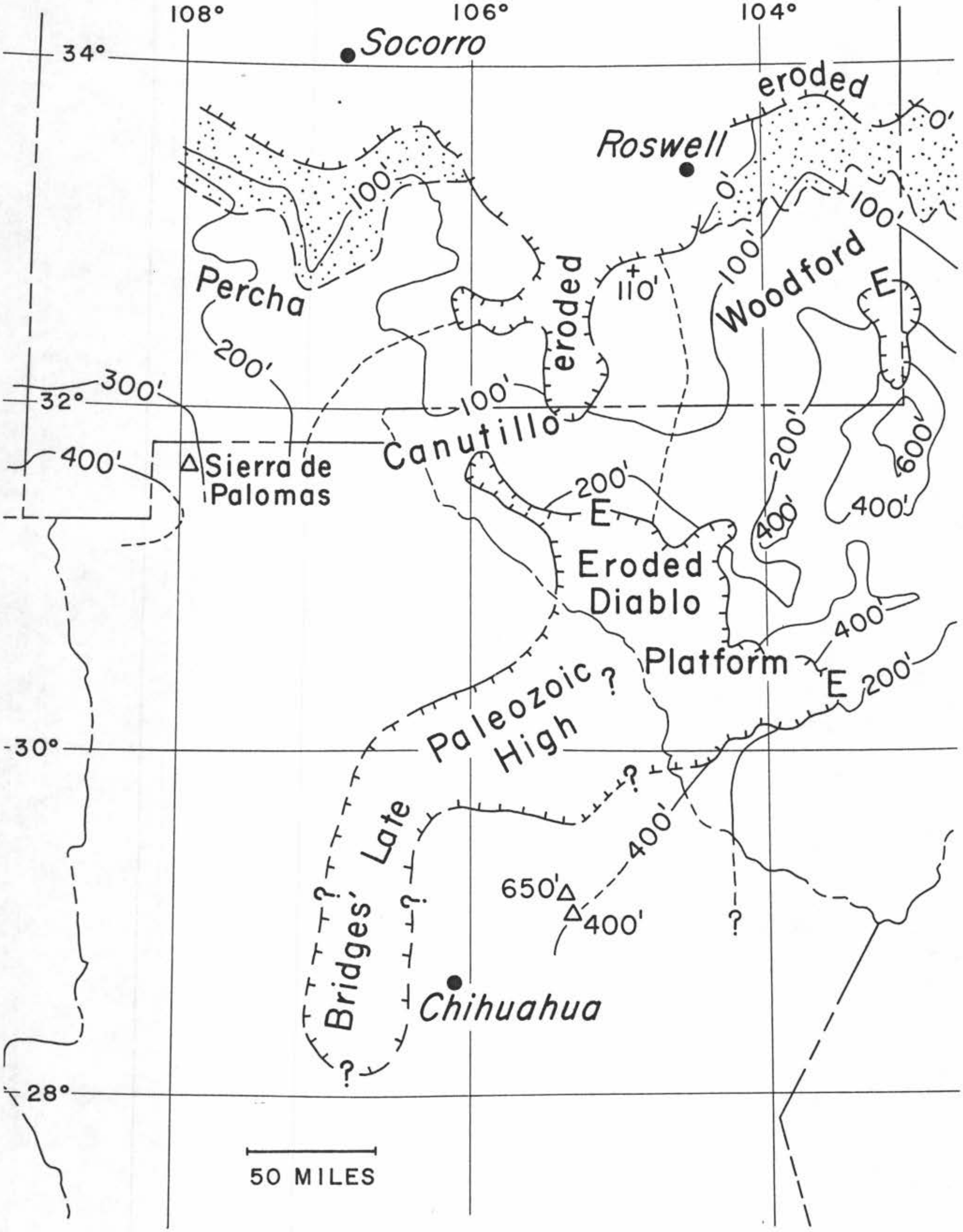

Figure 1
Devonian Isopach Map

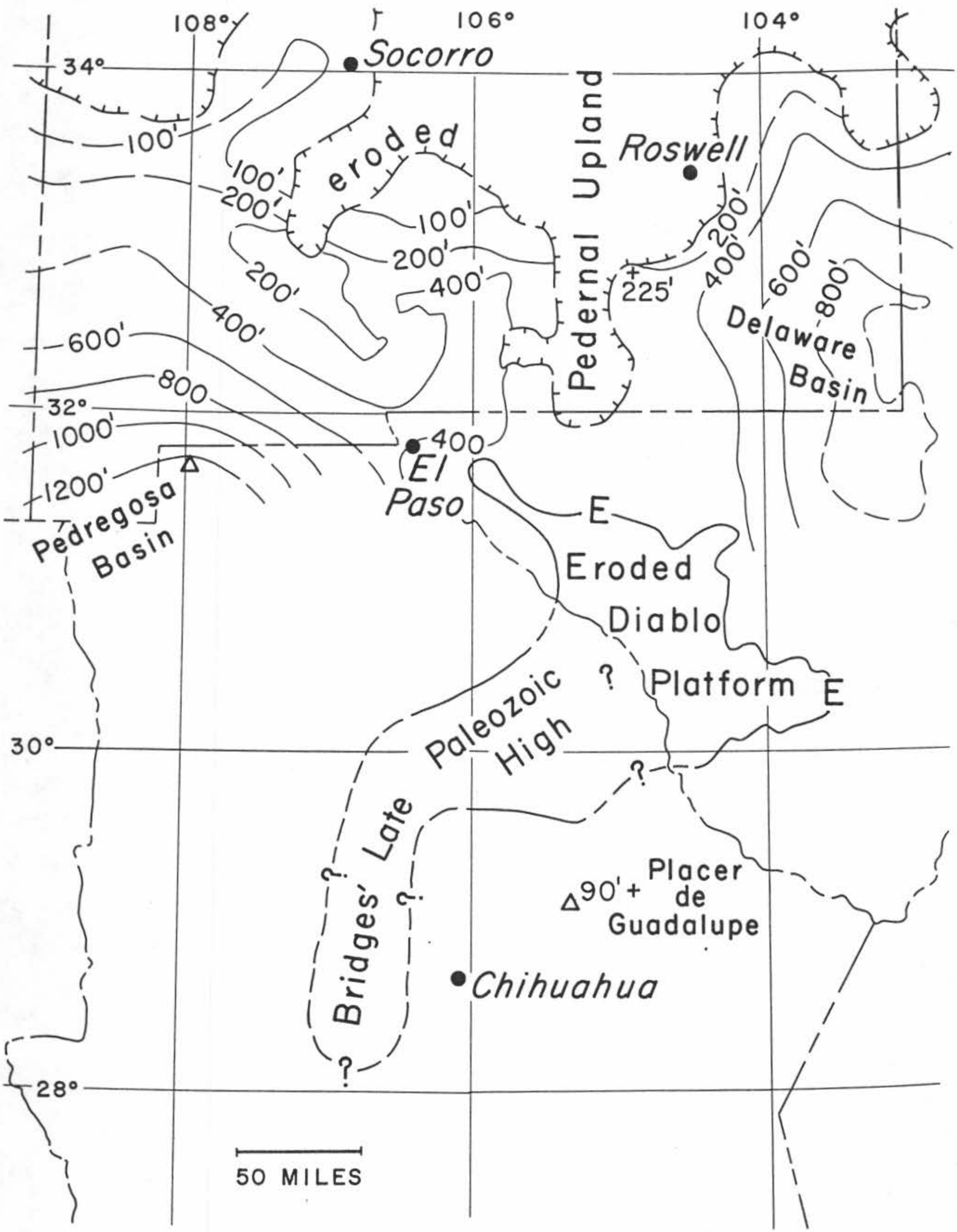

Figure 2
MISSISSIPPIAN ISOPACH MAP

The main mass of these Mississippian rocks is crinoidal limestones that thicken to the southwest into the Pedregosa basin (Kottlowski, 1960) of the southwest New Mexico panhandle and of northwest Chihuahua. Part of the thinning outward from the 800 feet (245 meters) of Mississippian in the Delaware basin is erosional, but part is also depositional thinning northward. The irregular northern erosional edge is due to erosion during early Pennsylvanian time. The southward-projecting erosional area of the Pedernal upland is a Pennsylvanian and early Permian feature.

Mississippian seas and Mississippian marine deposits probably covered most of the region shown on this map, as well as most of New Mexico to the north. Except for the Chesterian strata, the only nearshore Mississippian deposits are basal arkoses where the Mississippian overlies Precambrian granites, as west of Socorro, and far to the north in the northeastern part of New Mexico on the southwest edge of the Sierra Grande arch. Near the Sierra Grande arch, sandstone and conglomerate of the older Mississippian abuts against Precambrian-rock hills, just as the lower El Paso in the central Franklin Mountains abuts against the Precambrian rhyolite of the Thunderbird monadnock (LeMone, Foster, and Kottlowski, 1967).

The Late Mississippian, Chesterian beds are in the Paradise Formation of southeast Arizona and southwest New Mexico, the Helms Formation of south-central New Mexico and westernmost Texas, and the Barnett type of shales in southeast New Mexico and west Texas. Most of these Chesterian beds do not extend north of the thirty-third parallel, and their northward edge is probably rather close to their northern shoreline (Kottlowski, 1963). Central and northern New Mexico was uplifted during this Late Mississippian epoch, and locally karst features were developed (Armstrong, 1962; 1967).

An anomalous feature of the Mississippian was the development of the Rancheria facies during Middle Mississippian time. The dark siliceous Rancheria limestone occurs near El Paso in the Franklin Mountains and within a radius of 50 miles (80 kilometers) from the southern Franklins (Pray, 1961), as well as locally in southeastern New Mexico. The facies appears to grade northward, rather abruptly, into the more typical crinoidal Middle Mississippian limestones of the Lake Valley Limestone with its biohermal reefs. The Rancheria probably represents a relatively deep and stagnant basin, somewhat centered east of El Paso.

PENNSYLVANIAN STRATA

The Pennsylvanian isopach map (fig. 3) shows the overall erosional and depositional features of the Pennsylvanian. The Pedregosa basin in southwest New Mexico and northwest Chihuahua accumulated about 2500 feet (760 meters) of deposits, mainly shallow marine limestone. Reefoidal beds accumulated in the Big Hatchet Mountains area and to the southeast, with basinal deposits to the south and southwest. The Burro uplift is mostly a Mesozoic-age erosional feature, but its southeast tip, the Florida Islands, was a positive area during parts of the Pennsylvanian.

East of El Paso was the southern part of the Orogrande basin, a negative feature that may never have contained deep marine waters but did subside so that 3500 to 4500 feet (1060 to 1370 meters) of sediments were deposited therein. Northward, the Orogrande basin connected with various other basinal areas along the irregular central New Mexico seaway. Southward, it appears to have extended an unknown distance through westernmost Texas into northern Mexico. Between Alamogordo and Roswell, rising in early Pensylvanian and culminating in early Wolfcampian time, was the Pedernal uplift. During Virgilian and early Wolfcampian time, it must have been a true mountain range rising out of the late Paleozoic seas. In westernmost Texas and northeast Chihuahua, the early Wolfcampian Diablo platform and Bridges' Late Paleozoic high obscure the record of Pennsylvanian sedimentation, but to the east, the Marathon basin received almost two miles (3 kilometers) of sediments. In the Delaware basin, more than 3000 feet (910 meters) of rock materials were deposited, and a similar thick accumulation took place in western Eddy County, just off the southeastern flank of the Pedernal uplift.

The Pennsylvanian paleogeographic map (fig. 4) shows the relationships of El Paso area to the over-all picture to the north. Prior to the Pennsylvanian, this region had a general pattern of a low distant landmass, the Peñasco dome of central and northern New Mexico, fringed by a shallow, southern sea. In early Pennsylvanian time, this pattern vanished; north-south structural trends, as shown on this map, arose and dominated the processes of erosion and of deposition throughout the Pennsylvanian and early Permian time.

In early Pennsylvanian time, during the Morrowan (fig. 5), the main area being eroded was the southern Pedernal uplift. It supplied sands, silts, and clays to the Delaware basin to the southeast to form fairly thick Morrowan dark shales and conglomeratic sandstones. To the west in the Orogrande basin, only thin sandy shales were deposited. About 40 cubic miles (165 cubic kilometers) of detritus were swept westward and some 300 cubic miles (1250 cubic kilometers) were swept to the east. If we consider the main mass of the Pedernals to have been about 100 miles (160 kilometers) long and 50 miles (80 kilometers) wide, or 5000 square miles (12,900 square kilometers), an average of about 350 feet (106 meters) would need to have been eroded to provide the clastic material.

By Atokan time (fig. 6), the north-south trend of the Pedernal uplift was well defined; local clastic basins were the Orogrande to the southwest, the Socorro area to the west, several depressions on the Northwest shelf, and the Tucumcari basin to the northeast. About 405 cubic miles (1690 cubic kilometers) of detritus were washed westward and 420 cubic miles (1750 cubic kilometer) were washed to the east. The 10,000-square-mile (25,900 square kilometers) core of the Pedernals would need to be eroded about an average of 400 feet (122 meters) to supply this detritus.

Desmoinesian time (fig. 7) saw wide expansion of the

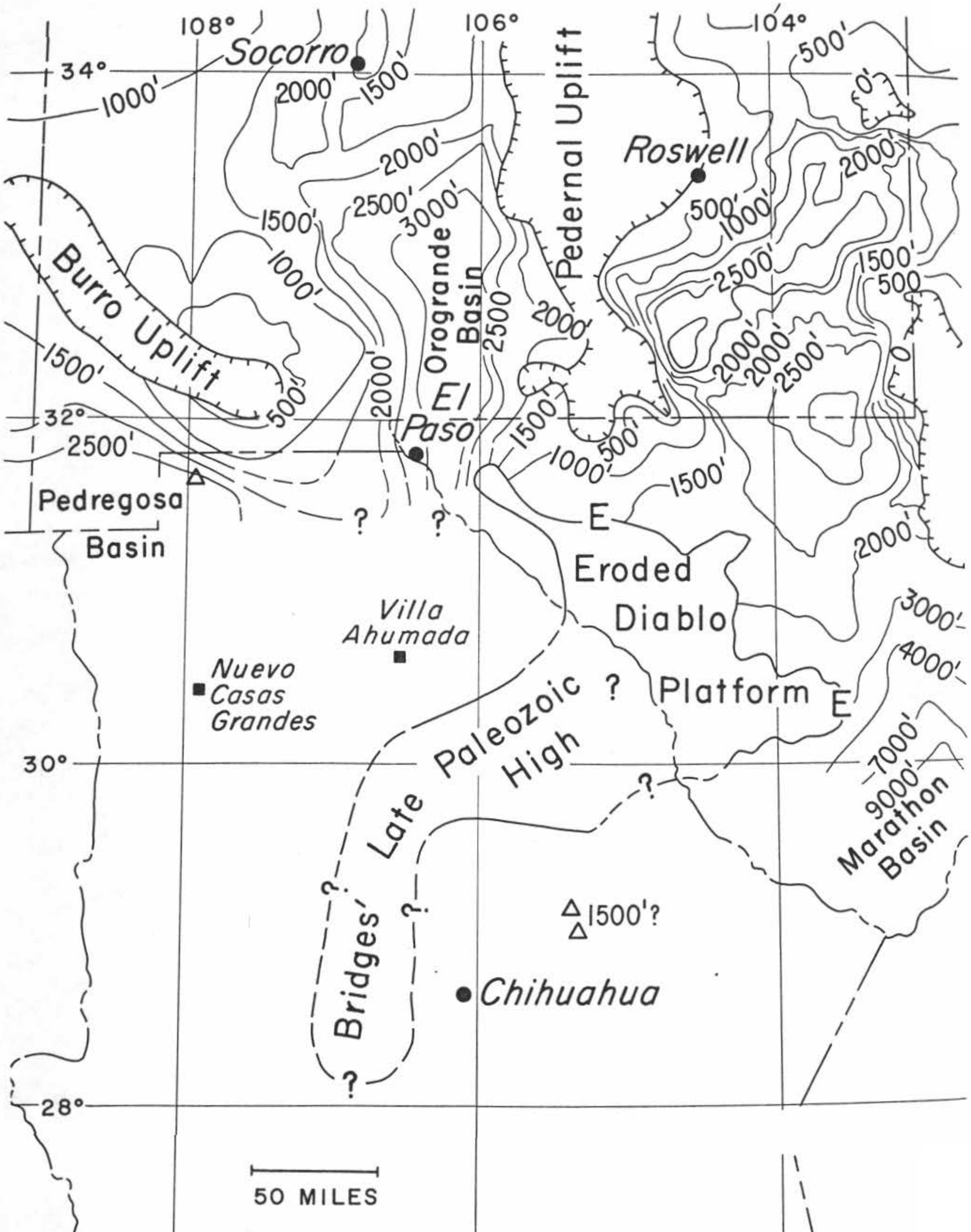

Figure 3
Pennsylvanian Isopach Map

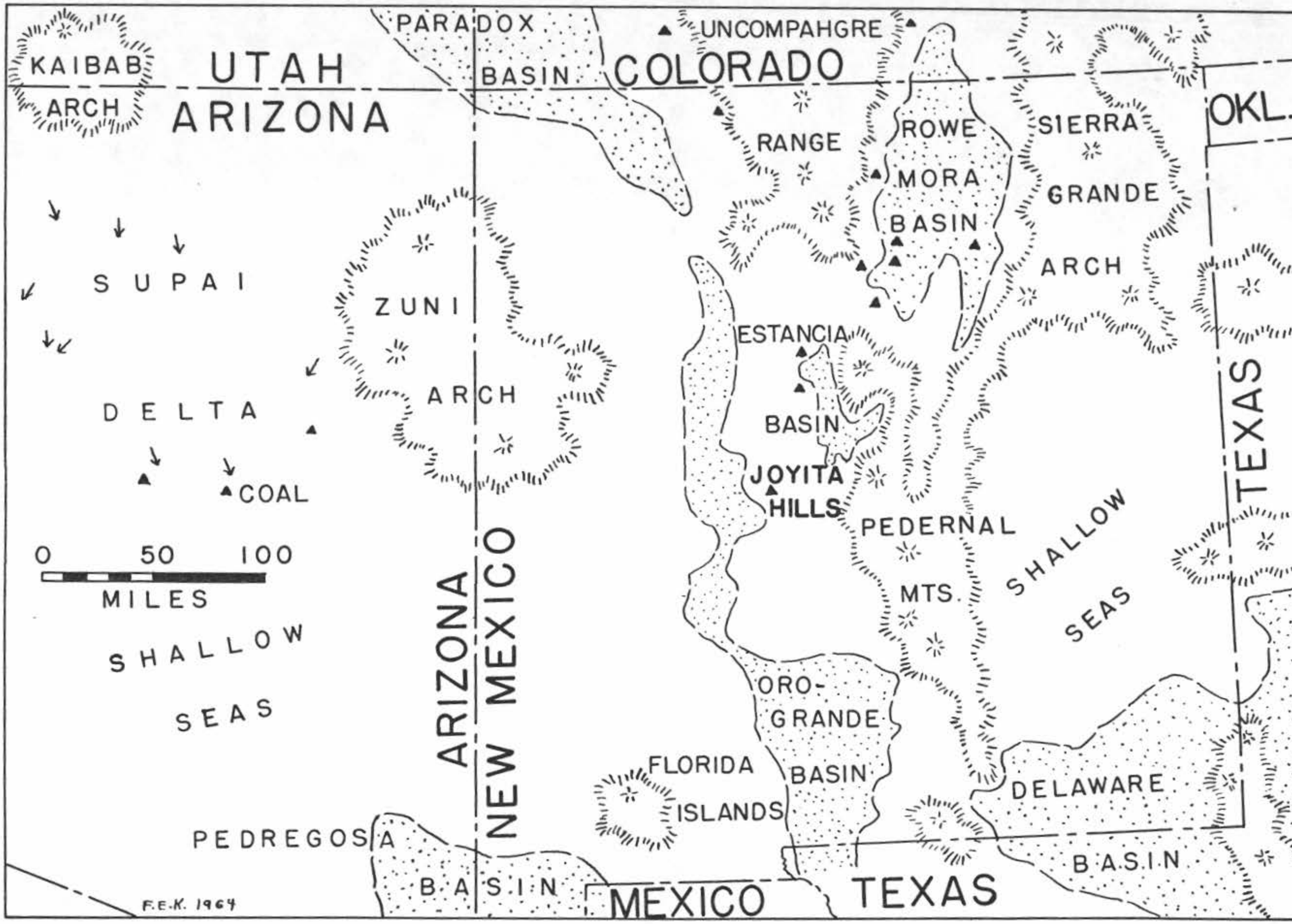

Figure 4
Pennsylvanian Paleogeographic Map

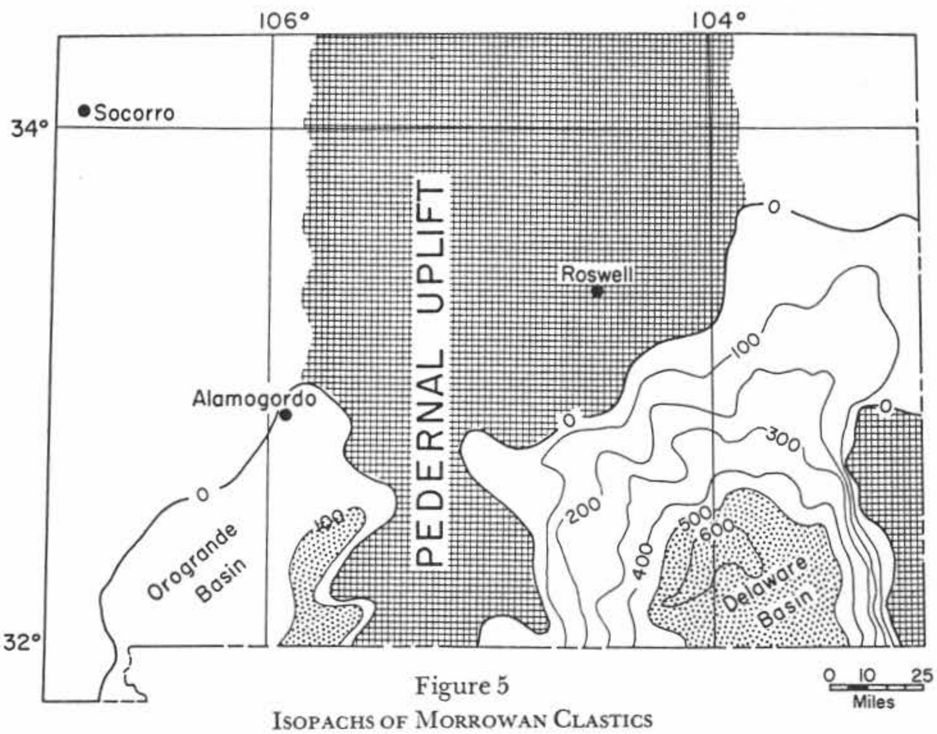

Figure 5
ISOPACHS OF MORROWAN CLASTICS

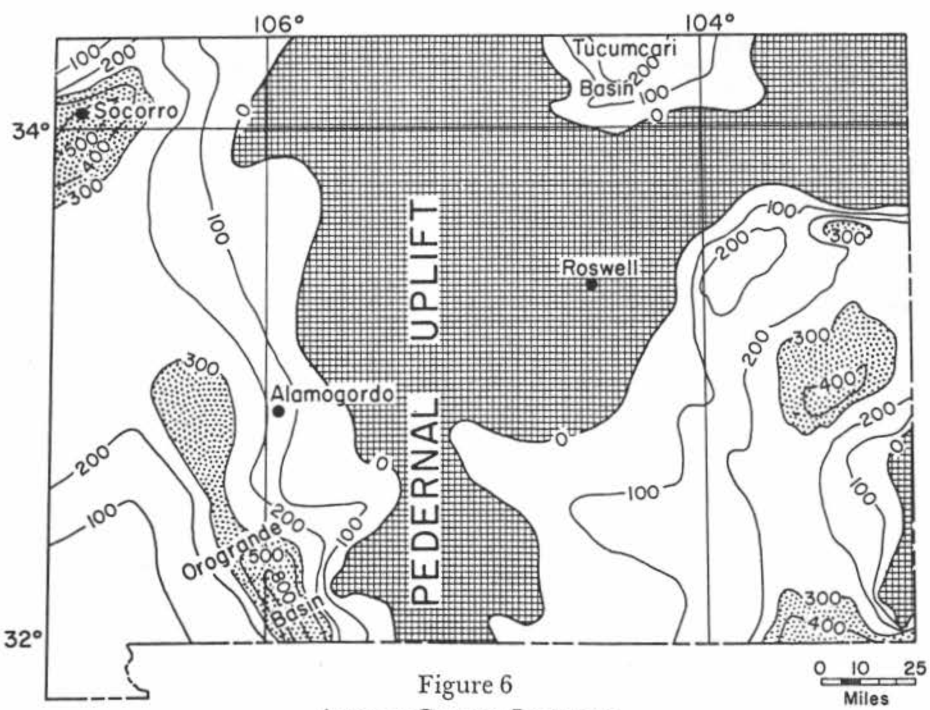

Figure 6
ATOKAN CLASTIC ISOPACHS

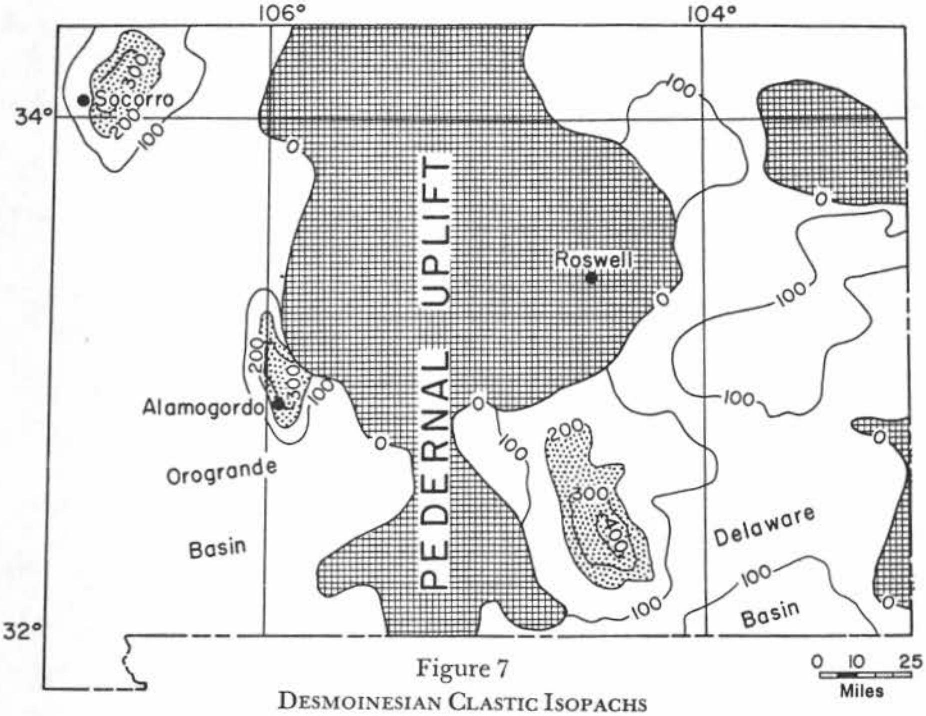

Figure 7
DESMOINESIAN CLASTIC ISOPACHS

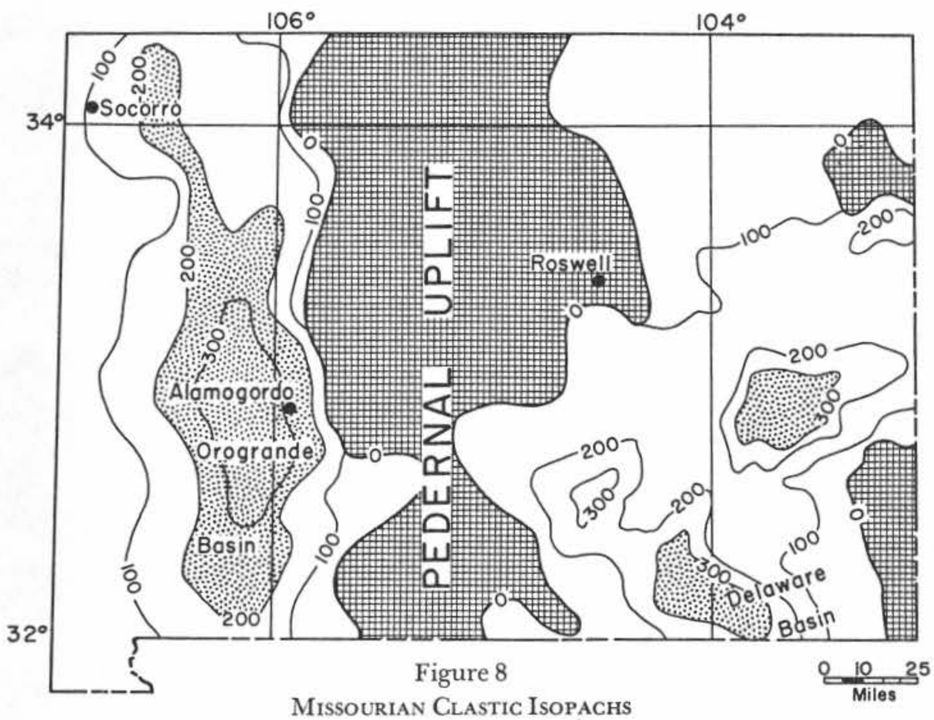

Figure 8
MISSOURIAN CLASTIC ISOPACHS

shallow Pennsylvanian seas. The Pedernal uplift was barely awash for most of the Desmoinesian and provided mostly silt and clay for the limestone-choked seas. Locally, on the east edge of the Orogrande basin and on the northwest side of the Delaware basin, deltas of subgraywacke developed. Late Desmoinesian uplift supplied arkose westward to the Socorro area near the present-day Joyita and Los Piños mountains. The Pedernals sent about 230 cubic miles (545 cubic kilometers) of detritus westward and 230 cubic miles (960 cubic kilometers) eastward; most of this was during late Desmoinesian time. The erosion stripped perhaps 180 feet (55 meters) off the 10,000 square miles (25,900 square kilometers) of the Middle Pennsylvanian Pedernals.

By late Missourian (fig. 8), the Pedernal uplift took on the aspect of a tilted fault block with the western side apparently higher and providing more detritus directly to the west into the Orogrande trough. Eastward into the Delaware basin, the clastic material is predominantly silt and clay, whereas appreciable arkose washed westward. About 270 cubic miles (1155 cubic kilometers) of detritus were dumped westward within 50 miles (80 kilometers) of the west edge, with some 375 cubic miles (1565 cubic kilometers) spread over the southeast region. This should have eroded an average of 350 feet (106 meters) from the exposed Pedernals.

It is difficult to grasp just how much material is involved in cubic miles of sediments. For comparison, if the Franklin Mountains were eroded to the level of their surrounding alluvial fans, about 11 cubic miles (46 cubic kilometers) of material would need to be removed. So we are talking about eroding major features when we move 375 cubic miles (1565 cubic kilometers) of sediments.

Major uplift of the Pedernals continued into Virgillian time (fig. 9), culminating during late Virgilian and early Wolfcampian with vast amounts of subgraywacke, arkose, and red to dark shale deposited westward in the Orogrande basin. The smaller amount of detritus washed eastward is shown in this figure. About 1810 cubic miles (7550 cubic kilometers) of clastic material accumulated to the west, with 415 cubic miles (1730 cubic kilometers) to the east; the 8500-square miles (22,000 square kilometers) Pedernal remnant should have been eroded 1300 feet (395 meters) to supply this amount of detritus; almost a quarter of a mile! So the Pedernals were mountains amid the late Pennsylvanian seas.

Early Wofcampian sediments (fig. 10) derived from the western Pedernals range from quartzite and granite cobble-conglomerates to red shale, but by middle Wolfcampian time, the major detritus source shifted far to the north, to the Uncompahgre highland of north-central New Mexico and southwest Colorado. About 800 cubic miles (3330 cubic kilometers) of detritus went westward into the Orogrande basin and 500 cubic miles (2090 cubic kilometers) to the southeast during early Wolfcampian. The last lingering stage of the major part of the Pedernal uplift was eroded about 700 feet (215 meters) as it buried itself amid its own debris.

Reddish clastics from the Uncompahgre flooded southward during middle Wolfcampian time to the shoreline belt where the Abo redbeds interfinger southward with the Hueco marine strata on top of the early Wolfcampian Diablo platform. By late Wolfcampian time (fig. 11), most of the Pedernal uplift was buried beneath red beds; only locally, as at present-day Pedernal Hills and Pajarita Mountain, did remnant Precambrian-rock monadnocks rise above the red flood. These higher remnants supplied minor detritus to the lagoonal seas of early Leonardian time.

During its 40 million years of major emergence, lasting from Morrowan to Early Wolfcampian time, the Pedernal uplift supplied about 5700 cubic miles (24,800 cubic kilometers) of sediments to adjoining basins and was eroded on the average about 3300 feet (1000 meters). Its detritus provided much of the source beds and reservoir rocks for southeast New Mexico's Pennsylvanian and early Permian oil and gas fields.

Figure 11 shows the outcrops on which the Leonardian strata were deposited, although there is considerable dispute as to where the Wolfcampian–Leonardian boundary is in the Permian rock sequence. It is not simple, but most of the Abo, most of the Cutler, most of the upper Sangre de Cristo, most of the Hueco, and in southwest New Mexico, most of the upper Earp are of Wolfcampian age. Basal Leonardian units are the Yeso in the south-central, central, and northern areas, the Epitaph Dolomite in the southwest, and the Bone Spring Limestone and Victorio Peak facies to the southeast.

There is the problem of correlation of the central New Mexico Abo, which is mostly of Wolfcampian age, with the subsurface so-called Abo of southeast New Mexico, which is claimed to be Leonardian in age. What happens across the buried Pedernals is not known for certain, but southward in the San Andres Mountains, one can walk out the outcrops as the Abo redbeds grade southward into the Wolfcampian Hueco marine starta.

Figure 12, the isopach map of the Yeso–Bone Spring–Victorio Peak–Epitaph units, suggests that the Burro uplift of Mesozoic age extended from the Burro Mountains area to the southeast during its early and middle Mesozoic erosional period, stripping off any early Leonardian strata deposited in that area. For example, in the outcrops of the Franklin Mountains, western Hueco Mountains (Seewald, 1968) east of El Paso, Potrillo and Florida mountains to the west, and the Organ and Robledo mountains to the north, the Wolfcampian Hueco Formation is the youngest Permian beneath Cretaceous strata. However, on the east side of the Huecos, the Bone Spring Limestone or Victorio Peak facies crops out and is thick. Thus, the southeast tip of the Burro uplift may stop abruptly just southeast of El Paso.

