BULLETIN 79

Paleozoic and Mesozoic Strata of Southwestern and South-Central New Mexico

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Abstract

Paleozoic strata, totaling 8000 to 11,000 feet in thickness for relatively complete sections, consist of the Cambrian and Ordovician Bliss Sandstone which thins depositionally northward; the Ordovician El Paso Limestone and Montoya Dolomite; the Silurian Fusselman Dolomite; argillaceous Devonian rocks; crinoidal Mississippian limestones; a thin to thick Pennsylvanian sequence; and thick, largely marine Permian strata with basal beds marked by a southward transition from red beds into limestones. Pre-Pennsylvanian units thin northward chiefly because of various erosional episodes but are thick in southern New Mexico. More than 3000 feet of Pennsylvanian beds were deposited west of the Pedernal landmass in north-south-trending basins such as the Orogrande and Pedregosa. Reefoidal masses locally characterize the Ordovician, Mississippian, Pennsylvanian, and Permian limestones.

The early Mesozoic was a time of uplift and erosion which accelerated during the Early Cretaceous when all Paleozoic rocks were stripped from the Burro uplift in western Grant County and all the upper Permian beds removed throughout large areas of southwestern New Mexico.

Early Cretaceous rocks are 7000 to 20,000 feet thick in the southwestern part of New Mexico and consist of red beds, shoreline sandstones, nearshore conglomerates, fossiliferous biohermal limestones, and volcanic detritus. The northernmost shoreline of this Early Cretaceous sea may have paralleled an east-southeast-trending line from Silver City toward the Cornudas Mountains. Late Cretaceous sediments, the Dakota(?) Sandstone, Mancos Shale, and Mesaverde Formation, are about 2000 feet thick and rest on middle Permian beds or on a northward-tapering edge of Early Cretaceous strata. The dark Mancos Shales of south-central New Mexico grade southward into the shaly Eagle Ford sandstones near El Paso. Thick sections of latest Cretaceous rocks near Steeple Rock and near Elephant Butte Dam are mainly of conglomeratic volcanic sediments. Erosion during Tertiary time locally removed the Cretaceous strata and cut down to lower Permian beds.

Introduction

There may be more unknown than known facts on the Paleozoic and Mesozoic stratigraphy of southwestern and south-central New Mexico but enough detailed "new" work has been done in the past 10 to 15 years to allow this study to be reasonably accurate, and to provide a springboard for future attacks on the more pressing problems. A summary of the conclusions from this study was presented before the Southwestern Regional Meeting of the American Association of Petroleum Geologists at El Paso, Texas, November 3, 1961, as part of a symposium on the sedimentary and tectonic framework of northern Mexico and southwestern United States. Requests for more detailed information than could be given in a talk led to the compilation of this report.

The basin-and-range country of southwestern and south-central New Mexico consists of isolated fault-block ranges scattered like islands amid a sea of sandy, semiarid plains. On the northwest is the Datil—Mogollon plateau where thick flows and huge pyroclastic masses of volcanic rocks have buried the pre-Tertiary strata. On the east is the Sacramento section of the Basin and Range province where long, narrow mountain ranges are separated by long, wide basins. In the central part of the area, the Rio Grande structural depression (Kelley, 1954) appears to die out southward against the syncline on the west flank of Sierra de las Uvas. South and west of Silver City, Deming, and Las Cruces (fig. 1 and table 1), complex structure is the rule—thrust faults, klippe, gravity faults, and many volcanic features are seen everywhere in the bedrock that is exposed above the bolson plains. One can merely hope that the pre-Tertiary strata buried in the bolsons have not been deformed greatly and have not been subjected to severe erosion during earlier Cenozoic time.

Much of the early geologic work was done as investigations of mineral deposits and lacked stratigraphic detail. Even some of the more recent publications give only cursory treatment to the sedimentary rocks. Some studies are stalled in manuscripts (for example, Robledo Mountains) or are in unpublished theses (Zeller, 1958; Epis, 1956). Future stratigraphic reports will add significant details, but enough published, manuscript, and unpublished information is now available to summarize the thicknesses, lithologies, and geologic history of the pre-Tertiary sedimentary rocks in this part of New Mexico. Most of the recent reports have been of the eastern part of the area describing the sequence in the Sacramento (Pray, 1961; Otte, 1959), Caballo (Kelley and Silver, 1952), San Andres (Kottlowski et al., 1956; Kottlowski, 1959), Franklin (Harbour, 1958, 1960; Pray, 1958), and Robledo (Kottlowski, 1960a) mountains. However, the pre-Tertiary sequence also has been described in some detail for Cooks Peak (Jicha, 1954; Elston, 1957), central Black Range (Kuellmer, 1954), and the Tres Hermanas (Balk, 1961;

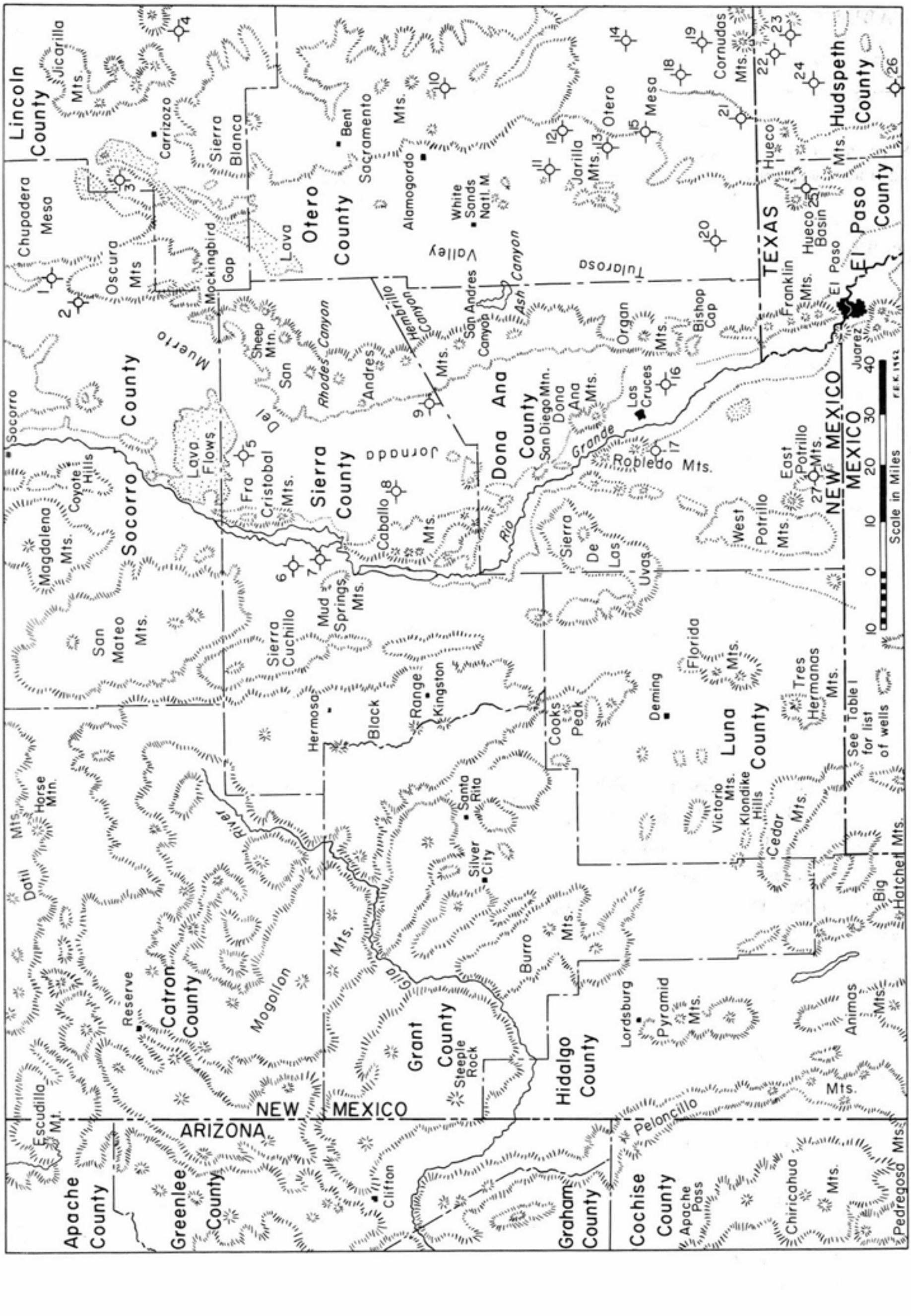

Figure 1

INDEX MAP OF SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO

TABLE 1. OIL TESTS SHOWN ON INDEX MAP OF SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO (FIG. 1)

Name	*No.*	*Location*
Lockhart No. 1	1	sec. 28, T. 4 S., R. 6 E.
Sun Oil Co. No. 1 Bingham State	2	sec. 23, T. 5 S., R. 5 E.
Standard Oil Co. of Texas No. 1 Heard	3	sec. 33, T. 6 S., R. 9 E.
Capoco Corp. No. 1 Spencer	4	sec. 36, T. 8 S., R. 14 E.
Sun Oil Co. No. 1 Victorio	5	sec. 25, T. 10 S., R. 1 W.
Gartland No. 1 Brister	6	sec. 8, T. 12 S., R. 4 W.
Summit Exploration No. 1-A Mims	7	sec. 2, T. 13 S., R. 4 W.
Sunray Mid-Continent Oil Co. No. 1-M Federal	8	sec. 23, T. 15 S., R. 2 W.
Western Drilling Co. No. 2 Guame Federal	9	sec. 21, T. 16 S., R. 2 E.
Southern Production Co. No. I Cloudcroft	10	sec. 5, T. 17 S., R. 12 E.
Plymouth Oil Co. No. 1 Evans	11	sec. 15, T. 20 S., R. 9 E.
Sun Oil Co. No. 1 Pearson	12	sec. 35, T. 20 S., R. 10 E.
Otero Oil Co. No. I McGregor	13	sec. 5, T. 22 S., R. 10 E.
Turner No. 1 Everett	14	sec. 34, T. 22 S., R. 13 E.
Kinney Oil & Gas Co. No. I State	15	*sec.* 14, T. 23 S.,. R. 10 E.
Snowden & Clary No. 1 State	16	sec. 36, T. 23 S., R. 2 E.
Picacho Oil & Gas Syn. No. 1 Armstrong	17	sec. 15, T. 23 S., R. 1 W.
Turner No. I Evans	18	sec. 22, T. 24 S., R. 12 E.
Union Oil Co. No. 1 McMillan	19	sec. 9, T. 25 S., R. 13 E.
Ernest No. 1 Located Land Co.	20	sec. 20, T. 25 S., R. 7 E.
Seaboard Oil Co. No. 1 Trigg Federal	21	*sec.* 18, T. 26 S., R. 11 E.
Magnolia Oil Co. No. 1-39881	22	sec. 36, Block 70, Univ. Lands
Seaboard & Shamrock Oil Co. No. I-C. Univ.	23	sec. 45, Block C, Univ. Lands
California Co. No. 1 Univ. Theisen	24	sec. 19, Block E, Univ. Lands
Jones No. 1 Sorley	25	sec. 17, Block 5, PSL Survey
Minnie Veal oil test	26	sec. 6, Block 14, PSL Survey
Pure Oil Co. No. 1-H Federal	27	sec. 24, T. 28 S., R. 2 W.

Kottlowski and Foster, 1962), Victorio (Griswold, 1961), Peloncillo (Gillerman, 1958), and Chiricahua (Sabins, 1957a) mountains.

Regional stratigraphic studies of discrete units are only those of the Devonian (Stevenson, 1945), Mississippian (Laudon and Bowsher, 1949; Armstrong, 1962), and Pennsylvanian (Kottlowski, 1960b, 1960c), along with areally limited or progress reports on the Cambrian, Ordovician, and Silurian strata (Pratt and Jones, 1961; Pray, 1953, 1958; Howe, 1959; and Flower, 1959).

Only 27 oil tests are shown on the index map, Figure 1. Other oil tests have been drilled in this area but either significant sections of pre-Tertiary strata have not been encountered or information on the beds penetrated has not been officially released. Exploration for oil and gas has been mainly in south-central New Mexico where the structure appears to be less complex. During the past two years, however, the southwestern part of the State has been an active exploration area. Oil tests have been drilled northwest and southwest of Las Cruces in eastern Luna and western Dona Ana counties.

Acknowledgments

Field aid and technical advice by Roy W. Foster, George B. Griswold, and Rousseau H. Flower, New Mexico Bureau of Mines and Mineral Resources, is gratefully acknowledged. Dr. Flower's faunal studies of the lower Paleozoic rocks have been a major basis for interpretation of that part of the sequence. Comment and criticism from Robert A. Bieberman, Frederick J. Kuellmer, Robert H. Weber, and Max E. Willard, Bureau staff, aided in preparation of this report. Appreciation is due to Alvin J. Thompson, director of the Bureau, and Dr. E. J. Workman, president of the Institute, for their indulgence and encouragement of studies in basic geology. Drafting excellence is due to the skill of Raymond Molina and William E. Arnold, Bureau staff; typing of the various versions of the manuscript owed much to the cheerful cooperation of Sharon L. Ballenger and Josie M. Baca; much thanks is given to Teri Ray for nursing this report from manuscript through the various publication stages to the final printing.

A summary report of this type cannot be compiled without full use of all published material and the gleaning of pertinent information from colleagues outside the Bureau staff and too numerous to mention for fear that some significant contributor might be slighted. Appreciation is due to all geologists that have worked or are working in southwestern and south-central New Mexico.

Precambrian Rocks

Granites, granite gneisses, and associated metamorphic rocks occur beneath pre-Tertiary strata in most of the region. However, there are some large areas of Precambrian metasedimentary rocks, and these rocks are types that could be mistaken for metamorphosed Paleozoic strata in isolated fault blocks. In the Sacramento Mountains, Pray (1961) and Foster (1959) reported shale, siltstone, and fine-grained quartzitic sandstone, intruded by dioritic sills, beneath the Bliss (Cambrian ?) Sandstone. Bachman (1954) and Foster (1959) found Precambrian quartzite and granodiorite beneath the Abo Redbeds south of Sierra Blanca near the village of Bent. In the Southern Production—Cloudcroft oil test (fig. 1, no. 10), the Precambrian beneath the Bliss Sandstone consists of quartzitic sandstones and siltstones with interbeds of green and red shales. The Precambrian in the central San Andres Mountains area, near Hembrillo Canyon, includes quartzite and siliceous dolomitic limestone but is chiefly phyllite, talc, amphibolite, metarhyolite, and various schists. In the Franklin Mountains, Harbour (1960a) reported algal limestone, and quartzitic sandstone, siltstone, and shale in the Precambrian sequence along with basalt-breccia, metarhyolite, and granite. Hewitt (1959) described metamorphosed sandstones, siltstones, siliceous dolomites, and agrillaceous limestones in the northern Burro Mountains. The Precambrian rocks reported from the rest of the area are almost entirely granitoid or highly metamorphosed.

Paleozoic Strata

Paleozoic sedimentary rocks in south-central and southwestern New Mexico include the Cambrian—Ordovician Bliss Sandstone; the Ordovician El Paso Limestone and Montoya Dolomite; the Silurian Fusselman Dolomite; the Devonian Onate, Sly Gap, Contadero, and Percha formations; the Mississippian Caballero, Lake Valley, Escabrosa, Rancheria, Helms, and Paradise formations; various Pennsylvanian units; and the Permian Bursum, Hueco, Abo, Yeso, Glorieta, San Andres, Bernal, Earp, Colina, Epitaph, Scherrer, and Concha formations. Somewhere near Deming is the poorly defined meeting ground where units bearing central New Mexico terminology mingle with those named from type sections in southeastern Arizona.

The Bliss Sandstone is essentially a basal hematitic arkosic clastic phase of Paleozoic deposition that appears to be slightly older to the west, perhaps in part of middle Cambrian age, and younger to the east where the unit is of Late Cambrian and/or Early Ordovician age. Above are the Ordovician and Silurian carbonate rocks with each unit thickening southward and truncated on the southwest by erosion during the late Silurian to middle Devonian interval. Devonian rocks record the first large-scale Paleozoic influx of clays and silts, and once formed a relatively uniform blanket across the region. Distinct facies occur with the Swisshelm sandy facies to the southwest, the Portal limy facies to the west, the Percha shale facies extending from Silver City east-southeastward, the older Canutillo cherty facies in the southeast, and the Onate and Sly Gap silty facies in the northeast part of south-central and southwestern New Mexico.

A low positive area, or an area of nondeposition, was present during early Mississippian time, and again during early (?) Pennsylvanian time near and southeast of the Jarilla Mountains. The Mississippian rocks are mainly crinoidal limestones that thicken southward and southwestward. Early Mississippian strata were deposited only an in east-westtrending basin in south-central New Mexico; Late Mississippian sandy and argillaceous beds occur only along the southern border of the region. The middle Mississippian Lake Valley Limestone appears to grade southeastward into the lower part of the siliceous Rancheria Limestone. Erosion during early Pennsylvanian time thinned or removed much of the Mississippian rocks, as well as some of the older strata, along the present-day Rio Grande Valley from the Fra Cristobal Mountains to Las Cruces.

The basic basin-and-uplift pattern changed in Pennsylvanian time. The Pedernal landmass rose slowly and intermittently along the northeast border of the region to its culmination in late Pennsylvanian and early Permian time. A line of north-south-trending basins formed west of the Pedernals, stretching from the Orogrande basin northward to the

San Mateo and Lucero basins. Thin nearshore marine deposits appear to have been deposited in the northwestern part of the region on the southern flank of the Zuni uplift. The forerunner of the Mesozoic-age Burro uplift, the Florida islands, formed an intermittent positive area in central and northwestern Luna County; to the southwest thick carbonate-rock deposits were laid down in the Pedregosa basin.

Wolfcampian strata thicken rapidly westward from the Pedernal landmass and southeastward from the Zuni uplift. The Orogrande basin existed as a sediment trap into Wolfcampian time. Southward and southeastward, the Abo Redbeds intertongue into the Hueco limestones. Erosion during earliest Permian time truncated pre-Permian rocks on the Diablo platform in the southeast corner of the region and along the west edge of the Pedernal landmass near Bent. The Leonardian Yeso Formation is thickest near Carrizozo in the eastern part of an extensive evaporite basin. The Glorieta Sandstone thins southward concurrent with a change in the overlying San Andres Formation from a gypsum-limestone facies southward into a limestone facies. In the southwest corner of the region, the Scherrer sandstones thicken northwestward, whereas the overlying Concha Limestone thins to the north and west. The late Guadalupian Bernal Formation has been preserved only in the northeast corner near Carrizozo.

Erosion during early and middle Mesozoic time stripped thick sections of the Paleozoic rocks from a northwest-trending area centered on the present-day Burro Mountains. This Burro uplift may have begun in early Pennsylvanian time as islands amid the late Paleozoic seas. The younger units, those of middle Permian age, apparently were removed from a wide belt extending completely across the region, whereas older Paleozoic units were eroded from a relatively small, narrow area in western Grant County. Total thicknesses of the Paleozoic strata (fig. 2) reflect this erosion around the Burro uplift, and show that only thin (2000 or less feet) sections were deposited and retained over the Pedernal landmass and Diablo platform, in contrast to the thick sedimentary sequences laid down in the Tularosa Valley and Pedregosa—Big Hatchet Mountains areas.

BLISS SANDSTONE

The Bliss Sandstone is the basal sandy phase of the Paleozoic sequence. Flower (1953b, 1959) suggested that this seemingly simple clastic unit underwent a varied complexity of paleogeographic events. Dresbachian faunas have been found only to the west in Arizona. Early Franconian faunas are reported only from the Silver City region; middle Franconian faunas are unknown in the State and Flower (1959) suggested emergence occurred during that epoch. Late Franconian faunas are definitely recognized only in the Mud Springs and Caballo mountains area, whereas Trempealeauan fossils have been found only in the

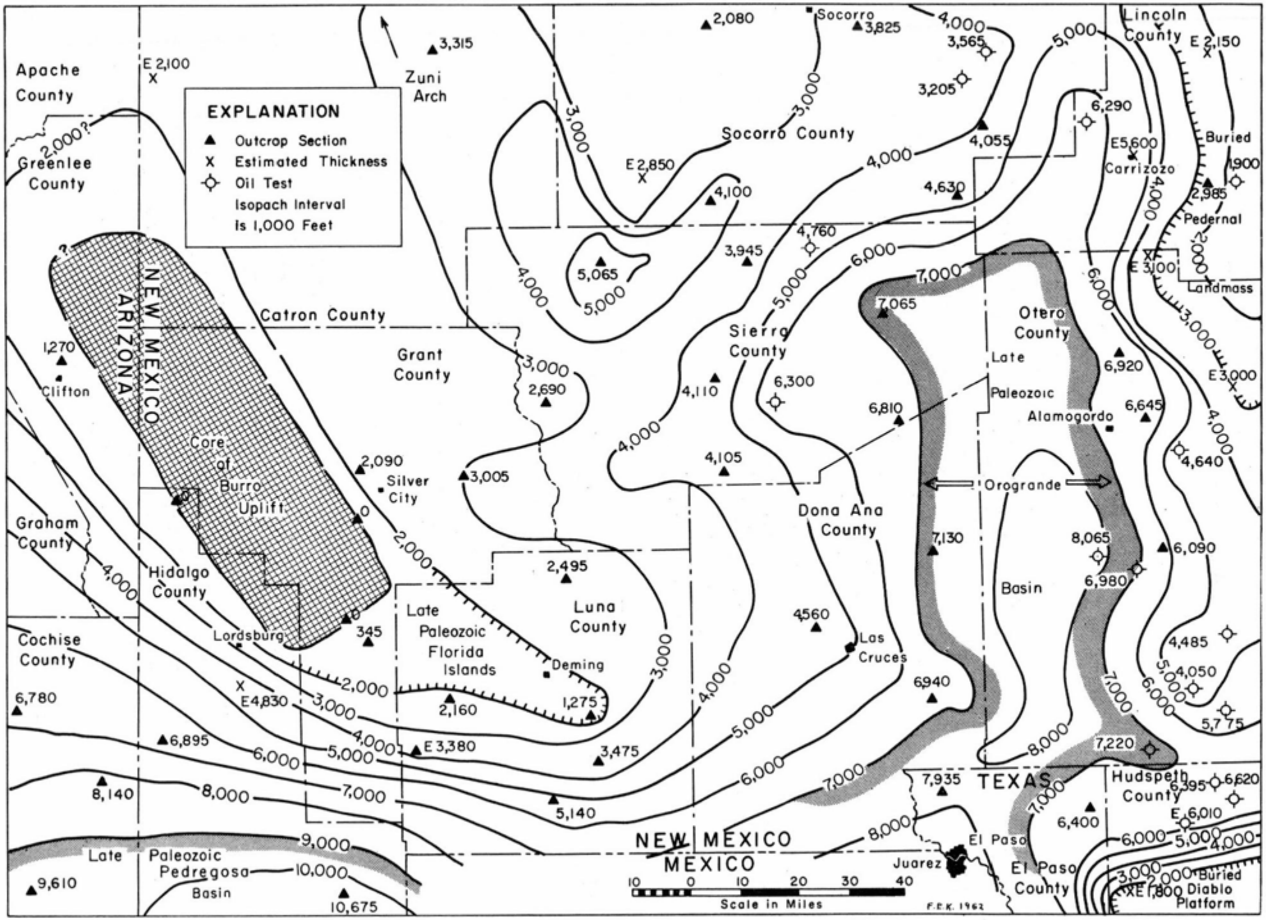

Figure 2

ISOPACH MAP OF PALEOZOIC STRATA IN SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO

Silver City—Cooks Peak area and furthermore do not occur, as far as is known, in southeastern Arizona. This restriction of the Trempealeauan fauna is suggested by Flower as partly due to a post-Trempealeau, early Gasconadian period of erosion. Early Gasconadian, earliest Ordovician faunas are widespread in the upper part of the Bliss Sandstone in most areas, and there appears to be a gradational lithologic change from this early Gasconadian sandstone up into the late Gasconadian arenaceous limestones of the lower El Paso Limestone. Widely scattered pebbles of igneous rock in the upper part of the Bliss Sandstone in the Franklin Mountains are believed by Flower (1959) to mark uplift and erosion during middle Gasconadian time. This Franklin Mountains' sequence is one of the thickest sections of the Bliss Sandstone, but Flower (1959) considers it to be entirely of early Ordovician age. Here, at the type section of the Bliss Sandstone, the lower 160 feet is barren, but sparse fossils date the upper 80 feet as Gasconadian in age.