The Yeso is mostly of interbedded gypsum, dolomitic limestone, and pinkish clastic beds, although southward toward the New Mexico–Texas line, it becomes more and more a limestone unit, grading southward into the Bone Spring–Victorio Peak Formation. One of the thicker sections of the Yeso occurs about 100 miles (160 kilometers) north of El Paso, west of Carrizozo, where a thick section containing much gypsum and salt was deposited. This Carrizozo basin is above the northern tip of the pre-Leonardian Orogrande basin and mainly west of the buried

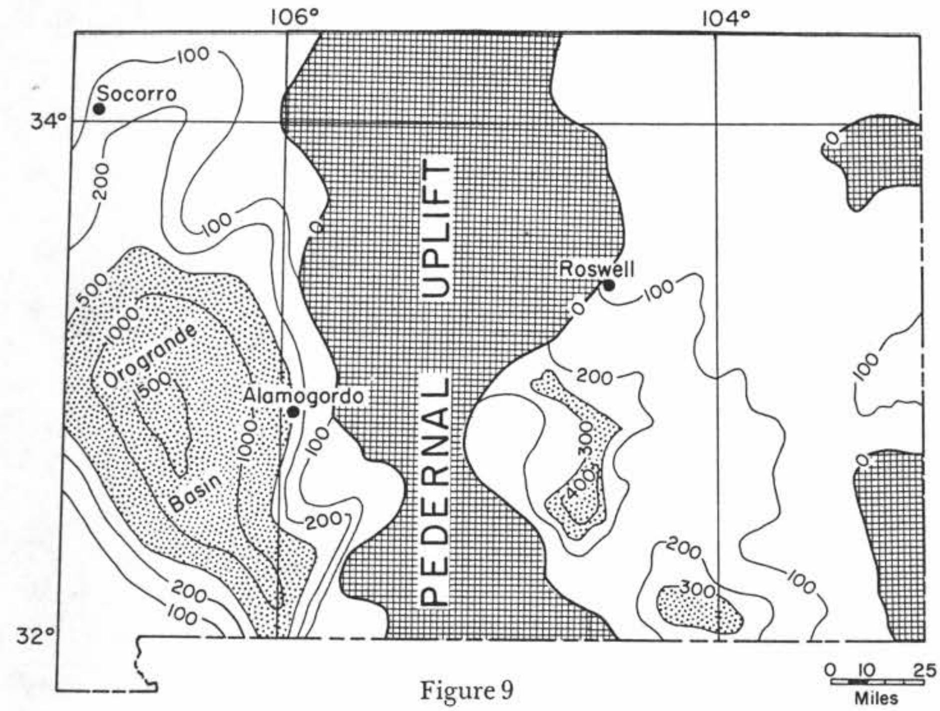

Figure 9
VIRGILIAN CLASTIC ISOPACHS

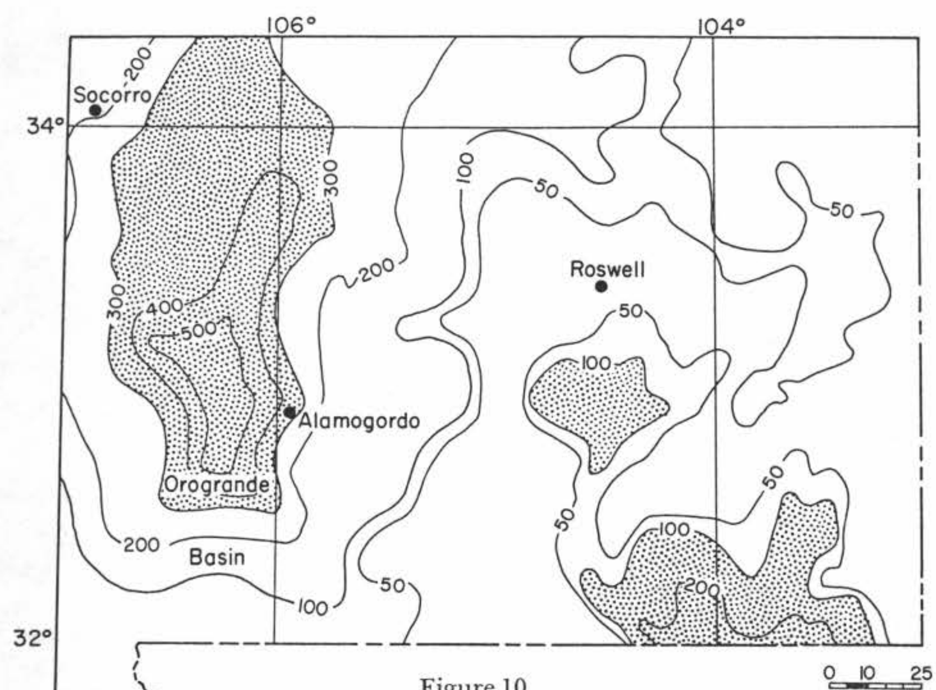

Figure 10
EARLY WOLFCAMPIAN CLASTIC ISOPACHS

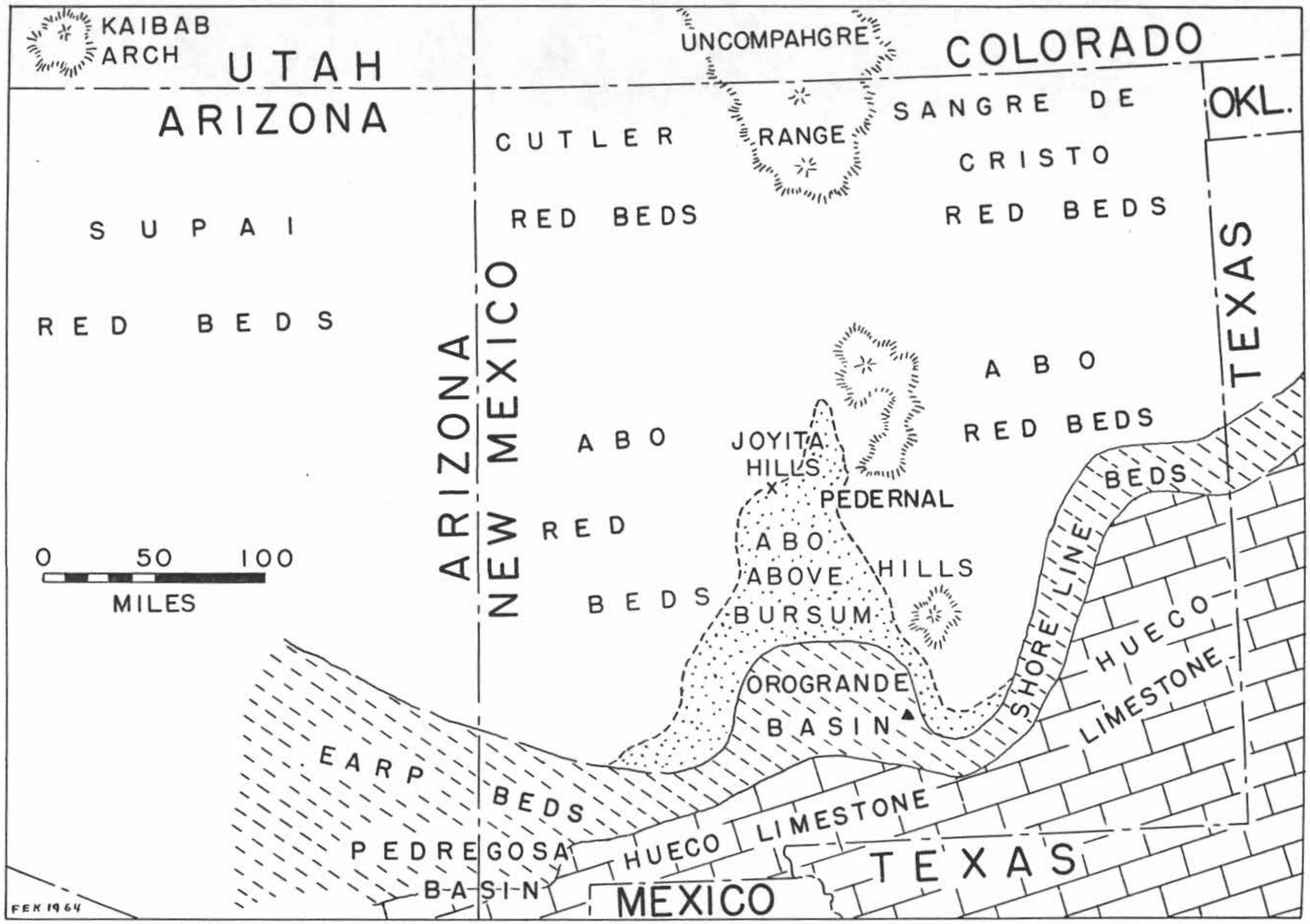

Figure 11
WOLFCAMPIAN PALEOGEOLOGIC MAP

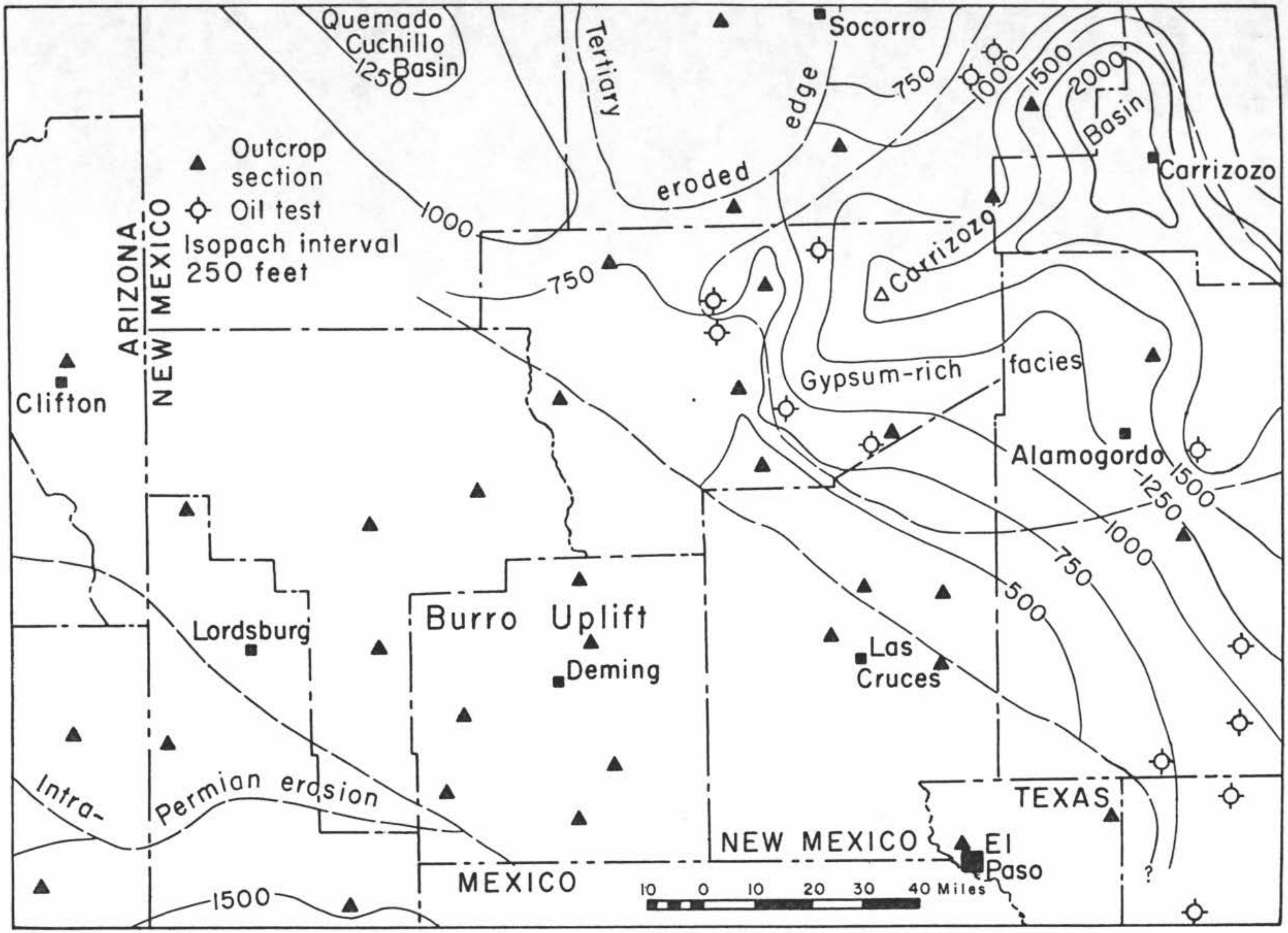

Figure 12

ISOPACH AND LITHOFACIES MAP OF LEONARDIAN YESO FORMATION AND EPITAPH DOLOMITE western edge of the Pedernal upland. A similar gypsum-rich basinal area occurs to the northwest in the Quemado area. A Yeso–Bone Spring Limestone facies probably was deposited near El Paso, but it was removed by later erosion.

The isopach map (fig. 13) of the Glorieta Sandstone–San Andres Limestone in south-central New Mexico and the Scherrer clastics and Concha Limestone in the southwest would include their early Guadalupian equivalents if extended to the east, the Goat Seep reef and the Brushy Canyon and Cherry Canyon basinal facies. Again the Burro uplift was responsible for stripping off any of these equivalents near El Paso; however, the Concha Limestone to the southwest is very similar to the San Andres north of El Paso and on the east side of the Burro uplift. Undoubtedly, the San Andres–Concha limestones were deposited over the site of the Burro uplift. The San Andres Limestone of south-central New Mexico is only the equivalent of the lower part of the thicker San Andres in southeast New Mexico.

Northward, the San Andres Limestone facies grades into an intertongued gypsum and limestone and still farther north, into a nearshore sandstone. The late Guadalupian Artesia Group of southeast New Mexico does not extend anywhere near El Paso; very likely, El Paso region was emergent during late Guadalupian time and remained above sea level until the Early Cretaceous seas rolled in from the south. Certainly, during the Ochoan, the dying phase of the Paleozoic, this area was a lowland, sweltering under the sun that to the east looked down on the land-locked salt and gypsum sea of the Delaware basin area.

What are the relationships of Bridges' late Paleozoic upland in northeastern and central Chihuahua to these Permian deposits near and north of El Paso? Bridges suggests this upland may have extended (figs. 1-3) northward to join the Diablo platform. However, the Diablo platform was covered by late Wolfcampian and Leonardian marine strata, whereas the post-Wolfcampian in northeast Chihuahua is mostly clastic rocks, suggesting that the central Chihuahua late Paleozoic positive area was exposed to erosion in Leonardian and later Permian time.

An oil test being drilled (April 1969) near Villa Ahumada by Pemex, about 80 miles (130 kilometers) south of El Paso and Juarez, encountered thick basinal sediments of Wolfcampian age, apparently beneath Cretaceous strata. This oil test is only about 20 miles (32 kilometers) northwest of the northwest edge of Bridges' upland. It suggests that a Wolfcampian basin may have extended southward from the Orogrande basin and southeastward from the Pedregosa basin but that erosion or nondeposition in Leonardian and later Permian time resulted in the lack of a post-Wolfcampian Permian sequence. Guadalupian strata do occur to the northeast in the Big Hatchet Mountains and Sierra de Palomas areas of the Pedregosa basin; perhaps in that region another Permian Basin occurs, partly hidden in the graben valleys of the basin-and-range country.

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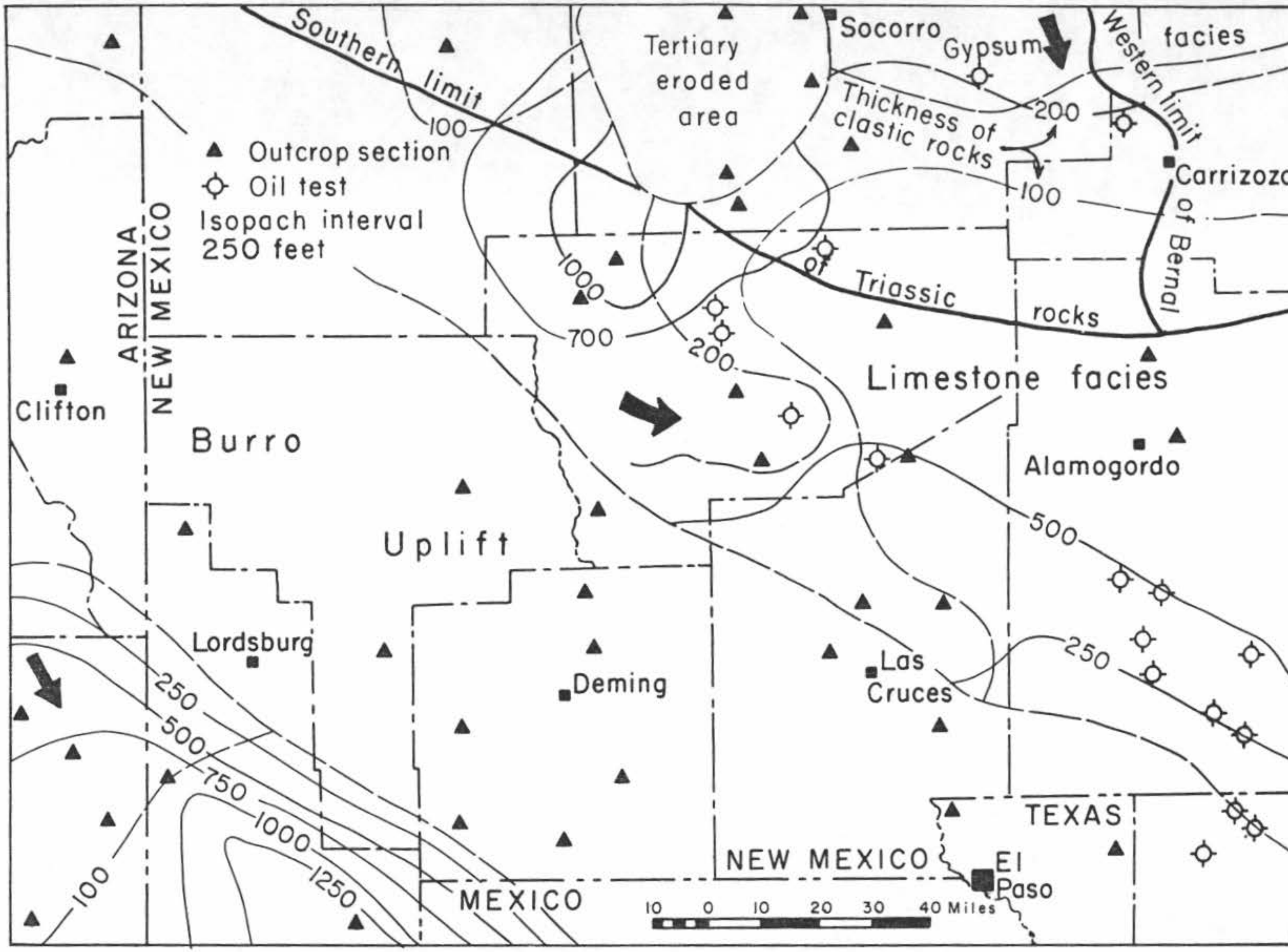


Figure 13

Isopach and lithofacies map of Glorieta, San Andres, Scherrer, and Concha (includes Rainvalley Formation) formations

The Santa Fe Group in the South-Central New Mexico Border Region

by John Hawley
Geologist, Soil Survey Investigations, Soil Conservation Service,
U.S. Department of Agriculture
Frank E. Kottlowski
Acting Director, New Mexico Bureau of Mines and Mineral Resources
William R. Seager and William E. King
Department of Earth Sciences, New Mexico State University
William S. Strain and David V. LeMone
Department of Geology, University of Texas at El Paso

ABSTRACT

The Santa Fe Group in the south-central New Mexico border region is a complex sequence of piedmont-slope alluvium; playa, lacustrine, and fluvial deposits; and some basaltic volcanics preserved in structural basins within and adjacent to the Rio Grande depression.

The upper limit of the group is the surface of the youngest basin fill predating initiation of the Rio Grande Valley entrenchment. The lower limit is placed above volcanic and associated sedimentary rocks of Oligocene-early(?) Miocene age that are well exposed in the Caballo-Selden area. Studies of vertebrate and invertebrate faunas, determination of the potassium-argon age of interbedded basalt, and correlation of volcanic ash lenses have established a general Miocene to mid-Pleistocene age for the Santa Fe Group in the border region. Early stages of intermontane basin filling occurred in a closed-basin (classic bolson) environment, while later stages were marked by coalescence of basin floors and development of a regional system of through-drainage. Thus, Santa Fe group deposition in the border region corresponds with Bryan's idealized concept of basin filling in the type Santa Fe region to the north.

Important economic resources in the Santa Fe Group include ground water, sand, gravel, clay, and caliche.

INTRODUCTION

The term *Santa Fe* first proposed by Hayden (1873), has been used in a variety of ways (Johnson, 1903; Bryan and McCann, 1937; Denny, 1940; and Stearns, 1953). The term generally designates a complex, late Cenozoic basin-fill sequence, including consolidated and unconsolidated sedimentary deposits, and volcanic rocks. The current status of the Santa Fe rock-stratigraphic unit in its type area in northern New Mexico has been summarized by Baldwin (1956, 1963). In 1963, Baldwin formally proposed that the term *Santa Fe Formation* be raised to group status, although informal use of the "group" concept was proposed by Baldwin, Kottlowski, and Spiegel in 1953 (Kottlowski, 1953). Baldwin's proposal (1963, p. 38-39) follows:

> It is proposed in this report, with informal agreement from a dozen geologists who have been concerned with the late Cenozoic geology of the Rio Grande trough, that the term Santa Fe be raised to group status, and that all the basin fill, whether Tertiary or Quaternary, be included in the Santa Fe group. Broad usage of the term Santa Fe group is an advantage in areas where the basin fill is not, or cannot be, subdivided. In those areas where subdivisions have been established by detailed mapping, local formation and member names may be applied until the basin fill is well enough understood that the correlation of units can be demonstrated.
>
> Therefore, the Santa Fe group is here considered to be a broad term including sedimentary and volcanic rocks related to the Rio Grande trough, with a range in age from middle(?) Miocene to Pleistocene(?). The lower limit is here placed above the latitic and limburgitic flows and breccias exposed in the Cienega area. It is placed at the base of the volcanic sediments (Stearns' Abiquiu(?) formation) that was exposed along the Santa Fe River about 5 miles (8 kilometers) west of Cienega (Stearns, 1953, pl. 1). The upper limit is here considered to include

> all but the terrace deposits and alluvium of present valleys; thus, the Santa Fe group includes the sediments that mantle remnant and buried graded surfaces (previously lumped together as the "Ortiz surface".)

This joint paper presents a summary of current knowledge on the Santa Fe Group in the south-central New Mexico border region. The authors believe that an attempt should be made to integrate the findings of a number of recent investigations (by many individuals) in the hope that a consensus now on stratigraphic terminology will facilitate current and future research on basin-fill geology and hydrology. This is particularly pertinent because the Santa Fe Group, as the major ground-water reservoir in the region, is coming under increasing scrutiny by hydrogeologists and others.

The region discussed in this paper lies in the Mexican Highland section of the Basin and Range province. It includes an area of New Mexico and west Texas bounded by the Animas–Goodsight–Uvas–Aden–Potrillo volcanic uplands on the west and the Sacramento–Hueco–Finlay–Malone–Quitman chain on the east (fig. 1). The northern and southern boundaries are not rigidly defined, but the intermontane basins discussed extend about 100 miles (161 kilometers) south into northern Chihuahua, Mexico, and north to the latitude of Elephant Butte Reservoir.

North of the International boundary, the major structural basins with thick Santa Fe Group fill include the Palomas, Jornada del Muerto, and Tularosa and the Mesilla and Hueco bolsons. The major ranges within the area include the Robledo, East Potrillo, Caballo, Doña Ana, San Andres, Organ, and Franklin mountains. The Palomas, Rincon, Selden, Mesilla, and El Paso segments of the Rio Grande Valley cross the region from northwest to southeast. The irregular series of structural basins partly occupied by the Rio Grande Valley has been called the Rio Grande depression (Bryan, 1938; Kelley, 1952, 1955). Kottlowski (1958) limits this feature to areas north of the Sierra de Las Uvas, whereas Kelley (1955, fig. 2) indicates that it extends through the Mesilla bolson into northern Chihuahua. The structural evolution of the region has been discussed in some detail by King (1935), Kelley (1952, 1955), and Kottlowski (1958). Previous work and current studies in New Mexico and western Texas suggest that the present structural basins and uplifts were outlined by basin-and-range type of block faulting that began in the Miocene and continued into the late Quaternary. Most of the tectonic deformation appears to be pre-Quaternary. The extent of basin-and-range type of fault control on the development of basins in northern Chihuahua is not well known, and discussion of the structural evolution of that area is beyond the scope of this paper.

Published maps and sections showing the detailed distribution and lithologic character of the Santa Fe Group (or its previously unnamed basin-fill correlatives) are available for only a few parts of the border region. An asterisk precedes those entries in the references that include such information. Several detailed studies of the basin fill are in progress and some unpublished information (including maps, cross sections, well logs, and measured-section descriptions) is available for inspection at the Earth Sciences Department, New Mexico State University, Las Cruces; Office of Soil Survey Investigations, Soil Conservation Service, University Park; and New Mexico Bureau of Mines and Mineral Resources, Socorro.

Major outcrop areas of the Santa Fe Group, as well as basin areas generally underlain by thick Santa Fe fills, are shown in Figure 1. Descriptions of measured sections in the Tonuco uplift–Selden Canyon area follow the end of this paper.

The authors wish to acknowledge the co-operation and assistance of the following colleagues who are or who have recently been actively involved in studies of the late Cenozoic in the border region: Robert V. Ruhe and Leland H. Gile, Soil Conservation Service; Artie L. Metcalf, University of Texas at El Paso; Frederick F. Peterson, University of Nevada; and Andrew M. Taylor, Colorado School of Mines.

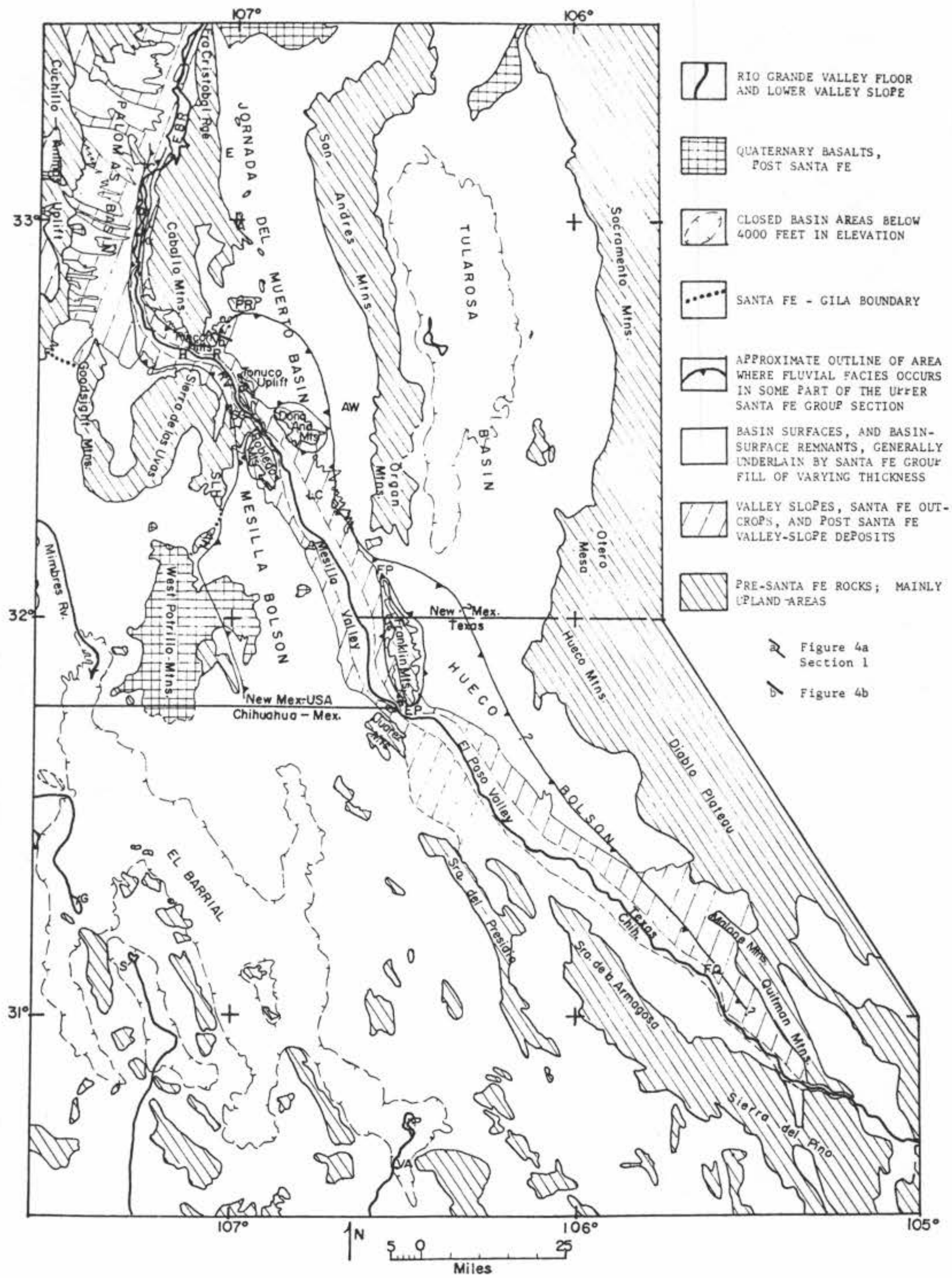
THE SANTA FE GROUP IN SOUTHERN NEW MEXICO AND WEST TEXAS

Bryan (p. 205) made the first definitive statement about the southern extent of the Santa Fe formation:

> The main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis Valley to and beyond El Paso, is considered to be the same general age and to belong to the Santa Fe formation.

Cope (1883, quoted in Kelley and Silver, 1952, p. 123), Baker (1927), Harley (1934, p. 29-30), and Dunham (1935), however, had previously recognized the probably correlation between at least part of the intermontane basin-fill deposits in the area here discussed and the Santa Fe formation of northern New Mexico.

According to Bryan (p. 205-207) and Wright (1946, p. 399-400), the Santa Fe formation was deposited in two basic types of environment, closed basins and basins with through drainage. Locally derived piedmont slope alluvium, characterized by wide textural variation and including pediment, alluvial-fan, and coalescent-fan deposits, was typical of both types of basins. In closed systems, piedmont slope alluvium graded into or intertongued with fine-grained playa and lacustrine deposits of the basin floors. In



A ALEMAN
AH ADEN HILLS
AW APOLLO WELLS
CR CABALLO RESERVOIR
E ENGLE
EBR ELEPHANT BUTTE RES.
EP EL PASO
FP FILLMORE PASS
FQ FORT QUITMAN
FS FORT SELDEN
G LAGUNA GUZMAN
H HATCH
LC LAS CRUCES
P LAGUNA PATOS
PR POINT OF ROCKS
R RINCON
RV RINCON VALLEY
S LAGUNA SANTA MARIA
SC SELDEN CANYON
SLH SLEEPING LADY HILLS
TC TRUTH OR CONSEQUENCES
VA VILLA AHUMADA

Figure 1

INDEX MAP OF THE BORDER REGION, NEW MEXICO, TEXAS, AND CHIHUAHUA SHOWING OUTCROP AREA OF THE SANTA FE GROUP open systems, coarse to fine fluvial deposits along the basin axis graded into or intertongued with piedmont-slope alluvium.

MESILLA AND HUECO BOLSONS AND UPPER LIMIT OF SANTA FE GROUP

Kottlowski (1953, 1958, 1960) did the first regional mapping of Santa Fe basin fill in southern New Mexico. He proposed that the unit be raised to group status (as noted previously) and subdivided it into two units: the lower Santa Fe Group of general late Tertiary age and the upper Santa Fe Group mainly of early mid-Quaternary age. Kottlowski (1960) also demonstrated that upper Santa Fe Group basin fill extended through Fillmore Pass (between the Organ and Franklin mountains) into the Hueco bolson, thus establishing the physical continuity of at least the upper part of the Santa Fe section in southern New Mexico and westernmost Texas. Results of test drilling in Fillmore Pass, reported by Knowles and Kennedy (1956, 1958), indicate that unconsolidated basin fill is locally as much as 970 feet (295 meters) thick in the gap between the Organ and Franklin mountains. Strain (1966, p. 11) suggested that, after coalescence of basin fill through Fillmore Pass, the Mesilla and Hueco bolsons "continued to aggrade with a common level" during the last 500 feet (150 meters) of basin filling. The two bolsons were also connected in El Paso Canyon area during later stages of basin filling; however, much of the stratigraphic evidence in that area has been removed during subsequent valley entrenchment.

Geologic studies in the Hueco bolson by Sayre and Livingstone (1945) and Albritton and Smith (1965) previously established the general correlation between the fill of that basin and the Santa Fe formation of New Mexico. Strain's (1959, 1966) intensive studies of basin-fill stratigraphy and vertebrate faunas in the southern part of the Hueco bolson further established that the exposed sections of fill near Fort Hancock are early to mid-Pleistocene (Nebraskan? to late Kansan) in age. However, at the time of his investigation, Strain (1966, p. 16) did not believe that extension of the Santa Fe formation terminology from Mesilla bolson into Hueco bolson was justified. He formally proposed that the bolson deposits be subdivided into two rock stratigraphic units, the Fort Hancock and Camp Rice Formations. The Fort Hancock Formation, composed of clay, silt, fine sand, and gypsum and containing a late Blancan vertebrate fauna, was deposited in a closed basin periodically occupied by large lakes. Strain (1966, p. 10) postulated that in early Pleistocene time, during periods of maximum flooding, a very large lake formed in the Hueco and southern Mesilla bolsons that was fed in part by an ancestral Rio Grande system heading in Colorado and New Mexico. He named this body of water "Lake Cabeza de Vaca, in honor of the first white man to enter its basin." In contrast with the Fort Hancock, the overlying Camp Rice Formation is coarser grained and contains some rock types in the gravel fraction derived from distant upstream sources, as well as lenses of Pearlette (?) volcanic ash. According to Strain (1966), this unit was deposited in an "open" basin system traversed by the ancestral Rio Grande. A late Blancan vertebrate fauna has been recovered from Camp Rice beds that are stratigraphically below the ash lenses. The upper limit of the Camp Rice Formation in the type area is defined by an erosion surface graded to the Rio Grande Valley. Both the Camp Rice and Fort Hancock Formations include locally derived alluvial-colluvial facies associated with piedmont-slope environments of deposition. These formations are discussed in more detail by Strain in a companion paper.

In light of Baldwin's definitive statement quoted above on the Santa Fe Group, evidence of basin connection in the Fillmore Pass and El Paso areas, and the age of vertebrate faunas and volcanic ash deposits in the basin fill, we here propose that the bulk of the Hueco bolson fill be included in the Santa Fe Group. The Fort Hancock and Camp Rice Formations would form basic subdivisions of at least the upper part of the group. One consequence of this proposal is that it would also require that the bulk of the fill of Tularosa Basin, the northward extension of the Hueco bolson, be included in the Santa Fe Group. This conforms to current U.S. Geological Survey practice in arbitrary separation of the Santa Fe Group and the Gila Conglomerate (Dane and Bachman, 1965). The Santa Fe Group is restricted to regions within the Rio Grande watershed, to closed basins east of the Rio Grande, and to basins between the Rio Grande and the West Potrillo and Uvas–Goodsight mountains (Elston and Netelbeek, 1965).

Studies of vertebrate and invertebrate faunas in the Mesilla Valley area (Ruhe, 1962; Hawley and Gile, 1966; and Metcalf, 1967) demonstrated that aggradation of the floor of the Mesilla bolson culminated in mid-Pleistocene time. An Irvingtonian (Late Kansan–early Illinoian) vertebrate fauna, including *Mammuthus, Cuvieronius,* and *Equus,* has been recovered from the youngest sand and gravel unit of the Santa Fe Group basin fill (fig. 2). This unit, which contains rounded pebbles of rock types foreign to the local area, has been informally designated the "mixed-rounded gravels" (Hawley and Gile). It is locally as much as 60 feet (18 meters) thick and probably is a time correlative of the upper part of the Camp Rice Formation in the Hueco bolson. In this paper, it is considered a fluvial deposit (see below). Underlying sand, gravel, silt, and clay beds, possibly indicating both fluvial and lacustrine depositional environments, appear to correlate with the lower Camp Rice–upper Fort Hancock sequence. Surface and subsurface mapping east of Las Cruces demonstrate that the "fluvial" sand and gravel facies of the central basin area laterally intertongues with a thick sequence of alluvial-fan deposits a short distance east of the Mesilla Valley border (fig. 3).

There has been general agreement that significant Rio Grande Valley entrenchment took place in early Wisconsin time; Metcalf reported the presence of a snail fauna of possible Illinoian age in older valley-fill deposits between Caballo Dam and El Paso (Hawley and Kottlowski, p.). It thus appears that initial cutting of present valleys and

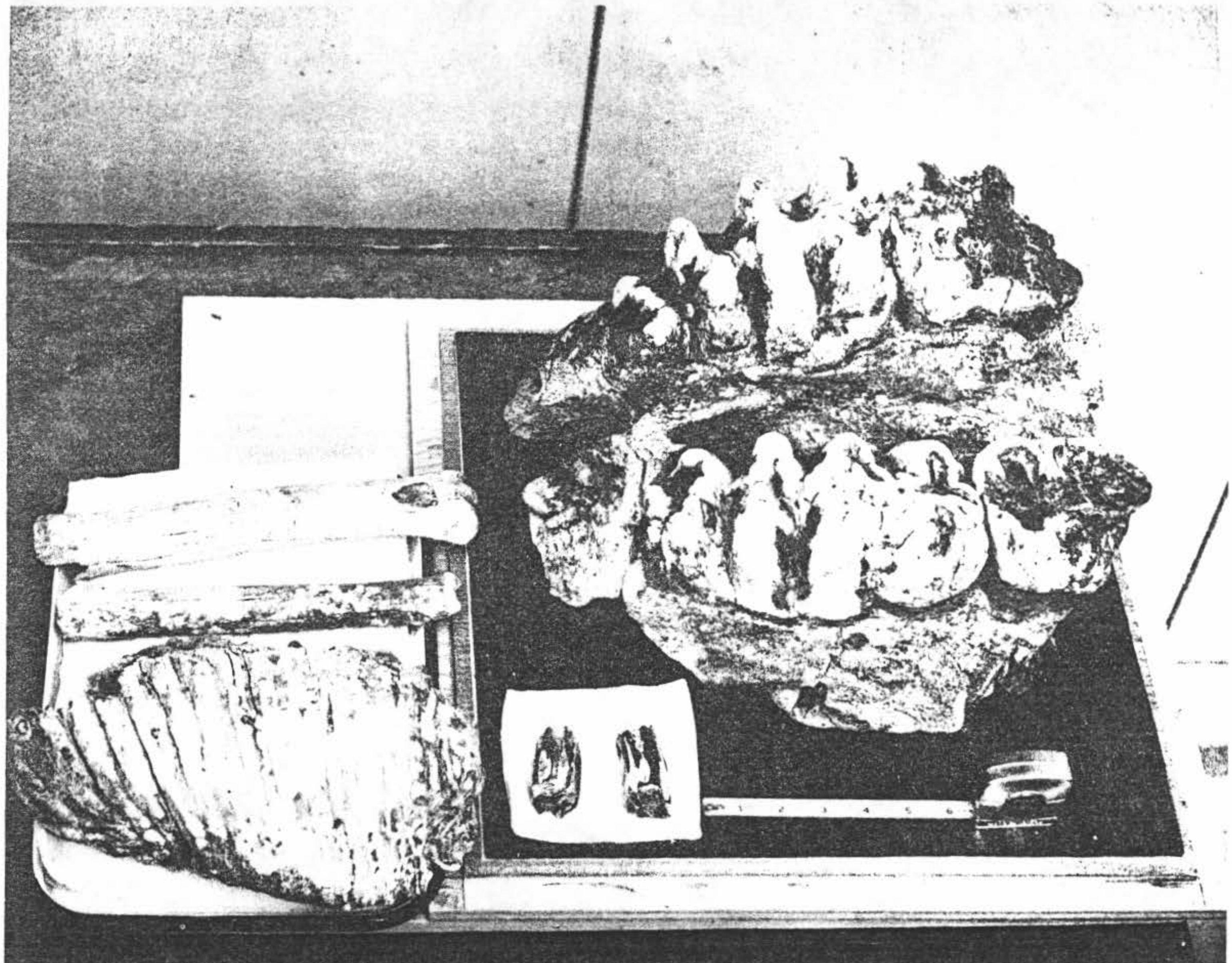


Figure 2

IRVINGTONIAN VERTEBRATE FAUNA

Collected from upper Santa Fe Group sand and gravel unit (equivalent to upper part of Camp Rice Formation) east of Las Cruces. Teeth of *Equus* and *Mammuthus;* upper plate of *Cuvieronious;* miscellaneous limb-bones.

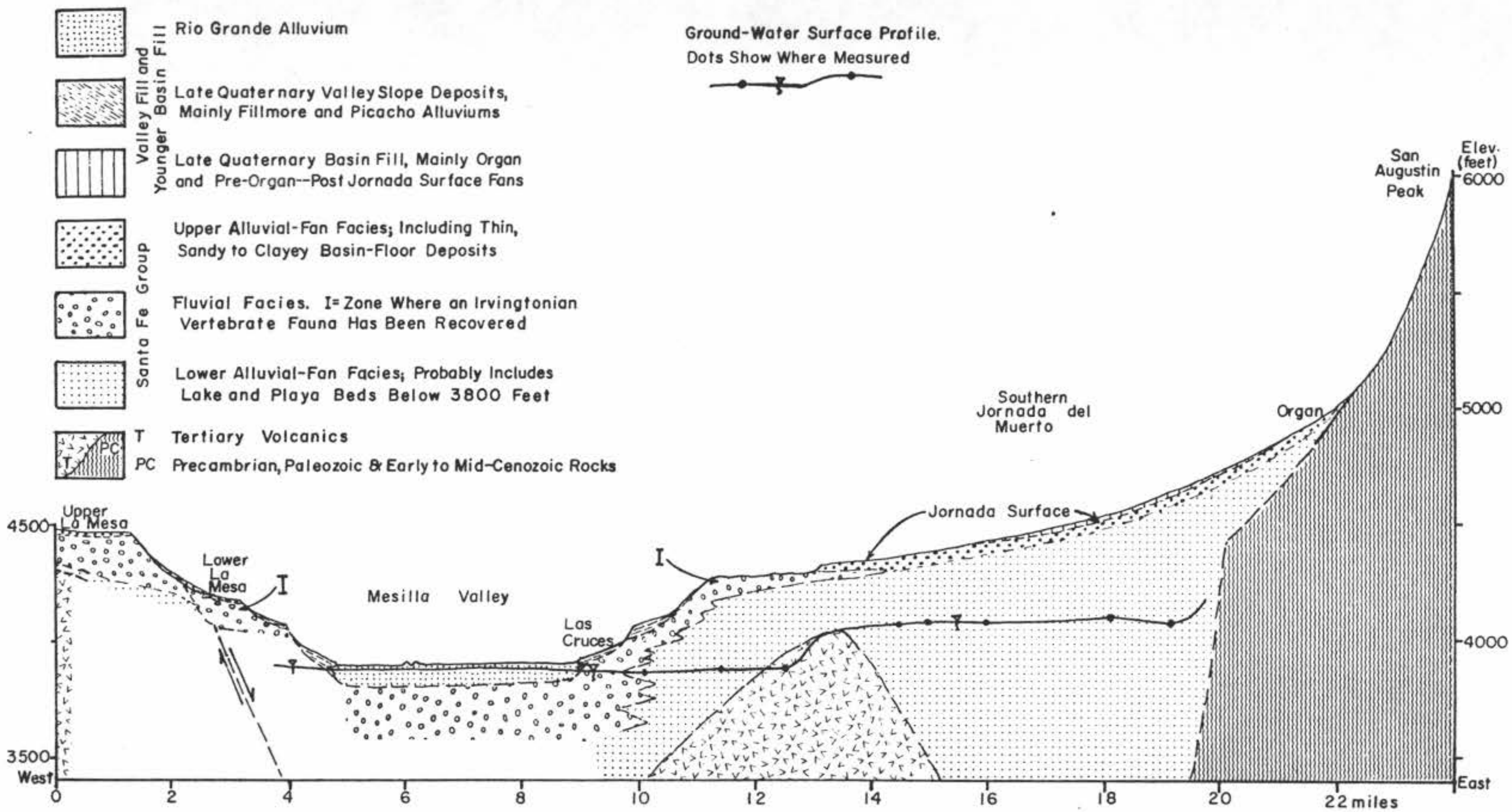


Figure 3

CROSS SECTION OF MESILLA VALLEY AND SOUTHERN JORNADA DEL MUERTO BASIN ALONG U.S. 70

Illustrates the Santa Fe Group subdivisions and water-table configuration Las Cruces area.

termination of Santa Fe Group deposition occurred in the Yarmouth–Illinoian interval.

The origin of the early- to mid-Pleistocene sand and gravel deposits, interpreted as fluvial sediments above, has been debated. Ruhe (1962) reviewed the literature on the subject and demonstrated the wide areal distribution of the upper part of these deposits in basins of southern New Mexico. Since this time-transgressive unit in the upper Santa Fe section occurs on both side of the Rincon Hills, the Tonuco–Selden Hills uplands, and the Robledo, Doña Ana, and Franklin mountains (fig. 1), it is certainly not a single channel deposit of an ancestral river, as described by Bryan and associates in basins north of Socorro (Bryan; Denny, 1941; Wright). Evidence that these are fluvial deposits and not lacustrine gravel and sand, as postulated by Ruhe (1962) and Reeves (1965), follows: (1) The widespread deposits of gravel and sand are confined to the ancient, often very broad, basin floors and do not occur as fringing bars on piedmont slopes. (2) The deposits tend to thicken toward basin axes and slope to the south. (3) The sediments contain some rock types, exotic to the particular basin, that are derived from areas to the north. (4) Sedimentary structures within the deposits (such as trough sets of cross beds and armored mud balls) are generally indicative of fluvial sedimentation. (5) Similar high-level gravel and sand deposits, at relatively constant altitudes above the present river floodplain, are preserved in many places along the Rio Grande trough from central New Mexico to western Texas (DeBrine, Spiegel, and Williams, 1963; Davie and Spiegel, 1967; Hawley, 1965; Strain, 1966; and Weber, 1963). Thus, the ancestral Rio Grande in the south-central New Mexico border region might best be characterized as a time-transgressive system of distributary channels, with shifting loci of deposition, that spread out from a more confined channel system in the Palomas Basin above Rincon. Before integration with the lower Rio Grande system southeast of the Quitman Mountains and initiation of valley entrenchment, the upper Rio Grande at various times fed large lakes in the border region (Lee, 1907; King; Brand, 1937; Bryan; Sayre and Livingston; Kottlowski, 1958; Reeves; Strain, 1966).