Earlier studies of the faunas in the Bliss Sandstone (Flower *in* Kottlowski et al.) had indicated only a lower Franconian zone and an upper Gasconadian zone. As more collecting is done in the sandstone, more faunal zones probably will be found. The relationship between the faunas and the sedimentation was aptly stated in one of Flower's (1953a) earlier comments on the age of the Bliss Sandstone: "It represents a period of slow and evidently highly intermittent deposition of sandy material. This interpretation is consistent with the abundance of glauconite and the coating of manganese, both of which are common in many parts of the formation. Intermittent deposition is also required to explain the absence of either beds which can be assigned with certainty to the Trempealeauan, or the absence of a clearly recognized break indicating nondeposition in Trempealeauan time."

Most of the Bliss beds are of quartz sandstone, glauconitic in part, with thin interbeds and lenses of siliceous hematite, arenaceous shale, and arenaceous limestone. Basal beds are pebbly, siliceous, hematitic sandstone, and, locally, oolitic hematite. The sandstone crops out as a conspicuous dark brown ledgy cliff, but most of the beds are thin-bedded and cross-laminated. Hematite occurs throughout the sandstone, but relatively thick beds of oolitic hematite appear to be limited to an east-west, 20-mile-wide belt (fig. 3) running from Rhodes Caynon in the San Andres Mountains westward to north of Silver City, as shown by Kelley (1951) in his study of this oolitic hematite facies.

The Bliss Sandstone, taken as a lithologic unit, suggests deposition in shallow marine waters far from shorelines; that is, a slow accumulation of fine-grained erosional detritus and stable chemical materials derived from weathering of a low peneplaned surface cut on Precambrian rocks. Nearly everywhere, the Bliss lies on a relatively even surface that was deeply eroded in crystalline rocks. Locally, however, there are thick channel-fill or basin-fill sandstones, and in some areas the thickness of the unit varies greatly in short distances. Under this type of deposition, representing a slow and uneven transgression by the early Paleozoic seas, a barren 2-inch-thick sandstone bed may be all the deposits of late Cambrian time, whereas a 6-foot-thick, channel-fill sandstone lens may have been deposited during a single day in the life of a Franconian trilobite.

Local faunas and local thicknesses may be extremely variable but the sandstone as a generalized unit appears to be slightly older toward the west and younger to the east. The oldest faunas found by Flower (1959) to date in New Mexico are in the Silver City area. He has not found Cambrian faunas in the Bliss of the San Andres, Sacramento, and Franklin mountains where lower beds, consisting of two thirds of the sandstone, are barren.

The Bliss is mainly quartz sandstone in the southwestern Sacramento Mountains (Pray, 1961) where it is about 110 feet thick. In the Southern Production—Cloudcroft oil test (fig. 1, no. 10), the Bliss is 95 feet thick, and a short distance to the north, the sandstone was removed by erosion during Pennsylvanian or early Permian time. To the south in westernmost Texas, the Bliss is 335 feet thick as penetrated in the California—University Theisen oil test (fig. 1, no. 24) on the east edge of the Hueco Mountains and 300 feet thick in the Jones—Sorley oil test (fig. 1, no. 25) in the eastern part of the range (Cooley, 1958). In the southern Franklin Mountains, Flower *(in* Kottlowski et al.) measured about 250 feet of the Bliss Sandstone as did Richardson (1909). Northward in the San Andres Mountains, the sandstone thins from 105 feet near Ash Canyon to 8 feet in Mockingbird Gap at the north end of the range; this northward thinning appears to be depositional rather than erosional.

In the area of the Caballo and Mud Springs mountains, the contact between the Bliss Sandstone and the overlying El Paso Limestone has been picked at several different horizons within a thick sequence of interbedded limy sandstone and limestone-dolomite. If one chooses the lower, predominantly sandstone beds as representing the Bliss Sandstone, the thicknesses range from 50 to 95 feet. If one includes much arenaceous limestone-dolomite in the upper part of the Bliss Formation (Kelley and Silver; Flower, 1959), thicknesses range from 108 to 155 feet. Whichever unit is used, there is no general northward thinning in central Sierra County except in the northern Fra Cristobal Mountains where the Bliss is abruptly cut out beneath Pennsylvanian or Devonian strata. To the south and west, thicknesses of the Bliss Sandstone are erratic, although they tend to increase toward the southwest corner of New Mexico (fig. 3). Extreme variation in thickness, and some variation in lithology, is shown in the Florida, Big Hatchet, and Peloncillo mountains. Locally, the sandstone thins over pre-Bliss hills to a knife-edge, and in other places depressions and channels (Lochman Balk, 1958) were filled by tens to hundreds of feet of arkosic cross-bedded conglomeratic sandstone.

In the Burro Mountains area, all pre-Cretaceous beds were stripped

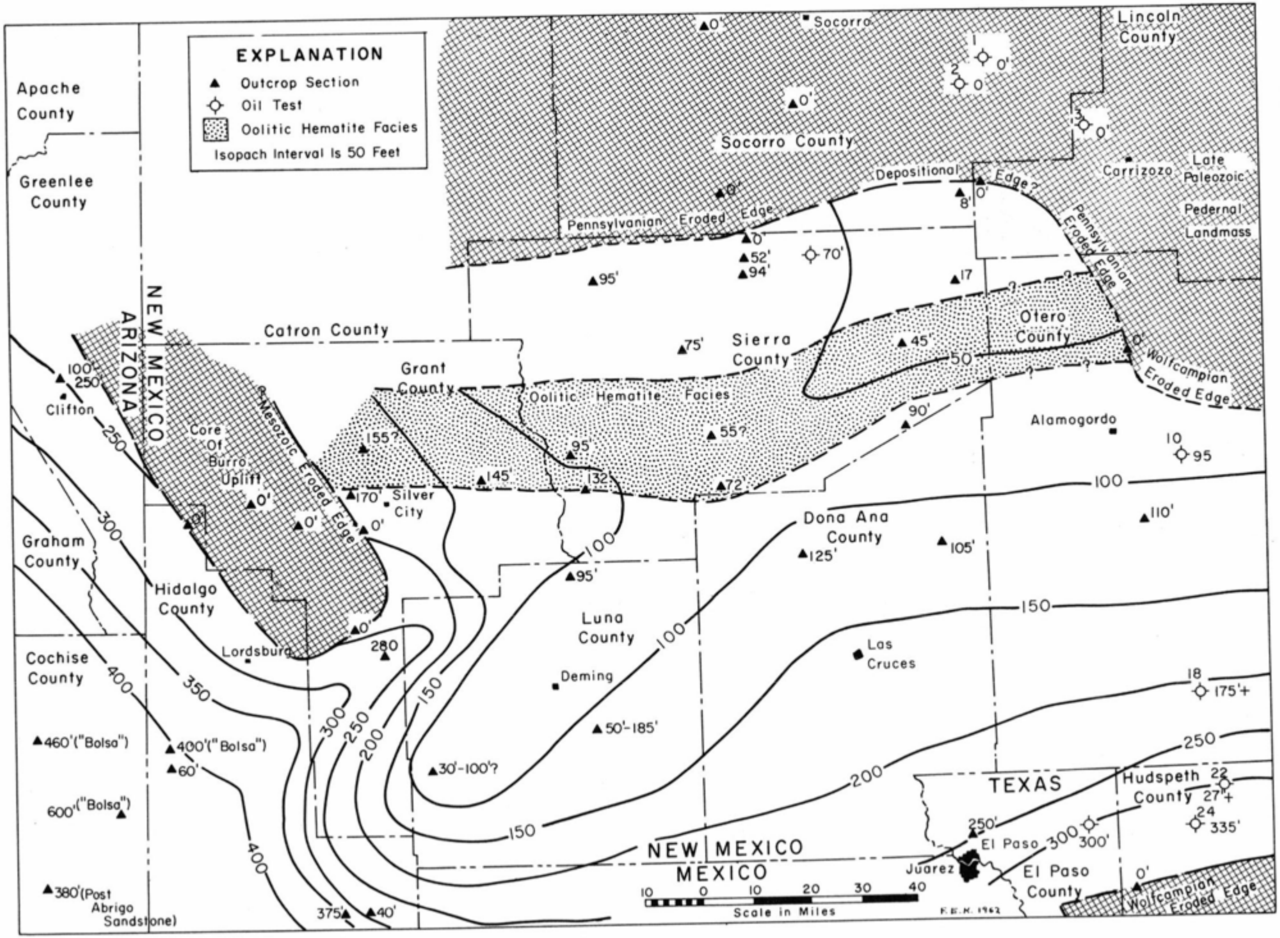

Figure 3

ISOPACH AND FACIES MAP OF THE BLISS SANDSTONE IN SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO off a northwest-trending positive feature, Elston's (1958) Burro uplift, during early and middle Mesozoic time. Near the New Mexico—Arizona state line is a transition zone where the Bliss Sandstone, as shown by Epis and Gilbert (1957), appears to grade westward from a thick sandstone into a tripartite sequence of an upper sandstone, the middle Abrigo Limestone, and the lower Bolsa Sandstone. The 400-foot-thick "Bliss" or "Bolsa" (Gillerman) of the central Peloncillo Mountains and eastern Chiricahua Mountains is probably of both Late and Middle Cambrian age and grades southwestward into the threefold sequence in the Pedregosa Mountains of an upper 380-foot-thick sandstone, a middle 400-foot-thick Abrigo Limestone, and a lower 520-foot-thick Bolsa Quartzite (Epis, 1958). To the north near Clifton, the Coronado Quartzite, 100 to 250 feet thick, is a partial equivalent of the western New Mexico Bliss Sandstone and suggests a western limit to the Burro uplift of Mesozoic age.

As shown on the isopach map, Figure 3, this basal Paleozoic sandstone blanket thickens to the southwest toward southeastern Arizona where, however, it includes deposits of Middle and Late Cambrian time. A southwest-trending "ridge" of thin sandstone is outlined by sections in the Klondike Hills, Cooks Peak, Florida Mountains, Caballo Mountains, and Rhodes Canyon. This positive-tending area may divide an older, basal Paleozoic sandstone on the west from a younger Bliss Sandstone on the east. Along the eastern border of the region, the Bliss Sandstone thickens southward, and much of the upper part of the arenaceous unit is of early Ordovician age. The oolitic hematite facies, as shown by Kelley (1951), is an east-west belt that appears to parallel an east-westtrending shoreline which was tens or scores of miles to the north.

The northern zero line appears to be a depositional edge in the southern Oscura Mountains. Just west of Sierra Blanca and along the southern margin of the San Mateo Mountains, this edge is due to erosion during Pennsylvanian time, whereas northeast of Alamogordo the older Paleozoic rocks were stripped off by erosion during both Pennsylvanian and Early Permian times. Lochman Balk (1956, pl. 6) showed most of New Mexico as part of the "Sierra Grande" landmass during Late Cambrian time; she recognized Cambrian deposits only in the northwest and southwest corners of the State. In southwestern New Mexico, the Cambrian is shown as confined west of the Rio Grande except in the Caballo Mountains and San Diego Mountain (northwest of the Dona Ana Mountains). If all the Bliss Sandstone east of the Rio Grande is of Ordovician age, Lochman Balk's depiction is correct; however, there is no indication of a north-south shoreline facies near the Rio Grande Valley, and there is the possibility that the barren, lower two thirds of the Bliss Sandstone is of Late Cambrian age. Locally, the Bliss Sandstone was removed by erosion during Early Permian time from the southern Otero County area, but it is a persistent unit to the east in the Delaware Basin.

EL PASO LIMESTONE

The El Paso Limestone, named by Richardson for exposures in the southern Franklin Mountains near El Paso, is of Early Ordovician, Canadian age. The formation has been raised to a group by Kelley and Silver on a bipartite lithologic basis, and by Flower *(in* Kottlowski et al.; Flower, 1953b, 1959), based on his numerous faunal zones. Locally, where the beds dip steeply, the El Paso can be mapped as at least two separate units roughly corresponding to Kelley and Silver's Sierrite (below) and Bat Cave (above) formations. For most areal mapping and stratigraphic studies, however, it is convenient to consider the El Paso as a single complex lithic unit. Flower's (1959) faunal zones, which he believes to be still tentative in some respects, are useful for regional correlations. His continuing faunal studies will give a more accurate and more detailed regional synopsis of the El Paso Limestone than can be presented by the writer.

Flower's zones, based on extensive collecting during the past ten years, are (1) basal Sierrite limestones of Gasconadian age; (2) *Kainella* zone, present only in southwesternmost New Mexico, of latest Early Canadian age; (3) Middle Canadian rocks consisting of (a) first endoceroid zone, (b) first piloceroid zone, (c) oolite zone, (d) *Orospira* zone, and (e) gastropod zone; and (4) Late Canadian beds chiefly in the second piloceroid zone. This latter zone is the highest remaining zone in much of south-central New Mexico. In the Franklin Mountains, Cooks Peak, and Florida Mountains, Flower (1959) reported younger strata; near Cooks Peak, the second piloceroid zone is overlain by thin-bedded, relatively barren limestones and then by the third piloceroid zone; the even younger Fort Cassin faunal equivalent occurs as the uppermost El Paso Limestone in the Florida and Franklin mountains.

The limestones of the El Paso are varied and have been erratically and irregularly dolomitized. Blue-gray-weathering, gray, thin- to medium-bedded, silty limestone is most typical, with many beds marked by irregular reticulated silica flakes, laminae, and stringers and scattered small, flat, chert nodules. Variants include limestone-pebble conglomerates, lenses with crinkled silty laminae and patches, unbedded mound-like algal structures, pink and buff pellet beds, calcirudite, silty laminated calcilutite, gastropod-rich calcarenite, stromatolith and sponge reefs, arenaceous oolitic beds, and massive medium-crystalline limestone. Lower beds include arenaceous glauconitic calcarenites and interbeds of quartzose micaceous sandstone and glauconitic sandstone grading downward into the Bliss Sandstone.

The El Paso Limestone thickens southward by the addition of younger beds, the northern sections having been thinned by erosion during post-El Paso, pre-Montoya time. Actually, the isopach map (fig. 4) is somewhat complicated, and more information both from additional measured sections and future oil tests probably will show complex local

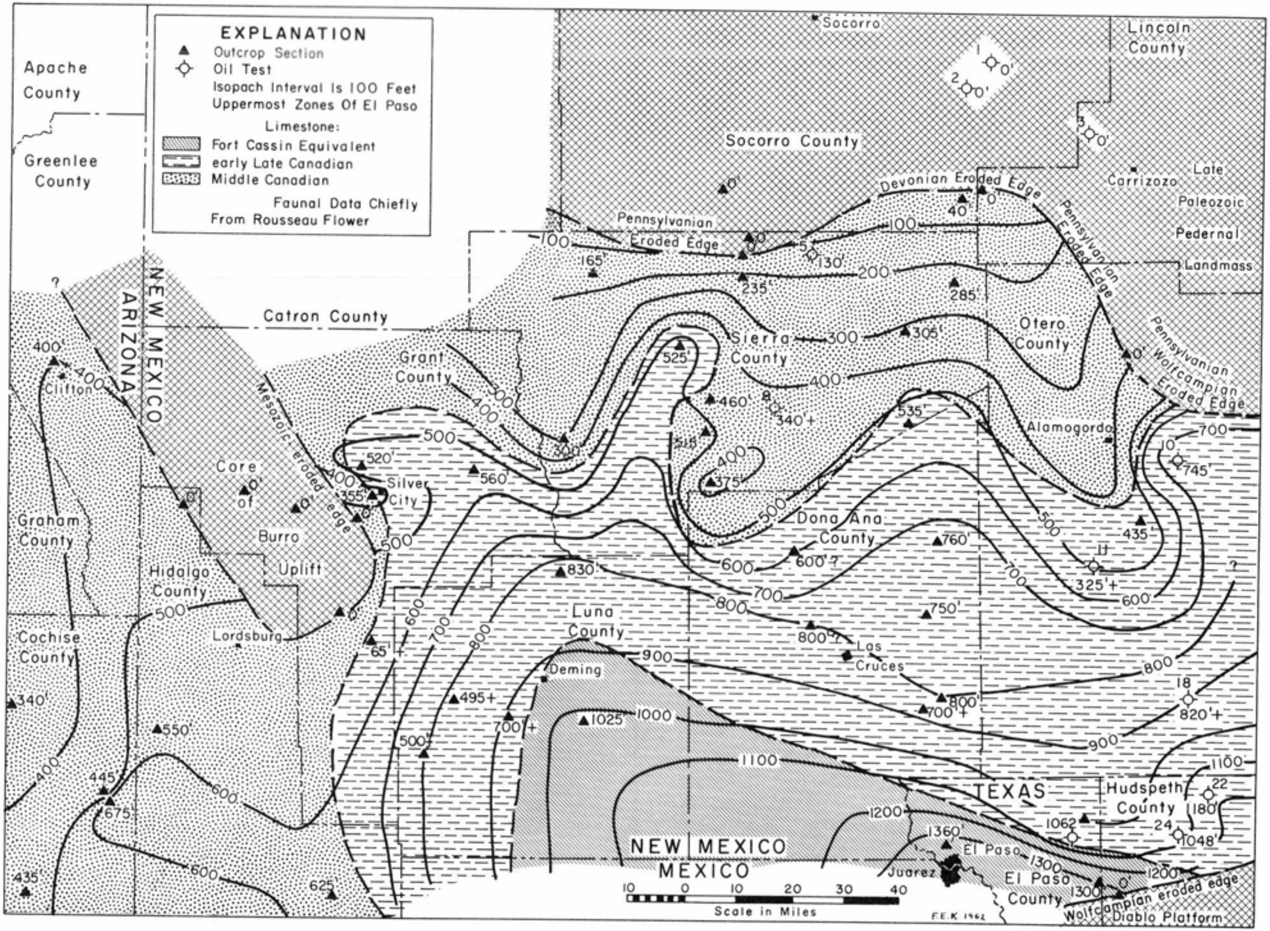

Figure 4

Isopach and zonal map of El Paso Limestone showing thickness and uppermost zones of El Paso beneath Montoya Dolomite in southwestern and south-central New Mexico variation. Evidence of northward depositional thinning is conflicting, the major part of this northward thinning being due to erosional truncation, as pointed out by Darton (1928), Kelley and Silver, Kottlowski et al., Howe, and others. This is best shown in the San Andres, Organ, and Franklin mountains. To the south in the southern Franklin Mountains, the El Paso Limestone is 1355 or 1590 feet thick (Cloud and Barnes, 1948) and includes very young Canadian beds, the Fort Cassin equivalent. Near Ash Canyon in the southern San Andres Mountains, the El Paso has thinned to 760 feet and uppermost beds are in the thin-bedded, relatively barren limestones between the second and third piloceroid zones. At Hembrillo Canyon, the limestone's thickness is 535 feet and erosion has cut down to the second piloceroid zone, whereas to the north at Rhodes Canyon and Sheep Mountain, thickness are 305 and 285 feet, respectively, and *Orospira* zone is the highest remnant. At Mockingbird Gap on the north end of the range, the basal Sierrite zone is only 40 feet thick and is unconformably overlain by Devonian rocks.

The northern zero line of the El Paso Limestone beneath the Montoya Dolomite is close to the truncated edge of the early Paleozoic strata beneath Pennsylvanian or Early Permian rocks. Near Mockingbird Gap, the edge is due to erosion during pre-Late Devonian time. To the east and west, the eroded edge underlies Pennsylvanian strata, whereas to the southeast, near Alamogordo, Wolfcampian beds overlie the early Paleozoic rocks. The El Paso Limestone was removed from the Burro uplift in western Grant County during early Mesozoic time, and the thick El Paso of westernmost Texas was eroded off the Diablo uplift southeast of El Paso during Early Permian time. Locally there are abrupt irregularities beneath the Montoya. On the east edge of the Chiricahua Mountains, Sabins (1957a) reported a southeastward increase in thickness of the El Paso Limestone from 445 feet to 675 feet in three miles. Near Silver City, Entwistle (1944) and Paige (1916), noted variations from 355 feet to 720(?) feet in thickness of the limestone between sections three to five miles apart. In the Mud Springs and Caballo mountains (Kelley and Silver), thicknesses of the El Paso range from 375 feet to 525 feet with no directional trend. Pray (1961) reported a thickness of 435 feet for his measured section of the El Paso Limestone from the southern Sacramento Mountains, whereas 14 miles to the *north-northeast(!)* the limestone is 745 feet thick in the Southern ProductionCloudcroft oil test.

The El Paso Limestone is thickest and includes its youngest faunas in the Franklin, Hueco, and Florida mountains. Cloud and Barnes measured about 1300 feet of the El Paso in the southern Hueco Mountains, and the oil tests to the north and northeast encountered thicknesses of 1048 to 1180 feet. In the northwestern Florida Mountains, Lochman Balk (1958) and the writer measured at least 1025 feet of the El Paso; the section is probably thicker, as some of the upper beds appear to be lost owing to faulting. The faunal zones exposed by pre-

Montoya erosion and the thicknesses of the remnant El Paso Limestone correspond closely; in general, Middle Canadian zones underlie the Montoya of south-central New Mexico in areas north of the 450- to 525-foot isopach lines (fig. 4). However, to the west, based on sparse faunal data, the Early and Middle Canadian zones appear to be thicker, perhaps more than 700 feet thick. In southeasternmost Arizona, Sabins (1957a) and Epis and Gilbert have found sparse faunal evidence that the lower El Paso Limestone in that area is of late Cambrian age. The youngest faunas, the Fort Cassin equivalent, occur only in sections where the El Paso is more than 1000 feet thick.

The El Paso Limestone is similar in many lithologic details to its partial equivalent, the Ellenburger Group, and the El Paso should have similar petroleum potentialities. The underlying Bliss Sandstone is locally porous and in places may be a petroleum reservoir rock.

MONTOYA DOLOMITE

The Montoya Dolomite has been extensively studied in recent years and Flower's continuing investigations of the faunas will lead to a more detailed regional interpretation of the unit. The studies have resulted in a varied and somewhat bewildering hash of terminology which is concisely summarized by Pratt and Jones; their usage of the Montoya as a mappable formation is followed by the writer. The various lithic and faunal divisions are considered to be members or zones, even though they have been raised to formational rank by Kelley and Silver, Flower (1959), Howe, and others. Not only, to quote Flower (1959), do "we have more than an abundance of names for these units," but there also is disagreement as to the lithology of the units. The Upham Dolomite of Kelley and Silver is the Upham Limestone of Howe; the Cutter Formation of Kelley and Silver is correlative with the Cutter Dolomite of Howe and the Valmont Dolomite of Pray (1961). Except for basal sandstones, the Montoya appears to have been deposited as a limestone but has since been irregularly dolomitized. About 50 percent of the Montoya is limestone in parts of Cooks Peak and the Hueco Mountains, but in most other areas dolomite dominates.