Geomorphic studies near Las Cruces (Ruhe, 1962, 1964, 1967; Hawley and Gile) demonstrate that basin filling in extensive areas adjacent to the Rio Grande Valley culminated with the development of the Jornada and La Mesa geomorphic surfaces, whose respective type areas are the southern Jornada del Muerto Basin and northern Mesilla bolson. The broad basin floors, generally underlain by Santa Fe fluvial sand and gravel deposits and locally with a thin veneer of eolian cover sands, comprise La Mesa geomorphic surface. Large areas of piedmont slopes (including pediment, alluvial-fan and coalescent-fan surfaces) and limited areas of the basin floors comprise the Jornada geomorphic surface. Jornada piedmont-toeslope deposits (uppermost Santa Fe alluvium) locally overlap or are inset slightly below remnants of La Mesa surface; thus, the Jornada is somewhat younger than La Mesa surface. Small remnants of alluvial fans and rock pediments preserved above the Jornada surface along the mountain fronts comprise the Doña Ana surface, which may be a piedmont-slope correlative of La Mesa surface. All these surfaces are complex, and each may represent several stages of development over a period of time.

As indicated by the stratigraphic evidence p. 55, development of the Jornada surface (and at least the younger part of La Mesa surface) apparently took place sometime during the late Kansan–early Illinoian interval and before initiation of Rio Grande Valley entrenchment. The Jornada–La Mesa complex is analogous to, but not necessarily a time-equivalent of, the younger or upper Ortiz surface of central and northern New Mexico (Bryan; Denny, 1941; Wright; Baldwin, 1956; Anderson, 1961; Ruhe, 1964), and it often marks the upper boundary of Santa Fe Group deposits in south-central New Mexico. Correlatives of the Jornada–La Mesa complex in the Caballo region include the Jornada and Palomas surfaces of Kelley and Silver. Hawley and Kottlowski present further discussion of ancient basin surfaces and the geomorphic evolution of the Rio Grande Valley.

Thick soils characterized by strong horizons of carbonate accumulation have developed in surficial deposits of the ancient basin fills (Gile, 1967; Gile, Peterson, and Grossman, 1965, 1966; Hawley and Gile). Upper Santa Fe Group sections reflecting coalescent-alluvial-fan and basin-floor sedimentation environments often contain one or more prominent buried soils (or paleosols) that mark disconformities in the depositional sequence. Sedimentation on the middle and lower parts of broad piedmont slopes particularly seems to have been characterized by marked periodicity. Vertical successions of as many as five buried soils, locally exposed in the upper 50 to 100 feet (15 to 30 meters) of Santa Fe piedmont-slope alluvium, indicate that major cycles of sedimentation and landscape instability alternated with extended periods of surface stability and soil formation during mid-Pleistocene time. As piedmont-slope deposits thin toward basin axes, horizons of carbonate accumulation in the succession of buried soils tend to merge into thick, complex, soil-carbonate horizons that are often indurated (Hawley and Gile; Ruhe, 1967). These carbonate horizons form caliche-caprock layers particularly well developed just beneath La Mesa surface and its correlatives.

In the basin areas that are still internally drained, gradation of parts of piedmont slopes and basin floors has continued to the present time. Such areas comprise the entire Tularosa Basin, much of the Jornada del Muerto Basin, the Mesilla and Hueco bolsons, and minor parts of the Palomas Basin.

In the reconnaissance map of Las Cruces area, Kottlowski (1960) included some bolson alluvium "ranging to Recent in age" in the upper Santa Fe Group. However, he mapped separately valley-fill deposits (including Picacho and floodplain alluviums), as well as extensive late Quaternary closed-basin fills (including playa, stream, and alluvial-fan sediments). In the type Santa Fe area, Baldwin (1963) included all sediments mantling the complex Ortiz surface in the Ancha Formation of the (upper) Santa Fe Group, no matter what their ages. Only deposits confined to valleys cut below the Ortiz surface (Plains, Airport, and Divide surfaces of Baldwin) were split from the Santa Fe.

The authors presently feel that expansion of the Santa Fe concept to include all fill of closed basins flanking the Rio Grande depression is not warranted. Such a broad interpretation would force inclusion in the Santa Fe Group of such units as the White Sands and Otero lake beds of the Tularosa Basin and the Organ alluvium (Ruhe, 1967) of the Jornada del Muerto. Therefore, herein, we propose that all rock-stratigraphic and morphostratigraphic units (see paper by Hawley and Kottlowski) demonstrably younger than initial entrenchment of the present valley system be excluded from the Santa Fe Group. In most closed-basin areas, this involves separating less than 25 feet (8 meters) of unconsolidated surficial deposits.

In many instances, deposits of closed basins, which demonstrably postdate entrenchment of the Rio Grande valley system, can be separated from underlying Santa Fe Group basin fill on the basis of distinct lithologic differences (including composition, color, cementation). Also, geomorphic characteristics of surficial deposits can play an important subsidiary role in determining stratigraphic differentiation. Since the primary surface form of the upper Santa Fe Group basin fill is preserved in many parts of the border region, constructional elements of geomorphic surfaces, such as La Mesa, Jornada, and Palomas (and associated soil features), often provide a relatively easily identifiable upper boundary of the group.

Obviously, the necessity and ability to distinguish younger basin fill from the Santa Fe Group depend on the purpose and intensity of a given field investigation. However, the authors feel that an attempt should be made to limit the already very broad Santa Fe concept to increase the precision and usefulness of the Santa Fe terminology in a wide range of geologic and geohydrologic studies.

SELDEN CANYON–RINCON VALLEY AREA AND BASE OF SANTA FE

The lower limit of the Santa Fe Group is more difficult to establish in the southern New Mexico border region. Vast areas of the intermontane basins are still undissected. Where valley entrenchment has occurred, only several hundred feet (60 meters) of section are well exposed in most places. Test drilling in the Tularosa Basin and Hueco and Mesilla bolsons indicates that basin deposits of the Santa Fe Group may locally exceed 1 mile (1.6 kilometers) in thickness and often are as much as 2000 feet (600 meters) thick (Sayre and Livingstone; Leggat, Lowry, and Hood, 1963; personal communication, current studies by King). Thick basal sections of the Santa Fe Group are exposed only where the valleys of the Rio Grande and tributary arroyos cross areas of moderate to intense deformation near basin margins.

The best exposures of the older Santa Fe Group, and underlying mid-Tertiary volcanic and sedimentary rocks, occur in the Selden Canyon–Rincon Valley area. The youngest, pre-Santa Fe unit is the Palm Park–Thurman–Bell Top–Uvas sequence (Kelley and Silver; Kottlowski, 1953) of intermediate to rhyolitic volcanics and volcanic-derived sedimentary rocks. One potassium-argon date of 31.0 ± 1.5 million years (Geochron Laboratories, Inc., RO-287) has been obtained from the youngest volcanic unit, the Uvas Basaltic Andesite (Kottlowski, 1953, 1965; Hawley and Kottlowski, 1965), indicating an Oligocene age for volcanics in the upper part of the sequence. However, current reconnaissance mapping in the Rincon Hills by Hawley and Seager has delineated a thick section of post-Uvas–pre-Santa Fe sedimentary rocks (previously mapped as Palm Park Formation, Kottlowski, 1953, maps 1-5) that could be of Oligocene or Miocene age.

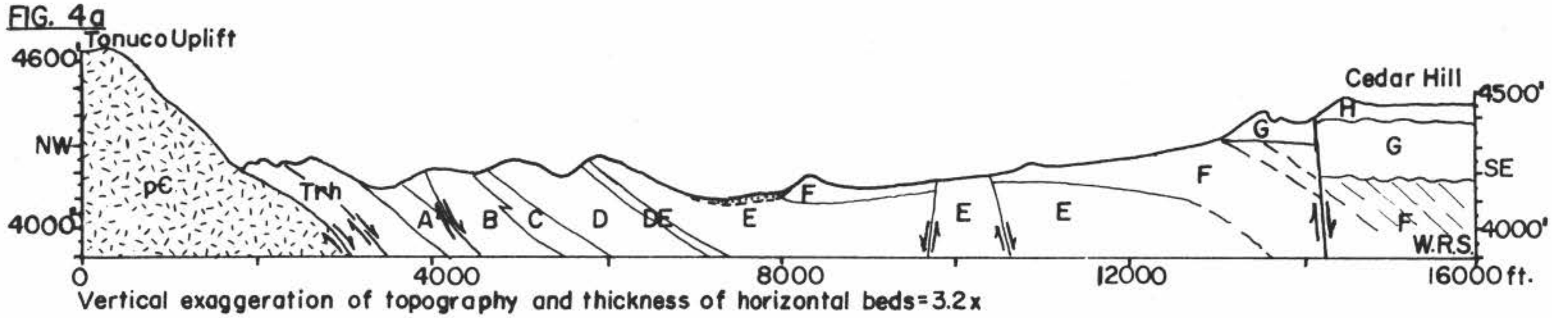
In the Tonuco uplift–Selden Cayon area, Kottlowski (1953, p. 146) described the thick basal Santa Fe section as consisting generally of comglomerates to conglomerate sandstone. The Selden (olivine) Basalt (Kottlowski, 1953, 1960), which is interbedded with lower Santa Fe Group beds in Selden Canyon, has a potassium-argon age of 13.2 ± 0.5 million years (Geochron Laboratories, Inc., RO-621; Hawley, 1967), indicating a general late Miocene age for the lower part of the Santa Fe section. However, it should be emphasized here that Santa Fe sedimentation could have been initiated in local basins long before extrusion of the Selden Basalt. Near the Tonuco uplift, more than 2800 feet (845 meters) of Santa Fe conglomerate may have been deposited before basalt extrusion.

The thick conglomerates in the basal Santa Fe and younger pre-Santa Fe sections in the Rincon Valley–Selden Canyon area bear witness of profound deformation in south-central New Mexico during late Oligocene and Miocene. Probably the structural configuration of basins and uplifts was outlined at that time, although faulting along the margins of the structural blocks recurred through the late Pleistocene. Fault displacement of mid-Tertiary rocks involved several thousand feet (600 meters) of vertical movement and possibly significant amounts of horizontal movement, as well (Kelley, 1955, p. 102). Evidence also of deep erosion of the younger pre-Santa Fe rocks before and during early Santa Fe deposition is indicated in exposures west of Seldon Canyon, where conglomeratic (pre-Selden Basalt) Santa Fe deposits locally fill valleys cut as much as 100 feet (30 meters) into Uvas Basaltic Andesite.

The basal Santa Fe conglomerate flanking the Tonuco uplift is greatly deformed. Beds are locally faulted, tilted nearly to vertical, and warped into broad folds. In places, low-angle, gravity-glide faults are present. Current mapping of the Tonuco uplift by Seager indicates that much of the section previously mapped as Palm Park and Thurman Formations (Kottlowski, 1953, maps 1-4; 1965) actually belongs to the Santa Fe Group. This includes the thick sandstone-to-conglomerate unit capping San Diego (Tonuco) Mountain, which contains evidence of barite-fluorite mineralization.

Immediately southeast of the Tonuco uplift (fig. 4a; sec. 1 of the appendix), the lower Santa Fe Group comprises a thick red to brown conglomerate (more than 2600 feet –780 meters– thick) conformably(?) overlain by light-

FIG. 4a



- Late Quaternary alluvium

SANTA FE GROUP

- Caprocks of Rincon and La Mesa surfaces
- Youngest gravel unit of the fluvial facies (mid-Pleist.)
- Op — Beds in GH? with opalized plant remains
- GH? — Sandstone to mudstone, partly conglomeratic & equiv.(?) G&H
- H — Loam to sand, with paleosols
- G — Lower sand and gravel unit of the fluvial facies (early? Pleist.)
- F — Reddish, brown-gray sandstone to claystone and clay (lake?)
- AE — Conglomerate; equiv.(?) to part of A to E sequence.
- E — Brown to pinkish gray sandstone to conglomerate
- DE — Reddish brown mudstone
- D — Brown to reddish brown conglomerate to sandstone
- C — Pinkish gray sandstone to siltstone
- AB — Red to reddish brown conglomerate to sandstone (basal SF)

OLDER ROCKS

- Trh — Pre-Santa Fe--post Thurman reddish sedimentary rocks
- Tv — Thurman and Palm Park Fms. including rhy. tuffs and basaltic andesite flows.
- pC — Precambrian granite, pegmatite and schist.

FIG. 4b

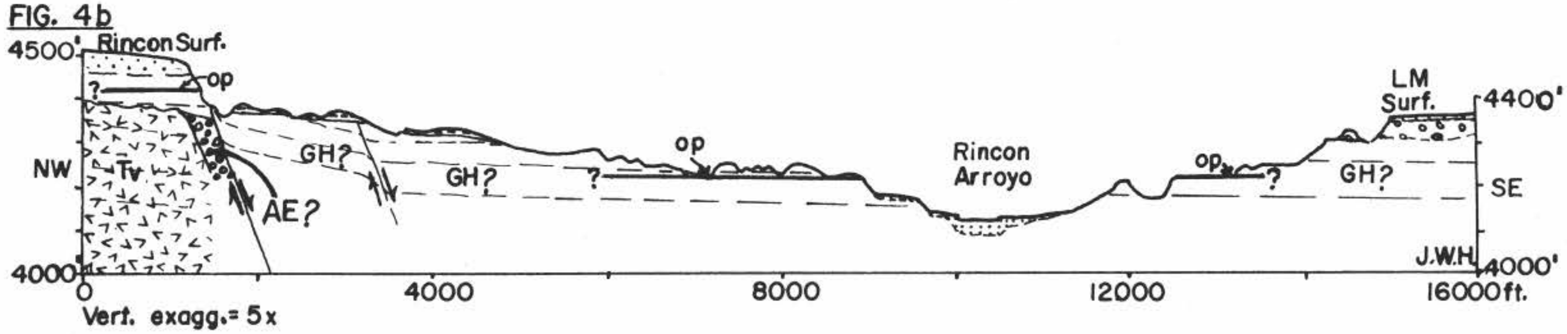


Figure 4a

CROSS SECTION, TONUCO UPLIFT TO CEDAR HILL

Illustrates the most complete exposed Santa Fe Group section in the border region.

Figure 4b

CROSS SECTION, RINCON SURFACE TO LAS MESA SURFACE

Across Rincon Arroyo, northeast of Rincon, New Mexico.

brown to red gypsiferous sandstone to claystone with interbedded conglomeratic sandstone in the upper part (more than 500 feet −780 meters− thick). The uppermost part of this section becomes thicker and coarser to the south and appears equivalent to beds containing the Selden Basalt tongue in Selden Canyon. The entire unit is tilted and faulted, with dips commonly ranging up to 45 degrees; it is overlain with angular unconformity by beds of the upper Santa Fe Group fluvial facies, which are generally only slightly deformed and primarily consist of clean, gray to light-brown sandstone to conglomeratic sandstone and sand. Horse teeth, of possible early to mid-Pleistocene age, recovered from near the base of the upper unit are currently being studied by Strain. Locally, a reddish-brown to white, fine- to medium-grained unit (as much as 100 feet −30 meters− thick) containing evidence of periodic sedimentation and soil formation comprises the uppermost part of the group and rests on an undulating erosion surface cut into the underlying sandstone. This part of the Santa Fe section has been offset more than 85 feet (26 meters) along an east-boundary fault of the Tonuco–Selden Hills uplift. The deformed older strata and angular discordance point to repeated intense deformation in late Tertiary to early Quaternary time. The youngest fault movements along the north edge of the Tonuco uplift have produced a scarp in upper Santa Fe Group sandstone that is still virtually undissected.

Between San Diego Mountain and Rincon, only the upper Santa Fe Group is exposed. The section is very similar to that exposed in the western wall of the Mesilla Valley south of Picacho Mountain. Several hundred feet (60 meters) of interbedded, partly indurated sand, gravelly sand, and minor silt-clay strata are capped by up to 60 feet (18 meters) of crossbedded sand and gravel in the eastern valley slope, which ascends to the floor of the Jornada del Muerto Basin. The uppermost unit represents an ancestral river channel fill that was once continuous with the "mixed-rounded gravel"–upper Camp Rice sequence–in Mesilla bolson. West of the valley, the high-level river channel deposits are discontinously preserved as thin tongues of rounded gravel and sand, interbedded with coarse-grained piedmont slope deposits derived from the Sierra de Las Uvas. In Selden Canyon, 4 miles (6 kilometers) south of San Diego Mountain and 280 feet (85 meters) above the floodplain, a lens of volcanic ash is interbedded between the river-channel gravels and overlapping bouldery fan alluvium(sec. 2 of the appendix; Hawley, 1965). This ash deposit has been tentatively correlated with lenses of Pearlette (?) Ash in sections of the Camp Rice Formation in its type area below El Paso (Strain, 1966), secs. 1 and 6; R. Wilcox, personal communication). The surface of the alluvial-fan gravels that overlap the Selden Canyon ash lens has been correlated with the Palomas and Jornada surfaces (Hawley, 1965). Previous workers (Kelley and Silver; Kottlowski, 1953) considered such fan (and pediment) gravels as post-Santa Fe bolson fill. Because these deposits represent continued basin aggradation before entrenchment of the present valleys, they are now included in the upper Santa Fe Group.

East of the Sierra de Las Uvas, continued faulting on the basin margins since mid-Pleistocene has resulted in several tens of feet (6 meters) of displacement of the Palomas–Jornada surface and associated gravel. Fault scarps in these deposits are still prominent features on the piedmont slopes.

PALOMAS AND CENTRAL JORNADA DEL MUERTO BASINS

At Rincon, the Rio Grande Valley separates from the Jornada del Muerto and makes a great bend to the west (upstream) around the Caballo–Fra Cristobal mountain chain. The Palomas basin, west of the Caballos, received a great thickness of sediment during late Cenozoic time, both from adjacent mountain uplifts and from upstream sources (Kelley and Silver; Davie and Spiegel).

The ancient Palomas Basin was (as is the present basin) asymmetric, with its axis located in the eastern part of the basin at the foot of the Caballo structural block. Piedmont slopes rising to the Black Range–Animas uplands are long and gentle, while piedmont slopes of the Caballo Mountains are short and steep. Surface and subsurface studies in the vicinity of Animas Creek (Davie and Spiegel, p. 9) show that the Santa Fe Group is composed of three facies: an alluvial-fan facies derived from bordering uplands; "a clay facies, possibly representing the distal. . .beds of alluvial-fan facies"; and "an axial-river facies consisting of well-sorted sand and gravel containing well-rounded quartzite pebbles, probably derived from northern New Mexico and Colorado." Near Caballo Reservoir, the exposed sections of Santa Fe deposits are generally medium- to coarse-grained, reflecting alluvial-fan (major) and "axial-river" (minor) environments of deposition. The clay and "axial-river" facies occur mainly in the subsurface near Caballo, but in the Hatch–Rincon area farther to the south, they are well exposed in valley walls. West of Hatch, a 400-foot (122 meter) section of silt, bentonitic clay, sand, and sandstone is exposed below a high-level, basin-floor remnant correlated with older parts of La Mesa surface near Las Cruces (Hawley and Kottlowski, p. 25). Vertebrate fossils have been recovered from this section and are currently being studied by Strain. Water-well tests near Hatch (Conover, 1954) indicate that the clay facies of the Santa Fe Group extends as much as 2000 feet (610 meters) below the valley floor.

Kelley and Silver presented a strong case against the possibility of any ancestral Rio Grande channel existing in the Jornada del Muerto east of the Fra Cristobal–Caballo mountains, as proposed by Lee and by Bryan. It is probable that the Rio Grande has maintained its course in the Palomas Basin since initiation of through-drainage in latest Tertiary or early Quaternary time. The studies by Davie and Spiegel in the Caballo Reservoir area demonstrate the existence of a through-flowing river during later stages of Santa Fe deposition. However, the time of onset of through-drainage in the upper Rio Grande system has not yet been established. Kelley and Silver postulated that it may not have occurred until Quaternary time because of presumed low relief in the San Juan–Sangre de Cristo headwaters area during Pliocene time. Kottlowski (1958, p. 46) also supported this hypothesis. However, it is possible that uplift took place in the headwaters area before onset of the "classic four-glacial" Pleistocene of the mid-Continent region. Many more sections of fluvial deposits have to be identified and their faunas and floras studied before the problem can be solved. According to Strain (1966), an integrated river system extended into the Hueco bolson by early Kansan time, but such a system may have reached the Palomas Basin at a much earlier date.

Previous studies in the central Jornada del Muerto (Kelley and Silver; Kelley, 1952; Kottlowski et al., 1956) and current work by Hawley do not support Lee's long-held hypothesis that the ancestral Rio Grande flowed east of the Fra Cristobal–Caballo mountains until diverted into the Rio Grande depression by extrusion of the San Marcial basalt. At many places in the axial parts of the basin north of Point of Rocks, pre-Santa Fe volcanic and sedimentary rocks crop out or are only shallowly buried, and the Santa Fe section is thin. Relatively thick Santa Fe sections may be present, however, in the eastern half of the basin beneath the broad piedmont slopes rising to the San Andres Mountains. As pointed out by Kelley and Silver and by Ruhe (1962), the basin floor is not a graded surface sloping gently to the south. Rather, the central Jornada del Muerto can be divided into three subbasins, Red Lake, Engle, and Jornada Draw, which are separated by distinct divides. The Red Lake–Engle Basin divide, 6 miles (10 kilometers) north of Engle, is particularly prominent and appears to be entirely underlain by rocks of the Mesaverde and/or McRae Formation. It is 100 feet (30 meters) higher than the Jornada basin floor at Black Mesa (28 miles–45 kilometers–to the north), where the Mesa Prieta basalt flow (Weber, p. 41) "overlies. . .riverine sands and gravels of the uppermost Santa Fe Group." If an ancestral Rio Grande flowed east of the Caballos, it was confined to a very narrow valley or canyon since completely buried by younger bolson deposits. Drilling 5 miles (8 kilometers) southeast of Aleman, where such a valley would be confined between spurs of McRae sandstone and Thurman–Uvas volcanics, would establish the presence or absence of an ancestral river channel.

SOUTHERN JORNADA DEL MUERTO

The Jornada del Muerto Basin south of Point of Rocks is distinctly different from its extension to the north. The basin floor is a constructional plain underlain by gypsiferous lake (?) beds and by fluvial deposits of the ancestral Rio Grande, which entered from the Palomas Basin to the west. The surface of the plain correlates with La Mesa surface south and west of Las Cruces. The broad, piedmont slopes rising to the San Andres Mountains bear evidence of post-Santa Fe, late-Pleistocene, and Holocene aggradation over large areas, but the amount of local aggradation since the culmination of Santa Fe basin filling has probably not exceeded 25 or 30 feet (8 or 9 meters). Well data and geophysical tests (Doty, 1963; Hawley and Kottlowski; Taylor, 1967) indicate that the Santa Fe Group is more than 1000 feet (305 meters) thick in the central parts of the southern Jornada Basin (fig. 3).

There are excellent exposures of the upper part of the Santa Fe Group in the valley of Rincon Arroyo, which extends up the west side of the Jornada del Muerto between Point of Rocks and Rincon Hills (fig. 4). The aggregate thickness of the exposed section is about 350 feet (105 meters). On the west side of the valley, the section appears thicker because it is repeated along the east boundary fault of the Rincon Hills structural block. Interbedded sandstone, sand, silt, and sandy mudstone predominate, but some pebble conglomerate and clay are also present. Coarse, lower Santa Fe conglomerate is present only in narrow belts along the basin margins. Two prominent opalized beds, with well-preserved plant fossils, crop out in the lower part of the section about 130 feet (40 meters) below the Jornada Basin floor and 80 to 120 feet (24 to 37 meters) below the base of river channel gravels having a mid-Pleistocene vertebrate fauna. David LeMone and Roy Johnson, page 77, of the University of Texas at El Paso are currently studying the opalized material that contains abundant remains of marsh-type vegetation. At the west edge of the basin, above the Rincon Hills east-boundary fault, possible correlatives of the opalized beds extend under the Rincon surface (Hawley, 1965; Hawley and Kottlowski, p. 24), an ancient basin-floor remnant preserved between the Rincon Hills and southern Caballo Mountains. This surface is 500 to 600 feet (150 to 180 meters) above the Rio Grande floodplain and 150 to 250 feet (45 to 75 meters) above La Mesa geomorphic surface. The Rincon surface is underlain by as much as 100 feet (30 meters) of carbonate- and silica-cemented, upper (?) Santa Fe sandstone to mudstone unconformably overlying deformed beds of the Palm Park and Thurman Formations. Most of the upper 50 feet (15 meters) of the section are cemented into a dense caliche caprock layer. "Pisolitic" or "Rockhouse" structures occurring in the upperseveral feet of the caliche are identical to those described by Bretz and Horberg (1949) and Swineford, Leonard, and Frye, (1958) in the upper parts of similar caprock sections below the High Plains surface of the southwestern Great Plains.

DISCUSSION

In spite of the limited amount of field work on basin-fill geology and the almost complete lack of petrographic information on individual units, some definitive statements can be made about the Santa Fe Group in the border region. Figure 5 diagrammatically shows some of the major characteristics of the group. The time scale in the illustration is distorted, being greatly compressed at the older end of the spectrum; also, the figure does not represent a cross

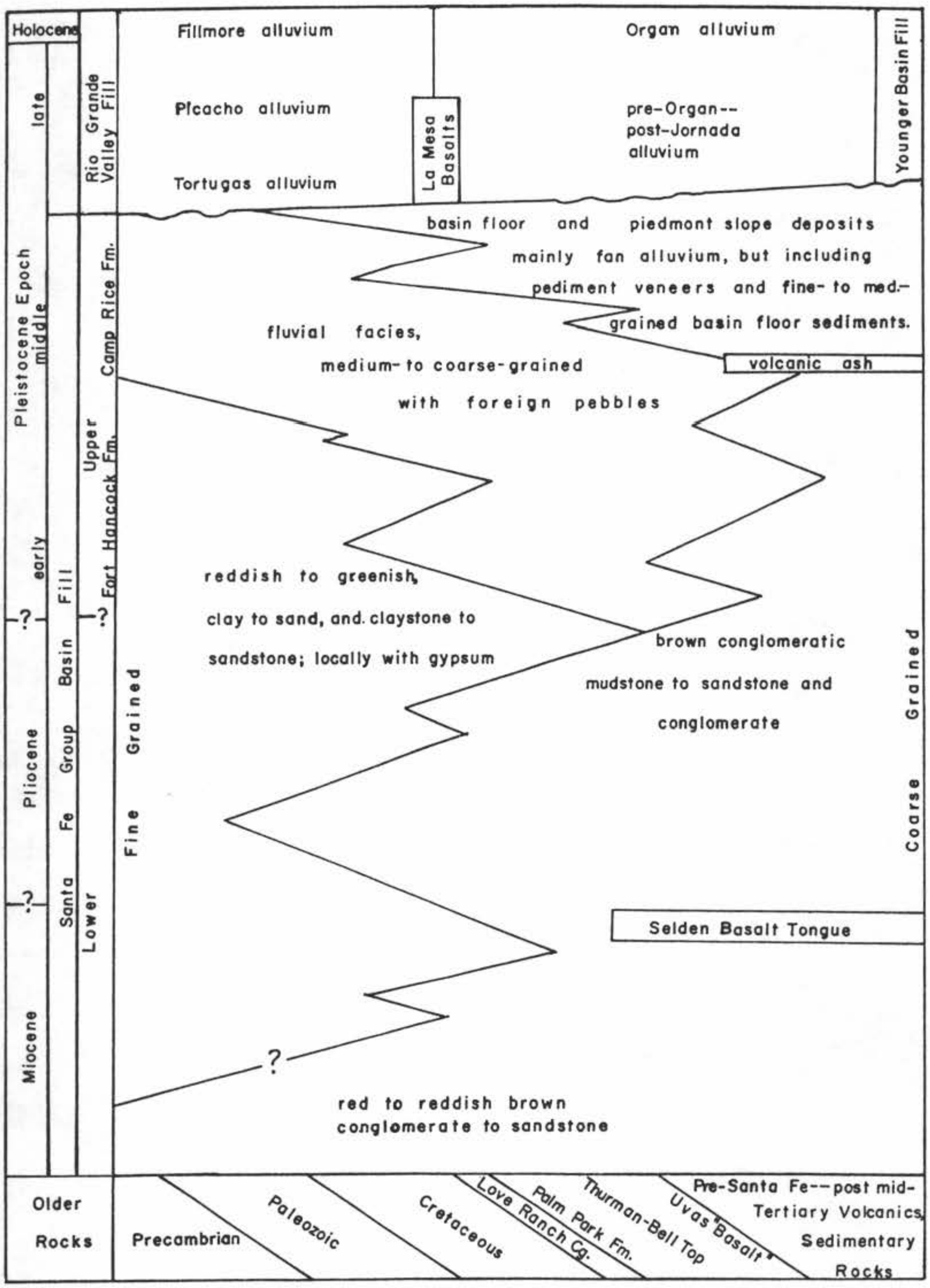


Figure 5

DIAGRAMATIC SUMMARY OF SANTA FE GROUP STRATIGRAPHIC TERMINOLOGY AND GENERAL LITHOFACIES DISTRIBUTION IN THE BORDER REGION
(Facies boundaries may be gradational or sharp erosional contacts)

section at a particular locality but rather an area extending from the Palomas Basin to the Hueco bolson. Three major stages of basin fillings are illustrated: (1) An early stage of closed-basin filling dominated by coarse-grained piedmont-slope and fine-grained basin-floor sedimentation. (2) An intermediate stage characterized by coalescence of basin fills, with fine-grained, partly lacustrine, sedimentation continuing in the south part of the region; transgressive fluvial sedimentation being initiated in the north; and continued gradation of piedmont slopes throughout the region. (3) A final stage of fluvial deposition in lower basin-floor areas extending from north of the Palomas Basin into the Hueco bolson, with encroachment of alluvial fans onto abandoned floodplain surfaces along the lower extremities of slopes. Major lacustrine and playa sedimentation continued only in the Tularosa Basin and the closed basins of northern Chihuahua. The history of basin filling and distribution of the respective basin-floor and piedmont-slope facies nicely fits Bryan's model of late Cenozoic sedimentation in intermontane basins along the Rio Grande depression. The coincidence of the hypothetical Plio–Pleistocene boundary and the extension of an ancestral Rio Grande into southern New Mexico, indicated in Figure 5, could be imaginary.

ECONOMIC RESOURCES IN THE BORDER REGION, SANTA FE GROUP

GROUND WATER

The Santa Fe Group is the major ground-water reservoir in the south-central New Mexico border region. The only other important aquifer system is the thin layer of late Quaternary gravel and sand comprising the alluvial fill of the inner valleys of the Rio Grande and major tributaries. These fluvial deposits are no more than 80 feet (24 meters) thick (Hawley, 1965; Davie and Spiegel). The bulk of the water supplies for El Paso and Las Cruces metropolitan areas comes from the Santa Fe Group, as do industrial supplies at the White Sands–Apollo Spacecraft centers. Many of the supplemental irrigation wells in the Mesilla and El Paso valleys tap not only the late Quaternary alluvium but also the upper Santa Fe Group.

Because of the wide range of depositional environments, the hydraulic properties of the Santa Fe Group show great variation. For instance, the clay facies in the Rincon–Palomas area and elsewhere is very impermeable, while the fluvial and better sorted parts of the alluvial-fan facies may have high coefficients of transmissibility. If poorly sorted, and/or well cemented, even medium- to coarse-grained material may be practically impermeable. The chemical quality of the ground water also reflects the variety of environments of Santa Fe deposition. Fine-grained facies notably affect water quality, either because of contained salts, such as gypsum, or because of resistance to being flushed by circulating waters of good quality.

On the west side of the Hueco bolson, measured coefficients of transmissibilities in the alluvial-fan and/or fluvial facies range from 38,000 to 164,000 gallons per day per foot (gpd/ft) of aquifer width, with average values of about 100,000 (Knowles and Kennedy, 1956, 1958). In a recently constructed, electric analog model of the fresh ground-water system in the western Hueco bolson (Leggat and Davis, 1966), assumed that transmissibilities range from less than 50,000 to greater than 350,000 gpd/ft in local areas. However, in most areas, assumed transmissibilities range from 50,000 to 150,000 gpd/ft. The assumed storage coefficient under water-table conditions (specific yield) is 15 percent.

In the city of El Paso's southern Mesilla Valley well field, wells completed in the Santa Fe Group, which locally exceeds 1200 feet (355 meters) in thickness, commonly produce between 1000 and 3000 gallons a minute (Leggat, Lowry, and Hood). Measured transmissibilities range from 34,000 to 73,500 gpd/ft, averaging about 50,000. (Permeabilities range from 128 to 150 gpd/ft^2, averaging about 140.) Local flowing wells and measured coefficients of storage on the order of 0.0007 demonstrate that artesian ground-water conditions exist. This should be expected because of the observed presence of extensive, fine-grained, confining beds above the major deep aquifer zone (600 to 1300 feet–180 to 395 meters–); medium to coarse sand; fluvial(?) facies).

In the northern Mesilla Valley, Las Cruces municipal wells produce large quantities of water from both the alluvial-fan and fluvial facies of the Santa Fe Group (Taylor). In the southern Jornada del Muerto Basin, between the San Andres and Doña Ana mountain, production wells for the NASA–Apollo Manned Spacecraft Center penetrate more than 1000 feet (305 meters) of Santa Fe Group fan alluvium. The saturated thickness of the section tested (400 to 500 feet–120 to 150 meters–) has measured coefficients of transmissibility ranging from 48,000 to 80,000 gpd/ft (Doty).

Depths to, and gradients of, the water table and/or piezometric surfaces also vary greatly. In open (Rio Grande-controlled) systems, the ground-water surfaces occur at depths ranging from 250 to 500 feet (75 to 150 meters) below the ancient basin floors and, as a general rule, slope gently toward the river valley, where water levels usually occur within 25 feet (8 meters) of the flood-plain surface (Conover; Conover et al., 1955). The water-table configuration thus reflects the generally good hydraulic conductivity of the basin fills that were drained during post mid-Pleistocene entrenchment of the valley. However, there are local areas with relatively high water-table gradients, such as where bedrock barriers form ground-water dams or where highly impermeable zones occur in the basin fill (Taylor). In closed ground-water systems, such as the Tularosa and Uvas–Goodsight basins, the water table may be very shallow in central basin areas, and Santa Fe Group deposits are essentially saturated.

SAND AND GRAVEL, GYPSUM, PUMICITE, AND CALICHE

Coarse-grained parts of the Santa Fe Group are extensively used for construction material. Well-graded alluvial-fan materials, as well as the better-sorted, more siliceous gravel and sand of the fluvial facies, are used in all types of construction from highway fill to concrete structures.

Gypsum is generally present in the finer grained facies of the Santa Fe Group in central basin areas. There appear to be particularly extensive deposits of gypsum in the upper Santa Fe beds in the Jornada del Muerto southeast of Point of Rocks, although they are undeveloped and have not been systematically explored. Because of the gypsum resources of late Quaternary age in the White Sands area of the Tularosa Basin, it is doubtful that the Santa Fe deposits will ever be significantly exploited.

Pumicite lenses are present in the upper Santa Fe Group in Selden Canyon (Hawley, 1965) and in the Camp Rice Formation near Fort Hancock (Strain, 1966). One attempt to mine the Selden Canyon deposit was soon abandoned. Considering the small size of the lenses and the vast quantities of pumice available in northern New Mexico, the deposits in the border region are probably not of commercial significance.

The caliche forming the extensive caprock of La Mesa and correlative surfaces is locally quarried for road metal.

NONMETALLIC MINERAL RESOURCES

The clay in the Santa Fe Group is predominantly calcium montmorillonite, although sepiolite and attapulgite have been reported in older soils of La Mesa surface west of Las Cruces (Vanden Huevel, 1966). Commercial clay production has come from beds of "bentonite" that crop out near the top of the upper Santa Fe section, 8 miles (13 kilometers) west of Hatch, and from the Fort Hancock Formation near Finlay, Texas. The Hatch "Bentonite" was processed for drilling mud during the 1930's and early 1940's (Patterson and Holmes, 1965). Adobe, a common term applied to mixtures of clay, silt, sand, and straw from which sun-dried bricks are made and frequently used for building material in this region, might also be considered an important clay product. Its mineral ingredients have been locally produced from the Santa Fe Group.

Recent work by Seager in the Tonuco uplift indicates that some barite-fluorite mineralization took place during very early stages of Santa Fe Group deposition. However, there is no evidence of veins capable of commercial production in basal Santa Fe conglomerates.

METALLIC MINERAL RESOURCES

Kelley and Silver (p. 211-213) reported commercial deposits of placer gold in the Shandon district northeast of Caballo Dam. Part of the deposits occur in gravel of the Santa Fe Group. They also suggested that very small, non-commercial deposits of placer manganese may "occur in what may be Santa Fe beds" at the south edge of the Rincon Hills.

CONCLUSION

The current status and historical background of the Santa Fe Group in the south-central New Mexico border region have been summarized herewith. This rock unit consists of a complex sequence of consolidated and unconsolidated sedimentary deposits and some volcanic rocks partly filling intermontane basins along and adjacent to the Rio Grande depression from the San Luis Valley to the lower El Paso Valley. The lower limit of the Santa Fe Group in the border region is placed above the volcanic and associated sedimentary rocks of Oligocene-early(?) Miocene age, which are well exposed in the Rincon Valley–Selden Canyon area. The upper limit of the Santa Fe Group is the surface of the youngest basin-fill deposits predating initial entrenchment of the present Rio Grande valley system in mid-Pleistocene (late Kansan-early Illinoian) time.

Regional mapping, studies of vertebrate faunas, volcanic ash correlation, and the potassium-argon age of interbedded basalt have established the physical continuity and general time correlation of the Santa Fe Group in the border region with the type Santa Fe in central and northern New Mexico.

Studies of the lithologic variations in basin-fill deposits, carried out in conjunction with investigations of basin geomorphology and basin-fill stratigraphy, demonstrate that environments of deposition included both closed and open intermontane basin systems. The former type, the classic bolson environment, prevailed during early stages of basin filling, while later stages were marked by coalescence of basin floors and development of a regional system of through-drainage. Thus, deposition of the Santa Fe Group in the southern New Mexico border region corresponds with Bryan's idealized concept of basin filling in the type Santa Fe region of central and northern New Mexico.

The Santa Fe Group is the major ground-water reservoir in the region. Santa Fe aquifers produce most of the water used in metropolitan and industrial centers, as well as a significant proportion of the ground water used to supplement surface irrigation supplies. Hydraulic properties of the basin fill and chemical quality of the ground water reflect the variety in environments of deposition in both open and closed basin system.

Other resources of economic importance in the Santa Fe group include sand, gravel, clay, and caliche.

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APPENDIX A

DESCRIPTION OF SANTA FE GROUP MEASURED SECTIONS

John W. Hawley and William R. Seager

Descriptions of two Santa Fe Group sections, one relatively complete and one partial, are presented. These sections are considered reference sections for the Santa Fe Group in the south-central New Mexico area. More sections need to be described, however, to properly characterize the group. Eventually, parts of these sections may serve as type sections for formally named formations and members within the Santa Fe Group.

Although measured and numbered or alphabetized upward in sequence, the sections are listed from top to bottom. Section 1 is composite and includes a number of lateral offsets to allow for more accurate characterization of the often structurally deformed and poorly exposed subunits. More detailed descriptions of these sections are on file at the offices of Soil Survey Investigations, Soil Conservation Service, and the Earth Science Department, New Mexico State University, Las Cruces.

The outline of the field description is generally as follows: (1) name of rock or unconsolidated sediment; (2) color of fresh and weathered surfaces (using the Munsell Color Company; Inc., Soil Color Chart; verbal and numerical notations for dry colors except where otherwise indicates); (3) induration; (4) composition of secondary void fillings, such as calcareous or gypsiferous; (5) bedding (thickness units, according to Ingram (1954), Geol. Soc. Am. Bull., v. 65, p. 937-938); (6) nature of the gravel (and sometimes sand) fraction, including textural parameters (AGI Data Sheet 7) and rock types; and (7) topographic expression, basal contact characteristics, and miscellaneous remarks.

The poorly consolidated to unconsolidated upper units of the Santa Fe Group are commonly described using pedologic textural class terms. For example: gravelly, 20 to 50 percent gravel; very gravelly, 50 to 90 percent gravel; low gravelly, gravel present, but less than 20 percent; sand, more than 85 percent sand, less than 15 percent silt, less than 10 percent clay; loamy sand, 70 to 90 percent sand, less than 30 percent silt, less than 15 percent clay; sandy loam, 43 to 85 percent sand, less than 50 percent silt, less than 20 percent clay; loam, 23 to 52 percent sand, 28 to 50 percent silt, 7 to 27 percent clay; clay loam, 20 to 45 percent sand 15 to 53 percent silt, 27 to 40 percent clay; sandy clay, 45 to 65 percent sand, less than 20 percent silt, 35 to 55 percent clay; and clay, less than 45 percent sand, less than 40 percent silt, more than 40 percent clay; (where gravel equals more than 2 mm, sand, 0.05 to 2 mm, silt, 0.002 to 2 mm, and clay, less than 0.002 mm).

SECTION 1. TONUCO, REFERENCE SECTION (COMPOSITE), SANTA FE GROUP, DONA ANA COUNTY, NEW MEXICO

Santa Fe Group measured southeast of Tonuco Uplift and north of Cedar Hill, San Diego Mountain quadrangle, NW¼ sec.16 to SE¼ sec. 6, T. 20 S., R. 1 W.

Subsection la. Location of start of composite section is the center of E½NE¼NW¼NW¼ sec. 16, about 0.5 mile northeast of the crest of Cedar Hill. Elevation estimated from topographic map, about 4450 feet. Description by Seager (5/28/68) with minor additions by Hawley (7/11/68).

UNIT	DESCRIPTION	THICKNESS (feet)
	Top of section on low dune-covered ridge at west edge of southern Jornada del Muerto Basin. Upper Santa Fe Group (Includes Upper Santa Fe Group and overlying bolson deposits of Kottlowski, 1953)	
H	Sandy loam; reddish brown (5YR 4/4) zones 3 to 4 feet thick, weathering light reddish brown (5YR 6/4) and commonly calcareous; alternating with white (N9) loamy zones 0.5 to 4 feet thick, weathering white (5YR 8/1), that are partly calcium-carbonate impregnated; with scattered rounded siliceous pebbles and minor interbedded sandstone; the upper surfaces of the reddish brown zones appear to mark disconformities.	70 (+85)

UNIT	DESCRIPTION	THICKNESS (feet)
	This unit is interpreted as a sequence of distinct depositional subunits on which soils have developed, reflecting periodic deposition and landscape stability, the reddish-brown zones representing soil "B" horizons that overlie white, pedogenic horizons of carbonate accumulation. Laterally, about 300 yards to the west, at least eight paleosolic subunits are present in an 85-foot section of unit H. The uppermost part of this unit often bears a well developed surface soil profile. The unit as a whole is moderately well to poorly exposed. It is apparently undeformed, except immediately adjacent to high-angle faults. Its base is marked by a disconformity with as much as 65 feet of relief, with unit H filling topographic lows eroded into underlying unit G.	
	OFFSET SECTION 900 to 950 feet to SSW, to obtain a greater thickness of unit G. Resume measurement in SW¼NW¼NW¼ sec. 16; elevation about 4475 feet	
G3	Sandstone to sand, gray (N5) weathers gray to light gray (5YR 6/1); arkosic; discontinuous zones stained with manganese oxide; discontinuous zones of calcite cementation; calcareous; coarse-grained; cross-bedded to laminated; few pebbly zones; lithologic types in gravel fraction include granite, chert, and mixed volcanics, pebbles commonly rounded, scattered mudballs and lime concretions; possibly disconformable on subunit G2.	8 (partial)
G2	Sandy loam, light reddish brown (5YR 6/4), to clay, reddish brown (5YR 5/3), with discontinuous white carbonate zones, calcareous to very calcareous; possible paleosol.	7
G1	Sand, sandstone, and conglomeratic sandstone locally with interbedded silty fine sand; arkosic; light grayish bronw (10YR 6/2) to light gray (N7), some limonitic stained beds, very pale brown to brownish yellow (10YR 7/4 to 6/6), many laminae rich in magnetite locally produce dark grayish streaks; friable, generally weakly indurated; calcareous in part; common prominent cross-bedding (very thick trough sets of cross-laminae), but also with very thick beds horizontally laminated or massive internally; sand units–medium- to coarse-grained, moderately well sorted, except for conglomeratic zones. Conglomeratic zones present as lenses and stringers within the unit; pebbles and scattered cobbles generally rounded and mixed lithology, chert, granite, mixed volcanics most common types; one prominent, 4-foot-thick, lenticular body of pebble-to-boulder conglomerate (50 feet above the base of subunit) contains subrounded clasts of rhyolite, rhyolite tuff, orthoquartzite (Dakota?), chert (pebbles), basaltic andesite (Uvas), granite, silty sandstone (Abo), and andesite-latite. Brown weathering, pebble- to cobble-sized, rounded lime concretions and calcite-cemented sandstone bodies, both spherical and flattened, are scattered throughout subunit, being particularly common in the lower beds. Varicolored clay and mudballs to fine boulder size are also present, as are scattered fragments of bone (mastodont, horse, unidentified) and petrified wood. The basal 20 feet of subunit is predominantly limonitic stained sandstone and conglomeratic sandstone, with gravel apparently coarsening downward; cross-bedding is prominent. A 4-inch-thick bed of well-indurated nodular carbonate locally occurs at the base of the unit. Unit G as a whole poorly exposed, forms moderate to steep slopes. Attitude of unit essentially horizontal; rests with angular unconformity on weak red (2.5YR 5/2) clay of unit F. Unit G is interpreted as a sequence of fluvial deposits of the ancestral Rio Grande.	197
	Partial thickness of unit G	212
	Partial thickness of upper Santa Fe Group	282
	OFFSET SECTION about 2250 feet to north to measure upper most exposed part of unit F. Resume measurement in SE¼NE¼SE¼ sec. 8; elevation about 4300 feet	
	Lower Santa Fe Group (Lower Santa Fe of Kottlowski, 1953)	
F6	Interbedded conglomerate to conglomeratic sandstone and claystone to clay, as respectively described in subunits 5 to 4 below. Poorly exposed to locally covered; laterally missing to west because of loss of section along angular unconformity (low-angle dips to east).	20 (partial)
F5	Conglomerate and conglomeratic sandstone, reddish gray (5YR 7/2) to light reddish brown (5YR 6/4); calcareous; poorly indurated to well indurated; thin- to medium-bedded; very poorly sorted, sandstones commonly silty; gravel fraction, mainly subangular to subrounded pebbles of rhyolitic volcanics. No andesite-latite, Paleozoic sedimentary rocks, basaltic-andesite (Uvas) or olivine basalt noted. One or two interbeds of reddish	160

UNIT	DESCRIPTION	THICKNESS (feet)
	claystone to clay, 5 to 8 feet thick, are present (identical to subunit 4). Subunit 5 has unsorted, heterogeneous appearance of conglomeratic units in the Selden Canyon–Broad Canyon area to the southwest.	
F4	Claystone to clay, pale red (5R 6/2), weathers weak red (10R 5/4), calcareous; bedding poorly expressed, generally appears massive; forms prominent badlands below unit G slopes.	52
F3	Claystone to clay, reddish brown (5YR 4/4), weathers light brownish gray (10YR 6/2) to reddish gray (5YR 5/2); minor lithologies include claystone to clay, pale red (5R 6/2), weathering pale red (10R 6/2); gypsum beds 2 to 6 inches thick (more numerous toward base); gypsiferous sandstone, cross-laminated, in beds less than 1 foot thick; gypsiferous claystone; and a few very thin pale greenish-yellow (10Y 8/2) siltstone zones. Entire subunit calcareous, about 25 percent of claystone gypsiferous; bedding generally poorly expressed, clay units often appear very thick-bedded; forms badland topography, many secondary gypsum veins along small faults. Basal part not exposed.	165 (partial)
	OFFSET SECTION about 675 feet to the south, across high-angle fault with 50 to 100(?) feet displacement (down to the east). Resume measurement in NW¼NE¼SW¼SE¼ sec. 8; elevation about 4240 feet	
F2	Interbedded sandstone, light brownish gray (10YR 6/2) and claystone to clay, reddish gray (5YR 5/2), weathering pinkish gray (5YR 7/2) to pale red (5R 6/2); very gypsiferous, partly calcareous, occasional interbeds of gypsum 4 to 6 inches thick. In upper 17 feet, gypsiferous and nongypsiferous claystone to clay, with 1 inch selenite interbeds dominate. Gypsiferous sandstone, in ledge-forming beds, 3 to 6 inches thick, dominates in lower 38 feet. Bedding is irregular in unit as a whole, with thicknesses commonly ranging from 3 to 18 inches; beds internally massive to finely laminated, with some low-angle cross-bedding noted in sandy zones. Subunit forms resistant cap of prominant hogback. Upper limit of subunit marked by fault; base conformable on subunit F1.	55 (partial ?)
F1	Claystone to clay, (70 percent of subunit); reddish gray (5YR 5/2) pale red (5YR 6/2), and grayish red (10R 4/2), weathering pinkish gray (5YR 7/2) to pale red (5R 6/2); with minor interbeds, 1 to 2 feet thick, of very clayey sandstone, pale red (10R 6/2), lenticular beds of fine sandstone, light gray (5Y 7/2), and pebble conglomerate in upper 10 feet; calcareous. Base covered.	83 (partial)
	Partial thickness of Unit F	535
	END subsection la (Jacob Staff and Brunton)	
	OFFSET SECTION about 3300 feet NNW across basin to foothills of Tonuco uplift, to measure main part of lower Santa Fe Group section. Resume measurement in center of NE¼NW¼ sec. 8; elevation about 4200 feet	
	START subsection 1b; described by Hawley and Seager on May 18 and 22, 1968 (Tape and Brunton)	
F2	Sandstone, gypsiferous, brown (5YR 5/3); noncalcareous where completely impregnated with gypsum, otherwise calcareous; cliff-former; upper part not measured, rests conformably on	15 (partial)
F1	clay, reddish brown (2.5YR to 5YR 5/3); essentially nonindurated; calcareous, gypsiferous in uppermost part; beds up to 5 feet thick, interbedded with sand as described below; grades downward into interbedded sand and sandy clay; sand, reddish brown (2.5YR 5/3); sandy clay, reddish brown (2.5YR 4/4); essentially nonindurated; calcareous; beds 1 inch to 1 foot thick. Subunit as a whole weathers reddish brown (5YR 5/3) to weak red (2.5YR 4/2); slope-former; base is covered. Unit F in this area is slightly deformed; dip to the east about 15°.	58 (partial)
	Partial thickness of Unit F	73
EF	Covered interval across basin floor; upper 31 feet, probable basal unit F; remainder could be unit E or EF transition; thickness calculated on assumed dip of 15°.	118
E	Mainly covered, but small outliers of unit E are laterally present (see description below); dips steepen from 15° to more than 35° (from east to west).	112

UNIT	DESCRIPTION	THICKNESS (feet)
	START of essentially continuous section to base of Santa Fe (dips to east or southeast, average 35 to 40°)	
E3	Interlensing sandstone and conglomeratic sandstone and conglomerate, pinkish gray (5YR to 7.5YR, 6/2 to 7/2), with minor interbeds of soft sandy mudstone; poorly to moderately well indurated; calcareous; thin- to thick-bedded, often internally cross-laminated; sandstones 50 to 60 percent of section, poorly sorted; gravel fraction, subangular to well rounded, pebble to cobble clasts of mixed volcanics (see below) and Paleozoic sedimentary rock types; conglomeratic beds form ledges.	268
E2	Conglomeratic sandstone to conglomerate, pinkish gray (7.5YR 6/2), interbeded with pinkish gray sandstone (as above), brown (7.5YR 5/4) sand and minor reddish (2.5YR) clay. Conglomeratic beds well cemented with calcite, generally less than 2 feet thick, and often internally cross-laminated; gravel fraction, subangular to well rounded, pebble to cobble (15 percent) size, 65 percent andesite-latite, 15 percent orthoquartzite-limestone-chert, 15 percent welded tuff, 5 percent basaltic andesite, and trace granite; sand, loose, calcareous, generally in less than 1-foot-thick beds. Clay, soft, calcareous, thin-bedded. Conglomeratic beds form prominent ledges.	234
E1	Sandstone to silty sandstone, brown (7.5YR 5/4), with thin interbeds of conglomeratic sandstone in upper part, and reddish clay in lower part; friable, poorly indurated; calcareous; slope former; conformable on Unit DE.	18
	Partial thickness of Unit E	632
DE	Upper: claystone to mudstone, light reddish brown (5YR 6/3) to reddish brown (2.5YR 5/4); with minor interbedded sandstone, calcareous. Middle: mudstone, light reddish brown (5YR 6/3), to friable silty sandstone, brown to light brown (7.5YR 5/4 to 6/4), with minor interbedded conglomerate; calcareous. Basal: soft mudstone to silty clay, weak red (2.5YR 5/2) to grayish brown (10YR 5/2); calcareous; unit as a whole is valley-former; conformable on Unit D.	83
	Total thickness of Unit DE	83
D6	Interbedded conglomeratic sandstone, and silty sandstone; silty sandstone reddish brown (2.5YR to 5YR 5/4), weathers reddish brown (2.5YR 5/4); pebbly coarse sandstone, very pale brown (10YR 7/3) weathers grayish brown (10YR 5/2); about same proportion of calcite cemented conglomerate, conglomeratic sandstone, and sandstone; conglomeratic beds, 1 to 3 feet thick, internally cross-bedded, form ledges; gravel fraction, predominantly mixed volcanics; pebbles and minor cobbles of limestones and quartzite (upper Paleozoic and Cretaceous types, 10 to 20 percent). Lower part of subunit poorly exposed because of discontinuous erosion-surface veneer and minor gully channel deposit.	148
D5	Sandstone to conglomeratic sandstone, reddish brown (4YR 5/4) interbedded with conglomerate and mudstone to siltstone, light reddish brown (5YR 6/4); calcareous; sandstone comprise 70 percent of subunit; slope-former.	66
D4	Silty sandstone to sandstone (70 percent), interbedded with conglomeratic sandstone to conglomerate (30 percent); fine silty sandstone, light reddish brown (5YR 6/4), weathers to reddish brown (5YR 5/4); coarse sandstone, brown (7.5YR 6/4); calcareous; conglomeratic beds lenticular, generally less than 5 feet thick, and internally cross-bedded; sandstone bodies are more continuous laterally and thinner bedded; gravel fraction, coarse (cobbles common, boulders present), mainly mixed volcanics, but common limestone and orthoquartzite clasts (post Cambro–Ordovician types). Conglomeratic units locally form predominent ledges.	89
D3	Alternating lenticular beds of conglomerate, conglomeratic sandstone, and sandstone; with minor interbeds of soft mudstone about 70 feet above base of subunit. Sandstone, reddish brown to light reddish brown (2.5 to 5YR 5/4 to 6/4), weather reddish brown (2.5 to 5YR 5/4) to brown (7.5YR 5/2 to 5/4); coarse- to fine-grained, silty in part, calcite cemented. Interbedded mudstone, weak red (10R to 2.5YR 5/3), calcareous, conglomeratic beds 1 to 3 feet thick, internally cross-bedded (trough sets with tangential bases); gravel subangular to rounded, mainly pebbles, but with common cobbles and scattered small boulders; gravel composition mainly andesite-latite, with common rhyolite (flow-banded and welded tuff varieties), minor basaltic andesite (Uvas–to boulder-sized), cherty limestone and orthoquartzite. Subunit forms three major ridges. The basal conglomeratic zone forms a prominent 12-foot cliff and probably is disconformable on the upper most fine-grained part of subunit D2.	217

UNIT	DESCRIPTION	THICKNESS (feet)
D2	Upper 8 feet of subunit: silty clay to claystone, pinkish gray (5YR 6/2), over silty sandstone with scattered pebbles; calcareous; massive; conformably rests on main body of subunit: Alternating conglomerate, conglomeratic sandstone and sandstone, light brown (7.5YR 6/4), weathers to brown (7.5YR 5/2 to 5/4); with zone of reddish brown beds (2.5YR 5/4) in lower part of subunit and zone of pinkish gray beds (5YR to 7.5YR 7/2) in upper part; calcareous; beds poorly to moderately well indurated; with a few resistant conglomeratic beds, less than 5 feet thick, cemented with sparry calcite; gravel fraction consists of mixed volcanic pebbles; general slope-former.	90
D1	Upper 40 feet interbedded conglomerate and conglomeratic sandstone, light brown (7.5YR 6/4) weathering to brown (7.5YR 5/2 to 5/4); calcite cemented; in lower part lenticular beds 1 to 2 feet thick, often pinching out laterally within 10 feet; in upper part, beds thinner and more extensive laterally; ridge-former. Basal 7 feet pebble conglomerate grading up into sandstone; pinkish gray (7.5YR 6.5/2), weathers brown (7.5YR 5/4); well indurated; clacareous; gravel fraction with about equal proportions of andesite-latite and rhyolite, and with minor basaltic andesite. This part of subunit is a prominent ledge-former and appears to fill a broad, shallow channel cut in uppermost beds of unit C.	47
	Total thickness of unit D	657
	OFFSET SECTION about 500 feet to NNE along D-C contact. Resume measurement in SE¼NW¼SE¼SE¼ sec. 6; elevation about 4200 feet	
C3	Upper and middle part interbedded conglomerate and conglomeratic sandstone, and minor silty sandstone; pinkish gray (5 to 7.5YR 7/2); with sparry calcite cement but not well indurated; thin- to medium-bedded. Gravel fraction, pebble-to-cobble size, mostly subangular; composition mainly andesite-latite, with common rhyolite (flow-banded and welded tuff varieties), and minor basaltic andesite (Uvas), Tertiary sedimentary rocks and chert. Basal part silty sand to friable sandstone, light gray (5YR 7/1), weathers to pinkish gray (7.5YR 7/2); calcareous; massive bed 4 to 5 feet thick; could be tuffaceous; grades down into pebbly sand and sandstone beds, light gray to white, of underlying, poorly exposed intervals.	32
C2	Conglomerate, with some interbedded conglomeratic sandstone and silty sandstone to sand; pinkish gray (5 to 7.5YR 7/2); poorly indurated; calcareous; weakly bedded. Conglomerate with silty fine to coarse sand matrix, subangular to subrounded pebbles and cobbles of mixed volcanic types, as well as trace of Paleozoic pebbles (Bliss(?) and Abo); slope-former; upper 90 feet covered to very poorly exposed.	114
C1	Upper 68 feet silty conglomeratic sandstone to sandstone, pinkish gray (5 to 7YR 7/2), light reddish brown (5YR 6/3), very poorly indurated, calcareous; very poorly sorted; gravel fraction: subangular to subrounded pebbles and cobbles of mixed volcanic types; grades down into sandy silt to silty sand (less than 20 percent clay), to sandy siltstone to silty sandstone; light reddish brown (5YR 6/3); very poorly indurated; calcareous; weakly bedded, with scattered 1- to 2-inch interbeds of calcite-cemented pebble conglomerate; gravel in conglomerate beds (and scattered through sandstone) consists of subrounded to rounded pebbles of mixed volcanic types. Subunit as a whole is poorly exposed and a slope-former. Basal contact with unit B, conformable or minor disconformity; very poorly exposed.	96
	Total thickness of unit C	242
B6	Conglomeratic sandstone, with minor interbedded sandstone to sandy siltstone, light brown to brown (7.5YR 6/4 to 5/4); in general poorly indurated; calcareous, calcite veins common; gravel fraction pebble size, mixed volcanic types (see below); slope-former.	78
	OFFSET SECTION about 250 feet to west to miss area covered with erosion surface veneer	
B5	Upper half, conglomerate to conglomeratic sandstone; light brown (7.5YR 6/4), weathering to brown (7.5YR); well indurated at base to poorly cemented at top; calcareous; thin- to thick-bedded, internally cross-bedded (trough sets); gravel fraction (see below); basal part forms prominent ledges. Lower half, sandstone to conglomeratic sandstone, light reddish brown (5 to 2.5YR 6/3), weathers to reddish brown (5YR 5/4); calcite cemented; lenticular beds 3 inches to 1 foot thick, internally laminated to massive,	104

UNIT	DESCRIPTION	THICKNESS (feet)
	with minor low-angle cross-laminae; gravel fractions, subangular to rounded pebbles, mainly rhyolite, with common andesite-latite and minor basaltic-andesite (Uvas); ledge-former.	
	OFFSET SECTION 200 feet west along base of subunit 5	
B4	Interbedded sandstone, conglomeratic sandstone and minor siltstone; reddish brown (2.5YR 5/4); sandstone, moderately to well indurated; siltstones, poorly indurated; calcareous; generally medium- to thick-bedded; gravel fraction as above, with percentage of andesite-latite increasing. General slope-former, with resistant conglomeratic sandstone to sandstones forming ledges. In the middle of subunit, crossed a low-angle fault and probably lost some section.	175 (partial)
	OFFSET SECTION 150 to west to miss low-angle fault	
B3	Sandstone, conglomeratic sandstone, and pebble conglomerate, with interbedded lenticular zones of silty sand and mudstone; sandstone, weak red (10R 5/3) and reddish brown (2.5YR 5/4); matrix of conglomeratic beds reddish brown (2.5YR 5/4); mudstone, light reddish brown (2.5YR 6/4); and silty sandstones weak red to reddish brown (10R to 2.5YR 5/4); calcareous, coarsely crystalline calcite common; subunit well indurated, coarser grained, thicker bedded at base; moderately to poorly indurated, finer grained, thinner bedded toward top; general cliff-former.	80
B2	Sandstone to siltstone interbedded with conglomerate to conglomeratic sandstone (sandstone-siltstone dominant); reddish brown (2.5YR 5/4) calcareous, calcite veins common; thick- to very thick-bedded; siltstone-sandstone poorly indurated; conglomeratic beds, well indurated, forming resistant ledges; in general, slope- or valley-forming unit.	64
B1	Sandstone, conglomeratic sandstone and pebble conglomerate with interbedded zones of silty sandstone and mudstone (like subuniit B3); sandstones, weak red (10R 4/3 to 5/3), with reddish brown (2.5YR 5/4) laminae; matrix of conglomeratic sandstone, reddish brown (2.5YR 5/4); sandstone weathers reddish brown (2.5YR 5/4 to 4/3) to weak red (10R 4/3); mudstone, light reddish brown (2.5YR 6/4); generally well indurated; calcareous, coarsely crystalline calcite cement and vein fillings common; thick to very thick lenticular beds, generally 2 to 4 feet thick with some lenticular conglomeratic beds 5 feet thick, internally laminated to cross-laminated; gravel fraction consists of subangular to rounded pebbles (few cobbles) of mainly andesite-latite, some rhyolite, and minor basaltic andesite. Subunit as a whole is a major ridge-former; lower 95 feet of subunit form a prominent cliff; basal contact, broad shallow channel cut into unit A.	152
	Partial thickness of unit B	653
A4	Upper 9 feet, silty sandstone with scattered pebbles in lower part, pale red to weak red (10R 6/2 to 5/2) with darker laminae (10R 4/3); grading upward into siltstone with local lenses of conglomeratic sandstone, weak red (10R 5/3); calcareous; weakly cross-bedded in lower part, massive in upper part. Lower 5 feet, ledge-forming conglomeratic sandstone, similar to beds described below in lower part of unit. Unknown amount of section between subunits A4 and A3 missing.	14 (partial)
	OFFSET SECTION about 300 feet ESE to obtain a greater thickness of unit A. Resume measurement in NE¼NE¼SW¼SE¼ sec. 6; elevation about 4200 feet	
A3	Interbedded sandstone to clayey siltstone and conglomerate to sandstone. Sandstone to siltstone weak red (10R 5/2), poorly to moderately well indurated, generally calcareous, zones generally less than 15 feet thick, slope-formers. Conglomerate to sandstone, weak red to pale red (10R 4/3, 5/2, 6/2); well indurated; calcareous; cross-laminated, medium- to thick-bedded, lenticular bodies 5 to 15 feet thick; gravel fraction as in subunit 1 below; noticed some rounded, large cobbles to small boulders of white welded tuff. Conglomerate-sandstone bodies form ledges in general slope.	103
	OFFSET SECTION about 200 feet to the west along top of conglomeratic ledge capping subunit 2 to miss effect of low-angle fault	

UNIT	DESCRIPTION	THICKNESS (feet)
A2	Alternating zones of conglomerate to sandstone (ledge-formers), and sandstone to clayey siltstone (slope-formers), as above. Conglomerate-sandstone bodies 10 to 15 feet thick (greater than 50 percent pebble conglomerate to conglomeratic sandstone). Sandstone-siltstone as previously described, except for one, greater than 30-foot-thick zone in midpart of subunit, weak to pale red (10R 5/2 to 6/2), with weak red (10R 4/3) laminae; basal part covered.	122
	Covered	43
A1d	Alternating conglomerate-sandstone, and sandstone-siltsone zones, as described below, generally less than 10 feet thick, respectively.	56
A1c	Sandstone to comglomeratic sandstone with interbedded conglomeratic lenses; sandstone, pale red (10R to 2.5YR 6/2) with weak red (10R 5/2) laminae; conglomerate matrix, weak red to pale red (10R 4/3 to 6/2); well cemented; calcareous, with sparry calcite locally prominent; subunit A1c comprises a lenticular body 200 to 300 feet wide, individual beds 1 to 1.5 feet thick, internally cross-laminated; gravel fraction as in A1a below. Abrupt basal contact with subunit A1b.	11
A1b	Interbedded sandstone and clayey siltstone; weak red (10R 5/2); moderately to (rarely) poorly indurated; generally calcareous, with some siltstone beds weakly calcareous; beds 1 to 3 feet thick; scattered mixed volcanic pebbles; poorly exposed, slope-former.	14
A1a	Basal lower Santa Fe Group, conglomerate, conglomeratic sandstone and sandstone; sandstones, weak red (10R 5/2 to 4/3); conglomerate matrix, weak red (10R 5/2) to pale red (10R 6/3); generally well indurated; calcareous, sparry calcite cement common in conglomeratic zones; subunit comprises a single lenticular body, less than 100 feet wide, consisting of alternating conglomeratic and sandstone beds, usually less than 1 foot thick; sandstones are internally cross-laminated (trough sets of low-angle foresets); gravel fraction generally pebble size with rare cobbles, subangular to rounded, dominantly andesite-latite, with common rhyolite (including flow-banded and welded tuff varieties), and minor basaltic andesite (Uvas). Contact with underlying "Rincon Hills" unit is disconformable and often poorly exposed. At this point, subunit A1a fills a channel cut less than 10 feet into the underlying beds. Laterally, where the basal conglomeratic subunit is absent and beds like subunit A1b occur at the base of the Santa Fe, the disconformity is poorly exposed and may be difficult to locate precisely. Contact dips about 40 degrees to the south.	12
	Partial thickness of Unit A	375
	Partial thickness of units A through F1	2818
	Measured thickness of Santa Fe Group (sec. 1b, A through F1; sec. 1a, F2 through H)	3567
	Upper "Rincon Hills" unit, an informally designated sedimentary sequence intermediate between Uvas–Thurman–Bell Top volcanics and the basal "red conglomeratic" subunits of the Santa Fe Group. In the Rincon Hills, this unit appears to grade down into the Thurman Formation	
RH	Silty sandstone to conglomeratic sandstone, with local lenses of conglomerate, weak red (10R 5/2, 4/4, 4/3, 4/2); poorly sorted; moderately well indurated to poorly indurated (friable), weakly calcareous, but calcite veins common along joints; tabular to lenticular beds 2 to 4 feet thick, with internal, gently inclined cross-laminae, and local conglomeratic scour and fills structures; gravel fraction, pebble to cobble size (mainly pebbles); subangular to rounded, dominantly rhyolite (common cobbles of white welded tuff) with some andesite-latite and basaltic andesite (Uvas).	30+
	END OF SECTION; NW¼SE¼NW¼SE¼ sec. 6, T. 20 S., R. 1 W. (0.25 mile east of abandoned Tonuco mining camp); elevation of base of Santa Fe Group about 4125 feet	

SECTION 2. SELDEN CANYON, "ASH MESA." REFERENCE SECTION FOR UPPER SANTA FE GROUP, DONA ANA COUNTY, NEW MEXICO

Upper Santa Fe Group measured on southeast and south faces of a triangular shaped mesa, capped by the Palomas (Jornada) geomorphic surface and rising 345 to 350 feet above the floor of Selden Canyon of the Rio Grande. Sierra Alta quadrangle, NW¼NW¼ sec. 25, T. 20 S., R. 2 W.

Subsection 2a, NE¼NW¼NW¼ sec. 25; elevation reference point is at base of corner fence post on mesa surface, near 24-25 section line; approximate elevation of reference point is 4345 feet.

UNIT	DESCRIPTION	THICKNESS (feet)
	Palomas surface; top of section at southeast edge of mesa. **Upper Santa Fe Group (possible equivalent of unit H of section 1a)**	
H?2	Bevelled slope at edge of mesa. Pavement with scattered cobbles to boulders of rhyolitic to basaltic volcanics. Pebble gravel and sand occur in the areas between the cobbles and boulders. Indurated caliche fragments are common, and a trace of rounded siliceous pebbles are present (including quartz, quartzite, chert, and granite).	5
H?1	Gravel, pebble to boulder (up to 3 feet), mainly localy basaltic andesite and rhyolite, with trace of rounded siliceous pebbles. Matrix in part clean loose sand and in part carbonate-impregnated sand. Surface caliche cap, from 3 to 5 feet thick, forms uppermost cemented gravel zone. Multiple laminar horizon with smooth upper surface forms top of caliche; lower boundary of caliche horizon gradual and irregular. From about 30 to 35 feet, a discontinuous low gravelly zone is present; low gravelly to gravelly loam, reddish and noncalcareous at top and whitened and calcareous at the base, comprises, this zone (perhaps a paleosol). Lower boundary is sharp and slightly undulating, with the gravel resting unconformably on, and apparently filling channels in the underlying ash unit.	65
	Upper Santa Fe Group–unit G of section 1a	
G2e	Loamy tuffaceous sand (less than 5 percent clay) with scattered fine pebbles, brown (7.5YR 5/4 m), noncalcareous, massive to laminated, grades to	6
G2d	loamy tuffaceous sand, as above, with lenses of pebble gravel and sand; sharp but conformable contact on	2
G2c	tuff, poorly consolidated, coarse silt to very fine sand-sized glass shards, white, massive to laminated, noncalcareous; with scattered tubular zones several inches in diameter, filled with brown pebbly silty sand (similar to overlying materials), which could represent burrow fillings. Sharp but conformable basal contact.	3
G2b	Tuff, white, well consolidated, slightly finer than above. Contact poorly exposed but appears to grade downward into	1.5
G2a	tuff, massive, poorly consolidated, as above (G2c), except that lower inch is very hard, dense, and carbonate cemented. Contact on underlying unit sharp, smooth, and disconformable.	1.5
G1d	Very fine sandy loam, brown, to dark brown (7.5YR 5/4 to 4/4 m); hard, blocky mainly weakly calcareous; gravelly (pebble) sandy loam zone in upper 3 to 5 feet, with carbonate coating on pebble bottoms (soil feature?); the basal 1 foot of this unit is a blocky red (5YR 3.5/4 m) clay. Laterally within 50 feet to the south, this subunit thickens to about 17 feet; the gravel zone in central part thickens and is represented by a gravelly (pebble) to low gravelly clay loam, reddish brown (6YR 4/4 m), noncalcareous, with lenses of sand and pebble gravel (rounded siliceous and local volcanics). The basal red clay zone also thickens to about 2 feet. The basal contact of this subunit is sharp but may be conformable on the underlying gravel unit.	11
G1a	Gravel (70-90 percent) pebbles to small cobbles (to 4 inches), well rounded to rounded, mixed lithology; quartzite, quartz, mixed volcanics (primarily acid-intermediate), chert, granite, miscellaneous; clean sand (10-30 percent); loose. This is the classic fluvial facies of the upper Santa Fe Group. Basal contact sharp and unconformable, may bevel beds of underlying unit.	5
	Total thickness of the Upper Santa Fe Group (units G and H?)	100

UNIT	DESCRIPTION	THICKNESS (feet)
F?	Gravelly to very gravelly loamy sand to sandy loam, partly cemented into conglomerate to conglomeratic sandstone; interbedded with loamy sand to sandy loam zones; moderately well stratified, very compact, weakly to well cemented, calcareous. Matrix colors typically brown to reddish brown. Gravel mainly pebble size with scattered cobbles; mainly acid volcanics, basalt rare. Exposed thickness exceeds 100 feet; base not exposed. This basal unit may be equivalent to the uppermost conglomeratic member of the lower Santa Fe Group south of the Tonuco uplift (sec. 1). Scarcity of basalt gravel, the greater induration, and possible slight tilting of this unit are in marked contrast to gravels above the ash.	100+
	Subsection 2b. About 1000 feet west of section 2a, NW¼SW¼NW¼ sec. 25; elevation reference point at about 4365 feet	
	Palomas surface; top of section at extreme west corner of mesa, south face. **Upper Santa Fe Group (possible equivalent of unit H of section 1a)**	
H?3	Pebble to boulder (to 3 feet) gravel, with clean sand matrix; upper 3.5 to 5 feet cemented by calcrete with abrupt upper troweled surface underlain by petrocalcic multiple laminar soil horizon grading downward into soft carbonate impregnated sand matrix (upper few inches of soil truncated). Trace of rounded, siliceous (quartz, quartzite, chert, granite) pebbles. Bulk of gravel; well rounded to subrounded, local basaltic to rhyolitic volcanics. Basal contact gradational to	13
H?2	sandy loam, low gravelly (less than 20 percent) to gravelly, brown (7.5YR 4/4 m), weakly calcareous to calcareous, laterally occurs as discontinuous zone at base of overlying gravel unit; basal contact gradational to	7
H?1	pebble to boulder gravel (50-90 percent gravel), with clean sand to calcareous loamy sand matrix; cobble to boulder fraction as above, but with common rounded siliceous rock types in the pebble fraction (quartz, quartzite with some chert, and granite). Unconformable on Unit F?.	10
	Thickness of Upper Santa Fe Group (unit H?)	30
F?	Interbedded conglomeratic sandstone, sandstones, and uncemented but compact loamy sands to gravelly loamy sands and gravels; matrix colors reddish brown (5YR 4/4 m) sandy loam, reddish brown to brown (6YR 6/3.5 m) loamy sandy, dark brown (7.5YR 4/2 m) slightly silty sand, and conglomeratic sandstone with calcite cement weathering to dark brown (7.5YR 3/2d). Unit moderately well stratified. Gravel sizes in pebble to cobble range; rock types mainly rhyolite. This unit is correlated with the lower conglomeratic member of Santa Fe Group of Kottlowski (1953) and to unit F of section 1a. It contrasts markedly with the upper bouldery, unconsolidated basaltic gravel of unit H?.	100+

Note: The top of the lower Santa Fe conglomeratic unit (subunit F?) in section 2b (elevation about 4335 feet) is about 60 feet higher than the top of the same subunit in section 2a, 1000 feet to the east (elevation about 4275 feet). The ash bed as a distinct unit is absent in section 2b, as is the basal rounded siliceous gravel zone. The sequence above subunit F? thickens from 30 feet at section 2b to about 100 feet at section 2a. Because of discontinuous exposures, it is not possible to determine how much of the upper part of this subunit has been removed by erosion. In the Selden Canyon area, these beds are locally faulted and tilted. But deformation is not usually apparent in limited outcrops. The general impression received in a cursory examination of the area between section 2b and section 2a is that a considerable amount of the conglomeratic lower Santa Fe had been removed by erosion prior to Upper Santa Fe Group deposition.

The rounded siliceous gravel–clay to loam–volcanic ash sequence probably represents a river floodplain deposit; the basal gravels with exotic pebbles are conformably overlain by fine-grained sediments, which are in turn disconformably overlain by pure tuff grading up into impure tuff. The upper bouldery gravels represent a return to alluvial-fan deposition with gravel mainly derived from mountain uplands to the west.

The tuff unit, as described in section 2a, is discontinuously present along the entire east face of the mesa (a distance of about 1000 feet), at a relatively constant elevation of about 4270 feet (75 feet below top of mesa and 275 feet above the Rio Grande flooplain). To the west of tuff, bed pinches out and is absent at section 2b. Samples from the ash unit are currently being studied by Dr. Ray Wilcox of the U.S. Geological Survey. A probably correlative of this tuff bed locally occurs in the Camp Rice section in El Paso and Hudspeth counties, Texas. A late Blancan vertebrate fauna has been recovered from beds stratigraphically below the ash (Strain, 1966; this volume), and an Irvingtonian fauna has been identified in units that are probably younger than the ash. The closest likely source of the tuff is the Jemez Caldera of north-central New Mexico.

Neogene Flora from the Rincon Hills, Dona Ana County, New Mexico

by David V. LeMone,
Deparment of Geology
The University of Texas at El Paso, Texas
R. Roy Johnson,
Center for Anthropological Studies
Prescott College, Arizona

ABSTRACT

An abundant and well-developed Neogene flora covering several square miles is observed on the southern flank of the Rincon Hills (Doña Ana County, New Mexico). The flora occurs in the Upper Santa Fe Group (Early to Middle Pleistocene). The opalized flora occurs in sediments that range from a weathered, loosely cemented, silicified matrix to a massive jasper. Basal stem segments from a new genus, *Palaeophragmites,* of grass (Gramineae) are designated as the species *Palaeophragmites gilei.* Four additional new species are named *Scirpus hawleyi* (Cyperaceae), from tubers and stems; *Scirpus kottlowskii,* from tubers; *Eleocharis todsenii* (Cyperaceae), from tubers; and *Iris seageri* (Iridaceae) from rhizomes. Additional materials, yet unclassified, including large striated stems; large, round stems (tree or shrub), and assorted round stems from woody angiosperms have been recovered. The environment of the flora is interpreted to be a spring-fed cienega. Current vegetation is typical of Southern Desert Shrub at the northern periphery of the Chihuahuan Desert. Heterogeneity of terrain (and geology) contributes to a diverse flora of shrubs, with few, mostly ephemeral annuals, and suffrutescent perennials. Trees are absent except along larger arroyos.

NEOGENE FLORA

An abundant Neogene flora occurs in beds of the Santa Fe Group on the southeastern flank of the Rincon Hills (Doña Ana County, New Mexico). Collections were made from the available exposures in eight localities (fig. 1) by the authors. The beds had been noted earlier by a number of geologists and amateur collectors. John W. Hawley, Soil Conservation Service, and William R. Seager, New Mexico State University, are in the process of mapping the area in detail. Lyle T. Alexander and Leland H. Gile, of the Soil Conservation Service, with John W. Hawley noted the extent of these beds during earlier field work. Frank E. Kottlowski is credited with completion of the first geological reconnaissance map of the Rincon Hills.

The Rincon flora occurs in unit G (Hawley et al., fig. 4, this volume,) of the Upper Santa Fe Group of Early to Middle Pleistocene age. One fragment of horse tooth was recovered about 100 feet (30 meters) above the Rincon flora and 2000 feet (610 meters) southeast of the easternmost outcrop. This very poor protocone has been identified by William S. Strain (The University of Texas at El Paso) as belonging to the genus *Equus.* Two horse teeth have been recovered from similar beds five miles (8 kilometers) south and east of the Rincon Hills in the Tonuco Mountain area. Species identification has not yet been made on the currently available material, but it appears that the fauna in unit G may range from Late Blancan to Irvingtonian in age. Cross-section Figure 4b (Hawley et al., this volume) from the Rincon Surface to La Mesa Surface crosses the Rincon flora locale. The position of the cross section is indicated in Figure 1.

The bed containing the Rincon flora (pl. IV, figs. 1, 3) is typically a resistant unit as a result of its carbonate content in the east (locale 8) and siliceous composition in the west (locales 1, 4). The flora occurs in sediments that range from a loosely cemented silicified matrix to a massive siliceous bed locally jasperoidal (locale 4) in the west to a calcareous silty sand in the east (locale 8).

The flora is exceptional in its opaline preservation of the normally destroyed soft-part anatomy of the plants by the process of histometabasis. Detailed studies of the histology of the flora by means of thinsection are in progress. Silicified casts of fibrous roots have also been noted.