Extreme lithic lateral variation is shown by sections measured near Cooks Peak. Jicha, in the SE1/4, sec. 11, T. 20 S., R. 9 W., measured 190 feet of the Aleman Member and 47 feet of the Upham Dolomite; the Aleman includes 151 feet of dolomite and 39 feet of dolomitic limestone, the Upham 25 feet of dolomite and 22 feet of limestone with some dolomite interbeds. Howe measured 91 feet of the Upham Member and 122 feet of the Aleman; both units are shown (Howe, fig. 27) to be completely limestone. Howe's section was measured within a mile of Jicha's section and illustrates an unusual amount of lateral variation.

In most parts of south-central and southwestern New Mexico, except near the Montoya type section in the southern Franklin Mountains, the

Montoya Dolomite has a distinct basal sandstone, the Cable Canyon Sandstone Member. Only scattered quartz sand occurs at the base in the Franklin and Hueco mountains, but this dolomitic-calcareous sandstone is as much as 21 feet thick in Ash Canyon, 35 feet thick in the Caballo Mountains (Kelley and Silver), more than 30 feet thick near Cooks Peak (Jicha; Howe), and as much as 28 feet thick in the Silver City region (Pratt and Jones). The contact with the overlying Upham Dolomite locally has been reported as abrupt, but most exposures show an upward gradation into arenaceous dolomite and then into the massive Upham Dolomite.

The contact with the underlying El Paso Limestone is deceptively sharp and parallel, especially in westernmost Texas where the Cable Canyon Sandstone or basal arenaceous dolomite of the Upham overlies younger El Paso Limestones. To the north, in the Caballo and San Andres mountains, pebbly lenses occur at the base of the sandstone, and in places karst topography appears to have been developed prior to deposition of the Montoya.

The sandstone in most localities is light to medium gray, weathers moderate to dark grayish brown, is massive to thick-bedded and locally cross-laminated. Grains are angular to well rounded, averaging 1 to 2 mm but ranging up to 30 mm in diameter. The grains are dominantly clear quartz, with minor amounts of smoky, brown, blue-gray, and purple quartz, as well as scattered white feldspars and black or light brown chert. Scattered rounded grains of the El Paso Limestones also occur. Basal sandy beds of the Upham Dolomite are arenaceous, dolomitized, coquinoid calcarenites where the Upham overlies the Cable Canyon Sandstone and in much of the rest of the region where the Cable Canyon is absent. The only Montoya outcrops that lack a prominent basal sandy phase are in westernmost Texas.

Thicknesses of the Cable Canyon Sandstone vary greatly laterally; for example, Pratt and Jones noted a range of 2 to 16 feet within the small exposure on Lone Mountain about seven miles southeast of Silver City. Lateral and vertical gradation into arenaceous dolomite is complex, the sandstone merely being a basal arenaceous phase of the Upham Dolomite. In some areas, dolomitic sandstone or arenaceous dolomite locally appear higher in the Upham and above relatively pure dolomites. Plotted thicknesses of the sandstone (fig. 5) show thinning to the east, southeast, and west; thicknesses in excess of 20 feet occur in the central part of the area, southeast of the "unknown" Paleozoic strata buried beneath the Datil—Mogollon volcanic plateau. If the thicker sections are nearer the source of the Cable Canyon sands, that source lay to the northwest. Comparison of the sandstone isopach map (fig. 5) and the El Paso isopach map (fig. 4) suggests that the thicker lenses of the Cable Canyon Sandstone may also be related to deeper erosion of the underlying El Paso Limestone in such areas as near Kingston and in the southwestern Caballo Mountains.

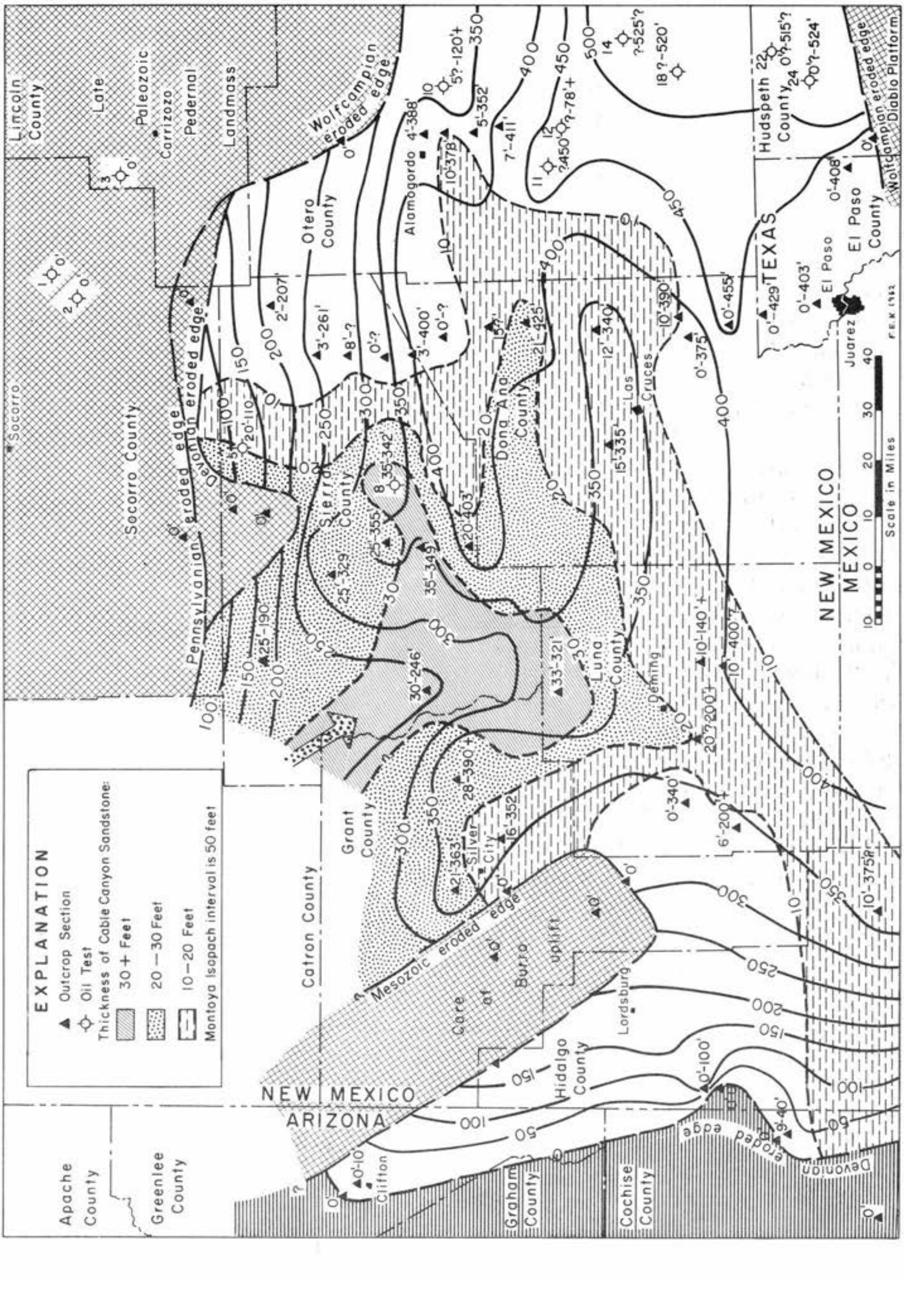

Figure 5

Isopach Map of Montoya Dolomite and Cable Canyon Sandstone in Southwestern and South-Central New Mexico

The Cable Canyon Sandstone and arenaceous beds of the Upham Dolomite are marine clastic rocks deposited in a shallow sea apparently south and southeast of a low positive area. The small amount of debris from the upland was washed relatively free of clay and nonresistant minerals; the erratic thickness distribution of the quartz sand suggests filling of shallow depressions and a scattering of low islands. Flower (1959) has suggested that scattered basal Cable Canyon or arenaceous Upham lenses of light gray, friable, saccharoidal, unfossiliferous sandstone, in most places less than two feet thick, are similar to and an equivalent of the Harding Sandstone of Colorado. Other geologists have noted the similarity of the Cable Canyon facies to some of the Simpson sandstones in the southeastern New Mexico and west Texas subsurface. The Cable Canyon may be a simple washed residuum of early Montoya time or, as Flower believed (1959), a complex of several marine sands.

The overlying Upham Dolomite is gray to dark gray, medium crystalline, and massive. Prior to recrystallization and dolomitization, it appears to have been a crinoidal calcarenite. Southward in the Robledo Mountains, Bishop Cap, and Franklin and Hueco mountains (Richardson; Pray, 1958; Howe), the amount of mottled carbonate-rock increases, the beds being composed of dark patches of dolomite in a medium gray matrix of dolomitic limestone and limestone, Howe's lithology A. Locally, as near Cooks Peak, limestone is the dominant lithology. The Upham Dolomite is rather constant in thickness (Kottlowski, 1957, fig. 2), being about 70 to 110 feet thick in most of the region except where it has been thinned by post-Montoya erosion.

Apparently gradationally above the Upham is the Aleman cherty Dolomite Member. It is a medium gray, finely to medium-crystalline dolomite, with some lenses of calci-dolomite, and is marked by numerous chert nodules, discontinuous chert bands, chert flakes, and some silicified fossils. Some of the beds are laminated, the bedding ranging from thin to massive. The Aleman also is reported to be mainly limestone in some localities. The thicknesses range erratically from 70 feet to more than 200 feet. This variation is probably due to varying chertification of the underlying Upham and overlying Cutter Member, rather than being the result of areal differences in deposition. Howe has correlated distinctive chert zones in the Aleman from his studies in the Franklin and Hueco mountains, Bishop Cap, and Cooks Peak; however, this is correlation among scattered outcrops and not a "tracing for a distance of at least 200 miles." Relatively continuous outcrops of the Montoya even in the San Andres Mountains, the longest range in the region, cover a distance of only 80 miles.

The upper member of the Montoya Dolomite is the Cutter Formation (Kelley and Silver) or Valmont Dolomite (Pray, 1953). This Cutter Dolomite Member is chiefly of light gray, aphanitic to finely crystalline dolomite with scattered, small, brown chert nodules and stringers. Bedding in most localities is mainly thin to medium but is massive in the

Silver City area (Pratt and Jones). The unit is relatively uniform in overall thickness, ranging from about 150 to 210 feet where not thinned by post-Montoya erosion. Locally, thicknesses of only 50 to 90 feet are reported (Jicha), but in most of these areas the underlying Aleman Dolomite Member is unusually thick. The Cutter Member thins abruptly along the northern edge of the Montoya outcrop chiefly because of erosion in post-Fusselman, pre-Onate time; that is, the period from late Silurian into middle Devonian time.

The Montoya has been divided into three faunal units by Flower (1959): (1) his basal remnant lenses of sandstone equivalent to the Harding Sandstone; (2) beds of Red River age, the Cable Canyon Sandstone and Upham Dolomite or the Second Value Member of Entwistle, which are age equivalents of the Cobourg (latest Trenton) and Eden (earliest Cincinnatian) of the eastern United States; and (3) beds of Richmond age, the Aleman and Cutter Dolomites. Flower (1959) envisioned uplift and erosion of the entire region prior to deposition of the Red River beds, and similar elevation and erosion of the Red River zone before the return of the Richmond age seas. The Aleman and Cutter Members have been subdivided by Flower (1959) into zones based on individual index fossils or faunules.

The isopach map of the Montoya Dolomite (fig. 5) shows many of the elements that also affected deposition and preservation of the Bliss and El Paso Formations; for example, the northeastward and southeastward eroded edges of early Wolfcampian time, the northward one of early Pennsylvanian time, and the Burro uplift of Mesozoic time. Erosion occurring during late Silurian and early Devonian time truncated the Montoya Dolomite in the southern Socorro County area and along the southwest border of the region near the New Mexico—Arizona state line. Devonian strata are unconformable on the Montoya west of Luna County and in northern Sierra and northern Otero counties. Remnants of the Montoya occur northeast of Clifton, near Portal in the eastern Chiricahua Mountains, and locally in the Peloncillo Mountains in the southwestern part of the region. Some of the abrupt and varied erosional relief near Hidalgo County is due to channeling in early Silurian time, prior to deposition of the Fusselman Dolomite; for example, in the Victorio Mountains, the relief on the top of the Montoya beneath the Fusselman is about 70 feet vertically within a thousand feet horizontally. Thinning of the Montoya to the west is due mainly to erosion during late Silurian and early Devonian time. The southward thickening of the dolomite from 350 to 400 feet in southeastern Sierra County to 500 feet in the subsurface of the Cornudas Mountains area appears to be chiefly depositional. The east-west-trending area of thin Montoya in northern Luna County and central Dona Ana County, where the dolomite is only 320 to 340 feet thick, may be related to pre-Fusselman erosion.

Locally, the Cable Canyon Sandstone and the Upham Dolomite are porous. In most areas the Aleman and Cutter Dolomites, by contrast, are tight and do not appear to be good reservoir rocks unless secondary porosity has been developed in places beneath post-Montoya erosion surfaces. For correlation purposes, the Cable Canyon Sandstone is the most easily identified subsurface marker within the lower Paleozoic carbonate-rock sequence.

FUSSELMAN DOLOMITE

The Fusselman Dolomite is aphanitic to coarsely crystalline, grayish brown to dark gray, massive, and weathers light brown to dark yellowish brown. Most of the bedding has been destroyed by dolomitization but indistinct thin bedding, laminations, and local cross-laminations occur. Locally, secondary porosity is well developed. In some sections, such as in the Silver City area, Franklin Mountains, and Florida Mountains, chert is sparse or absent, but in other areas, such as the Robledo Mountains, chert comprises as much as 15 percent of the dolomite. Most of the fossils are obscured by recrystallization, but scattered pentameroid brachiopods, corals, and sparse gastropods are reported. Most of the faunas that have been collected suggest a Niagaran, Middle Silurian age. From the lower part of the dolomite in the Sacramento Mountains, however, Pray (1953) and Arthur L. Bowsher collected fossils that they regarded as Alexandrian, Early Silurian in age; a similar early Silurian zone may be present in the Franklin Mountains area. As Flower (1959) has noted, "alteration of original lithologies, destruction of many fossils and poor preservation of many others, make evaluatin of the Fusselman extremely difficult, and at present the task is far from adequately accomplished."

The Fusselman Dolomite thins northward in a remarkably uniform pattern, and unconformably underlies Devonian strata (fig. 6). The northward thinning is due mainly to post-Fusselman erosion, but in part the southward thickening corresponds to a thickening of lower beds that may be of Early Silurian age. In the San Andres Mountains, there is a gradual southward increase in thickness of two to three feet a mile, from a knife-edge to 125 feet near Ash Canyon, but southward in the Organ Mountains, Bishop Cap, and Franklin Mountains the thickness increases 17 to 20 feet a mile to more than 850 feet (Pray, 1953). The thicknesses are erratic in the Caballo Mountains area (Kelley and Silver) but there is a general southward and southeastward increase; westward, the Fusselman is 15 to 85 feet thick in the Black Range (Kuellmer) and Sierra Cuchillo (Jahns, 1955) and 150 to 295 feet thick in the Silver City region (Pratt and Jones). The Fusselman was cut out by erosion during early Mesozoic time in the Burro uplift area; however, just 20 miles southeast of this Mesozoic-age uplift, in the Victorio Mountains (Kottlowski, 1960b, p1. 13), the Fusselman Dolomite is more than 900 feet thick, and in the Florida Mountains perhaps 1000 to 1400

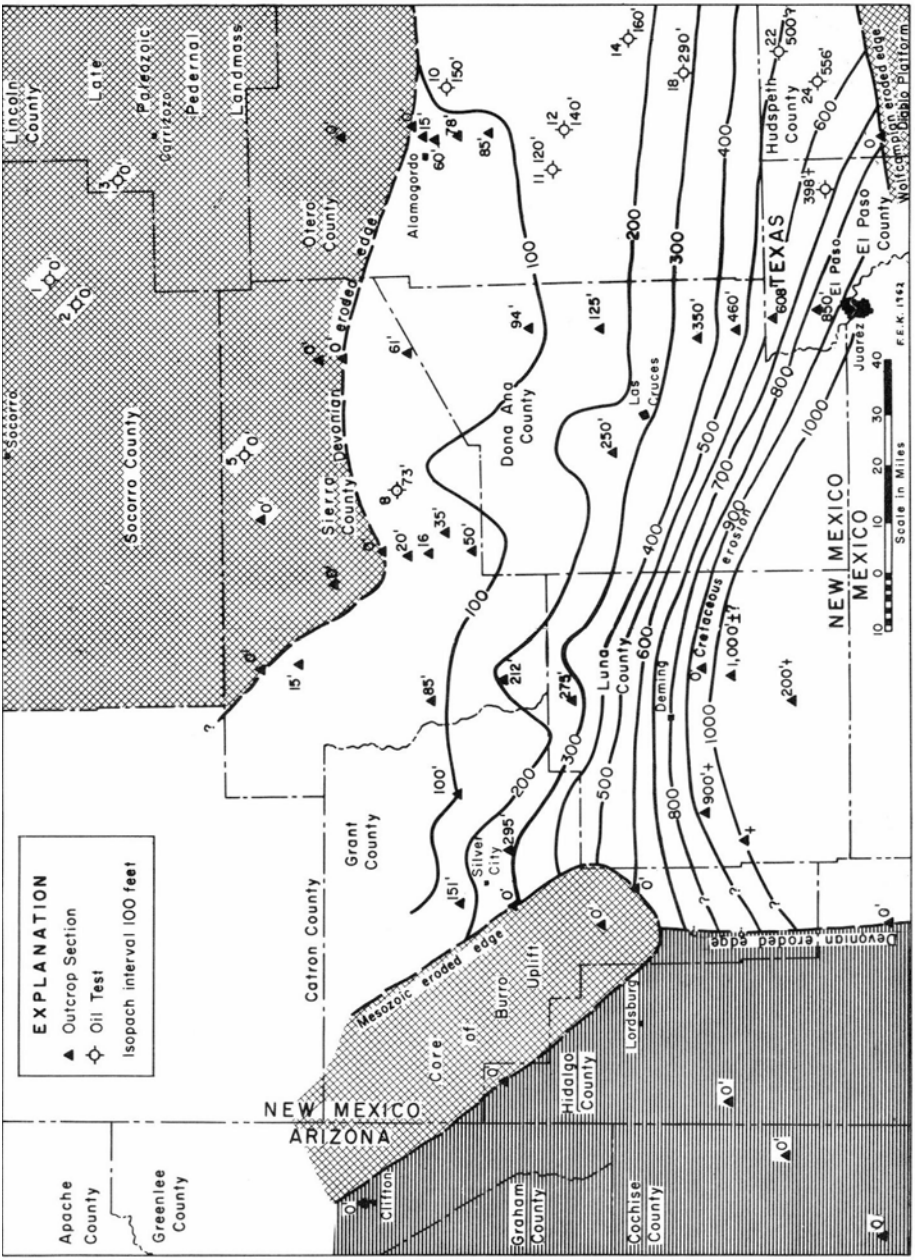

Figure 6

Isopach map of Fusselman Dolomite in southwestern and south-central New Mexico feet thick (Kelley and Bogart, 1952). The rocks of the latter range are cut by many thrust faults which may make it impossible to obtain a true thickness of the uniform thick unfossiliferous Fusselman Dolomite. To the southwest, the Fusselman is absent or thin (30 feet thick ?) in the Big Hatchet Mountains (Zeller, 1958). In southern Luna County, the Fusselman Dolomite is probably thick as judged from fault slices of the unit in the Tres Hermanas Mountains (Kottlowski and Foster).

The Fusselman Dolomite appears to have been abruptly truncated by erosion during late Silurian and early Devonian time along a north-south-trending eroded edge west of the Victorio, Cedar, and Big Hatchet mountains—parallel with westward thinning of the underlying Montoya Dolomite (fig. 5). The isopach lines may actually swing around sharply to the south in the southern Grant and eastern Hidalgo counties area rather than being cut off by the suggested north-south eroded edge shown in Figure 6.

The 212- to 250-foot-thick sections of Cooks Peak (Jicha) and the Robledo Mountains (Kottlowski, 1960a) areas suggest undulations in the east- and east-southeast-trending isopach lines of south-central New Mexico. Pray (1961) reported eastward thinning in the Sacramento Mountains, but the section penetrated in the Southern ProductionCloudcroft oil test is thicker than outcrop sections to the west. Sparse data from scattered oil tests in Hudspeth County, Texas, suggest an abrupt truncation of the Fusselman during early Wolfcampian time on the northwest edge of the Diablo uplift.

In the southern part of the area, the Fusselman may underlie Devonian strata with relative conformity. Throughout most of the region, however, the Fusselman is erosionally unconformable or disconformable beneath the Devonian; in many areas, the upper few feet of the Fusselman is silicified and iron-stained. The actual contact is not exposed at most places, but where debris from the shaly Devonian beds has been removed, the top of the dolomite is an undulating, knobby, ridged and channeled, silicified surface, with relief of at least several inches. This erosional surface was formed during late Silurian and Early and middle Devonian time; regionally, it bevels the Fusselman Dolomite, Montoya Dolomite, El Paso Limestone, and Bliss Sandstone, south to north, in the San Andres Mountains and other north-southtrending ranges.

DEVON IAN STRATA

As noted by Dunham (1935) and others, the Devonian beds mark a change in the sedimentary history of the region, being the first Paleozoic unit composed mainly of clays and silts. This argillaceous Devonian sequence is relatively thin, but forms a widespread blanket of lithified calcareous mud overlapping older Paleozoic rocks. The beds in most localities are covered on the steep slope between underlying Silurian or Ordovician dolomites and the overlying Mississippian strata. Actual outcrops may be miles apart, and only in a few places can the individual beds be traced more than a few tens of feet laterally. Where exposed, most of the Devonian beds are fossiliferous, so that numerous formational names have been applied to thin lithic-faunal units. How much the variation of the faunas is due to facies control is not known. As noted above, the lower contact is on a pronounced erosion surface carved during late Silurian and Early and middle Devonian time, the surface truncating northward all pre-Devonian strata. The contact with the overlying Mississippian beds appears to be one of slight erosion but not much angular unconformity; locally, the contact between uppermost shaly Devonian strata and the argillaceous limestones of the Early Mississippian Caballero Formation appears almost gradational.

In the San Andres Mountains (Kottlowski, 1959; Flower *in* Kottlowski et al.), the Devonian units are, in ascending order, the Onate Formation, Sly Gap Formation, Contadero Formation, and faunal equivalents of the Three Forks Shale of Montana. The Onate Formation is dominantly dolomitic siltstone, with lenses of tan silty dolomite. Thicknesses average 15 to 32 feet, except for the thick type section (Stevenson) of 86 feet in San Andres Canyon and southward, thinning to about ten feet at Ash Canyon. Pronounced local variations are the rule, as near Rhodes Canyon where thicknesses vary from 9 to 32 feet chiefly because of filling of low spots on the pre-Onate surface. There is an upward lithic transition into the overlying Sly Gap beds, and there may be a similar lateral transition, with the Onate being merely a basal facies of the Sly Gap. Flower (1959) noted that the Onate Formation is either latest Middle or earliest Upper Devonian in age.