The fossil flora is suggestive of extant communities occurring in marshy areas along slow-running streams or spring-fed cienegas, usually at higher elevations in nearby mountains. Although representatives of the same genera may be found in these areas, the species composition, when compared to our Rincon flora, is different. Examination of the opaline material by spectrographic methods is contemplated to determine the presence or absence of select trace elements.

Current vegetation of the Rincon Hills is typical of Southern Desert Shrub at the northern periphery of the Chihuahuan Desert. Heterogeneity of terrain (and geology) contributes to a diverse flora of shrubs with few, mostly ephemeral, annuals and suffrutescent perennials. The

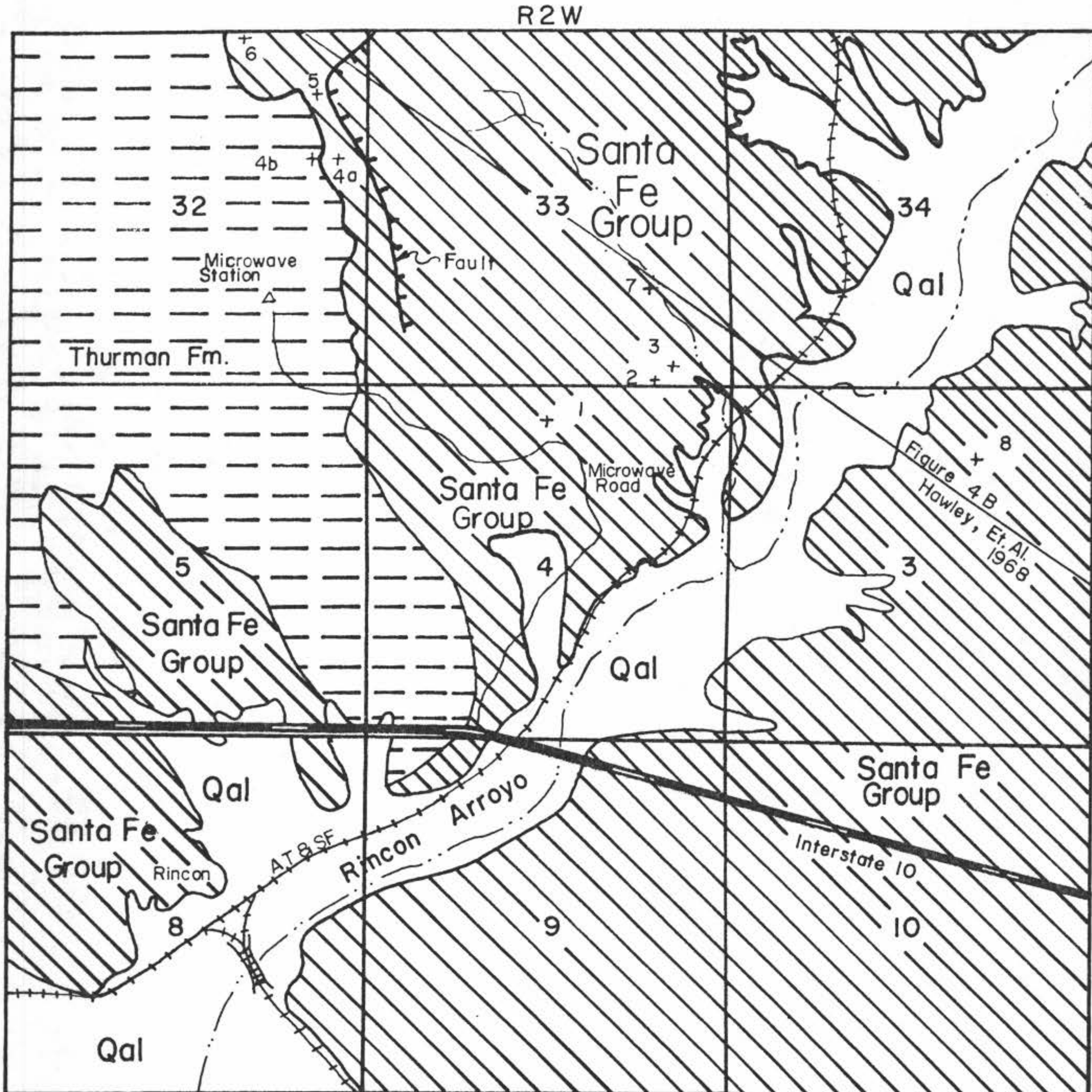


Figure 1
RINCON QUADRANGLE, DONA ANA COUNTY, NEW MEXICO

immediately adjacent rocky terrain supports a creosote bush-mesquite vegetation with creosote bush *(Larrea divaricata)* and common mesquite *(Prosopis juliflora)* being the most prevalent shrubs, accompanied by feather dalea *(Dalea formosa)*, mormon tea *(Ephedra* sp.), Wright Aloysia *(Aloysia wrightii)* and scattered ocotillo *(Fouquieria splendens)*. Subshrubs include mariola *(Parthenium incanum)*, coldenia *(Coldenia* sp.), snakeweed *(Gutierrezia lucida)*, prickleaf dogweed *Dyssodia acerosa)*, and scattered tarbush *(Flourensia cernua)*, while the family Cactaceae is represented by several genera and species, including prickly pear *(Opuntia* spp.) and claretcup hedgehog *(Echinocereus triglochidiatus)*, Small perennial and herbaceous dicots include blackfoot *(Melampodium leucanthum)*, desert marigold *(Baileya multiradiata)*, hairyseed bahia *(Bahia absinthifolia)*, dogweeds *(Dyssodia* spp.), desert holly *(Perezia nana)*, trailing four-o-clock *(Allionia incarnata)*, and stickleaf *(Mentzelia pumila)*. Prevalent grasses include fluffgrass *(Tridens pulchellus)*, threeawns *(Aristida* spp.), sideoats grama *(Bouteloua curtipendula)*, and bush muhly *(Muhlenbergia porteri)*.

Arroyo vegetation is composed largely of common mesquite, whitethorn *(Acacia constricta)*, soaptree yucca *(Yucca elata)*, fourwing saltbush *(Atriplex canescens)*, and littleleaf sumac *(Rhus microphylla)*. Trees are absent except along larger arroyos, (such as Rincon Arroyo, where, in addition to tree-sized common mesquite, whitethorn, and desert willow *(Chilopsis linearis)*, there occur large fourwing saltbush, broom dalea *(Dalea scoparia)*, and soaptree yucca.

SPECIES LIST

Type specimens for the five new species named here are deposited in the museum of the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico.

FAMILY: Gramineae

Palaeophragmites n. gen.
Pl. I, fig. 1; Pl. III, fig. 1

Type species: *Palaeophragmites gilei* n. sp.

Generic diagnosis. Culms round, hollow, or with large, pithy center, about 9 mm in greatest diameter at about 20 mm above the base, decreasing to about 6 mm at the base. Nodes prominent, crowded at the base. Roots few, stout, more than 1.5 mm in diameter, continuing adventitiously for about 18 mm up the culm from the base.

Palaeophragmites gilei n. sp.
Pl. I, fig. 1; Pl. III, fig. 1

Diagnosis. The generic diagnosis is to be considered also as the specific diagnosis. In addition, this grass has numerous culms arising in a cluster from a common source, apparently from a creeping rhizome similar to that in *Phragmites communis* Trin.

Discussion. Specimens of this plant are rare, not so well preserved, more fregmentary, and harder to diagnose than the other four species described herewith. We have recovered specimens of *Palaeophragmites* from two separate sites in the Rincon beds, suggesting that it was probably widespread but may have grown in drier sites, allowing poorer preservation, or was in small, scattered populations. This species is named in honor of Leland H. Gile, soil scientist, Soil Conservation Service, University Park, New Mexico, currently studying Quaternary pedology of southern New Mexico.

Types Holotype: NMBM 1370, sec. 4, T. 19 S., R. 2 W., locality 2 (pl. I, fig. 1; pl. III, fig. 1),

FAMILY: Cyperaceae

Scirpus hawleyi n. sp.
Pl. I, fig. 2; Pl. II, figs. 5, 6; Pl. III, fig. 2; Pl. IV, fig. 2

Diagnosis. Tubers rough, irregular, up to 21 mm in height and 19 mm in diameter, greater measurement usually parallel to the axis of the single culm. Scale ridges rough, irregular, obscure to prominent, perpendicular to the axis of the culm. Culms triangular, striated (pl. II, fig. 5), up to 10 mm in diameter at the base, which is often surrounded by a round sheath that continues up from the tuber along the culm about 1 or 2 mm. Scattered vascular bundles clearly visible in culms. Lateral and ventral connectives (= interconnecting rhizomes) up to 5 on larger tubers. Root scar depressions coarse, scattered over the entire surface of the tuber, about 0.5 to 1 mm in diameter and 1 mm or less in depth; some specimens with short root fragments.

Discussion. Presumably the connectives interconnected groups of tubers, as is currently true in the similar species, *S. fluviatilis* (Torr.) Gray, of the northern United States. However, since we have no reproductive structures from our materials, we do not feel it advisable to assign our material to that species. Since both the tubers and stems of this *Scirpus* are among the most abundant materials from our samples, we assume that this species was very common, widespread, or both. It is a pleasure to name this species in honor of John W. Hawley, geologist, Soil Conservation Service, University Park, New Mexico, currently studying late Cenozoic stratigraphy and geomorphology of the Rincon area. His aid and encouragement have been a valuable asset during our studies of this flora.

Types. Holotype: NMBM 1371 (pl. I, fig. 2; pl. IV, fig. 2), sec. 4, T. 19 S., R. 2 W.; paratypes: NMBM 1372 (pl. II, fig. 6; pl. IV, fig. 2), NMBM 1373 (pl. III, fig. 2); same locality as NMBM 1371.

Scirpus kottlowskii n. sp.
Pl. I, fig. 3; Pl. III, fig. 5

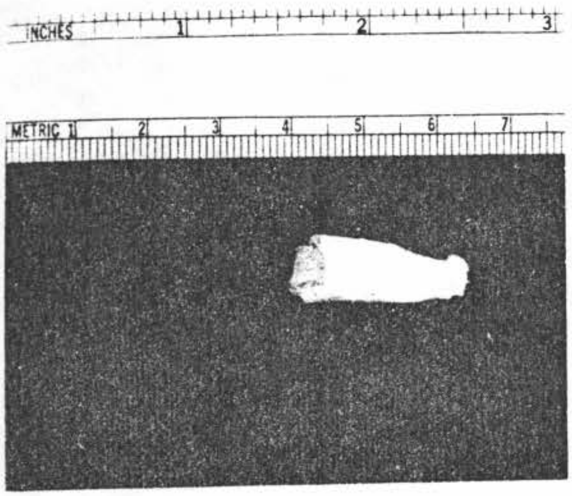
Diagnosis. Tubers in crowded series of 3 or more; individual tubers 6.0 to 7.3 mm in diameter and 5.8 to 7.5 mm

PLATE I

PHOTOGRAPHS OF HOLOTYPES

Figures

1. Holotype of *Paleophragmites gilei,* basal stem fragment, NMBM 1370.
2. Holotype of *Scirpus hawleyi,* tuber, NMBM 1371.
3. Holotype of *Scirpus kottlowskii,* tubers, NMBM 1374.
4. Holotype of *Eleochairs todsenii,* tuber (side view), NMBM 1376.
5. Holotype of *Iris seageri,* rhizome, NMBM 1378.
6. Holotype of *Eleocharis todsenii,* tuber (dorsal view), NMBM 1376.


INCHES
METRIC

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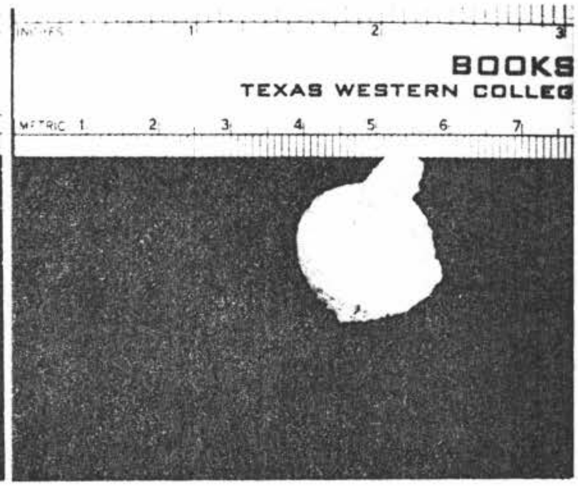
BOOKS
TEXAS WESTERN

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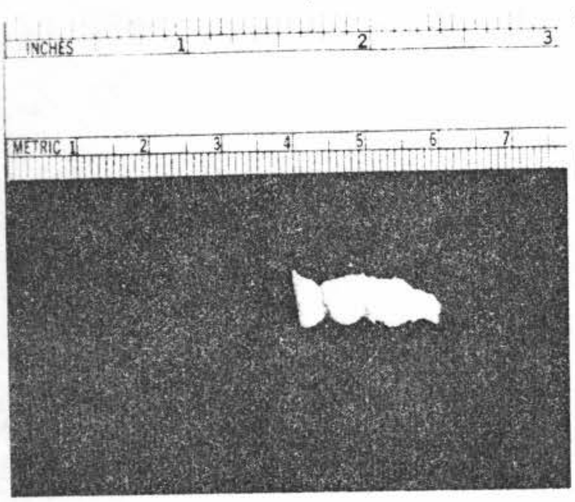
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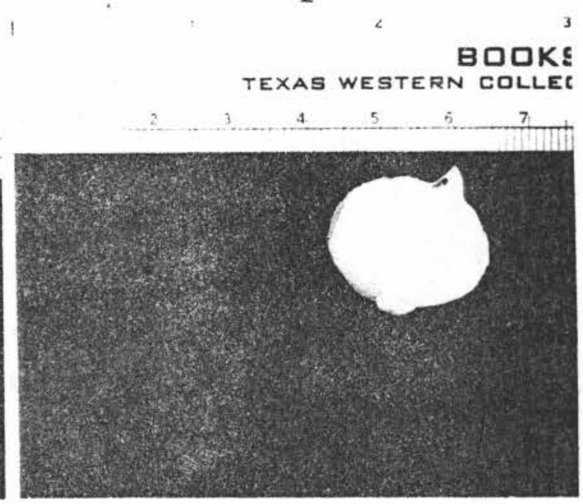
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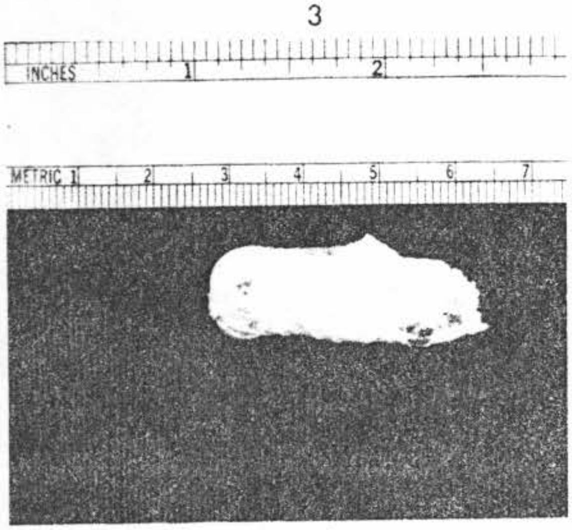
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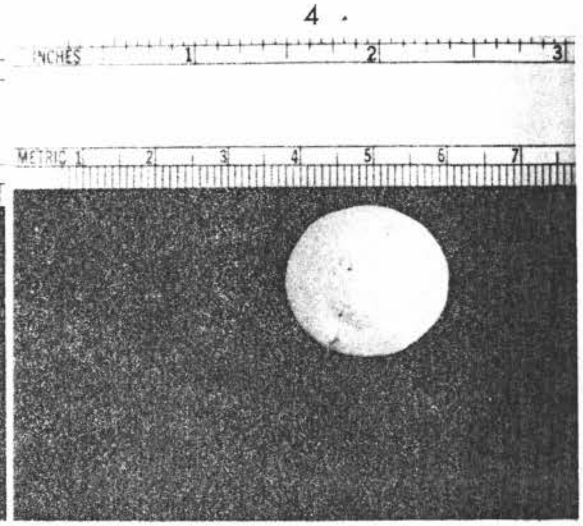
INCHES
METRIC

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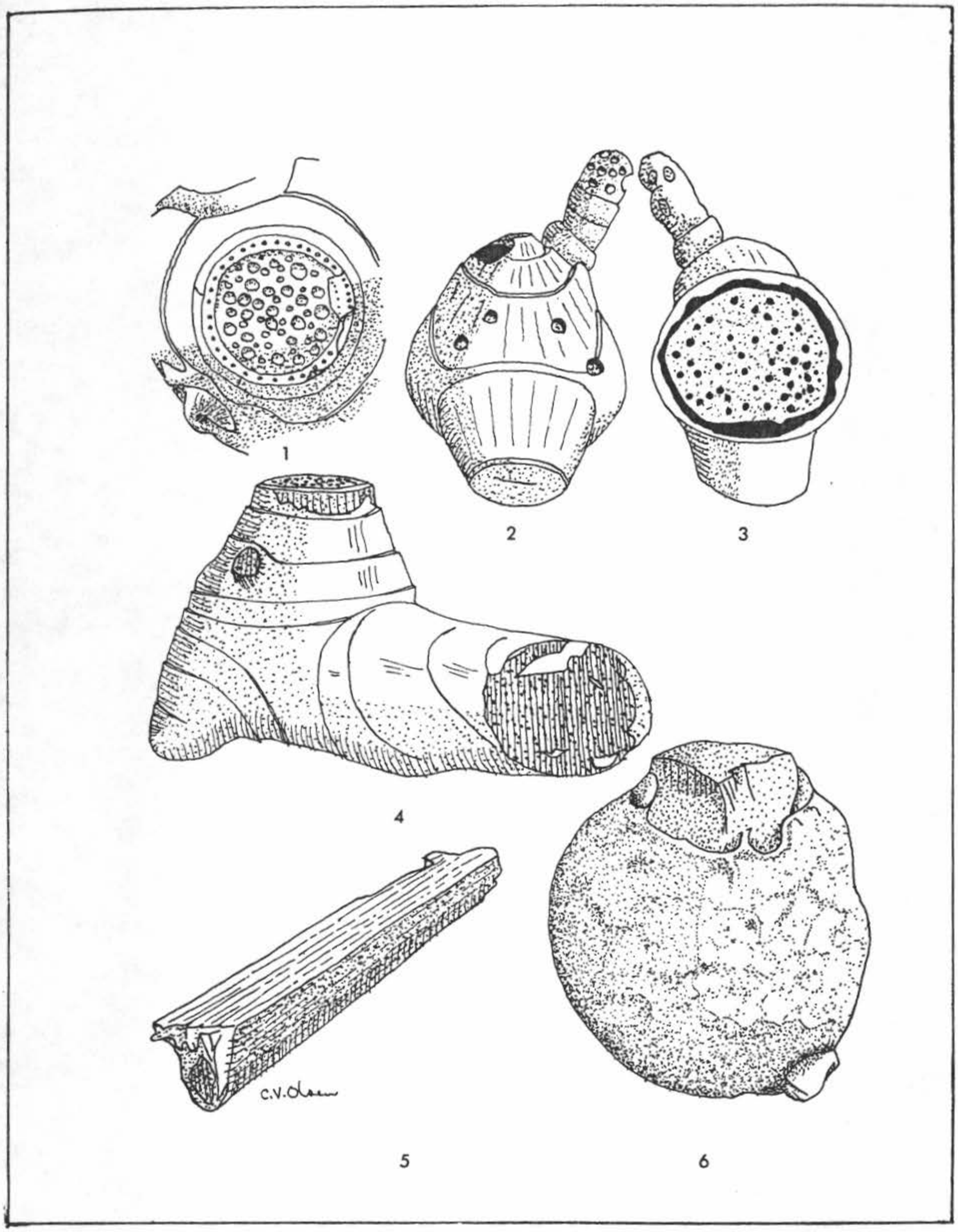
PLATE II

DRAWINGS OF PLANT SPECIMENS

Figures

1. Basal scar of branch on rhizome of *Iris sageri,* paratype NMBM 1379 (X 5) .
2. Dorsal view of unidentified rhizome fragment (fig. 3) (X 5) .
3. Ventral view of fragment shown in fig. 2 (X 5) .
4. Rhizome from *Iris seageri,* paratype NMBM 1379 (X 4) .
5. Triangular stem from *Scirpus hawleyi* (X 4) .
6. Tuber of *Scirpus hawleyi,* paratype NMBM 1372 (X 4) .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2
3
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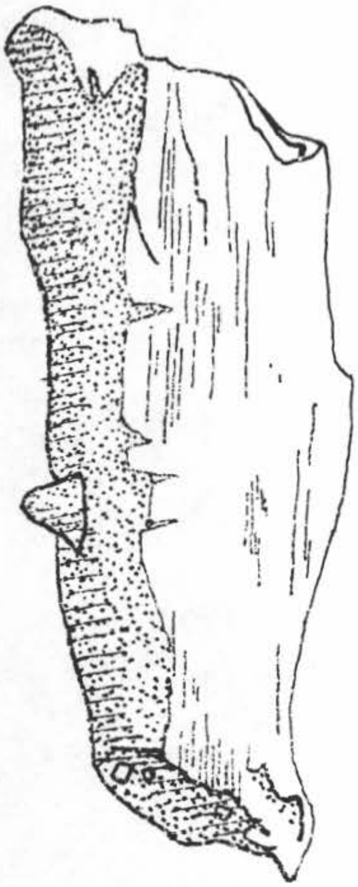
PLATE III

DRAWINGS OF PLANT SPECIMENS

Figures

1. Basal stem fragment of *Palaeophragmites gilei,* holotype NMBM 1370 (X 5).
2. Tuber of *Scirpus Hawleyi,* paratype NMBM 1373 (X 5).
3. Fragment of unidentified rhizome (X 5).
4. Terminal portion of *Allenrolfea*-like stem (X 5).
5. Tubers of *Scirpus kottlowskii,* paratype NMBM 1375 (X 5).



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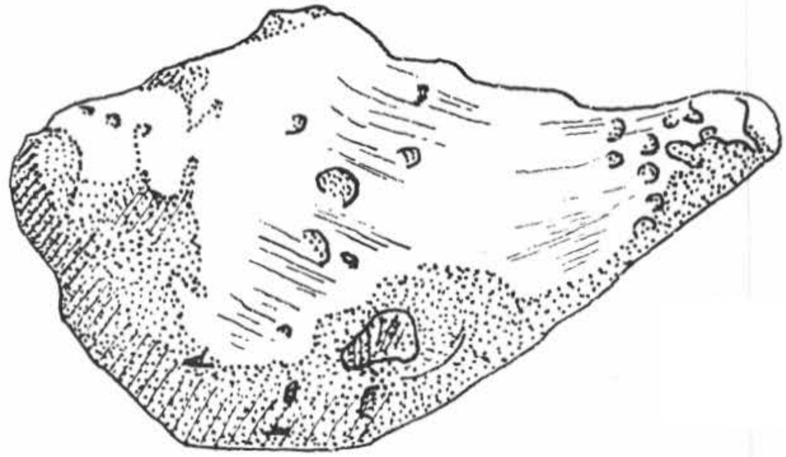

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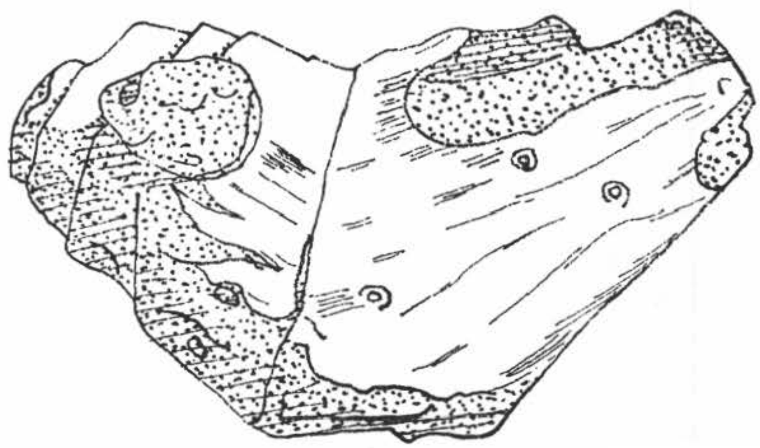

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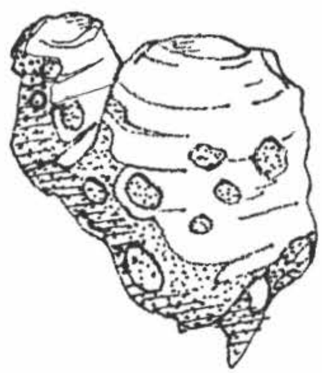

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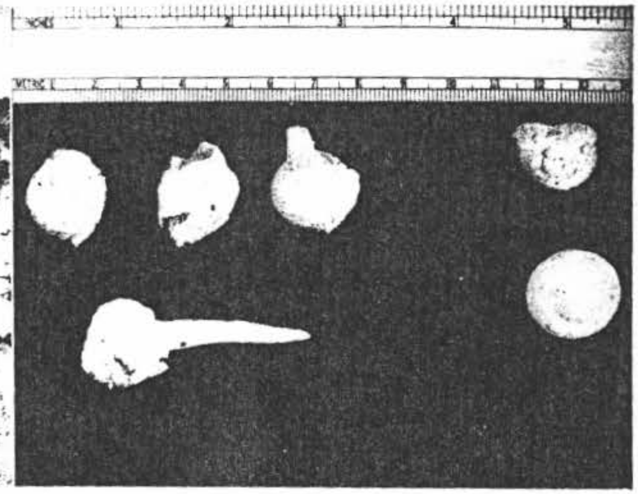
PLATE IV

PHOTOGRAPHS

Figures

1. Closeup of outcrop at site 1. The large rock in right center is composed almost entirely of a solid mass of silicified plant materials partly cemented with a sintery silicified matrix.
2. Comparison of four tubers of *Scirpus hawleyi* (on left) with two tubers of *Eleocharis todsenii* (on right). Types shown: *Scirpus hawleyi*—upper left, paratype NMBM 1372; upper right, holotype NMBM 1371; *Eleocharis todsenii:* upper (extreme right) paratype NMBM 1377; lower (extreme right) holotype NMBM 1376.
3. Panoramic view of the outcrop at site 1.
4. Stems from a medium-sized succulent (?) plant which apparently shriveled up before fossilization.
5. Fragments from a smooth, rhizome with few roots.
6. Fragments from limbs of trees or shrubs.

1



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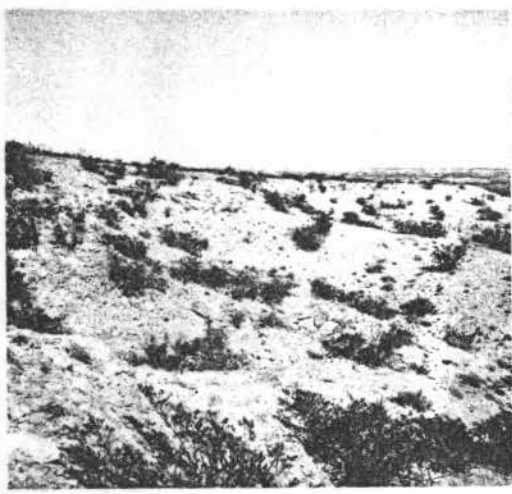

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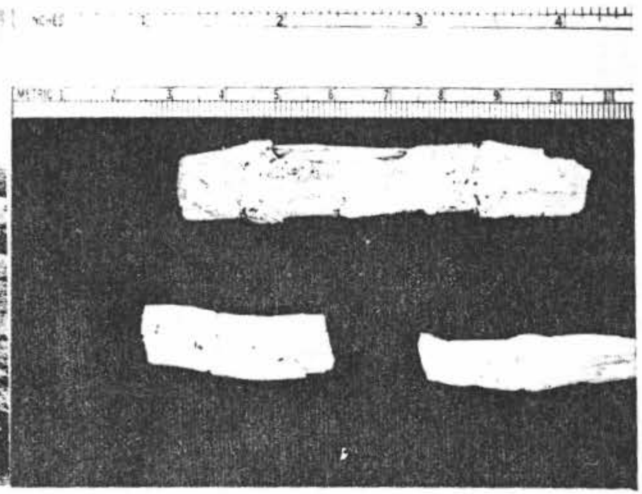

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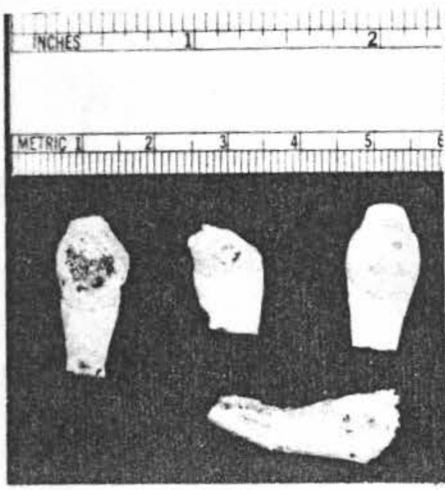

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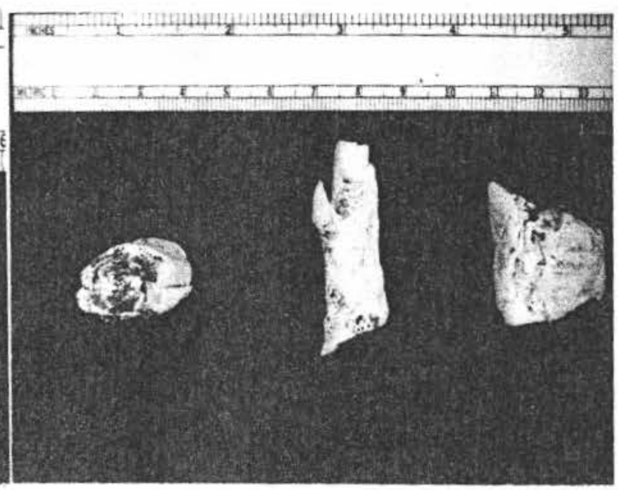

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in height. Scale ridges regular to irregular, prominent, perpendicular to the axis of the culm. Culms triangular, about 1 to 2 mm in diameter at the base, surrounded by a round sheath with an outside diameter of about 3 to 4 mm. Scattered vasular bundles clearly visible in culms. Root scar depressions relatively large, scattered over the entire surface of the tuber, usually 0.5 mm or less in diameter and depth; some specimens with short root fragments.

Discussion. Some recent species of *Scirpus,* as well as other Cyperaceae, have triangular culms arising from small tubers. However, these tubers are usually separated by connecting rhizomes of considerable length (as in *S. paludosus* A. Nels.). We know of no named species with tubers in a crowded series. These tubers are well preserved but uncommon in our samples. This species is named in honor of Frank E. Kottlowski, acting director, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, who conducted the basic geological mapping of the Rincon area.

Types. Holotype: NMBM 1374 (pl. I, fig. 3) sec. 4, T. 19 S., R. 2 W.; paratype: NMBM 1375 (pl. III, fig. 5); same locality.

Eleocharis todsenii n. sp.

Pl. I, figs. 4, 6; Pl. IV, fig. 2

Diagnosis. Tubers smooth, regular, up to 17.0 mm in height and 23.4 mm in diameter, greater measurement perpendicular to the axis of the culms. Scale ridges often prominent, smooth, perpendicular to the axis of the culms. Primary culm, 1 on each tuber, often surrounded by 1 to 3 secondary culms; all round to angular, often with a short, round sheath at the base. Ventral connectives (interconnecting rhizomes) common. Lateral branch fragments rising near the middle (widest part) of the bulb are either similar (lateral) connectives or secondary culms. Root scar depressions usually fine, scattered over the entire surface of the tuber, less than 1 mm in diameter and depth; some specimens with short root fragments.

Discussion. These tubers closely resemble those of *E. tuberosa* Schultes, which, according to Muenscher (1944, p. 160), is native to China. Presumably, the connectives interconnected groups of tubers as they do in *E. tuberosa.* The comparison between the smoother tubers of *E. todsenii,* which are wider than long, and the rough tubers of *Scirpus hawleyi,* which are usually longer than wide, is shown in Plate IV, fig. 2. The tubers are well preserved but uncommon in our samples, all thus far coming from one small area. This species is named in honor of Thomas K. Todsen, Las Cruces, New Mexico, currently Director of Test Operations, White Sands Missile Range who has been of aid in securing specimens.

Types, Holotype: NMBM 1376 (pl. I, figs. 4, 6; pl. IV, fig. 2), sec. 4, T. 19 S., R. 2 W.; paratype: NMBM 1377 (pl. IV, fig. 2); same locality.

FAMILY: Iridaceae

Iris seageri n. sp.

Pl. I, fig. 5; Pl. II, figs. 1, 4

Diagnosis. Rhizomes nonbranching, stout, from 11.9 to 13.2 mm in diameter with prominent scale ridges spaced irregularly up to 4.3 mm apart. Scale ridges diagonal to the axis of the rhizome except at the origin of erect lateral branches, where ridges are concentric to the branch base. Lateral branches about 15 to 20 mm apart and up to 7.7 mm in diameter at the base, with scattered vascular bundles clearly visible. Root scar depressions mostly on ventral two thirds of the rhizomes, about 1 mm in width, about 1 mm or less in depth, often with a minute bundle pit in the center.

Discussion. The rhizomes of *Iris seageri* are intermediate in size between *Iris missouriensis* Nutt., which is common locally in pine forests of nearby mountains, and cultivated iris (*Iris* spp.). This material from Rincon is well preserved but uncommon, suggesting the possibilities of the species existing either in small numbers or only in a restricted habitat, as is currently true of *Iris missouriensis,* or both. This species is named in honor of William R. Seager, assistant professor, Department of Geology, New Mexico State University, University Park, New Mexico, who is currently studying Cenozoic stratigraphy and structural geology of the Rincon area.

Types. Holotype: NMBM 1378 (pl. I, fig. 5), sec. 4, T. 19 S., R. 2 W.; paratype: NMBM 1379 (pl. II, figs. 1, 4); same locality.

In addition to the named species, several others are represented by materials that we have not been able to classify. Most notable is a large number of fragments from a species represented by medium-sized, smooth rhizomes (pl. II, figs. 2, 3; pl. III, fig. 3; pl. IV, fig. 5); stems from a coarse, succulent plant (pl. IV. fig. 4); and *Allenrolfea*-like stems (pl. III, fig. 4). Other materials include large, round stems from trees or shrubs (pl. IV, fig. 6), striated stems of grass or *Equisetum*-like plants, and a vast amount of assorted materials, including stems and roots, but to date no leaves or reproductive structures. It is hoped that future studies will determine much of this remaining flora and that palynological studies will further aid in the characterization of the palaeoflora and palaeoecology of the Rincon Hills.

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Quaternary Geology of the South-Central New Mexico Border Region

by John W. Hawley
Geologist, Soil Survey Investigations, Soil Conservation Service,
U.S. Department of Agriculture, University Park, New Mexico.
Frank E. Kottlowski
Acting Director, New Mexico Bureau of Mines and Mineral Resources,
Socorro, New Mexico.

ABSTRACT

In early to mid-Quaternary time, the intermontane basins of the south-central New Mexico border region were still internally drained. Environments of deposition ranged from alluvial-fan piedmont slopes to broad basin floors that were often sites of lacustrine sedimentation. In later stages of basin filling, local upland sediment sources were supplemented by the ancestral upper Rio Grande, which extended into the region by early Kansan time. Studies of vertebrate and invertebrate faunas and correlation of volcanic ash lenses indicate that basin filling in extensive areas adjacent to the Rio Grande Valley culminated in late Kansan to early Illinoian time. The complex of late Cenozoic basin fills predating Rio Grande Valley entrenchment comprises the Santa Fe Group. The Jornada and La Mesa geomorphic surfaces cap the Santa Fe sequence.

Cyclic entrenchment of the Rio Grande was initiated after mid-Pleistocene integration of the lower and upper segments of the ancestral Rio Grande. Subsequently, four major, climatically controlled cycles of valley cutting have taken place. Aggradation of basin surfaces has continued in broad areas still not integrated with Rio Grande drainage. Parts of basin floors were occupied by large lakes during late Pleistocene pluvials.

Significant structural deformation of basin- and valley-fill deposits and extrusion of basalts and maare formation in Mesilla bolson represent continuation of deep-seated disturbances in Quaternary time.

INTRODUCTION

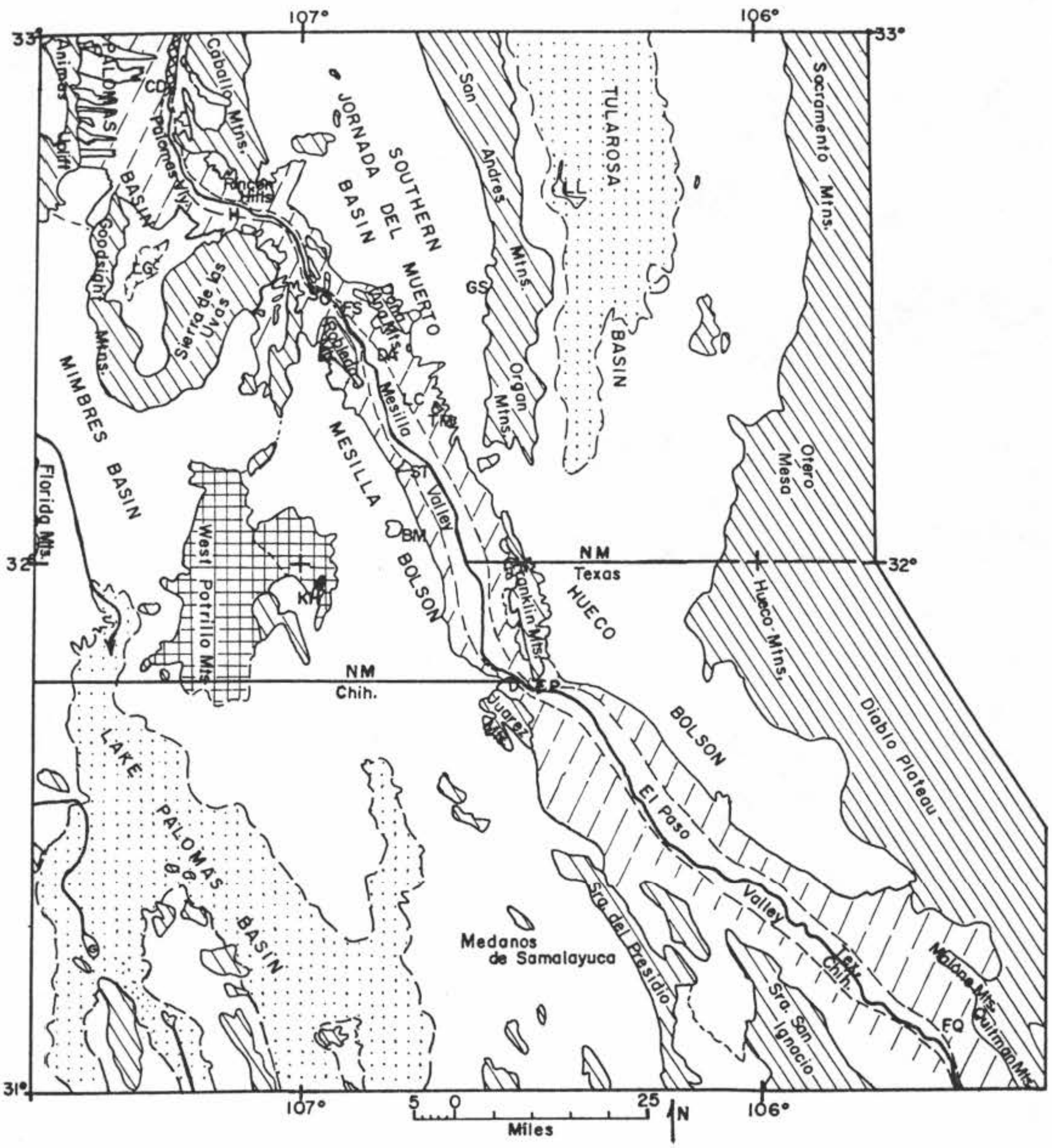
The region discussed in this paper is in the Mexico Highland section of the Basin and Range province. It includes an area of New Mexico and west Texas bounded by the Mimbres River Basin on the west and the Sacramento–Hueco–Finlay–Malone–Quitman mountain chain on the east (fig. 1). The northern and southern boundaries are not rigidly defined, but the deposits and surfaces described extend south into the bolsons of northern Chihuahua, Mexico, and north into the Rio Grande depression and intermontane basins of south-central New Mexico.