The Sly Gap Formation consists of alternating fossiliferous limy silty shales, silty limestone, and limy siltstone, yellowish gray to dark gray, in thin lenticular beds. Thicknesses range from 30 to 75 feet with the thicker sections in the southern part of the San Andres Mountains. Southward also, there appears to be a gradational facies change from the calcareous, shaly Sly Gap beds of the type section on Sheep Mountain into dark gray to black fissile shale—the latter lithologically similar to the lower Ready Pay Member of the Percha Shale near the Black Range. The prolific Sly Gap fauna is of early Late Devonian age.

The Contadero Formation, as restricted by Flower *(in* Kottlowski et al.; Flower, 1959) at its type section in Rhodes Canyon (Stevenson), consists of dark gray to pale olive, fissile silty shale, interbedded with gray to dark brownish gray siltstone, and an upper nodular silty coral-bearing limestone. The unit is 20 to 45 feet thick in the northern part of the mountains near Rhodes Canyon but is believed to be absent in Hembrillo and Ash canyons. Contact relations and faunas suggest only a minor sedimentation break, if any, with the underlying Sly Gap beds.

Strata above the Contadero on Sheep Mountain and in Rhodes Canyon, and overlying the Sly Gap beds in Hembrillo Canyon, bear a fauna similar to that of the Three Forks Shale of Montana and have therefore been placed in two provisionally named units by Flower (1959). The older unit, the "Thoroughgood" formation, consists of tan, blocky, silty, fine-grained sandstone and shaly calcareous siltstone and thins from 12 feet on Sheep Mountain to 6 to 24 inches in Rhodes Canyon. The younger unit, the "Rhodes Canyon" formation, is made up of 50 feet of interbedded light to dark gray, silty, fissile shale and dark gray to brownish gray micaceous siltstone with some thin, tan, channel-fill sandstone beds in Hembrillo Canyon, and 75 feet of pale to dark olive-gray, calcareous, silty, micaceous shale with a few lenses of gray or olive-gray, calcareous, micaceous siltstone in Rhodes Canyon. The younger unit is missing on Sheep Mountain where Mississippian strata rest on the older "Three Forks" beds; southward, the younger unit may grade laterally into the Sly Gap beds in Ash Canyon, the dark shales of lower Percha Shale aspect.

Total thicknesses of the Devonian beds appear to thin both north and south from Rhodes Canyon (185 feet) to 105 feet on Sheep Mountain and to 85 feet in Ash Canyon. This thinning appears due both to (1) mild truncation prior to deposition of Mississippian rocks and (2) local basinal deposition.

The Percha Shale is typically developed west of the San Andres Mountains in the Black Range and Silver City area. Stevenson divided it into two members, the lower Ready Pay Member of black unfossiliferous shale which appears to grade upward into the Box Member of greenish dark gray shale with limy nodules and some argillaceous fossiliferous limestone beds. The prolific Percha brachiopod fauna is almost exclusively from the upper Box Member and is of late, possibly latest, Devonian age (Flower, 1959). The Onate, Sly Gap, Contadero, and Three Forks beds are older than the Box Member of the Percha Shale and appear to be preserved, or originally deposited, largely in the San Andres and Sacramento mountains area. The sections in the San Andres Mountains suggest a southward facies change from the above-listed pre-Box Member calcareous units into a black shale indistinguishable from the Ready Pay Member of the Percha. Flower (1959) reported a similar southward transition near Hermosa where 43 feet of Onate overlain by 25 feet of Sly Gap grade southward into black shale within one-eighth mile; the Sly Gap, however, is overlain by 130 feet of Percha Shale with both members represented. Lithic-faunal equivalents of the Onate and Sly Gap appear to be present (fig. 7) in the Hermosa area and Mud Springs, Caballo, San Andres, and Sacramento mountains; they may correlate with the lower part of the Ready Pay Member of the Percha Shale to the south and west, and are overlain by at least part of the Ready

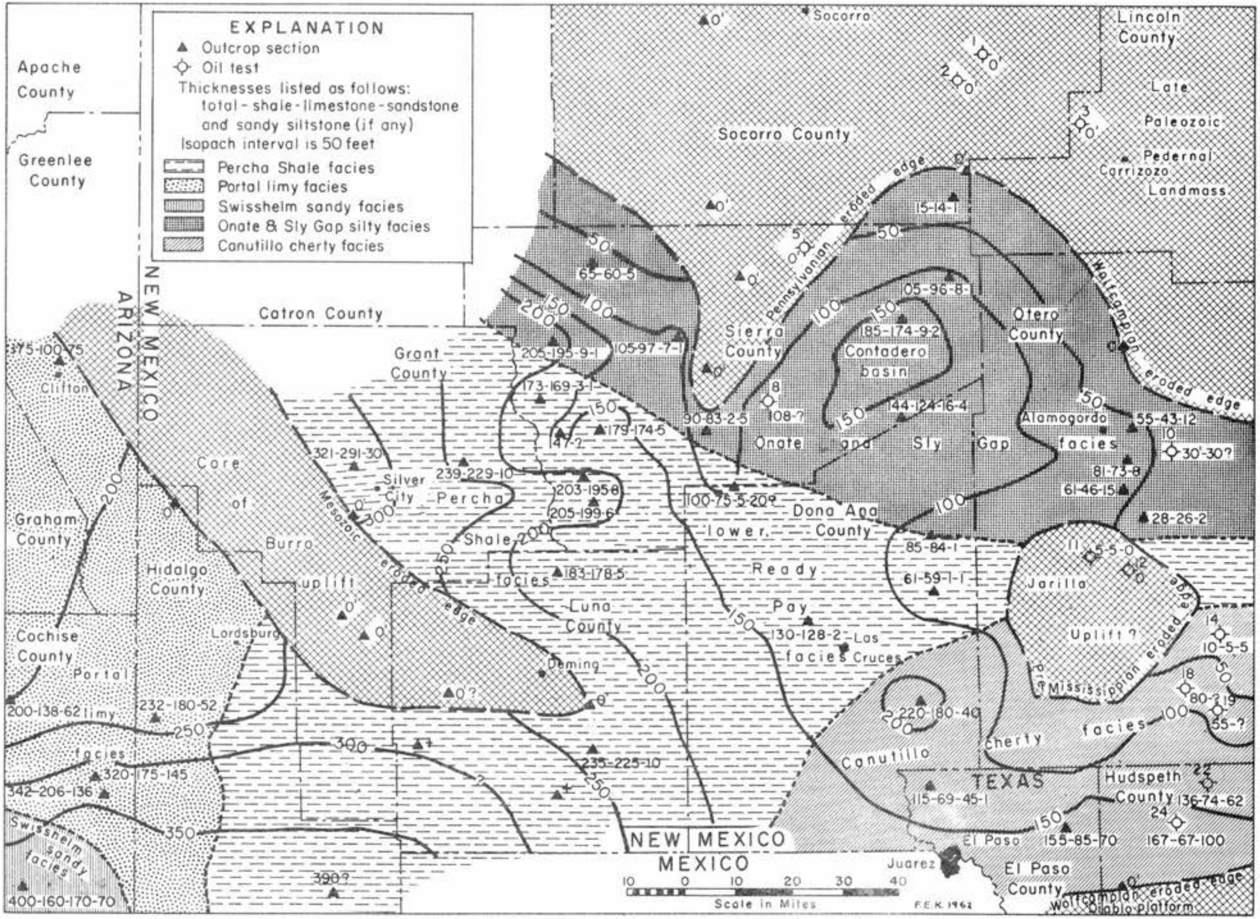

Figure 7

ISOPACH AND FACIES MAP OF DEVONIAN STRATA IN SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO

Pay Member in the areas south and west of the northern and central San Andres and Sacramento mountains.

The Contadero and Three Forks beds appear to be limited to the northern and central San Andres Mountains with a possible thin extension into Alamo Canyon in the Sacramento Mountains near Alamogordo. Their unfossiliferous equivalents may be present in the middle of the Ready Pay Member.

Pray (1961) reported that the Onate Formation persists throughout the Sacramento Mountains but that the Sly Gap is restricted to the northern and central parts of the range, whereas the Percha Shale is limited chiefly to the southern outcrops. Thicknesses of the total Devonian appear to range from 25 feet to 100 feet with southward thinning. Sparse data from oil tests south of the Sacramento Mountains outcrops show the Devonian to be thin or absent in the Jarilla Mountains area. Pray (oral communication, 1956) reported only five feet of dark shales from the Plymouth—Evans oil test (fig. 1, no. 11), and the Mississippian Rancheria Formation appears to rest on the Fusselman Dolomite in the Sun—Pearson oil test (fig. 1, no. 12). About ten feet of dark shale and underlying cherty limestone occur between Pennsylvanian rocks and the Fusselman Dolomite in the Turner—Everett oil test (fig. 1, no. 14).

Kelley and Silver reported a rather erratic variation in thickness and lithology of their Percha Formation in the Caballo and Mud Springs mountains; locally at least it includes faunal zones of the Onate and Sly Gap formations and of the type Percha Shale. They found 4 to 20 feet of fine-grained, pale-red sandstone in the upper part of the formation in the southern part of the range and correlated these silty arenaceous beds with upper sandstones in the northern San Andres Mountains, at and north of Sheep Mountain. The Sheep Mountain sandstones are very silty and can be called sandy siltstones; moreover, they are amid the "Three Forks" beds, and are older than the southern Caballo Mountains sandstones which are in beds containing a Percha fauna. Locally, erosion prior to depositon of early Pennsylvanian rocks stripped off the Mississippian and part of the Devonian strata in the Caballo Mountains, and Kelley and Silver's (their fig. 2) geologic map shows the Devonian to be absent in the northern part of the range.

The type section of the Percha Shale is near Hillsboro where Steveson measured 132 feet of the lower black fissile shale in the Ready Pay Member and 47 feet of fossiliferous gray calcareous shale with interbeds and nodules of gray limestone as the upper Box Member. Most of the sections in the Black Range and Cooks Peak area range from 173 to 205 feet in thickness (Laudon and Bowsher), although Kuellmer measured only 147 feet in the much faulted sections near Kingston. Westward near Santa Rita and Silver City, the Percha Shale is 239 to 321 feet thick, and the Box Member includes some thick limestone beds. Southward, poorly exposed Devonian dark shales with upper interbedded limestones occur in the southeastern Florida Mountains where they may be 235 feet thick (Bogart, 1953). The Devonian sequence is not exposed in the Tres Hermanas and Victorio mountains and only the upper few feet crop out in the Klondike Hills but it is probably present in the subsurface. Zeller (1958) reported almost 400 feet of the Percha Shale from parts of the Big Hatchet Mountains; Gillerman measured 232 feet of the Percha in the central Peloncillo Mountains where almost one fourth of the unit is limestone.

In southeasternmost Arizona, the Devonian beds have been given four different names, corresponding to four varied facies. Near Clifton, Lindgren (1905) named and mapped the Morenci Formation, consisting of a lower 75 feet of black aphanitic argillaceous limestone and an upper 100 feet of black fissile shale. Farther west (west of fig. 7) near Bisbee, Ransome (1904) defined the Martin Limestone as 340 feet of dark gray fossiliferous limestone with some interbeds of pinkish calcareous shale. For Devonian rocks in the Chiricahua Mountains, Sabins (1957a) named the Portal Formation; it is 200 to 342 feet thick and consists of four lithologic members: (1) a basal unit of thin-bedded, alternating olive calcareous shale and dark olive-gray shaly aphanitic limestone, (2) black siliceous fissile shale, (3) thin-bedded alternating olive shale and dark olive limestone, and (4) thick alternating beds of limestone and shale. Lithologically, the Portal Formation appears to be a limy phase of the Percha Shale of the Silver City area and a shaly phase of the Martin Limestone of the Bisbee area. Near Silver City the percentage of limestone in the Percha Shale increases threefold westward within 20 miles. From the sparse fauna, Sabins (1957a) concluded that the Portal Formation is correlative with the Sly Gap Formation and the Martin Limestone and that it is probably older than the Percha Shale (Box Member ?).