Major ranges in the area include the Animas–Hillsboro, Caballo, Goodsight–Uvas, Robledo, Potrillo, Doña Ana, San Andres, Organ, and Franklin mountains. Major basins are the southern Palomas, east Mimbres, Mason Draw, southern Jornada del Muerto, and southern Tularosa and Hueco and Mesilla bolsons. The Palomas–Rincon, Selden, Messila, and El Paso segments of the Rio Grande Valley cross the region from northwest to southeast. The Rio Grande floodplain forms the local base level for all open-drainage basins. Its altitude range from about 4150 feet (1265 meters) at Caballo Dam to 3500 feet (1060 meters) at Fort Quitman, about 160 miles (260 kilometers) to the southeast. The highest point within the area is Organ Needle, with an altitude of 9012 feet (2744 meters).

The authors wish to acknowledge the co-operation and assistance of the following colleagues who are or who have been actively involved in studies of the Quaternary of southern New Mexico: Robert V. Ruhe and Leland H. Gile, Soil Conservation Service; Artie L. Metcalf and William S. Strain, University of Texas at El Paso; Frederick F. Peterson, University of Nevada; William E. King and William R. Seager, New Mexico State University; and Andrew M. Taylor, Colorado School of Mines.

INTERMONTANE BASIN DEPOSITS OF THE SANTA FE GROUP

The early to mid-Quaternary landscape of the border region was characterized by a complex of broad, internally drained, structural basins and intervening north-south- to



RIO GRANDE VALLEY FLOOR

QUATERNARY BASALTS

CLOSED-BASIN AREAS BELOW 4000 FEET, SITES OF LARGE PLEISTOCENE LAKES

POST-MIDDLE PLEISTOCENE VALLEY-BORDER SURFACES AND ASSOCIATED DEPOSITS ON: SANTA FE GROUP AND OLDER ROCK UNITS

INTERMONTANE BASIN SURFACES, AND BASIN-SURFACE REMNANTS ABOVE RIO GRANDE AND TRIBUTARY VALLEYS

MOUNTAIN UPLANDS OF PRE SANTA FE ROCKS

LOCALITY SYMBOLS

BM	BLACK MOUNTAIN	FQ	FORT QUITMAN	H	HATCH	LL	LAKE LUCERO
CD	CABALLO DAM	FS	FORT SELDEN	KH	KILBOURNE HOLE	SC	SELDEN CANYON
DA	DONA ANA	G	LAGUNA GUZMAN	LC	LAS CRUCES	ST	SANTO TOMAS-SAN MIGUEL
EP	EL PASO	GS	GARDNER SPRING	LG	LAKE GOODSIGHT	TM	TORTUGAS MOUNTAIN

Figure 1

INDEX MAP OF THE BORDER REGION, SHOWING BASIN AND VALLEY AREAS THAT HAVE BEEN SITES OF SIGNIFICANT AMOUNTS OF EROSION AND DEPOSITION northwest-southeast-trending mountain ranges. The filling of these basins with detritus derived from erosion of surrounding uplands had commenced in late Tertiary time and continued through mid-Quaternary time. In places, deposits of Quaternary age probably exceed 500 feet (150 meters) in thickness. Environments of deposition ranged from steep, upper piedmont slopes to broad basin floors that were often sites of lakes. In the later stages of basin filling, local sediment sources were supplemented by contributions from an ancestral, upper Rio Grande drainage system that extended from Colorado to northern Chihuahua by Kansan time. Hawley et al. disucss evidence for development of a major through-flowing river system in early to mid-Pleistocene time in another paper herewith (p. 62).

The late Cenozoic basin-fill complex just described, composed of consolidated to unconsolidated sediments and a minor amount of basalt, comprises the Santa Fe Group (Baldwin, 1963; Kottlowski, 1953, 1960; Hawley et al., this circular).

INITIAL DEVELOPMENT OF THE RIO GRANDE VALLEY

Studies of vertebrate faunas and volcanic ash in upper Santa Fe Group sediments near El Paso indicate that aggradation of extensive areas of basin floor culminated in late Kansan to early Illinoian time (Kottlowski, 1958; Ruhe, 1962; Kottlowski, Cooley, and Ruhe, 1965; Strain, 1966; Hawley and Gile, 1966). The fluvial facies of the upper Santa Fe Group basin fill contains Blancan and Irvingtonian vertebrate faunas and scattered lenses of volcanic ash that may have been deposited during the late Kansan "Pearlette" eruption (Strain, 1958, 1966; Hawley, 1965).

Studies by Strain (1966), Kottlowski (1960), and Knowles and Kennedy (1956, 1958) indicated that the floors of the Mesilla and Hueco bolsons, at the southern end of the ancestral upper Rio Grande system, had coalesced by early Quaternary time and subsequently aggraded as a unit. The ancestral Rio Grande first entered Hueco bolson through a gap between the Franklin and Organ mountains, 25 miles (40 kilometers) north of El Paso, and probably was diverted to its present course through El Paso Canyon in late mid-Pleistocene time (Strain, 1966). Distribution of gravels of probably fluvial origin on La Mesa west of El Paso indicates the presence of another ancestral channel system that extended into the relict lake basins of northern Chihuahua. Thus, the ancestral Rio Grande in the southern New Mexico border region appears to have been characterized by a system of distributary channels, radiating from a more confined channel system to the north, with loci of deposition shifting through time. Before integration with the lower Rio Grande–Conchas–Pecos system southeast of the Quitman Mountains and subsequent valley entrenchment, the upper Rio Grande fed large lakes in northern Chihuahua and westernmost Texas (Reeves, 1965; Strain, 1966). These lakes may have extended into southern New Mexico during early to mid-Pleistocene pluvial maxima (Reeves).

While fluvial and lacustrine sedimentation occurred on the broad basin floors, piedmont slopes flanking the mountain uplands also continued to develop. Gradation along the mountain fronts resulted in alluvial-fan and rock-pediment development. Away from the mountains, alluvial fans coalesced to form broad, piedmont, alluvial slopes or bajadas. At the lower parts of these slopes, alluvium derived from the local uplands intertongued with and overlapped the sediments of the basin floors.

Extensive remnants of the ancient basin landscape exist on both side of the Rio Grande Valley. Ruhe (1962, 1964, and 1967) formally named a number of the geomorphic-surface components of this landscape near Las Cruces. The broad basin plains, generally underlain by fluvial sand and gravel deposits and, locally, with a thin veneer of eolian cover sands, comprise La Mesa geomorphic surface. Large areas of piedmont slopes (including alluvial-fan and pediment surfaces) and limited areas of basin floors that stabilized some time after development of La Mesa surface make up the Jornada surface. Small remnants of alluvial fans and rock pediments preserved above the Jornada surface along the mountain fronts comprise the Doña Ana surface, which may be the mountain-front analogue of La Mesa surface. All these surfaces developed during or shortly after deposition of the widespread fluvial gravels of general mid-Pleistocene age and before significant river valley entrenchment. Development of the Jornada surface marked the final stages of basin filling in many areas and the end of Santa Fe Group deposition in the area under discussion. Figure 2 shows the relationship between the Santa Fe Group and younger deposits and the sequence of geomorphic surfaces flanking the inner valley of the Rio Grande.

In the Palomas Valley of south-central New Mexico, a geomorphic surface complex, generally equivalent to the three surfaces discussed above, has been designated the Palomas surface by Kelley and Silver (1952). In southern New Mexico, only a few remnants of a high-level basin surface may be equivalent to the end–Tertiary High Plains surface of eastern New Mexico. This is the Rincon surface (Hawley, 1965), which is well preserved in a small area between the Caballo Mountains and the Rincon Hills.

Thick soils, characterized by strong, often indurated, horizons of carbonate accumulation (Gile, 1967; Gile, Peterson, and Grossman 1965, 1966) developed in the surficial deposits of the ancient basin fills. The soil carbonate horizons formed particularly strong and thick caliche caprock layers just below the Rincon, Doña Ana, and La Mesa surfaces.

The possible mechanisms of integration of the upper and lower Rio Grande systems to form a river flowing from the San Juan Mountains of Colorado to the Gulf of Mexico. have been discussed by several workers (Lee, 1907; P. B. King, 1935; Bryan, 1938; Sayre and Livingston, 1945; Kottlowski, 1958; Strain, 1966). Headward erosion and capture by the lower system, spillover of the upper systems, and certainly tectonic uplift and subsidence may all have played a part in development of through-drainage.

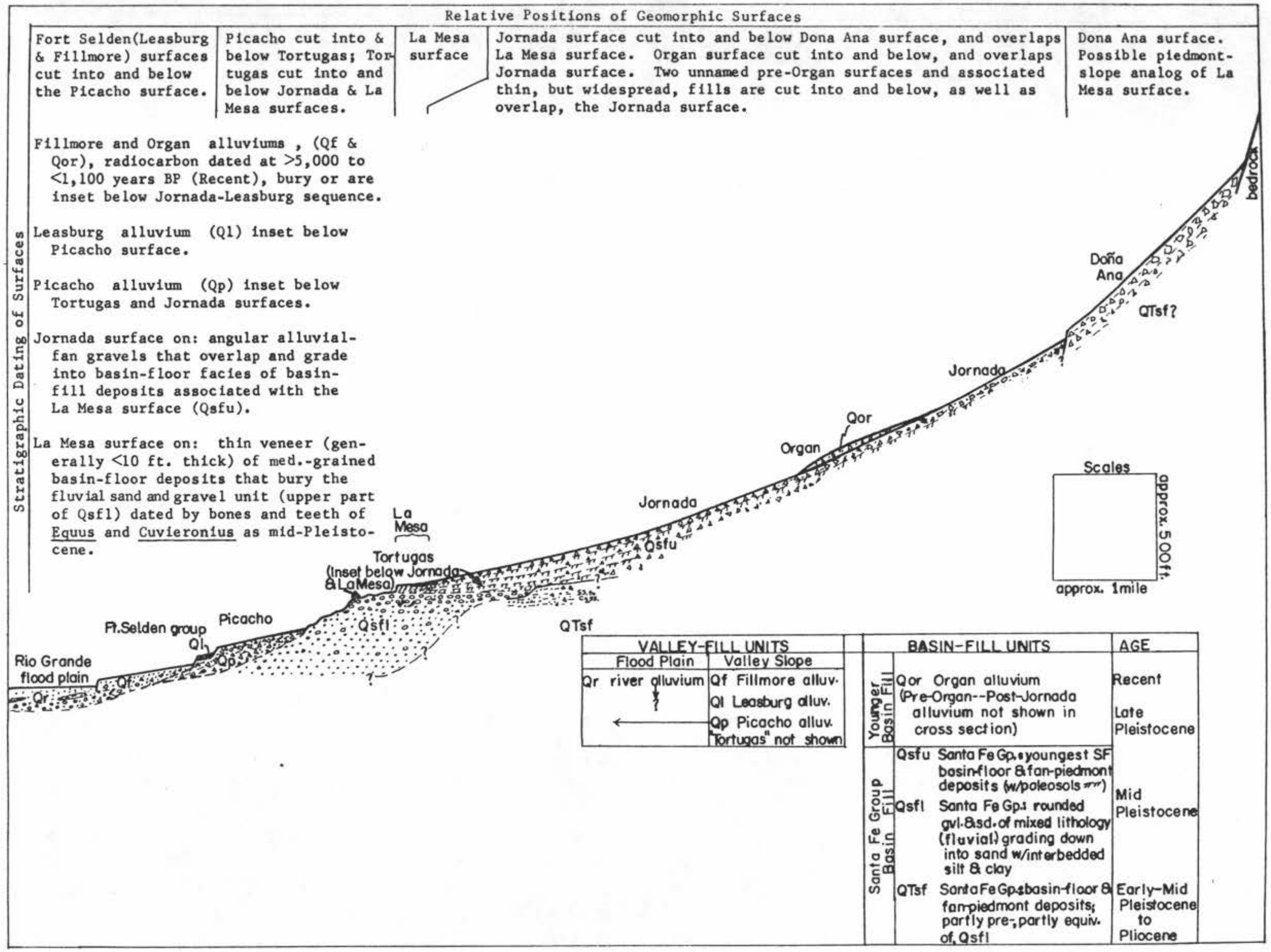


Figure 2

QUATERNARY ROCK-STRATIGRAPHIC, MORPHO-STRATIGRAPHIC AND GEOMORPHIC SURFACE UNITS EAST OF LAS CRUCES, NEW MEXICO

Valley entrenchment probably began soon after drainage integration. Study of molluscan faunas in the Rio Grande Valley north of El Paso by Metcalf (1967) suggested that significant valley entrenchment may have occurred by late Illinoian time. According to Metcalf, sediments associated with the Tortugas surface, which marks the first major stage of valley incision, contain a snail fauna of possible Illinoian age. This age designation was based on a paleoecological interpretation involving recognition of cyclic depression of life zones (indicating pluvial conditions) and correlation of certain alluvial sequences in the Rio Grande Valley with parts of major pluvial cycles.

The Tortugas surface and its correlative at El Paso, the Kern Place terrace (Kottlowski, 1958), represent valley cutting to a level 150 to 200 feet (46 to 61 meters) below adjacent basin floors. Where cut in unconsolidated fill of the upper Santa Fe Group, this mid- to late-Pleistocene valley attained a width of about 6 miles (10 kilometers).

LATE QUATERNARY DEVELOPMENT OF THE RIO GRANDE VALLEY

Three major geomorphic surface units have been described in Las Cruces area. They comprise a stepped sequence of stable remnants of graded landscapes that formed during temporary halts in the entrenchment of the Rio Grande. Regional mapping has demonstrated that correlatives of these surfaces are present in all sements of the valley from Albuquerque to below El Paso (table 1; Ruhe, 1964; Hawley, 1965; Kottlowski, Cooley, and Ruhe). The Tortugas surface is the highest and oldest unit, followed in order of decreasing age and elevation by the Picacho and Fort Selden surfaces.

Each of these major geomorphic-surface units, as mapped, consists of a number of member surfaces graded to a relatively limited range of local and regional base levels. The individual member surfaces result from gradational activity over a span of time and contain four basic geomorphic elements preserved at one place or another along the valleys of the Rio Grande and its tributatries: (1) uplands, which may consist of bedrock highs or older basin or valley-border surfaces, (2) backslope and footslope erosion-transporation surfaces formed below and at the expense of the uplands, (3) toeslope alluvial-fan and coalescent-fan surfaces, and (4) stream terraces (relict bottomland surfaces). At a very few places, notably near or within constrictions of the valley, such as in El Paso and Selden canyons, rock-defended river terrrace remnants are preserved. Elsewhere, the valley-border fan and erosion surfaces are all that remain, and the minimum elevations of these sloping remnants give only a maximum elevation for any projected level of ancestral floodplain stability, barring consideration of faulting or warping. Sediments associated with depositional elements of the Tortugas and younger valley border surfaces are derived from a variety of sources, including local bedrock uplands and basin and older valley fills that may contain exotic rock types. Figure 3 shows the distribution of major valley-border surfaces in the upper Mesilla Valley near Doña Ana.

TORTUGAS SURFACE

The Tortugas surface (Ruhe, 1962, 1964, 1967; Hawley, 1965) in its type area east and southeast of Las Cruces is an erosion surface cut below the Jornada fan-piedmont and La Mesa Basin-plain surface into older basin fill. A graded component of the surface extends a short distance up major arroyos heading in the Organ Mountains in a position intermediate to the Jornada and Picacho surfaces. The valleyward part of the Tortugas surface consists of very small ridge-summit remnants of an erosion surface cut into the exhumed fluvial gravel facies of the Upper Santa Fe Group. This gravel unit resists erosion and forms a prominent structural bench on both sides of the Mesilla Valley. The bench has been modified by erosion since initial valley entrenchment and therefore comprises a complex of backslope and upland surface elements ranging in age from mid-Pleistocene to Holocene.

The lower, graded, footslope and toeslope elements of the Tortugas surface are not preserved in the type area. However, north of Las Cruces on the piedmont slopes of the Robledo and Doña Ana mountains, the Tortugas occurs as a well-preserved graded surface, intermediate between the Jornada and Picacho surfaces, that extends to elevations as low as 125 to 135 feet (38 to 41 meters) above the floodplain (fig. 3). It comprises erosion surfaces on bedrock and older fill adjacent to the mountains and constructional fan surfaces in valleyward positions. This surface is downfaulted along the east boundary fault of the Robledo Mountains (hereafter referred to as the Robledo Fault); however, displacement appears to be generally less than 20 feet (6 meters).

Although no river-terrace remnants of the Tortugas surface are preserved near Las Cruces, it appears that related floodplain deposits are interbedded with Tortugas fan alluvium at the valleyward extremities of the fan remnants flanking the Robledo Mountains north of Doña Ana. In that area, the section below the Tortugas surface consists of one or two lenticular bodies of rounded pebble-to-cobble gravel, with exotic rock types and some sand and silt beds, intertonguing with and overlain by locally derived fan gravel (dominantly limestone) commonly cemented into a cliff-forming fanglomerate. This sequence, which locally is as much as 100 feet (30 meters) thick and fills broad channels cut into Sant Fe Group deposits, is designated Tortugas alluvium (Hawley and Gile; Metcalf), conforming to the morphostratigraphic unit concept of Frye and Willman (1962). Descriptions of two sections of Tortugas alluvium are given in sections 1 and 2 of the appendix.

Constructional river terrace remnants in Selden Canyon, underlain by fills 60 to 80 feet (18 to 24 meters) thick, appear to be Tortugas surface correlatives. They stand from 120 to 140 feet (37 to 43 meters) above the present valley floor, and support the idea of a period of floodplain sta-

TABLE 1. REGIONAL CORRELATION OF VALLEY–BORDER SURFACES*

EL PASO (TEX.) (Kottlowski, 1958)	LAS CRUCES (Ruhe, 1964; Hawley, 1965)	SAN ACACIA (Denny, 1941)	ALBUQUERQUE-BELEN (Wright, 1946)
5-20 ft., non-paired terraces	Fillmore - Holocene (H, 9-12 ftR)† Leasburg - Late Wisconsinan to Holocene (<30 ft.) Surface of maximum river entrenchment (minus 80 ft.)		
Gold Hill (±70 ft.) ‡	Picacho Mid-Wisconsinan (70-90 ft.; 71-79 ft.R)†	Canada Mariana (50-75 ft.) ‡ Fill Terrace (100 ft)	Llano de Sandia (50-75 ft.) ‡
Kern Place (±130 ft.)‡	Tortugas Illinoian (early Wisconsin?) (115-140 ft.; 147 ft.)†	Valle de Parida (150-175 ft.) ‡	Segundo Alto (125 ft) ‡
Intermediate surface between Kern Place & La Mesa pediment (Jornada equiv.?)	"High Tortugas" in Selden Canyon and Rincon Valley (180-200 ft.; R)†		Cochiti (200 ft) ‡

MIDDLE PLEISTOCENE BASIN SURFACES
Jornada-LaMesa-Doña Ana

* Correlations between Las Cruces area and El Paso, San Acacia, and Albuquerque-Belen areas from R. V. Ruhe (1964), table 3.

† Estimated elevations above present valley floor of ancestral floodplain levels to which valley-border surfaces were graded. "H" figures, from Hawley (1965), based on position of rock-defended river terraces and remnants of river gravel deposits and on minimum elevation of valley-border surface termini; "R" figures based on mathematical analysis of graded slopes of valley-border surfaces in Desert Project area by R. V. Ruhe (1967).

‡ Estimated elevations above the present valley floor of correlated ancestral floodplain levels (based on descriptions by the cited authors).

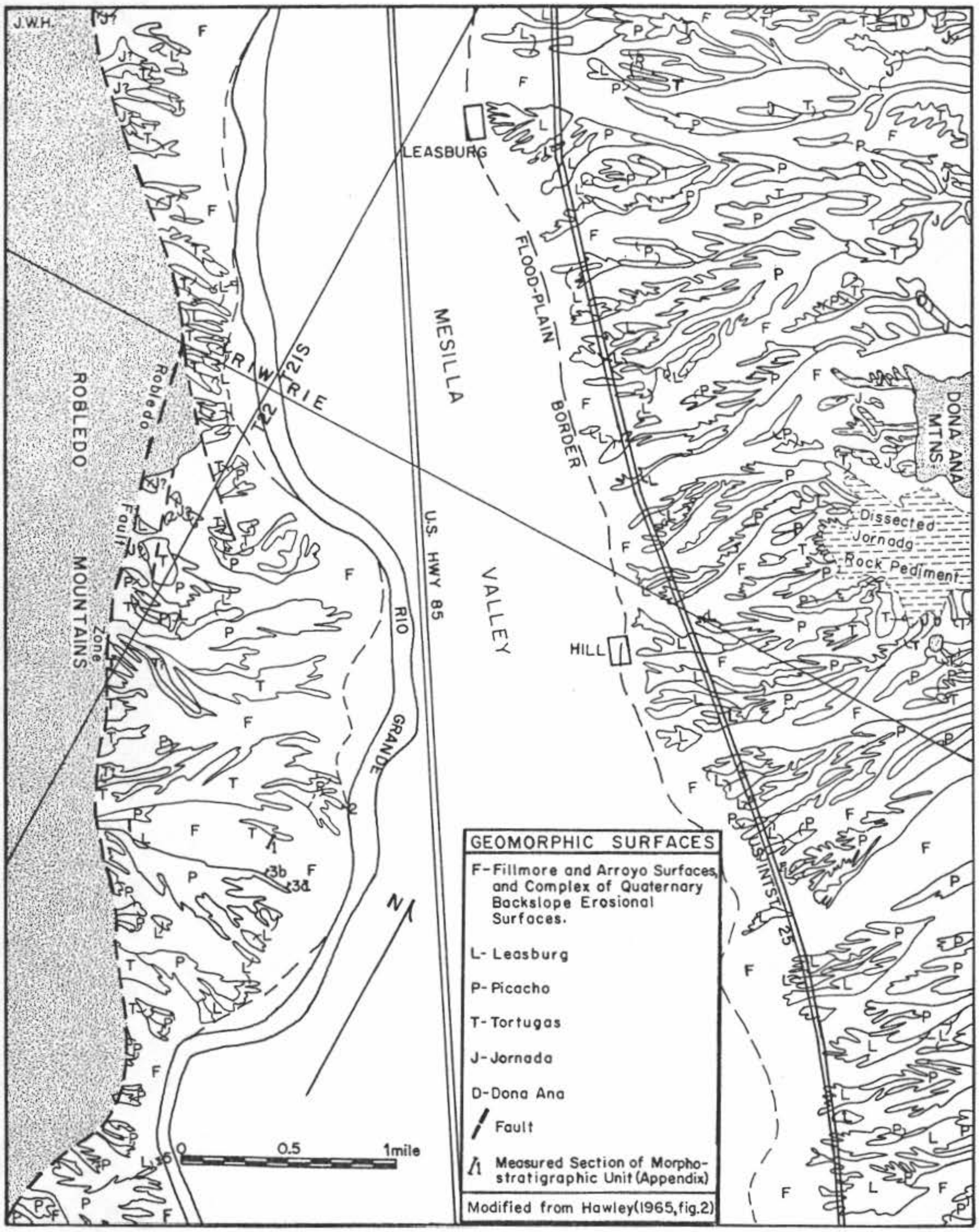


Figure 3

DISTRIBUTION OF RELATIVELY STABLE, FOOTSLOPE AND TOESLOPE REMNANTS OF PLEISTOCENE GEOMORPHIC SURFACES FLANKING THE RIO GRANDE FLOOD PLAIN IN THE UPPER MESILLA VALLEY bility at that general position immediately following a cycle of valley cutting and minor subsequent aggradation. The Kern Place "terrace" at El Paso (Kottlowski, 1958) was also graded to a temporary base level about 130 feet (40 meters) above the present valley floor, and it isregarded as a correlative of the Tortugas surface (Ruhe, 1964). Near El Paso, in Selden Canyon, and in the Palomas–Rincon Valley area, there are often one or two graded erosion surfaces intermediate between the 120- to 140-foot (37- to 43-meters) levels discussed above and the Jornada and La Mesa surfaces. These are considered early stage members of the Tortugas surface complex, perhaps controlled by local, temporary, base levels in canyon areas.

PICACHO SURFACE

The type area of the Picacho surface (Dunham, 1935; Kottlowski, 1953, 1960; Ruhe, 1962, 1964, 1967; Hawley, 1965) is east of Picacho Mountain (sec. 5, T. 23 S., R. 1 E.) on the eastern Robledo piedmont slopes (fig. 3). The Picacho surface here comprises erosional backslope and footslope surfaces along the mountain front that grade to a relict, coalescent, alluvial-fan piedmont surface. East of Picacho Mountain, the surface descends to a point about 100 feet (30 meters) above the modern floodplain where it is abruptly terminated by a scarp. No ancestral floodplain surface remnants are preserved in the type area. However, north of Doña Ana, on both sides of the valley, gravelly fan alluvium of Picacho age, derived from the Robledo and Doña Ana mountains, overlies and possibly intertongues with beds of clean, unconsolidated sands and gravels with abundant foreign pebble constituents. These beds appear to represent a river-channel gravel facies deposited by the ancestral Rio Grande during the Picacho cycle of erosion and deposition. Terrace and alluvial-fan deposits genetically related to constructional parts of the Picacho surface are also designated in the morphostratigraphic sense (Frye and Willman) as Picacho alluvium (fig. 2; Kottlowski, 1960, Hawley and Gile; Metcalf). They locally attain a thickness of 50 to 70 feet (15 to 21 meters) and extend below the channel level of tributary arroyos. Descriptions of two sections of Picacho alluvium are given in sections 3 and 4 of the appendix.

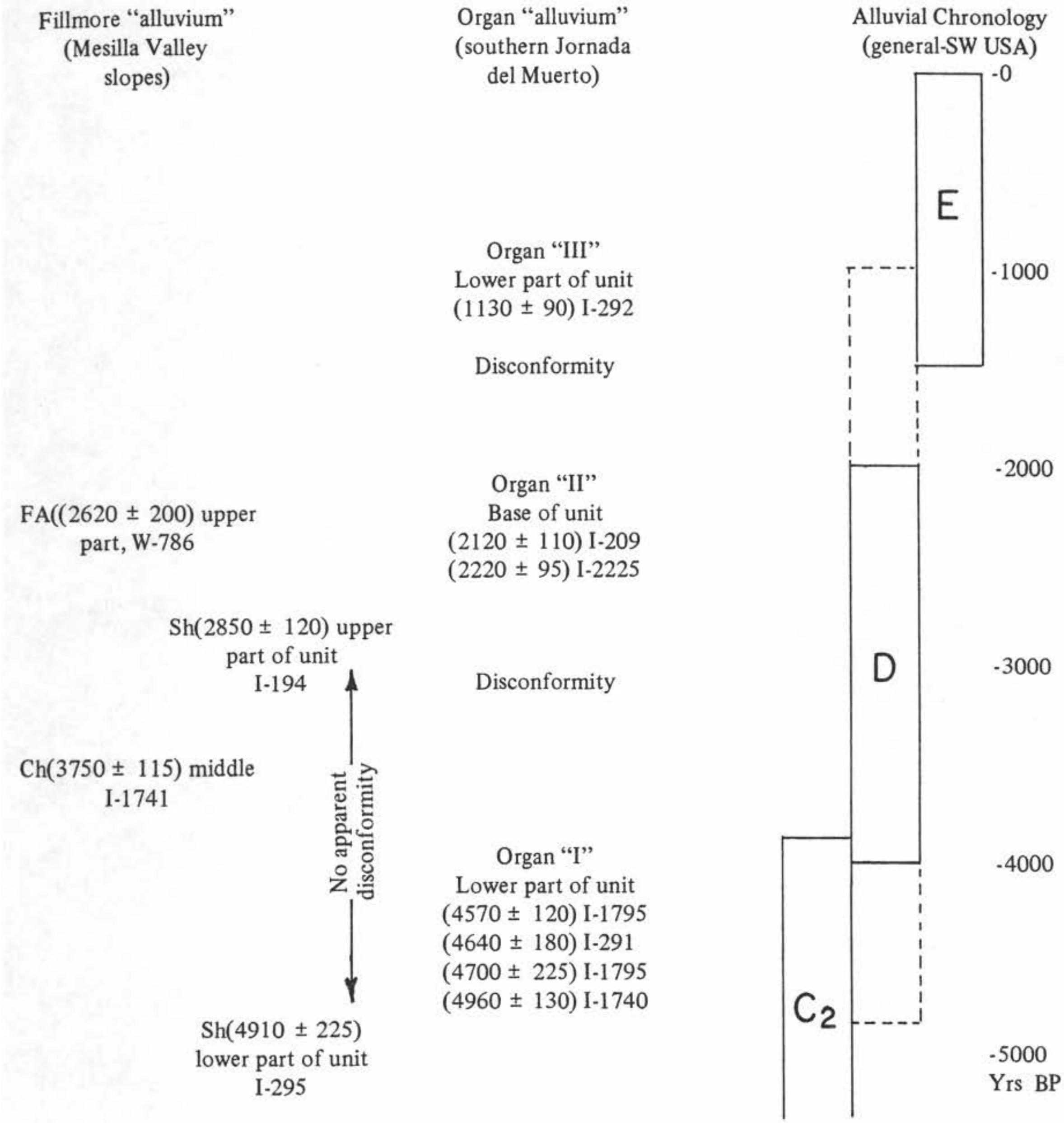
Surfaces of rock-defended river terraces that have been correlated with the Picacho valley-slope surfaces are preserved in Selden and El Paso canyons (Hawley, 1965). These terrace surfaces are about 70 feet (21 meters) above the modern floodplain and are underlain by Picacho fills as much as 50 feet (15 meters) thick. The terrace at El Paso represents the temporary base level to which the Gold Hill "terrace" of Kottlowski (1958) was graded.

The Picacho surface is also well preserved along the east side of the Rio Grande Valley near Las Cruces–University Park, below residuals of upper Santa Fe Group gravels whose exhumation began with the Tortugas cycle of valley cutting. Here the Picacho surface is represented by individual alluvial fans at the mouths of major arroyos heading in the Organ Mountains, as well as by terraces extending back up the arroyos. Gravelly to very gravelly loamy sand deposits, as thick as 70 feet (21 meters), comprise the Picacho alluvium and unconformably rest on poorly consolidated sand, with interbedded silt and clay, of the upper Santa Fe Group. In most instances, Picacho fan and terrace deposits partly fill broad channels cut to about the level of present arroyo bottoms, thus indicating a major cycle of aggradation after an initial episode of valley cutting. Carbon-14 dating of organic carbon sealed in petrocalcic horizons of soils on the Picacho surface indicates that the surface formed some time before 10,000 years B.P. (before present) (Gile, Peterson, and Grossman).

FORT SELDEN, ARROYO, AND HISTORICAL FLOODPLAIN SURFACES

Ruhe (1962, 1964) designated the complex of surfaces terminating at low scarps that rise from 5 to 40 feet (1.5 to 12 meters) above the floodplain as the Fort Selden Group of geomorphic surfaces. On the basis of detailed mapping, a twofold subdivision of the Fort Selden Group has been made (Hawley, 1965) to designate surfaces ranging in age from late Pleistocene to Holocene. The older subdivision of the Fort Selden Group has been named the *Leasburg surface.* The type area of this surface lies along the Mesilla Valley border from Doña Ana to Radium Springs. The Leasburg surface is typically expressed by one or two minor erosion surfaces cut below the riverward extremities of Picacho fans into Picacho alluvium. In several places, such as east of Leasburg (sec. 30, T. 21 S., R. 1 E.) and north of Doña Ana, the Leasburg comprises graded surfaces consisting of fans along the river and inset terraces up the arroyos (fig. 3). At the site of Fort Selden, the Leasburg surface is associated with a thin terrace veneer that buries an older river-terrace fill (of possible Picacho age) and paleosol. The surface of this terrace is 25 to 30 feet (8 to 9 meters) above the floodplain. Charcoal recently recovered from flood-plain deposits in the Palomas Valley near Hatch that appear to be correlative with Leasburg alluvium has yielded a Carbon-14 date of 9360 ± 150 years B.P. (Isotopes, Inc. 3784; A. L. Metcalf personal communication).

A major cycle of degradation of tributary drainage basins took place after formation of the Leasburg surface, resulting in cutting of valleys to depths of at least several feet below the floors of modern arroyos. In places, as much as 40 feet (12 meters) of subsequent aggradation occurred along the inner valley borders during deposition of fans at the mouths of arroyos tributary to the Rio Grande. On the basis of radiocarbon dates obtained from charcoal interbedded with this alluvium on both sides of the valley (Ruhe, 1964; Hawley and Gile), this cycle of aggradation began before 5000 years B.P. It culminated some time after 2600 years B.P. in development of a major coalescent alluvial-fan surface along the inner-valley borders adjacent to the river floodplain (fig. 4). This lowest, major, valley



All dates are in years B. P. (before present); see Sections 5 to 8 in Appendix.
Dated sites in Fillmore alluvium are: Sh = Shalem Colony; FA = Fillmore Arroyo; Ch = Old Chamberino.
All samples of Organ alluvium are from the Gardner Spring site (Gile and Hawley, in press).
Alluvial chronology of the Southwest is from C. V. Haynes, 1968, Figure 3.

Figure 4

HOLOCENE ALLUVIAL CHRONOLOGY, SOUTH CENTRAL NEW MEXICO AREA

Correlated with the general alluvial chronology for the southwest border fan surface and its associated arroyo terraces and valley-slope erosion surfaces Hawley (1965) designated the Fillmore surface. It is graded to a level very close to that of the modern floodplain. As for the Tortugas and Picacho alluviums, deposits associated with constructional elements of the Fillmore and Leasburg surfaces are treated as morphostratigraphic units and designated by their respective geomorphic surface name (figs. 2 and 4). Two sections of Fillmore alluvium are described in sections 5 and 6 of the appendix.

One or two minor cycles of erosion-sedimentation have occurred on the valley slopes since development of the Fillmore surface. The present arroyo system is entrenched from about 3 feet (0.9 meters) to as much as 40 feet (12 meters) below the surface. Part of this was caused by lateral shifting of the Rio Grande channel during the past several hundred years (U.S. Reclamation Service, 1914), which resulted in the cutting of scarps of various heights in the fan toes as the river impinged on the inner valley borders.

The maximum stage of entrenchment of the Rio Grande in latest Pleistocene time (Picacho–Leasburg interval) may be represented by a buried surface occurring at relatively shallow depths below the present floodplain surface (Lee; Kottlowski, 1958; Hawley, 1965). Information from well drillers, examination of cuttings from several wells, and review of published information on local ground-water conditions (Sayre and Livingstone, 1945; Conover, 1954; Leggat, Lowry, and Hood, 1963; Davie and Spiegel, 1967) indicate that the late Quaternary river deposits extend no more than 80 feet (24 meters) below the floodplain level. This depth represents the approximate thickness of unconsolidated sediments over bedrock at the International Dam Site in El Paso Canyon (Slichter, 1905) and over Tertiary volcanics and sediments in the lower Selden Canyon area. The deepest occurrence of gravels below the floodplain (more than 200 feet–61 meters–near Las Cruces) does not represent the depth of late Quaternary entrenchment (Conover) or the depth of scour from great floods (Bryan). Rather, these deeper gravels are part of the ancient basin fill and are stratigraphically below the basin deposits exposed in the valley walls.

STRUCTURAL COMPLICATIONS

Faulting and downwarping have taken place along structural trends bounding the Rio Grande depression through late Pleistocene time, suggesting tectonic control of the river valley position (Kottlowski, 1958). The Tortugas to La Mesa geomorphic surface complexes are definitely displaced from about 20 (0.6 meters) to as much as 200 feet (61 meters) by major faults, such as the Robledo Fault (Kottlowski, 1953, 1958, 1960; Ruhe, 1962; Hawley, 1965). There are also indications of slight warping and faulting of the Picacho and younger late Pleistocene surfaces (Ruhe, 1964, p. 157-158; Frederick F. Peterson, personal communication) on both sides of the upper Mesilla Valley.

GEOMORPHIC HISTORY OF THE RIO GRANDE VALLEY

Despite the above-mentioned structural complications, the Tortugas, Picacho, and Fillmore surfaces can be identified with considerable certainty in the regions upstream and downstream from their type areas near Las Cruces (Ruhe, 1964; Hawley, 1965). The fact that regional correlation of the major valley-border surfaces is possible (table 1) indicates that other than local factors played a role in development of the existing sequence of geomorphic surfaces. Cyclic climatic change taking place since mid-Pleistocene time and operative over the entire Rio Grande watershed of Colorado and New Mexico probably was the major influencing factor. Kottlowski (1958), Ruhe (1964), Hawley (1965), and Metcalf have discussed this possibility. Unfortunately, geologic dating of deposits and surfaces is limited to the fossil mammal chronology for the mixed-rounded gravels and older basin-fill deposits (Strain, 1958, 1966; Ruhe, 1962), the radiocarbon chronology for Holocene alluvial deposits (fig. 4; Gile and Hawley, 1968), and a few carbon-14 dates on organic matter sealed in soil carbonate horizons. Thus, only the relative ages of the various valley-border surfaces between the mid-Pleistocene basin surfaces and the Holocene Fillmore member of the Fort Selden Group can be determined. In this part of the Rio Grande Valley, correlation of major alluvial events with glacial-fluvial or interglacial-interpluvial cycles still cannot be accomplished with precision.

A hypothetical model of the late Pleistocene history of the Rio Grande Valley near Las Cruces, developed by Metcalf, is outlined below. It is based on a study of living and fossil molluscan faunas found in the various units of valley-fill alluvium. Significant faunal shifts through the stratigraphic succession of deposits associated with the Tortugas, Picacho, and Holocene surfaces are related to important cyclic climatic changes.

According to Metcalf's ecological reconstruction of past events, significant Rio Grande entrenchment first took place during the Illinoian (Sacagawea Ridge) glacial stage. Reaggradation of valley floors commenced in Latest Illinoian time, with Tortugas valley-border fans encroaching onto an aggrading to stable, ancestral floodplain during the Sangamon interglacial. The next major cycle of river entrenchment (early stage Picacho) took place during the early Wisconsinan (Bull Lake) glacial stage, with a significant amount of floodplain aggradation occurring in the latest part of that glacial-pluvial interval. Subsequent aggradation by tributary arroyos along the inner valley border, controlled by a slowly aggrading to stable floodplain surface, culminated in development of the Picacho valley-slope fan surface during the mid-Wisconsinan (Bull Lake–Pinedale) interstadial. Fort Selden surfaces were formed during late Wisconsinan (Pinedale) and Holocene time, with Fillmore member surfaces mainly representing Holocene episodes of aggradation and stability along and at the mouths of drainage systems tributary to the Rio

Grande. The last significant lowering of the river floodplain base level (perhaps as much as 80 feet–24 meters–below the present valley floor) apparently took place during the early part of the late Wisconsinan (Pinedale) glacial-pluvial maxima.

The above model closely approximates the "scheme of river activity" outlined by Schumm (1965, p. 790-792, table 2) for the semiarid midsection of the river system in the unglaciated continental interior, with a headsection affected by Pleistocene glaciation. According to his scheme, fluvial processes follow this cyclic sequence: late interglacial, stability; early glacial and glacial, erosion; late glacial and early interglacial, depostion; and interglacial, stability. Encroachment of fans of tributary arroyos onto the river floodplain might be expected during an interglacial.

The writers feel that Metcalf's model is a very reasonable interpretation of the geomorphic evolution of the Rio Grande Valley in southern New Mexico. It agrees with Kottlowski's (1958) hypothetical model of valley development near El Paso; and it is not in conflict with available chronologic, sedimentologic and pedologic information. However, considering the length and complexity of the early Wisconsinan glacial-pluvial substage (Richmond, 1965; Smith, 1968), we suggest that the above model should be modified slightly to include the possibility that the Tortugas surface and associated alluvium might date from the earliest part of the Wisconsinan Stage.

The dynamic equilibrium concept (Hack, 1960) has recently been applied in an alternative explanation of the geomorphic evolution of the Rio Grande Valley in the San Acacia area (Denny, 1941, 1967). This concept may well apply to certain sequences of surfaces formed during limited spans of time (up to several tens of thousands of years) when hydrologic conditions were essentially constant. However, it has major limitations when long-time spans, often encompassing several pluvial and interpluvial stages, are involved. The extensive preservation of relict landforms and soils in the area and the paleoecologic works cited above indicate that cyclic shifts in climate exerted significant control on the evolution of the landscape in the region under discussion. As Lustig (1965) has well illustrated, the dynamic equilibrium concept, developed in a humid-temperate region should be applied with caution in the arid and semiarid Southwest, a region characterized by significant cyclic shifts in the intensity of various epigene processes during the Quaternary Period.

POST–SANTA FE EVOLUTION OF BASINS NOT INTEGRATED WITH RIO GRANDE DRAINAGE

Large areas of the ancient basin-floor surface (La Mesa) are preserved, with only minor surface modification, in parts of intermontane basins adjacent to the Rio Grande Valley where the surface drainage is limited but still not integrated with the river system. Only the ground-water regime of these closed basins has been markedly affected by cyclic entrenchment of the Rio Grande Valley. Ground-water levels now range from 250 to 500 feet (76 to 152 meters) below the basin floors and reflect relatively good hydraulic connection between Santa Fe Group basin fills and the river valley (Conover; Taylor, 1967).

On many parts of the piedmont slopes, however, gradational processes have actively continued, and large areas of the Jornada geomorphic surface have been buried or eroded. On the upper piedmont slopes, younger alluvial deposits and erosion surfaces are inset below a moderately to deeply dissected Jornada surface. On lower, still undissected, piedmont slopes, these deposits spread out as coalescent alluvial-fan aprons that bury the Jornada surface. The youngest and best-preserved surface of such alluvial-fan and valley-fill deposits has been designated the Organ (Ruhe, 1964). The associated sediments are designated in the morphostratigraphic sense as Organ alluvium. Descriptions of three sections of Organ alluvium are given in sections 7a, 7b, and 8 of the appendix. The thickness of this alluvium rarely exceeds 15 feet (4.5 meters), and the deposits are considered Holocene in age (greater than 5000 to less than 1000 years B.P.) on the basis of radiocarbon dating of charcoal recovered from buried fired horizons (fig. 4; Hawley and Gile; Ruhe, 1967; Gile and Hawley, 1968). The Organ surface is the mountain-front analogue of the Fillmore valley-slope surface. The several periods of deposition associated with the formation of these surfaces, particularly the Organ (fig. 4), correlate well with the general "alluvial chronology" of the Southwest, as recently summarized by Haynes (1968). Cycles of erosion and deposition associated with formation of the Fillmore surface are complicated by the fact that lateral cutting by the Rio Grande into valley-slope fans can locally affect sedimentation processes at any time.

In some piedmont-slope areas, one or two pre-Organ, post-Jornada surfaces and associated deposits are preserved, both in land-surface and buried positions. These geomorphic surfaces, which include both constructional and erosional elements, have not been separately mapped, except in areas of very detailed study. Investigation in such areas (Gile and Hawley, 1966; Hawley and Gile, p. 12, 22, 45-56) show that piedmont slope sedimentation has been periodic, with cycles of landscape instability and concurrent erosion and sedimentation alternating with long periods of surface stability and soil formation. It is not yet known how major, late Pleistocene cycles of landscape evolution in closed basins correlate with major geomorphic cycles in the Rio Grande Valley (that is, Tortugas–Picacho–Fillmore cycles).

Sediments derived from erosion of mid-Pleistocene to Holocene piedmont-slope deposits are presently in transit toward the basin axes. Erosion of a silty facies of Organ alluvium has resulted in a striking Holocene to Modern scarplet-erosion surface, designated the Whitebottom surface by Ruhe (1964, 1967). This surface is characterized by a repeated sequence of low scarps, miniature footslope and backslope erosion surfaces, alluvial toeslopes, and stable, grass-covered flats being scarped downslope and receiving increments of sediments upslope.

Information from deep test borings in areas of piedmont slope-basin floor mergence and gully exposures of piedmont-slope deposits elsewhere in the basins reveal that the complex processes of erosion-sedimentation presently active were also periodically active in the past. The type Jornada surface, best preserved at the land surface along the Jornada del Muerto basin axis and on the upper piedmont slopes, may be buried by as much as 25 feet (8 meters) of pre-Organ basin fill in lowermost piedmont-slope positions (fig. 5). Hawley et al. (this volume) discuss the problem of separating the younger fill of closed basins from the Santa Fe Group on page 59.

A number of playa-lake plains (Lake Tank geomorphic surface, Ruhe, 1964) occur on the basin floors. Lake Lucero, in the Tularosa Basin west of White Sands National Monument, is the second largest ephemeral-lake plain in the region. In December 1942, 8.5 square miles (22 square kilometers) of the playa surface were flooded. Relict shorelines and gypsum deposits of Lake Lucero's Wisconsinan predecessor, Lake Otero (Herrick, 1904), indicate that the latter's area reached 700 square miles (1820 square kilometer) during at least one pluvial cycle (INQUA, 1965). Reeves presented evidence for the existence of Lake Palomas, a large (more than 1500 square miles–3900 square kilometers) late-Pleistocene lake in northern Chihuahua, Mexico, southwest of El Paso (fig. 1). Pleistocene Lake Goodsight, a small lake in the Uvas–Goodsight Basin, has been briefly described by Hawley (1965).

QUATERNARY VOLCANISM

Quaternary olivine basalt flows and cinder cones are prominent features of the landscape south and west of Las Cruces (fig. 1). Flows and associated cones cover an area of about 350 square miles (900 square kilometers). The West Potrillo Mountains form the largest volcanic field and include at least 85 cinder cones. Six smaller volcanic fields occur on La Mesa surface, between the Potrillo Mountains and the Mesilla Valley. One of these, the Black Mountain field, is disucssed by Hoffer on page 116. The oldest basalts appear to intertongue with basin-floor sediments of the upper Santa Fe Group. However, the bulk of the basalts east of the Potrillo field, and perhaps in that field as well, postdate development of La Mesa surface and thus are post late Kansan in age. Two basalt flows that spilled into the Mesilla Valley during an early stage of valley entrenchment rest on a possible correlative of the Tortugas surface. Thus, they may be younger than Illinoian. The minimum age of the youngest group of flows, the Aden basalts, is definitely established. Remains of a Shasta ground sloth *(Nothrotherium shastense)* in one of the lava tunnels of Aden volcano date the youngest eruption at greater than 11,080 ± 200 years B.P. (Simons and Alexander, 1964). Potassium-argon dates obtained on samples from five "post La Mesa" flows range from 2.8 to 0.5 million years (table 2). With the possible exception of the youngest date, from a flow mapped as one of the oldest in the area (Kottlowski, 1960; DeHon, 1965), it is felt that the isotope ages obtained are "too old." Further detailed work on post-La Mesa basalts is in progress, however, and it is hoped that the age problem will be resolved soon.

Three huge, rimmed depressions of volcanic origin occur near the western edge of Mesilla bolson about 25 miles (40 kilometers) northwest of El Paso. These explosion features, termed maare by DeHon and Reeves and DeHon (1965), formed after initial extrusion of basalts on La Mesa surface. The largest of the three, Kilbourne Hole, is about 2 miles (3 kilometers) in diameter. Its floor is about 280 feet (85 meters) below and its rim as much as 170 feet (52 meters) above La Mesa surface. Excellent exposures in the southeast wall of the Hole show a thick section of rim ejecta resting on a thin basalt flow, which in turn rests on fine-grained sediments of the upper Santa Fe Group. A strong soil profile, developed in the upper part of the Santa Fe section, marks the buried La Mesa surface. The basalt flow has been dated at 0.5 (± 0.1) x 10^6 potassium-argon years (Geochron Laboratories, Inc., RO-802).

CONCLUSION

In early to mid-Quaternary time, the intermontane basins of the south-central New Mexico border region were part of a closed system, unconnected with the lower Rio Grande. The major basins were the Palomas and Jornada del Muerto and the Mesilla and Hueco bolsons.

A widespread, fluvial sand and rounded-gravel unit, containing some rock types foreign to any local watershed, forms the uppermost deposit beneath the central basin floors. It represents extension of the ancestral Rio Grande into the region by early Kansan time. This unit is underlain by a thick section of fine-grained beds, partly of lacustrine origin. Laterally, toward adjacent mountain uplands, the basin-floor deposits locally interfinger with, are inset against, or grade into coarse-grained, piedmont slope alluvium. The upper 300 to 500 feet (91 to 152 meters) of this basin-fill sequence, considered part of the Santa Fe Group, range from early to mid-Pleistocene age on the basis of vertebrate faunas and volcanic ash stratigraphy.

La Mesa and Jornada geomorphic surfaces, and associated strong soils, cap the basin-fill sequence. Cyclic entrenchment of the Rio Grande was initiated after development of La Mesa basin-floor surface, after an episode of pedimentation and alluvial-fan deposition on adjacent piedmont slopes that resulted in formation of the Jornada geomorphic surface, and after integration of the lower and upper segments of the ancestral Rio Grande. Subsequently,

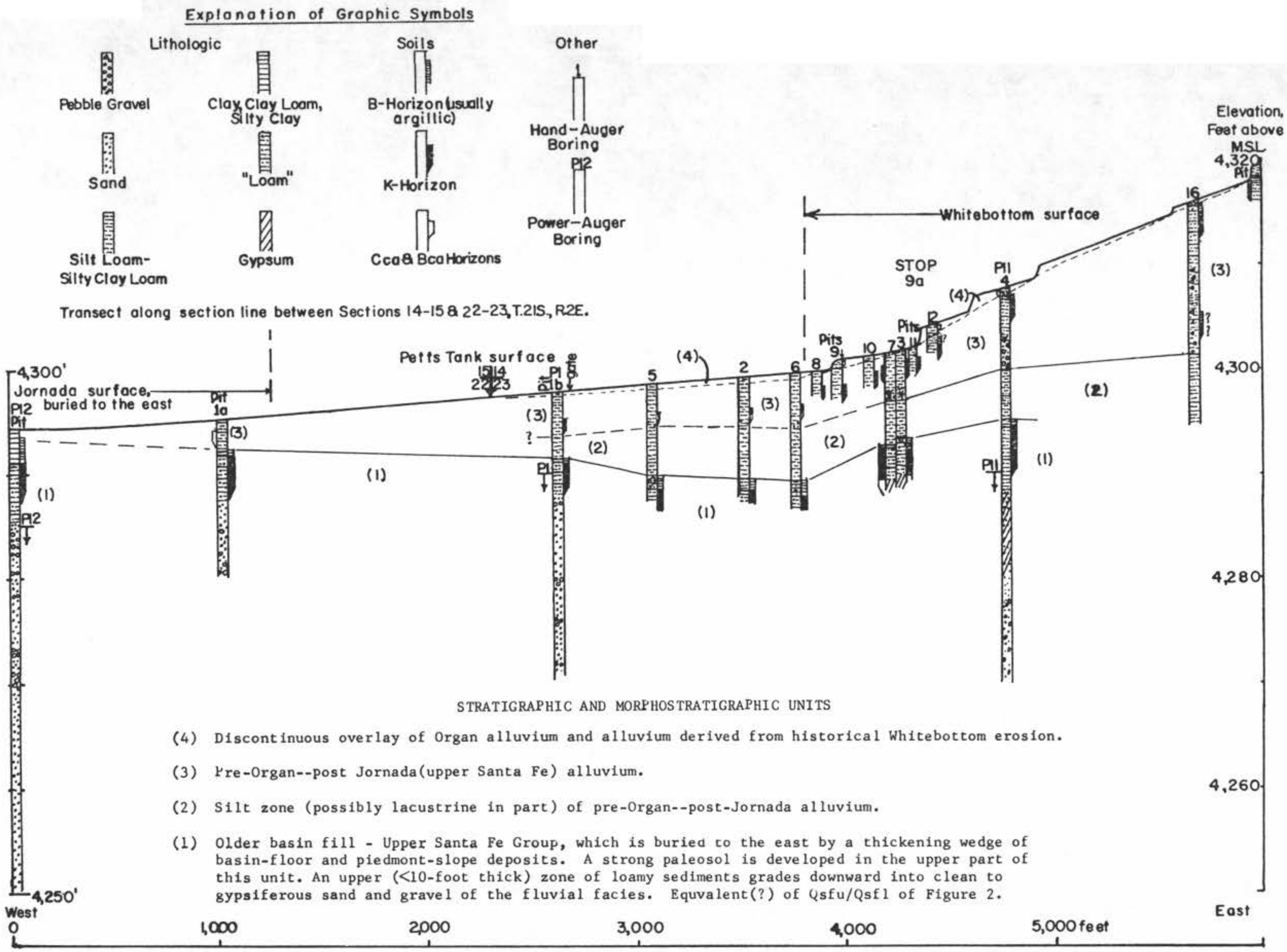


Figure 5

GENERAL RELATIONSHIPS BETWEEN DEPOSITS AND GEOMORPHIC SURFACES, JORNADA DEL MUERTO BASIN FLOOR AND LOWER PIEDMONT SLOPES, BETWEEN THE DONA ANA AND SAN ANDRES MOUNTAINS

TABLE 2. RESULTS OF CURRENT MAPPING AND ISOTOPE DATING OF QUATERNARY OLIVINE BASALTS IN LA MESA AREA, SOUTHWEST OF LAS CRUCES, NEW MEXICO

BASALTS	RELATED BASIN AND VALLEY FILL	BASALTS	K-Ar DATES (yrs)*
Qb3 Aden (+11000 yrs)		Qb3 Aden	
	Fills associated		
QB2 Afton, Black Mt,	with Rio Grande	Qb2 Black Mt.†	$1.69 \pm 0.15 \times 10^6$ R0620
San Miguel Finger	valley-border	San Miguel	$1.84 \pm 0.10 \times 10^6$ R0619
Flow, Santo Tomas	surfaces (post-La Mesa)	Santo Tomas (late)	$2.65 \pm 0.35 \times 10^6$ R0803
		(early)	$2.35 \pm 0.20 \times 10^6$ R0804
		(early)	$8.5 \pm 0.5 \times 10^6$ R0288
			$8.9 \pm 2 \times 10^6$ R0288
Ob1 Kilbourne Hole,		Qb1y Kilbourne Hole	$0.5 \pm 0.10 \times 10^6$ R0802
	La Mesa surface		
Radar Hill	and associated soil,		
	on upper Santa Fe G_p		
	sand and gravel (with		
	Irvingtonian vertebrate fauna)		

* Dating by Geochron Laboratories, Inc.

† Sample taken from youngest of a group of flows currently being studied by Prof. Jerry Hoffer, Dept. Geology, University of Texas at El Paso.

References for the first two columns include Kottlowski, 1953, 1960; Simons and Alexander, 1964; DeHon, 1965; Hawley, 1965, 1967; for the last two columns this paper.

four major cycles of river and arroyo entrenchment, accompanied by some aggradation, have taken place. Disregarding faulting and warping of surfaces, levels of ancestral floodplain stability can be reconstructed at elevations of about 130 feet (40 meters), 70 feet (21 meters), and 25 to 30 feet (8 to 9 meters) above the present valley floor. The two higher levels correspond with the Kern Place–Tortugas and Gold Hill–Picacho surfaces, in order of decreasing ages and elevations, which are of Illinoian (?) –middle Wisconsinan age. The Fort Selden (Leasburg and Fillmore) surfaces include late Wisconsinan and Holocene surfaces graded to ancestral floodplain levels less than 30 feet (9 meters) above the valley floor. Maximum entrenchment of the Rio Grande in late Wisconsinan to Holocene time was about 80 feet (24 meters) below the present floodplain level.

Major physiographic features such as the intermontane basins and certain valley segments are of structural origin. However, regional studies show that the valley-border surfaces described can be correlated with similar stepped sequences elsewhere in the Rio Grande Valley, indicating that cyclic climatic change has also played a significant role in Quaternary landscape development.

Aggradation of basin surfaces has continued in the broad areas still not connected with the Rio Grande drainage system. A developing radiocarbon chronology of younger events indicates that major cycles of piedmont-slope and basin-floor erosion-sedimentation may also have been controlled by regional climatic shifts. Large lakes occupied the floors of several basins during late Pleistocene pluvials.

Pleistocene volcanism has locally played an important role in landscape evolution. The most prominent features are the large fields of basaltic lava and cinder cones and maare in La Mesa–Potrillo mountain area. Structural deformation continued throughout the Quaternary, resulting in several hundred feet of displacement of basin- and valley-fill deposits.

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APPENDIX A

DESCRIPTION OF MEASURED SECTIONS OF QUATERNARY ALLUVIUM

John W. Hawley

Descriptions of ten measured sections of middle to late Quaternary alluvium are presented. These sections represent type sections of four morphostratigraphic units (Frye and Willman, 1962), the Tortugas, Picacho, Fillmore, and Organ alluviums. The first three are subdivisions of the Rio Grande Valley fill, and the fourth is a closed-basin fill. All are associated with distinct constructional land forms, either alluvial terraces or alluvial fans, and are distinguished from older and younger stratigraphic units primarily on the basis of geomorphic position and surface form. Because a single section cannot adequately characterize any of these units, two or three sections are proposed as "composite types" for each morphostratigraphic unit.

Early to mid-Quaternary strata are defined in the traditional way as rock-stratigraphic subdivisions of the Santa Fe Group (refer to papers by Hawley et al. and Strain in this volume).

Although numbered or alphabetized upward in sequence, the sections are presented from top to bottom. More detailed descriptions of parts of these sections, particularly where soils occur, are on file at the office of Soil Survey Investigations, Soil Conservation Service, New Mexico State University, Las Cruces.

The outline of the field description is generally as follows: (1) name of unconsolidated sediment or rock; (2) color (using Munsell Color Company, Inc., soil color chart; verbal and numerical notations are for dry colors except where otherwise indicated); (3) induration where pertinent; (4) composition of secondary void fillings, such as calcareous; (5) bedding (thickness units according to Inman (1954), Geol. Soc. Am. Bull., v. 65, p. 937-938); (6) nature of gravel and sand fraction, including textural parameters (AGI Data Sheet 7) and rock types; and (7) topographic expression, basal contact characteristics, and miscellaneous remarks.

Since these morphostratigraphic units are generally unconsolidated, pedologic textural class terms are commonly used. For example: gravelly, 20 to 50 percent gravel; very gravelly, 50 to 90 percent gravel; low gravelly, gravel present, but less than 20 percent; sand, more than 85 percent sand, less than 15 percent silt, less than 10 percent clay; loamy sand, 70 to 90 percent sand, less than 30 percent silt, less than 15 percent clay; sandy loam, 43 to 85 percent sand, less than 50 percent silt, less than 20 percent clay; loam 23 to 52 percent sand, 28 to 50 percent silt, 7 to 27 percent clay; clay loam, 20 to 45 percent sand, 15 to 53 percent silt, 27 to 40 percent clay; sandy clay loam, 45 to 80 percent sand, less than 28 percent silt, 20 to 35 percent clay; sandy clay, 45 to 65 percent sand, less than 20 percent silt, 35 to 55 percent clay; clay, less than 45 percent sand, less than 40 percent silt, more than 40 percent clay; silty clay loam, less than 20 percent sand, 40 to 73 percent silt, 27 to 47 percent clay; and silt loam, 20 to 50 percent sand, 50 to 80 percent silt, 12 to 27 percent clay; (where gravel equals more than 2 mm, sand, 0.05 to 2 mm, silt, 0.002 to 05 mm and clay, less than 0.002 mm).

SECTION 1. TORTUGAS ALLUVIUM (UPPER PART)–ROBLEDO SITE

Location: W½NW¼SW¼SW¼ sec. 8, T. 22 S., R. 1 E., Las Cruces quadrangle; north wall (30 to 15 degree slope) of unnamed arroyo valley, between Robledo Mountain front and the Rio Grande Valley; about 1700 feet west of the West River Road and 800 feet NNW of section 3b. Elevation of top of section is about 4080 feet (elevation of Rio Grande floodplain about 3930 feet). For further discussion of this site, see Hawley and Gile (1966, stop 15, p. 64).

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from crest of ridge remnant of Tortugas alluvial-fan surface	
	Tortugas alluvium	
3b	Bevelled slope, on caliche-cemented fan gravel, eroded below the original Tortugas fan surface.	8
4b	Gravel, to very gravelly sandy loam; white (5YR 8/1) to light gray (10YR 7/2), carbonate-impregnated matrix; cemented into caliche caprock layer; massive; gravel fraction mainly pebble to cobble size, with scattered small boulders noted laterally, angular to subrounded, mainly limestone with common reddish to tan sandstone and siltstone (Hueco–Abo), minor chert and rhyolite, and trace of rounded pebbles of quartz and granite; grades into	2
4a	gravel, and very gravelly sand to loamy sand; sandy matrix brown to light brown (7.5YR 5/4 to 6/4), with minor thin lenses of light brown, very coarse sandy loam near top; calcareous; poorly stratified and very poorly sorted; gravel fraction mainly pebble to cobble size with scattered boulders (up to 18 inches in diameter), angular to rounded, dominantly limestone with common reddish to tan sandstone and siltstone, minor rhyolite, and a trace of well-rounded pebbles of granite, quartz, chert and mixed volcanics. The lower 3 feet of this unit is better sorted (mainly pebbles with a few cobbles) and fills channels as much as 2 feet deep cut into underlying fine-grained beds.	10
3b	Silt loam to silty clay loam, pinkish gray to very pale brown (7.5YR to 10YR 7/3); hard; calcareous; blocky to platy, locally finely laminated. The upper 6 inches consist of loam with scattered pebbles (mainly limestone). Lower 2 to 3 inches, clay, reddish brown (5YR 4/4) to light brown (7.5 YR 6/4) with discontinuous black stainings, hard, calcareous, blocky; conformable on	2
3a	loam to sandy loam with scattered pebbles, light brown (7.5YR 6/4); with thin, discontinuous beds of silt loam (as above) and coarse, loam sand; calcareous; massive; pebbles well rounded to angular, including mixed, siliceous sedimentary and igneous types and limestone. a trace of shell fragments (snail?) noted.	4
3-2	Transition zone. Silt loam to loam, light brown (7.5 6/4), with reddish yellow (7.5YR 6/8) limonitic zones; calcareous, with small tubular carbonate concretions; massive; grades down into fine to very fine sand to loamy sand, light brownish gray (10YR 6/2), calcareous, micaceous, finely laminated; with discontinuous zones of calcareous, light yellowish brown (10YR 6/4) and yellowish brown (5/6) sandy loam. Basal contact slightly undulating; conformable on	2
2c	fine to coarse sand, pale brown (10 YR 6/3), and pebbly sand; clean, loose; noncalcareous to weakly calcareous; cross-laminated; mixed composition, quartz, feldspar, mica, dark minerals; poorly exposed; grades into	7
2b	very gravelly sand to gravel, with local black (manganese oxide) coatings; loose; weakly calcareous to calcareous; crossbedded; gravel fraction mainly pebble size but with scattered small cobbles (of locally derived carbonate rocks), subangular to well rounded, dominantly rhyolitic to andesitic volcanics, with common limestone and sandstone, and some quartz, chert, and granite; unit poorly exposed; apparently conformable on	4
2a	sand, like unit 2c above, light brownish gray to light gray (10YR 6/2 to 7/2), weakly calcareous; lower part covered by as much as 3 feet of colluvium; appears to grade into underlying, cemented sand and gravel unit.	6
2-1	Transition zone; sand, as above, to pebbly sand, discontinuously cemented with calcite (light gray, 10YR 7/2); grading down into gravelly sand, discontinuously calcite cemented, with scattered angular, coarse pebbles to	2

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	small cobbles of limestone and reddish siltstone; fine to medium pebble fraction mainly rounded, mixed igneous and siliceous sedimentary rock types; apparently transitional to unit 1. This point in the section is at the level of the Picacho surface on the south side of the valley (sec. 3b).	
1b	Conglomeratic sandstone, sandstone, and conglomerate; sandstones weather to light gray (10YR 7/2), fresh exposures often white; discontinuously, very well cemented with calcite, but with common thin sand zones (light gray to pale brown, 10YR 7/2 to 6/4) that are uncemented; thin- to medium-bedded, with thicker strata often internally cross-bedded. The gravel fraction includes a wide range of types, sizes, and shapes of rocks; larger sizes (coarse pebbles to small cobbles) tend to be angular-subrounded and locally derived (limestone, siltstone, and sandstone); smaller sizes are usually rounded and include a wide variety of lithologies as in subunit 2b above. The unit is generally well exposed in steep gullies; differential erosion of uncemented zones produces very irregular outcrop surfaces.	20
1a	As above; generally poorly exposed; apparently with greater proportion of poorly cemented beds; base covered.	21
	Partial thickness of Tortugas alluvium	88

Remarks on Section 1

The arroyo channel is about 15 feet below bottom of exposed section. Sediments like unit 1a are locally exposed in arroyo cuts downstream, indicating that Tortugas alluvium extends to at least the level of the arroyo channel. About 700 feet downstream and 15 feet below the level of the arroyo channel of section 1, another sequence of beds like subunits 3b-2b is exposed. This sequence underlies unit 1 and may correlate with similar silt, sand, and gravel at the base of Tortugas alluvium in section 2.

Units 3 and 2 are interpreted respectively as floodplain and river channel deposits of the ancestral Rio Grande. They are overlapped by locally derived alluvial deposits associated with construction of the Tortugas alluvial-fan surface. Unit 1 (equivalent to unit 3 of sec. 2) is interpreted as an alluvial-fan or fan-floodplain transition facies deposited during an earlier phase of valley aggradation but still within the Tortugas episode of valley entrenchment and back filling.

SECTION 2. TORTUGAS ALLUVIUM (LOWER PART)–RIO GRANDE BLUFF SITE (LOCALITY T 4 OF METCALF, 1967)

Location: SE corner SE¼SW¼NW¼ sec. 8, T. 22 S., R. 1 E., Las Cruces quadrangle; east-facing bluffs bordering the Rio Grande floodplain, 1.5 miles southwest of the village of Hill; about 400 feet west of the river; and 2000 feet northeast of section 1. Section measured near pipeline marker post on west side of river road. Elevation of top of section is about 4050 feet (elevation of floodplain–river road–about 3930 feet).

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from level summit of erosion surface (probably early Picacho), cut into Tortugas alluvium, which forms a prominent bench about 120 feet above the floodplain	
	Tortugas alluvium	
3b	Bevelled slope, between level summit of erosion surface and top of cliffs; discontinuous exposures of caliche caprock in lower 10 feet.	25
3a	Conglomerate to comglomeratic sandstone, very poorly sorted; carbonate-cemented, very fine pebbly, sandy matrix, light gray to light brownish gray (10YR 7/2 to 6/2); thin- to medium-bedded, with common low-angle cross-bedding; gravel fraction mainly pebble to cobble size with scattered small boulders, rounded to angular,	53

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	with coarser fragments tending to be angular, dominantly limestone, with common tan to reddish sandstone and siltstone, some rhyolite, and rare fine pebbles of mixed rounded igneous and siliceous sedimentary rock types. Except for the carbonate-cemented basal 6 to 12 inches, the lower 6 to 8 feet of this unit are poorly cemented and nonbouldery and contain a greater proportion of rounded pebbles of mixed composition; some thin lenses of light brownish gray (10YR 6/2), fine to coarse sand are also present. The unit rests disconformably on underlying beds of unit 2. At this point, the basal contact is smooth, and there is no evidence of channeling. The unit 1-2 contact appears to rise to the south.	
2	Interbedded silty clay, silty clay loam, silt loam, and very fine sand; light brownish gray (10YR 6/2) with local, yellowish brown (10YR 5/6) limonitic zones; upper 6 inches consist of clay to sandy clay, pale brown to light yellowish brown (10YR 6/3 to 6/4); lower 3 feet mainly very fine sand to loamy sand; calcareous throughout, with irregularly shaped lime concretions in pebble size range (tubular, platy, and spherical forms are common); snail shells are locally present, particularly in the upper part; unit rests conformably on	7
1b	sand, medium to coarse, grayish brown, light brownish gray and pale brown (10YR 5/2, 6/2, 6/3), weakly calcareous; interbedded with very fine (partly silty) sand, light brownish gray (10YR 6/2) with discontinuous limonitic zones, calcareous; few hard carbonate nodules; medium to coarse sand beds internally cross-laminated; mixed mineralogy, including quartz, feldspar, and dark minerals; grades down into	5
1a	very gravelly sand; gravel fraction mainly rounded to well rounded, pebbles to small cobbles of rhyolite, andesite, quartzite, quartz, chert, and granite with minor limestone and basalt. Unconformable basal contact; gravel fills shallow channels (less than 1 foot deep) cut into underlying unit. Laterally, this gravel zone appears to thicken at the expense of the underlying and overlying units and locally, it may be immediately overlain by unit 3b.	1
	Partial thickness of Tortugas alluvium	91
	Upper Santa Fe Group	
G?	Sand, medium to very coarse, with scattered pebbles, light olive brown (2.5Y 5/6 to 5/4), loose, weakly calcareous; gravel fraction, rounded, fine to medium pebbles of quartz, chert, rhyolite, and granite. In the eastern half of the 6-foot-wide exposure, the sand is overlapped by a wedge (base dipping about 20 degrees to the north) of silt loam to silty clay loam, pale brown (10YR 6/3), massive, calcareous. The lower part of section (first 25 feet above road and 30 feet above high river stage) is generally covered; however, the sand unit appears to become more gravelly with depth.	4

Unit G(?) is tentatively correlated with part of the fluvial facies of the upper Santa Fe Group (Hawley et al., this volume; sec. 1 and 2, unit G).

Remarks on Section 2

Units 1 and 2 appear to be river-channel and floodplain deposits laid down during an early cycle of Rio Grande Valley entrenchment and back filling. Unit 3 is interpreted as a thick tongue of fan alluvium deposited in a floodplain border environment, with some beds possibly being fluvial in origin. This "fanglomerate" unit can be traced to the west and is at least partly equivalent to unit 1 of section 1.

General Remarks on Sections 1 and 2

The interpretation of the Tortugas morphostratigraphic unit illustrated by sections 1 and 2 indicates that a major, complex cycle of valley cutting and aggradation occurred after the culmination of Santa Fe basin filling and before the Picacho episode of valley entrenchment. The total thickness of Tortugas alluvium in the area of these two sections exceeds 100 feet but is probably less than 125 feet. At least two tongues of river gravel are preserved in the general alluvial-fan gravel sequence.

SECTION 3. PICACHO ALLUVIUM–ROBLEDO SITE (For further discussion of this site, see Hawley and Gile, 1966, stop 15, p. 64)

Section 3a. Locality P18 of Metcalf (1967); SE¼SW¼SW¼SW¼ sec. 8, T. 22 S., R. 1 E., Las Cruces quadrangle; south wall (33-degrees slope) of unnamed arroyo valley, between Robledo Mountain front and the Rio Grande; 1000 feet southeast of section 1, about 1500 feet west of the river, and 500 feet west of river road. Elevation of top of section is about 4010 feet (Rio Grande floodplain elevation 3930 feet).

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Picacho geomorphic surface (here a relict alluvial-fan surface), 50 feet west of east end of remnant	
	Picacho alluvium	
4b	Gravel to very gravelly sandy loam; white to light gray (10YR 8/1 to 7/2), carbonate-impregnated matrix; cemented into caliche caprock layer; massive; gravel mainly in pebble to cobble size range with scattered small boulders, angular to subrounded, dominantly limestone (Hueco) with common sandstone (Abo) and rhyolite and minor rounded siliceous pebbles of mixed compositions; grades into	2
4a	gravel as above without impregnation and cementation with carbonate, in part open-work; massive; disconformable (?) on	2
3	very gravelly sand to loamy sand, brown to pale brown (10YR 5/3 to 6/3); laterally to west contains lenses (up to 1 foot thick) of light brown (8YR 6/4) to pink (8YR 8/4) sand; calcareous; massive to weakly stratified; gravel fraction mainly subangular to subrounded, pebbles to large cobbles of limestone, sandstone, and rhyolite, as above, but with increasing percentage of rounded pebbles of mixed igneous and siliceous sedimentary rock types with depth. Lower 3 feet primarily consist of very gravelly to gravelly sand; gravel fraction mainly pebble size, subangular to rounded, limestone still common. Unit as a whole is poorly exposed; disconformable (?) on	8
2	fine sandy loam to loam with stringers of loamy sand to sand, brown (10YR 5/3), calcareous; massive; with scattered fine pebbles as in unit 3; scattered snail shells. Lowermost 1 to 1.5 feet consist of silty clay loam to silt loam, pale brown (10YR 6/3), with reddish yellow (7.5YR 6/8) limonite staining around very fine tubular pores and along thin sandy streaks; calcareous; apparently conformable on	6
1b	upper 1.5 feet; consist of fine to medium sand, pale brown (10YR 6/3), calcareous; with two 4-inch layers of silt loam, light brown (7.5YR 6/4), very pale brown (10YR 7/3) and brown (10YR 5/3), with limonite stains as above, very calcareous. The upper zone grades down into medium to coarse sand, light brownish gray (2.5Y to 10YR 6/2), with local black and orange stains; loose; noncalcareous to weakly calcareous; cross-laminated; mineralogy mixed, quartz, feldspar, mica, with common dark minerals (often concentrated along bedding planes); conformable on	5
1a	pebble gravel to very gravelly sand, loose; interbedded with sand, as above; gravel fraction mainly rounded pebbles of mixed volcanic types including rhyolite, andesite-latite, basalt; with chert, quartz, granite, and minor limestone; generally noncalcareous, but thin zones with carbonate coatings on pebble bases noted in lower part of unit. Base of unit covered, and unit as a whole covered by as much as 2 feet of colluvium.	21
	Partial thickness of Picacho alluvium	44

Arroyo channel is about 12 feet below bottom of section; refer to notes on section 3b

Section 3b, SE¼SE¼SW¼SW¼ sec. 8; south wall (30-degree slope) of arroyo valley, 500 feet west of section 3a and 800 feet south-southeast of section 1. Elevation of top of section about 4025 feet (15 to 20 feet above section 3a datum)

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Picacho geomorphic surface (relict alluvial-fan surface)	
	Picacho alluvium	
4b	Gravel to very gravelly sandy loam; carbonate-impregnated matrix, light gray to white (10YR 7/2-8/2 fresh) and light brownish gray to light gray (10YR 6/2-7/2 weathered); cemented into caliche caprock layer; massive; gravel fraction as in unit 4b, section 3a (mainly limestone, reddish sandstone, and rhyolite); grades into	3
4a	gravel (pebble to cobble), very gravelly sand, and minor interbedded, loamy sand streaks, brown to pale brown (10YR 5/3-6/3); sandy matrix calcareous, but not impregnated or cemented with carbonate; massive to weakly bedded; gravel content as above, with common large cobbles in upper part; lower part mainly fine to medium pebble gravel; conformable (?) on	2.5
3b	coarse sandy loam to loam, light yellowish brown (9-10YR 6/4); calcareous; massive; rests conformably on	2
3a	gravel and very gravelly sand to loamy sand, very poorly sorted; sandy matrix pale brown (10YR 6/3), calcareous; with interbeds, less than 1 foot thick of loamy material as in subunit 3b; gravel size ranges from pebbles to small boulders; gravel composition as above. Subunit appears to fill channels cut as much as 3 feet into underlying beds.	6.5
2	Loamy sand (very fine to coarse) to sandy loam, with scattered pebbles, pale brown (9-10YR 6/3). In lower part, grades down into silty clay loam, pale brown (10YR 6/3), with thin stringers of clean sand; basal 1 to 2 inches consist of reddish gray (5YR 5/2) to light reddish brown (5YR 6/3) clay; calcareous throughout; conformable on	6
1b	upper 2 feet; consist of interbedded loamy (coarse) sand, very fine pebbly, light brownish gray (10YR 6/2); silt loam to silty clay loam (10YR 6/2); and clay, dark brown (10YR 4/3); calcareous throughout. The upper zone grades down into fine to coarse sand, light brownish gray (10YR 6/2) with local, reddish yellow (7.5YR 6/8) limonitic zones; loose, with very discontinuous calcite cementation along bedding planes in lower 3 to 4 feet; weakly calcareous to calcareous; cross-laminated; mineralogy as in subunit 1b, section 3a. Subunit as a whole poorly exposed, usually covered with 1 to 2 feet of colluvium; conformable on	11.5
1a	pebble gravel to very gravelly sand; loose; matrix generally calcareous (very calcareous in basal part); gravel composition like subunit 1a, section 3a. Subunit poorly exposed, usually covered with 2 feet of colluvium; unconformable on underlying fine-grained unit.	4.5
	Total thickness of Picacho alluvium	36
	Tortugas (?) alluvium	
T?2	Clay, reddish brown (5YR 4/3, moist) with olive gray (5Y 5/2, moist) mottles; with thin sandy streaks in lower several inches; scattered soft to hard carbonate nodules, pinkish gray (5YR 7/2, moist); calcareous; thin-bedded; poorly exposed; conformable on	2
T?1	fine to very coarse sand, light brownish gray (10YR 6/2); with thin interbeds of silty clay loam, light gray (10YR 7/2), to coarse sandy loam, brown (10YR 5/3); calcareous throughout; base covered. Arroyo channel is about 10 feet below bottom of section.	4

Unit T?, which also includes sandstone and conglomeratic sandstone beds several hundred feet upstream, is tentatively correlated with the lower part of the Tortugas alluvium previously described in section 1 on the north side of this arroyo. However, it is possible that this material may be equivalent to part of the fluvial facies of the upper Santa Fe Group (Hawley et al., this volume, sec. 1 and 2, unit G).

Remarks on Sections 3a and 3b

Units 1 and 2 appear to be, respectively, river channel and floodplain facies of the Picacho alluvium that wedge out a short distance to the west. The uppermost part of unit 2 was probably deposited in a floodplain border environment, because the lithologies of the scattered pebbles reflect the composition of the overlying fan sediments rather than the mixed lithologic assemblage in the channel facies. Units 3 and 4 represent alluvial-fan sediments derived from outcrops of bedrock and older basin- and valley-fill deposits along the Robledo Mountain front. The fan deposits overlapped the floodplain facies during final stages of Picacho aggradation, much as Fillmore and historical arroyo-mouth fan deposits have encroached into the Holocene floodplain.

SECTION 4. PICACHO ALLUVIUM–PENA BLANCA ARROYO SITE
(Near locality P21 of Metcalf, 1967)

Location: SE corner NE¼NE¼SW¼ sec. 30, T. 24 S., R. 3 E.; San Miguel quadrangle; south wall of arroyo below Pena Blanca dam, 0.2 mile ENE of east frontage road along Interstate 25, 1 mile NNW of Mesquite interchange; elevation of top of section about 4065 feet

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Picacho geomorphic surface (relict alluvial-fan surface)	
	Picacho alluvium	
4	Gravel, pebble with scattered cobbles, with carbonate impregnated loamy sand matrix, pinkish white (7.5YR 7/2 to 8/2); partly cemented into weak caliche caprock layer; rock types in gravel fraction described below; grades into unit 3.	2
3	Interbedded gravelly to very gravelly sand to loamy sand, light brown (7.5YR 6/4); unconsolidated; calcareous; thin to medium beds, internally thin-bedded to -laminated, locally with very low-angle cross-laminae; gravel fraction mainly pebble size, but with scattered cobbles (up to 8 inches intermediate diameter), angular to well rounded; gravel composition mainly rhyolite (pebbles to cobbles), but with common rounded pebbles of andesite-latite, quartz, chert, and granite; one large angular cobble of bedded chert was also noticed. The coarsest gravel in the section is in this unit. A 1.5-foot-thick layer about 4 feet above the base of unit 3 consist of low gravelly loamy sand to sandy loam, brown to reddish brown (7YR 5/4), calcareous, with scattered carbonate modules. Basal contact is sharp and smooth.	11
2	Interbedded lenticular zones of very gravelly sand and very fine to very coarse sand, brown 7.5YR 6/4; generally soft to slightly hard; calcareous; very gravelly zones, thin- to medium-bedded as above, with some gravel, gravelly sand, and sand interbeds; sandy zones contain minor lenses of pebble gravel and are generally massive to very weakly bedded; zones of a given texture are generally less than 2.5 feet thick, but locally may be 5 feet thick; gravel composition as above but cobbles are rarer. Unit 2 is conformable on unit 1. The upper 1.5 feet of unit 2 consist of an upper brown to reddish brown (7YR 5/4), loamy sand to sandy loam horizon that is locally noncalcareous, and a lower pinkish white (7.5YR 7/2) very gravelly to low gravelly sandy loam to loamy sand horizon that is locally carbonate impregnated. This sequence may represent a weakly developed B/Cca soil profile, with its upper surface representing a minor disconformity between units 2 and 3.	25
1	Very gravelly sand, with some gravel, gravelly sand, and sand interbeds; light brown to brown (7.5YR 6/4 to 5/4), with streaks of light reddish brown (5YR 6/4) loamy sand and thin pinkish white (7.5YR 8/2) carbonate-impregnated zones; loose to slightly hard; weakly calcareous except in thin zones of carbonate impregnation; thin to medium beds, often with internal laminae and some low-angle cross-bedding; gravel composition as above, with cobble-sized clasts rarely present. Unit 1 locally fills channels, as much as 5 feet deep, cut into the already deeply eroded Upper Santa Fe Group basin fill.	15
	Total thickness of Picacho alluvium	52
	Upper Santa Fe Group	
G?	Sandy clay, light gray (2.5Y 5/2), hard, generally noncalcareous to weakly calcareous, but with scattered, indurated carbonate nodules; grades down into clean, fine to very coarse sand to pebbly sand at very base of cut (about 5 feet) above arroyo floor. Laterally to the east, the bed described above is overlapped by a thin bed of calcareous clay to sandy clay, light gray (10YR 7/2) to light brown (7.5YR 6/4), which is in turn overlain by an isolated block of sandstone, calcite cemented and cross-laminated. Laterally to the west, Picacho alluvium extends to below the arroyo floor level. This unit is tentatively correlated with part of the fluvial facies of the Upper Santa Fe Group (Hawley et al., this volume; sec. 1 and 2, unit G; and with part of the Camp Rice Formation; Strain, this volume).	2+

SECTION 5. FILLMORE ALLUVIUM–FILLMORE ARROYO CHARCOAL SITE

Located in unsectioned area, Doña Ana Bend Colony, 3 miles southeast of New Mexico State University; Tortugas Mountain quadrangle (center S½SE¼ sec. 35, T. 23 S., R. 2 E., projected); north bank of Fillmore Arroyo, about 3000 feet ENE of Fillmore dam and 1500 feet WSW of telephone line arroyo crossing; elevation about 4090 feet

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Fillmore geomorphic surface (alluvial fan-terrace surface)	
	Fillmore alluvium	
2	Coarse loamy sand with scattered pebbles (about 15 percent silt-clay; brown (10YR 5/3) in upper part; brown (7.5YR 5/4 to 10YR 5/3) in lower part; unconsolidated, soft to slightly hard; calcareous, except for noncalcareous upper 10 inches; massive except for finely stratified upper 5 inches (very young overlay). Discontinuous darkened lenses, with scattered charcoal fragments, 3.5 feet below surface; (charcoal previously sampled from lens about 3 feet below Fillmore surface at this point was C14-dated at 2620 ± 200 years B.P.–U.S. Geol. Surv., W-786).	4
	Base of arroyo bank exposure; remainder of section described in shallow pit and hand-auger boring	
1	Interbedded gravelly to very gravelly sand and loamy sand, light brown (7.5YR 6/4) to brown (7.5YR 5/4); slightly hard to loose; calcareous in upper part, slightly calcareous in lower part; gravel fraction: pebble size, subangular to well rounded, mainly rhyolite, with minor andesite-latite, quartz, chert, and granite.	3
	Total (?) thickness Fillmore alluvium	7
	Picacho alluvium?	
	Sandy loam to sandy clay loam, in part gravelly, yellowish red (5YR 5/6 to 4/6, moist), 3 to 4 feet below arroyo floor; may represent a deeply channeled remnant of Picacho alluvium.	

SECTION 6. FILLMORE ALLUVIUM–SHALEM COLONY CHARCOAL SITE
(Near locality R40 of Metcalf, 1967)

Location: SW¼SE¼NW¼ sec. 20, T. 22 S., R. 1 E.; Las Cruces quadrangle; south bank of arroyo, about 80 feet west of Rio Grande; elevation about 3925 feet

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Fillmore geomorphic surface (alluvial-fan surface)	
	Fillmore alluvium	
8	Gravelly loamy sand with low gravelly zones, brown (7.5YR 5/4) in upper 6 inches; grading down into very gravelly loamy sand, brown (7.5YR 5/2) and pinkish gray (7.5YR 6/2); loose; calcareous, with secondary carbonate coatings on gravel in lower part; massive; gravel, mainly pebble size with scattered cobbles; angular to subrounded; primarily limestone (Hueco) with common calcareous sandstone (Abo); and minor basalt; possible disconformity at base.	2

UNIT NO.	DESCRIPTION	THICKNESS (feet)
7	Nongravelly to low gravelly, sandy loam to loam; brown (7.5YR 5/4); with local lenses of gravel; calcareous; massive. Subunit thickens to west and once contained a lenticular bed of charcoal (38 to 41 inches below surface) that was C14-dated at 2850 ± 120 years B.P. (Isotopes, Inc., 294).	1 to 1.5
6	Low gravelly to nongravelly sandy loam; brown (7.5YR 5/4), calcareous, massive; unit grades laterally to the east into very gravelly sandy loam, mainly pebble gravel with scattered cobbles, as above.	2 to 1.5
5	Very gravelly sandy loam to loamy sand, brown (7.5YR 5/4), calcareous, massive; unit grades laterally to the west into gravelly to low gravelly sandy loam; cobbles and small boulders are locally present; possible disconformity at base.	1.8
4	Low gravelly to gravelly sandy loam, brown (7.5YR 5/4); with nongravelly zone in lower part; calcareous; massive; laterally to east middle part of subunit contains a very gravelly lens. Basal 4 inches, gravelly to very gravelly, mainly pebble gravel but with scattered cobbles and small boulder. Subunit once contained a lenticular bed of charcoal (86 to 95 inches below surface) that was C14-dated at 4910 ± 225 years B.P. (Isotopes, Inc., 293).	2.0
3	Low gravelly to nongravelly sandy loam, brown (7.5YR 5/4); calcareous; massive; very compact; subunit grades to east into very gravelly material.	1
2	Very gravelly sandy loam (upper part) to sandy loam (lower part); brown (7.5YR 5/4); calcareous; lenticular beds internally massive; gravel content and size (to cobbly) increases to west and decreases to east.	2
1	Very gravelly loamy sand, with interbeds of very gravelly sand and sandy loam, brown (7.5YR 5/4); calcareous; internal structure of individual beds massive; mainly pebble gravel but with scattered cobbles and trace of small boulders; lithology as above, units 1 to 8.	2
	Partial (?) thickness of Fillmore alluvium	14

Unit 1 rests conformably (?) on very gravelly sand to loamy sand, brown (7.5YR 5/4); friable; calcareous; poorly stratified; gravel mainly pebble size, with scattered cobbles; only one boulder noticed. Sediments are generally cleaner, better sorted, and gravel better rounded than in units 1 to 8. Possibly this lower unit (exposed in pit dug 5 feet below arroyo bottom) represents a river-reworked deposit that predates the main episode of Fillmore fan building.

SECTION 7. ORGAN ALLUVIUM–GARDNER SPRING SITE
(For detailed discussion of this site see Gile and Hawley, 1968; Hawley and Gile, 1966, p. 60-61; and Freeman, C. E. (1968) A pollen study of some post-Wisconsin alluvial deposits in Doña Ana County, New Mexico, Ph.D. dissertation, New Mex. State Univ. (unpub).)

Section 7a. Organ II/Organ I alluvium (charcoal site 5–pollen site a); W½NW¼SW¼NE¼ sec. 2, T. 21 S., R. 3 E.; Bear Peak quadrangle; north bank of Gardner Spring Arroyo, about 575 feet ENE of Apollo highway crossing (3 culverts); 6.1 miles north of Organ, N. Mex.; elevation about 4780 feet

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Organ geomorphic surface (alluvial terrace)	
	Organ II aluvium	
2	Gravelly to very gravelly sandy loam, brown (9YR 5/3); soft; loose; calcareous; poorly stratified; gravel fraction; mainly pebble size with scattered cobbles, primarily limestone, with calcareous sandstone,and siltstone and minor rhyolite and quartzite; disconformable on unit 1.	1.5
	Organ I alluvium	
1c	Loam to fine sandy loam with few scattered pebbles, brown (9YR 5/3); unconsolidated but hard; calcareous; massive; gradational contact with unit 1b.	3.5
1b	Gravelly sandy loam to loam, brown (9YR 5/3); unconsolidated, slightly hard to hard; calcareous; massive; discontinuous coarse-grained layer in generally nongravelly sediments; gradational contact with unit 1a.	1
1a	Loam to fine sandy loam, with few scattered pebbles, brown (9YR 5/3); unconsolidated, hard to slightly hard; calcareous; massive; base not exposed (arroyo floor). Subunit contains lenticular zone with scattered charcoal (about 83 to 94 inches below surface) that was dated at 4700 ± 120 years B.P. (Isotopes, Inc., 1794).	3
	Partial thickness of Organ alluvium	9

Section 7b. Organ II/Organ I alluvium (charcoal site 7, pollen site c); SE¼NW¼SE¼NW¼ sec. 2, T. 21 S., R. 3 E.; Bear Peak quadrnagle; north bank of Gardner Spring Arroyo, about 400 feet WNW of Apollo highway crossing (3 culverts) and about 900 feet west of section 7a; elevation about 4770 feet

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Organ surface (alluvial terrace)	
	Organ II alluvium	
2c	Very gravelly (upper 2 inches low gravelly) sandy loam, brown (9YR 5/3); soft, loose; calcareous; poorly stratified; gravel fraction, mainly pebbles, but with scattered cobbles present laterally; gravel lithology as in section 7a.	2.1
2b	Sandy loam with minor gravel, brown (8YR 5/3); unconsolidated but slightly hard, calcareous, massive.	0.5
2a	Very gravelly sandy loam, like 2c above. Disconformable on unit 1; subunit contains lenticular zone of scattered charcoal (at base) that has been dated at 2220 ± 95 years B.P. (Isotopes, Inc., 2225).	0.5
	Organ I alluvium	
1b,	Gravelly sandy loam, to sandy loam with minor gravel, brown (9YR 5/3); unconsolidated, slightly hard; calcareous; massive; gradational contact with unit 1a.	0.5
1a	Loam, brown (9YR 5/3); unconsolidated but hard; calcareous; massive; base not exposed, (arroyo floor).	6.5 +
	Exposed thickness of Organ alluvium	10.1

A hand-auger boring at this site encountered material similar to subunit 1, with some gravel lenses, to a depth of about 6 feet below the arroyo floor. At that depth, Organ I alluvium rests disconformably on the well-developed paleosol marking an erosion surface on late Pleistocene basin fill.

SECTION 8. ORGAN ALLUVIUM–ISAACK'S GULLY CHARCOAL SITE

Location: NE¼NE¼NE¼SE¼ sec. 32, T. 21 S., R. 3 E.; Organ Peak NW quadrangle; Backhoe pit, 80 feet north of Isaack's Ranch gully and 250 feet west of boundary fence between sections 32 and 33; 3.2 miles WNW of Organ, N. Mex.; elevation about 4600 feet

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Start measurement from Organ geomorphic surface (alluvial-fan surface)	
	Organ alluvium	
1c	Sandy loam, with scattered fine pebbles; upper part, brown (7.5YR 5/4 to 10YR 4.5/3) and lower part, brown (7YR 4/4 to 5/4); loose to slightly hard; noncalcareous to weakly calcareous; massive; arkosic sand derived from breakdown of monzonite; gradational contact with unit 1b.	0.75
1b	Gravelly to very gravelly sandy loam, light brown (7.5YR 6/4) with pinkish white (7.5YR 8/2) carbonate-coated pebble surfaces; loose to slightly hard; very calcareous, matrix in upper part, impregnated with carbonate, most pebbles and coarse sand grains coated with secondary carbonate; massive; arkosic, angular to subrounded,sand and fine pebble gravel, derived from breakdown of monzonite, scattered pebbles up to 2 inches in diameter; gradational contact with unit 1a. Charcoal was sampled from zone near unit 1b/1a contact, one hundred feet to the south, in south wall of Isaack's Ranch gully. This material was dated at 4035 ± 115 years B.P. (Isotopes, Inc., 2902).	1.25
1a	Interbedded sand to loam sand and pebble gravel, brown to strong brown (7.5YR 5/4 to 5/6), slightly hard to loose; calcareous in uppermost part, to weakly calcareous in main part of unit; well stratified, with common trough sets of low-angle cross beds and laminae, sets less than 1 foot thick; sand and pebble fraction consists of monzonite grus, primarily composed of subangular grains of plagioclase feldspar. Sand fine to very coarse, pebbles generally in the fine to very fine size range; disconformable basal contact, with channels as much as 1 foot deep cut into underlying unit 0.	2.5
	Partial (?) thickness of Organ alluvium	4.5
0	Sandy clay loam to loam with very thin stringers of coarse sand to very fine pebble gravel, brown (7.5YR 5/4); hard to slightly hard; calcareous; massive; disconformable basal contact with underlying unit. Unit 0 could be an early phase deposit associated with initial development of the Organ surface, or it could represent an unnamed pre-Organ–post-Jornada deposit.	2
	Total (?) thickness of Organ alluvium	6.5

The bottom of the pit, 6.5 feet below the Organ surface, is at the disconformable contact of unit 0 on an underlying unit that definitely predates Organ fan deposition. An auger hole below the pit floor encountered dark reddish brown to reddish brown (5YR 3.5/4, moist) coarse sandy clay loam, noncalcareous to calcareous from 6.5 to 8 feet; and very calcareous, reddish brown to pinkish white, coarse sandy loam from 8 to 9.5 feet. This sequence represents a buried soil, with well-developed textural B and K horizons. This paleosol apparently formed in sediments, interpreted as being of late Pleistocene age, which were laid down during an episode of alluvial-fan aggradation after development the Jornada geomorphic surface (and hence after termination of Santa Fe Group deposition). This buried unit is tentatively correlated with sediment "b" of the U.S. 70 gully and with buried "Jornada II" deposits in the Gardner Spring area (Gile and Hawley, 1966, 1968).

Preliminary Note on the Black Mountain Basalts of the Potrillo Field, South-Central New Mexico

by Jerry M. Hoffer
Department of Geology,
The University of Texas at El Paso

ABSTRACT

The Black Mountain area consists of about eight cinder and spatter cones associated with six successive intervals of alkaline olivine basalt extrusion. The individual basalt flows are porphyritic and can be differentiated on the basis of the phenocrysts, which consist of plagioclase fledspar, clinopyroxene, and olivine.

LOCATION

The Potrillo Tertiary volcanic field, occupying an area more than 400 square miles (1040 square kilometers) in south-central New Mexico and northern Mexico, consists of a series of basaltic volcanic cones, flows, and maare (Dane and Bachman, 1961; Kottlowski, 1960; DeHon, 1965a,b). Geographically, the region can be divided into three separate areas (fig. 1).

A western section, called the West Potrillo Mountains, is composed of numerous cinder and spatter cones and associated lava flows. In areal extent, it comprises more than 80 per cent of the total field.

The central region is represented by a series of maare, such as Kilbourne Hole, Hunt's Hole, and Potrillo Maare, and several associated cones and basaltic lava flows (DeHon, 1965a,b; Reeves and DeHon, 1965). This area occupies about 75 square miles (195 square kilometers).

The eastern part of the Potrillo field is composed of four individual cone and flow clusters, aligned in a north-south orientation, with a total areal extent of less than 15 square miles (40 square kilometers). Black Mountain, at the south end of this chain, about 20 miles (32 kilometers) south of Las Cruces and about 28 miles (45 kilometers) northwest of El Paso, Texas (fig. 1), is the most prominent feature, a 300-foot (91-meters) cinder cone in the center of the area.

VOLCANIC CONES

Two major types of volcanic craters exist at Black Mountain, cinder and complex spatter-driblet cones. A total of eight cones is present in various stages of preservation (fig. 2).

The largest cinder cone, called Black Mountain, is almost symmetrical in outline, with a diameter of about 2000 feet (610 meters) and a height of more than 300 feet (91 meters). A small quarry on the north side has produced a cross-sectional cut exposing well-developed stratification with layers of cinder and included volcanic bombs. Most of the bombs range in size from several inches to several feet in diameter, with hollow or dense interiors. Sand Hill, just north of Black Mountain, may represent another cinder cone because of its similarity in shape to Black Mountain; however, because the cone is almost completely covered with windblown sand, its composition is not know.

The most common cones in the area are the spatter or driblet types. Typically, they possess a low, sloping base composed primarily of cinder and spatter. Above the base is a steep, rugged rim of agglutinated spatter and driblet, with layers dipping alternately inward and outward at steep angles. In most of these cones, the spatter rim is breached at one or more places because of subsequent erosion or lava extrusion. Six spatter-driblet cones have been identified, ranging in diameter from tens of feet to 200 feet (61 meters) and in height from 15 to 50 feet (5 to 15 meters). The spatter-driblet cones are much smaller in size than the cinder cones.

LAVA FLOWS

Associated with the volcanic cones are representatives of at least six periods of basaltic lava extrusion, covering an area of about 9 square miles (23 square kilometers). These flows are porphyritic alkaline olivine basalts ranging in thickness from 5 to 10 feet (1.5 to 3 meters). Typically, the flows show good vesicular tops with a dense, less vesicular interior. Columnar jointing is only crudely developed, with the best formed columns in the thickest flows.

Positive determination of the cone or center from which each flow originated is almost impossible. Only the youngest flow, the Black Mountain can be traced to a

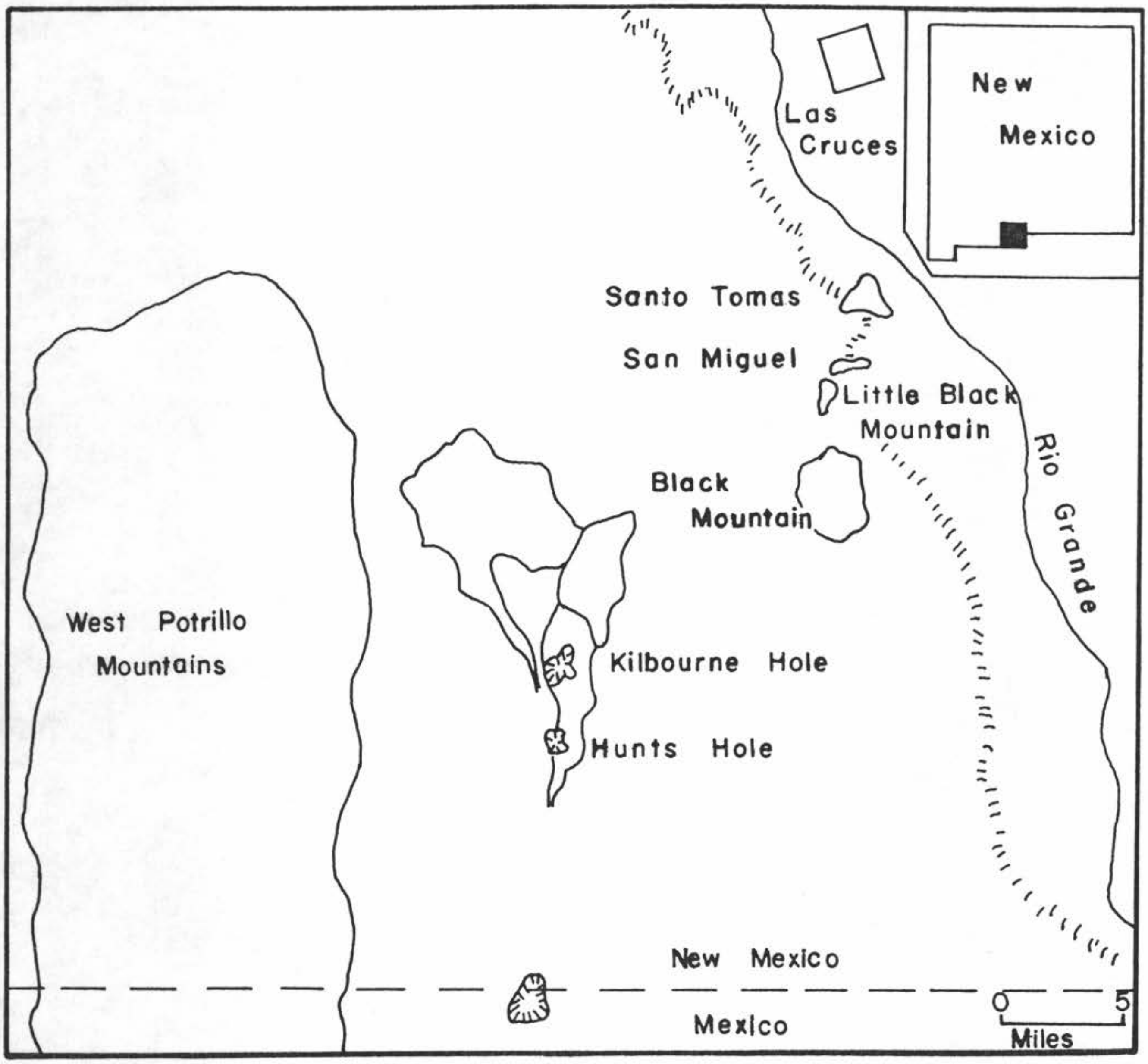

Figure 1
INDEX MAP OF THE BLACK MOUNTAIN AREA
(modified from DeHon, 1965a)

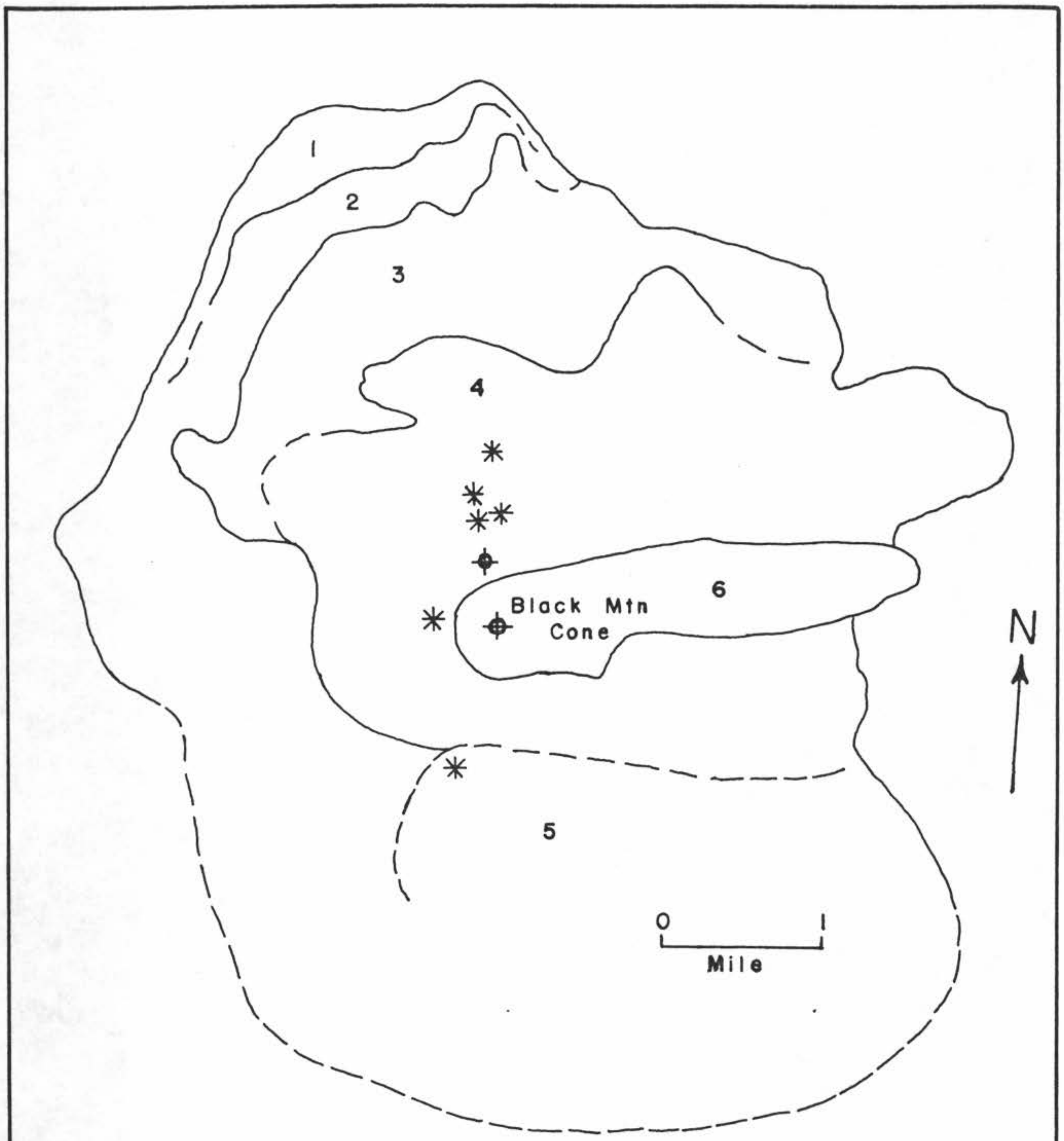

Figure 2

PRELIMINARY MAP OF THE DISTRIBUTION OF FLOWS AND CONES AT BLACK MOUNTAIN

(* - spatter-driblet cones and + - cinder cones) specific cone, where it probably erupted through a lateral vent.

The individual flows have been mapped in only preliminary form (fig. 2). Mapping and correlation of the individual flows have been initiated on the basis of phenocryst mineralogy and topographic position. In some places, especially on the south side of the area, the basalt exposures are very poor because of the covering blow sand.

PETROLOGY

The Black Mountain basalts are porphyritic and hypocrystalline. The amount of glass varies from approximately 50 percent in the quick-cooling, vesicular flow tops to less than 5 percent in the slower cooling flow interiors. Phenocrysts, ranging in size up to 2 mm, are composed primarily of plagioclase feldspar, olivine, and clinopyroxene, comprising from 15 to 30 percent of the total rock. The fine-grained groundmass, averaging less than 0.1 mm, is composed of small lath-shaped crystals of plagioclase, small anhedral grains of clinopyroxene, light- to dark-colored glass, and magnetite.

The plagioclase phenocrysts are generally subhedral to euhedral with a few crystals showing evidence of moderate resorption. The pehnocrysts are moderately zoned with calcic cones (An_{60-66}) and more sodic exteriors (An_{55-60}). The groundmass plagioclase, 0.04 to 0.66 mm, is less calcic than the phenocryst plagioclase, averaging An_{35-45}, and unzoned.

Clinopyroxene occurs as phenocryst and groundmass crystals. The phenocryst pyroxene is generally subhedral and smaller than the plagioclase phenocrysts, averaging only 0.5 mm. The pyroxenes are generally moderate to dark brown in color with a 2V of from 40 to 60 degrees, thus indicating a composition of titanium-rich augite. The groundmass pyroxenes occur in small anhedral grains, averaging 0.05 mm in diamter, which are probably pigeonite.

Olivine is most abundant as subhedral to euhedral phenocrysts showing moderate glomeroporphyritic development. Most of the crystals show irregular fractures and some evidence of resorbed edges from reaction. A high 2V (80 to 85 degrees) and a negative sign indicate a high magnesium content (Fo_{80}-Fo_{65}).

Subhedral to anhedral magnetites, ranging in size from 0.08 to 0.05 mm, occur as inclusions within the mafics and as scattered subhedral crystals in the groundmass associated with the glass. Most of the glass is dark-colored because of the presence of finely divided opaque oxides.

Most of the samples examined, megascopically and microscopically, give very little evidence of weathering or alteration. The large subhedral to euhedral olivine phenocrysts show no evidence of alteration, except for occasional small border zones of minor iddingsite. Minor amounts of magnetite show slight weathering to hematite-limonite compounds.

Textural relationships indicate that olivine and magnetite were the first minerals to crystallize from the basaltic magma at depth. Inclusions of magnetite within subhedral to euhedral olivine phenocrysts and small anhedral magnetite crystals in the ground mass show that magnetite formation was continuous throughout the crystallization of the magma.

Crystallization of plagioclase feldspar followed the initial olivine formation. The more calcic content and larger size of the phenocryst feldspars indicate their early formation under conditions of high temperature and slow cooling in the magma chamber before extrusion.

Pyroxene crystallization started just before or during extrusion of the basalt toward the surface, as very little pyroxene is present as phenocrysts.

The groundmass phase of crystallization took place at or near the surface in a more rapid cooling environment. Almost simultaneous crystallization of more sodic plagioclase in subhedral laths displaying good flow structure and small interstitial anhedral pyroxene occurred during flowage. Disequilibrium with the final liquid and the initially formed phenocrysts is shown by the presence of resorbed and embayed boundaries on the plagioclase and olivine phenocrysts. The last stage in crystallization is represented by formation of interstitial glass.

The concentration of escaping gases, at both the top and bottom of the flows, produced the resulting vesicular textures and locally prolonged crystallization. In some instances, volatile concentrations have produced locally coarse intergrowths of subhedral groundmass plagioclase and anhedral pyroxene.

INDIVIDUAL FLOWS

FLOW 1

The oldest flow at Black Mountain is exposed at the north end of the area (fig. 2). The thickness of this flow is unknown because of the heavy sand cover to the north and the cover of younger basalt flows to the south. At present, this flow has not been studied microscopically or megascopically.

FLOW 2

Resting directly on Flow 1 at the north end of the area is Flow 2. The flow is approximately 5 to 6 feet (1.5 to 1.8 meters) in thickness and consists of an upper vesicular zone (3 to 3.5 feet) and a lower, dense, less vesicular zone (3 feet–0.9 meters). Flow 2 has been identified only at the north end of the area; to the south, it is covered by the next youngest flow, Flow 3.

Petrographically, the flow averages about 28 percent phenocrysts composed of almost equal amounts of plagioclase (42 percent), olivine (38 percent), and subordinate pyroxene (20 percent).

FLOW 3

Flow 3 outcrops on the north and west sides of the area and rests directly on Flow 2. It is approximately 8 feet (2.4 meters) thick. The phenocrysts average 30 percent of the rock, with plagioclase feldspar the most abundant (45 percent), followed by clinopyroxene (31 percent) and olivine (26 percent).

FLOW 4

Flow 4, or the feldspar flow, is one of the most megascopically distinctive units at Black Mountain. This flow contains only 20 percent phenocrysts, but 65 percent of them are plagioclase. The flow typically weathers to a light to moderate gray with an abundance of small (1 to 2 mm), white-colored plagioclase laths. Its thickness is approximately 6 feet (1.8 meters).

The flow outcrops on the north, west, and south sides of Black Mountain. A possibility exists that the feldspar flow on the south side of Black Mountain is not the same unit as that on the west and north sides; it may represent lava extruded at the same time and from the same magma chamber but through a different vent. We hope that more detailed mapping will yield more conclusive evidence.

FLOW 5

Flow 5, or the olivine flow, rests on top of the feldspar flow on the south side of Black Mountain; its complete extent has not been fully defined. This flow is distinctive megascopically because of the abundance of olivine phenocrysts. Phenocrysts make up only 15 percent of the rock, but olivine averages 62 percent of the phenocrysts, followed by plagioclase (27 percent) and pyroxene (11 percent).

This flow is about 10 feet (3 meters) thick, with an upper, highly vesicular zone 1 to 2 feet (0.3 to 0.6 meters) thick.

FLOW 6

Flow 6, the youngest or Black Mountain flow, extends from the Black Mountain cinder cone to the east edge of the field, a distance of 3 miles (5 kilometers). The flow is 6 to 7 feet (1.8 to 2.1 meters) thick and occupies an area of 2 to 3 square miles (5 to 8 square kilometers).

The Black Mountain flow is porphyritic (15 percent), with plagioclase accounting for 60 percent of the phenocrysts and lesser amounts of clinopyroxene (30 percent) and olivine (10 percent). The phenocryst mineralogy of this flow is very similar to that of Flow 4, the feldspar flow.

A sample taken near the base of the Black Mountain flow, and dated by the K-Ar method, has given an apparent age of 1.69 ± 0.15 million years (Hawley, 1967).

Mineralogically, the flows examined at Black Mountain are all porphyritic olivine basalts. However, the phenocryst mineralogy of the individual flows is distinctly different, as Figure 3 graphically shows.

Textural and mineralogical evidence definitely establishes the intratelluric origin of the phenocrysts. Therefore, the mineralogical difference in the basalts represent either origin from slightly different magma sources or, more likely, a similar source but tapping of magma at different levels or stages in time. Most of the flows are mineralogically similar throughout, indicating that very little differentiation took place after extrusion.

Further work is in progress to obtain more samples of these individual flows, plus sampling and mapping of the other three volcanic centers to the north, Little Black Mountain, San Miguel, and the Santo Tomas flows.

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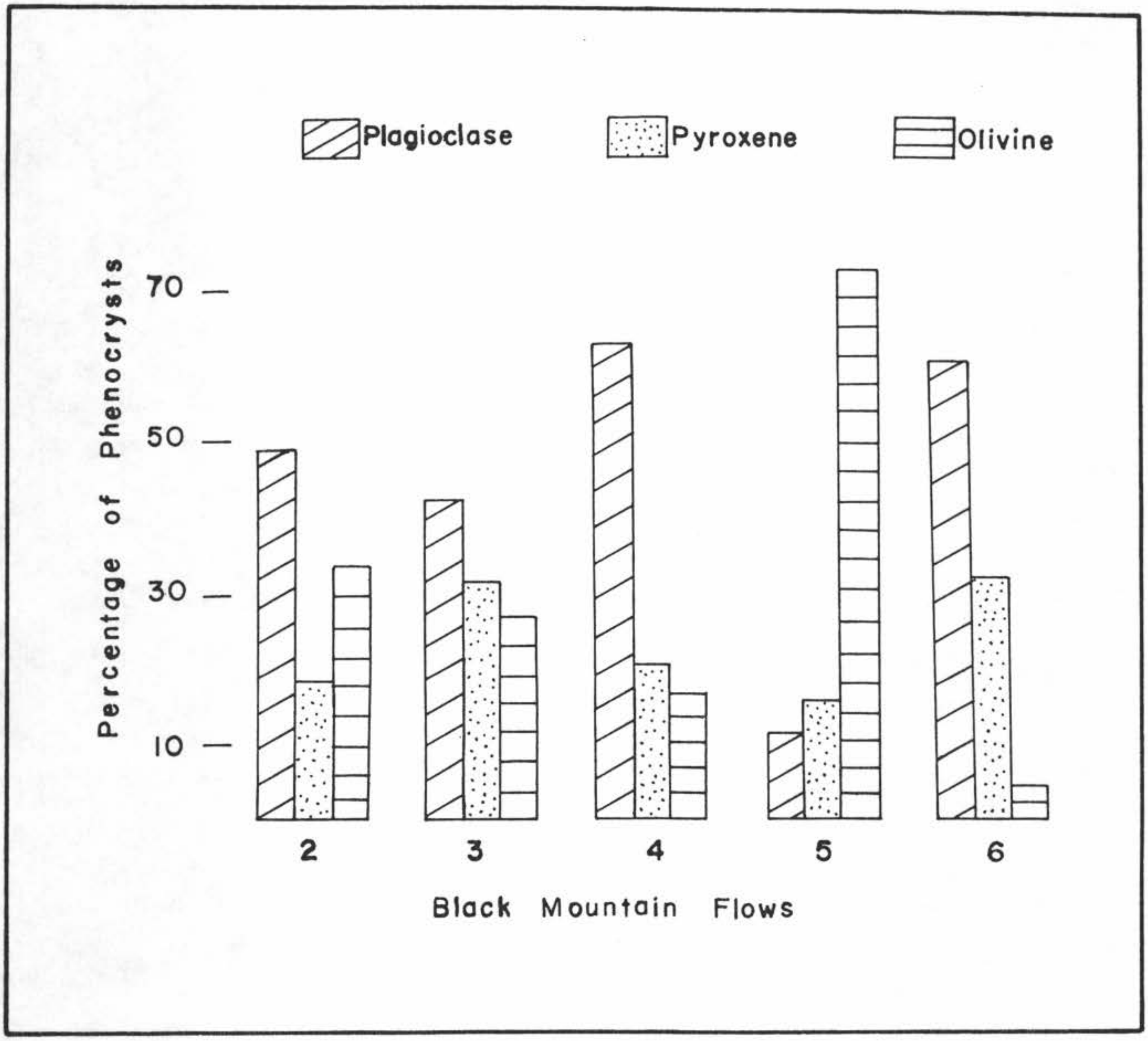

Figure 3
PHENOCRYST MINERALOGY OF THE BLACK MOUNTAIN BASALTS

Late Cenozoic Strata of the El Paso Area

by William S. Strain
The University of Texas at El Paso

By middle Cenozoic time the major structural features present in the El Paso area today had been established. Of these, the Hueco Bolson and the Mesilla Bolson were the prominent basins of deposition. Initially these basins filled separately, but by early Pleistocene their floors had merged and a continuous sheet of lacustrine deposits extended between the mountains. The formation of Lake Cabeza de Vaca (Strain, 1966), which existed until middle Kansan time, brought about this coalescence. Exposures of Cenozoic rocks in the El Paso, Texas area are almost entirely limited to the Hueco and Mesilla bolsons where there is a vertical thickness of about 600 feet of strata.

Albritton (1938), Sayre and Livingston (1945), Kottlowski (1958), Hawley (1965), Albritton and Smith (1965), Strain (1966), et al., have studied Cenozoic strata near El Paso. Strain has formally proposed that two lithic units be recognized, the Fort Hancock Formation and the Camp Rice Formation. The Camp Rice is the youngest and is separated by a disconformity from the Fort Hancock. Both formations are exposed in the Rio Grande Valley in the Hueco and Mesilla bolsons.

FORT HANCOCK FORMATION

The Fort Hancock Formation is composed of horizontal bentonitic claystone, siltstone, and silt. It is dominantly yellowish-brown, but the color ranges from grayish-red to brown and occasionally greenish-yellow. A single stratum is seldom more than 15 feet thick and usually lenses out or grades into a different lithic type in a mile or less. Generally the strata are evenly bedded, but occasionally lenses of crossbedded silt interrupt the uniform layering of the rock. In many places, particularly in the southeastern part of the Hueco Bolson, gypsum in the form of selenite occurs as veins or laminae.

Although the maximum exposure of the Fort Hancock at any one locality is about 80 feet, a composite section 350 feet in thickness can be assembled. The base of the formation is not exposed, but wells drilled for oil indicate that it may be several thousand feet thick.

The upper boundary of the Fort Hancock Formation is a disconformity which separates it from the overlying Camp Rice Formation. The even bedding and fine texture of the deposits indicate the Fort Hancock Formation was deposited in a lacustrine (Lake Cabeza de Vaca) and playa environment.

Erosion of the Fort Hancock produces a badlands-type topography except where it is protected by the overlying Camp Rice Formation and there it forms steep slopes.

Fossils are extremely rare, but bones of vertebrate animals belonging to the Blanca fauna indicate that at least the upper part of the Fort Hancock is Aftonian or early Kansan in age.

CAMP RICE FORMATION

In Kansan time, outlet cutting drained Lake Cabeza de Vaca, closed the lacustrine depositional environment in which the Fort Hancock formed, and introduced a fluvial environment for the deposition of the Camp Rice.

After the lake was drained, a stream quickly established a course traversing the Hueco and Mesilla bolsons and formed a through-flowing stream (the Rio Grande) from the Rocky Mountains to the Gulf of Mexico. Vertebrate fossils indicate the river began to entrench itself in the old basin fill in Kansan time and the downcutting has continued to the present.

The Camp Rice Formation rests unconformably on the Fort Hancock and is composed of gravel, sand, silt, volcanic ash, and caliche. The color range varies from very light gray through shades of pink and orange to light brown. The strata are horizontal and mainly stream channel and floodplain deposits, interfingering with fanglomerate around the margin of the basin. The Camp Rice is easily distinguished from the Fort Hancock because it is unevenly bedded, has a wide range in particle size, and is lighter in color. The Camp Rice is capped by wind-blown sand, soil, caliche, floodplain, and pediment deposits of late Pleistocene and recent date.

Pearlette? volcanic ash occurs in discontinuous lenses in the southeastern part of the Hueco Bolson. Channel gravel and sandstone are common in the lower part of the Camp Rice and typical exposure càn be observed at numerous places from near Las Cruces down river to the Quitman Mountains at the eastern end of the Hueco Bolson.

Grayish orange-pink to light brown, moderately well-bedded, clayey siltstone, probably representing a floodplain environment, constitutes an important facies of the Camp Rice.

Caliche capping the Camp Rice Formation is as much as 15 feet thick. In many areas along the edge of the escarpment of the valley the caliche may represent a more or less continuous accumulation from middle Kansan time to the present.

The topographic expression of the Camp Rice varies from low, rounded hills to badlands-type topography.

Vertebrate fossils indicate the Camp Rice Formation varies in age from late early to middle Pleistocene.

STRATIGRAPHIC RELATIONSHIP

At the time the Fort Hancock and the Camp Rice formations were named, I believed their source areas were mostly different from those of the formations of the Santa Fe Group in New Mexico (Strain, 1966, p. 16). More recent investigation demonstrates that there is a genetic relationship, and for this reason I now believe the Fort Hancock Formation and the Camp Rice Formation should be included in the Santa Fe Group as described by Hawley et al., elsewhere in this publication.

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