A few months later, Epis, Gilbert, and Langenheim (1957) named the Devonian strata in the Pedregosa and Swisshelm mountains, a few miles southwest of the Chiricahua Mountains, the Swisshelm Formation. This Devonian facies is dissimilar to the Martin Limestone facies to the west, the Chiricahua Mountains Portal facies, and the "eastern" (southwestern New Mexico) Percha Shale facies, the Swisshelm Formation differing in a dominance of sandstone and siltstone over carbonate rocks and shale. Amid the sandstones, siltstones, and arenaceous cherty limestones, bioherms of coral- and bryozoan-rich dolomite were found. In the Pedregosa Mountains, the basal beds (75 feet thick) are dolomitic sandstone and siltstone, lithologically similar to the Onate Formation and bearing a similar fauna; above are nodular fossiliferous limestones, yellow calcareous siltstone, and a thin lenticular dolomitic fine-grained sandstone (unit totals 200 feet in thickness), lithologies somewhat similar to that of the Sly Gap and Contadero formations and bearing a similar fauna. Upper beds (140 feet thick) are of interbedded, laminated, sandy calcarenite and thin beds of fine-grained sandstone; these clastic rocks grade upward into cherty, argillaceous limestone and calcarenite at the top of the formation.

The faunas in the lower and middle parts of the Swisshelm Formation appear to be of early Late Devonian age, correlative to those of the Onate, Sly Gap, Contadero, and "Three Forks" beds of the San Andres Mountains area; faunal equivalents of the upper Box Member of the Percha Shale may occur in the upper unfossiliferous beds of the Swisshelm. The writer concurs with the opinion of Epis, Gilbert, and Langenheim that the Percha Shale, Portal Formation, and Swisshelm Formation are different facies of essentially time-equivalent units.

The Canutillo Formation of westernmost Texas is more of an enigma. As defined by Nelson (1940) at the type locality in Vinton Canyon, west-central Franklin Mountains, the formation consists of lower light brown, cherty limestone; medial thin, gray, fossiliferous limestone overlain by a thin dark gray, brown-weathering sandstone (or sandy silt-stone) and upper black fissile shale. Thickness appears to range from 115 to 175 feet within short distances. G. H. Girty in a personal communication to Kirk called the fossils from the single fossiliferous bed "medial Devonian." Laudon and Bowsher believed the lower 42 feet of very cherty limestone to be probably Devonian in age, restricted the name *Canutillo* to the medial 15 feet of dark gray, calcareous, fossiliferous siltstone, and correlated the upper 57 feet of gray-black fissile shale with the Percha Shale. They noted that the medial unit, their restricted Canutillo, is lithologically identical with the Onate Formation. The brown-weathering fossiliferous sandstone and dark gray calcareous siltstones do appear to be similar to parts of the Onate as exposed in the southern San Andres Mountains.

Stevenson noted that the species of *Leiorhynchus* from the medial Canutillo is similar to a *Leiorhynchus* sp. which is very abundant in the type Onate Formation, and thus correlated that part of the Canutillo Formation with the Onate. Cooper et al. (1942), however, pointed out that the fauna may equal part of the Sly Gap fauna, and therefore would be of Late Devonian age.

From a regional viewpoint, the name *Canutillo* should be restricted to the lower cherty limestone which is of uncertain age. To the east in the Hueco Mountains, King and Knight (1945) measured 40 to 95 feet of this chert and limestone; interbeds of gray shale occur in **the** lower part. On Bishop Cap, Harbour (1960b) reported 40 feet of Canutillo (as restricted) cherty limestone. To the east, the lower half of the ten feet of Devonian in the Turner—Everett oil test (fig. 1, no. 14) is cherty limestone, as is 62 feet in the Magnolia No. 1-39881 oil test (fig. 1, no. 22) and 100 feet in the California—University Theisen well (fig. **1,** no. 24).

The upper shales of the Devonian in the Hueco Mountains area present another problem. They are sparsely fossiliferous, containing a fauna like that of the medial fossiliferous limy siltstone of the Franklin Mountains (Laudon and Bowsher), that is, Onate—Sly Gap equivalents. Dark gray fissile shale forms only a small part of the sequence which is mostly soft, calcareous, silty shale with lenses of silty limestone. These beds appear to be a sparsely fossiliferous equivalent of the Onate, Sly Gap, and Percha formations of the southern Sacramento Mountains, and a "gray" facies of the gray-black Percha Shale in the Franklin and Robledo mountains and at Bishop Cap. The unit is 60 to 105 feet thick in the Hueco Mountains and 65 to 75 feet thick in the two oil tests to the east. At Bishop Cap, the dark gray shales above the Canutillo cherts are 180 feet thick, and on Robledo Mountain about 130 feet thick.

As shown on the isopach map (fig. 7), the Devonian strata generally increase in thickness in a southwestward direction with thickest sections in the Pedregosa and Big Hatchet mountains, except for a thick section west of Silver City. The local thick sections in the northern San Andres Mountains appear to be due mainly to local basinal deposition of the Contadero Formation. The Pennsylvanian eroded edge along the northern border has a south-southwestward erosional prong into the central Caballo Mountains area, which extends 30 to 40 miles south of Devonian erosional remnants to the east and west. The eroded edge of the Mesozoic-age Burro uplift may have extended southeastward to the northwestern Florida Mountains and southward to the Victorio Mountains. A new positive element occurred in southwestern Otero County near the present Jarilla Mountains where the Devonian is thin or absent beneath Mississippian strata.

The silty facies of the Onate, Sly Gap, Contadero, and "Three Forks" (fig. 7) beds grades westward and southwestward into the black shales of the lower Ready Pay Member of the Percha Shale; in southern Dona Ana and southern Otero counties this Ready Pay facies may grade southward into the upper part of the Canutillo cherty facies, but most of this cherty unit appears to come in beneath the Ready Pay—Onate zone, thickens toward the southeast, and may be of Middle Devonian age.

The Percha black shale facies appears to grade westward into the Portal limy facies, and this limy unit grades southwestward into the Swisshelm sandy facies. The silty Onate, Sly Gap, Contadero, and "Three Forks" facies suggests deposition far from a shoreline to the north and northeast. The Percha black shale and Canutillo cherts were probably deposited in restricted stagnant basins; the Portal limy facies and the sands of the Swisshelm Formation suggest a shoreline near and south of the Pedregosa Mountains area. Three generalized faunal elements are present: a possible late Middle Devonian element in the unfossiliferous (as far as is known) Canutillo cherty limestones, the early Late Devonian faunas of the Sly Gap Formation and related beds, and the late Late Devonian faunas of the Box Member of the Percha. Sly Gap equivalents occur throughout the region wherever Devonian beds have been preserved from later erosion; correlatives of the Box Member were not deposited or were removed by later erosion from the northeast part of the region, and perhaps from the southwest margin.

The Swisshelm sandy facies may be related to an elevated area in southeastern Arizona that was exposed to erosion during late Silurian and early and middle Devonian time. This erosion stripped off much of the Ordovician and Silurian strata with the westward extent, the "eroded edge," of the El Paso being near the west border of Figure 4, the eroded edge of the Montoya (fig. 5) being near the New Mexico—Arizona state line, and the western eroded edge of the Fusselman Dolomite (fig. 6) being near the Big Hatchet and Little Hatchet mountains area.

MISSISSIPPIAN STRATA

The Mississippian of south-central New Mexico was adequately described by Laudon and Bowsher, although some detail has been added by more recent reports. Armstrong's (1962) work in southwestern New Mexico and Cochise County, Arizona, has completed coverage of the region, except for some details of local sections, and was correlated northward with his studies (Armstrong, 1958) in west-central New Mexico.

The Mississippian is the oldest Paleozoic system in southern New Mexico with remnants as far north as central Socorro County. In southern Socorro County and north-central Sierra County, the Pennsylvanian rests on older rocks down to the Precambrian. Jahns reported about 80 feet of Mississippian strata in the northern Sierra Cuchillo; these outcrops suggest the possibility that Mississippian beds may be present in the subsurface of southwestern Socorro County and may connect with the Mississippian rocks of the Magdalena Mountains and Coyote Hills.

Near the ghost mining town of Kelly in the northwestern Magdalena Mountains, the Mississippian as measured by Armstrong (1958) consists of the Caloso Formation of early Osage age, 35 feet of massive, light gray algal limestone with basal pebbly arenaceous limestone and limy sandstone; the overlying Kelly Limestone, of late Osage age, consists of 70 feet of gray massive crinoidal cherty limestone. In the Coyote Hills to the southeast, only 36 feet of the Caloso Formation remain beneath a local erosion surface cut during early Tertiary time. However, on the east side of the Rio Grande opposite Socorro, and on the southeast margin of the San Mateo Mountains, conglomeratic clastic beds of early Pennsylvanian age are unconformable on Precambrian rocks, the Mississippian strata having been removed by erosion during late Mississippian and early Pennsylvanian time.

In the Caballo Mountains, Kelley and Silver noted only scattered remnants of the Mississippian except near the southern tip of the range where the lower beds of the Lake Valley Limestone are about 60 feet thick. As Mississippian strata occur both to the west in the Black Range and to the east in the San Andres Mountains, the Fra Cristobal, Mud Springs, and Caballo Mountains were the site (fig. 8) of a southward-projecting erosional area in late Mississippian and early Pennsylvanian time.

Most of the Mississippian of south-central New Mexico is contained in the Lake Valley Limestone of Osage age. In a limited area, the Lake Valley is underlain by the Caballero Formation of Kinderhook age. Laudon and Bowsher divided the Lake Valley Limestone into six members, in ascending order, as follows: Andrecito, Alamogordo, Nunn, Tierra Blanca, Arcente, and Dona Ana. Armstrong (1962) believes the Caloso Formation is equivalent to the Andrecito and Alamogordo Members of the Lake Valley Limestone. The Kelly Limestone, of late Osage age, overlies the Tierra Blanca Member in the Silver City area, but may be equivalent to the Arcente and Dona Ana Members of the Sacramento Mountains. In the southern Sacramento Mountains, southernmost San Andres Mountains, and Franklin and Hueco mountains, the Lake Valley Limestone, where present, is overlain by the Rancheria Formation of Laudon and Bowsher. Locally, the Las Cruces Formation occurs below the Rancheria Formation but as it appears to be a facies of the Rancheria Formation, it is not differentiated by the writer in this brief survey of the Mississippian. The Rancheria is overlain by the Helms Formation of Chester age in the southeastern part of the region. The Rancheria Formation is believed to be of Meramec age by Laudon and Bowsher, but Armstrong (1962) suggests that the lower part may be of Osage age.

To the southwest and west, the Arizona terms, the *Escabrosa Limestone* and *Paradise Formation,* have been used (Armstrong, 1962; Gillerman; and others). The Paradise Formation is mainly of Chester age and roughly correlates with the Helms Formation. The Escabrosa Limestone has been raised to group status by Armstrong (1962) and subdivided into two formations, the lower Keating Formation and the upper Hachita Formation. Some of the basal beds of the Keating Formation may be of latest Kinderhook age, but most of the unit is of early and middle Osage age, correlative with the Lake Valley Formation or at least with the lower four members up to and including the Tierra Blanca Member. The Hachita Formation is of late Osage and Meramec age, its lower beds being correlated with the Kelly Formation and its middle and upper beds not represented in south-central New Mexico except for the middle and upper parts of the Rancheria Formation. Near Clifton and Morenci in Arizona, the Modoc Limestone of Lindgren appears to be a 170- to 200-foot-thick northward remnant of the lower Escabrosa Limestone, unconformably overlain by Pennsylvanian or Late Cretaceous rocks.

The isopach and facies map of the Mississippian (fig. 8) shows elements similiar to that of the other early Paleozoic systems: a Wolfcampian and Pennsylvanian eroded edge on the northeast; northward and

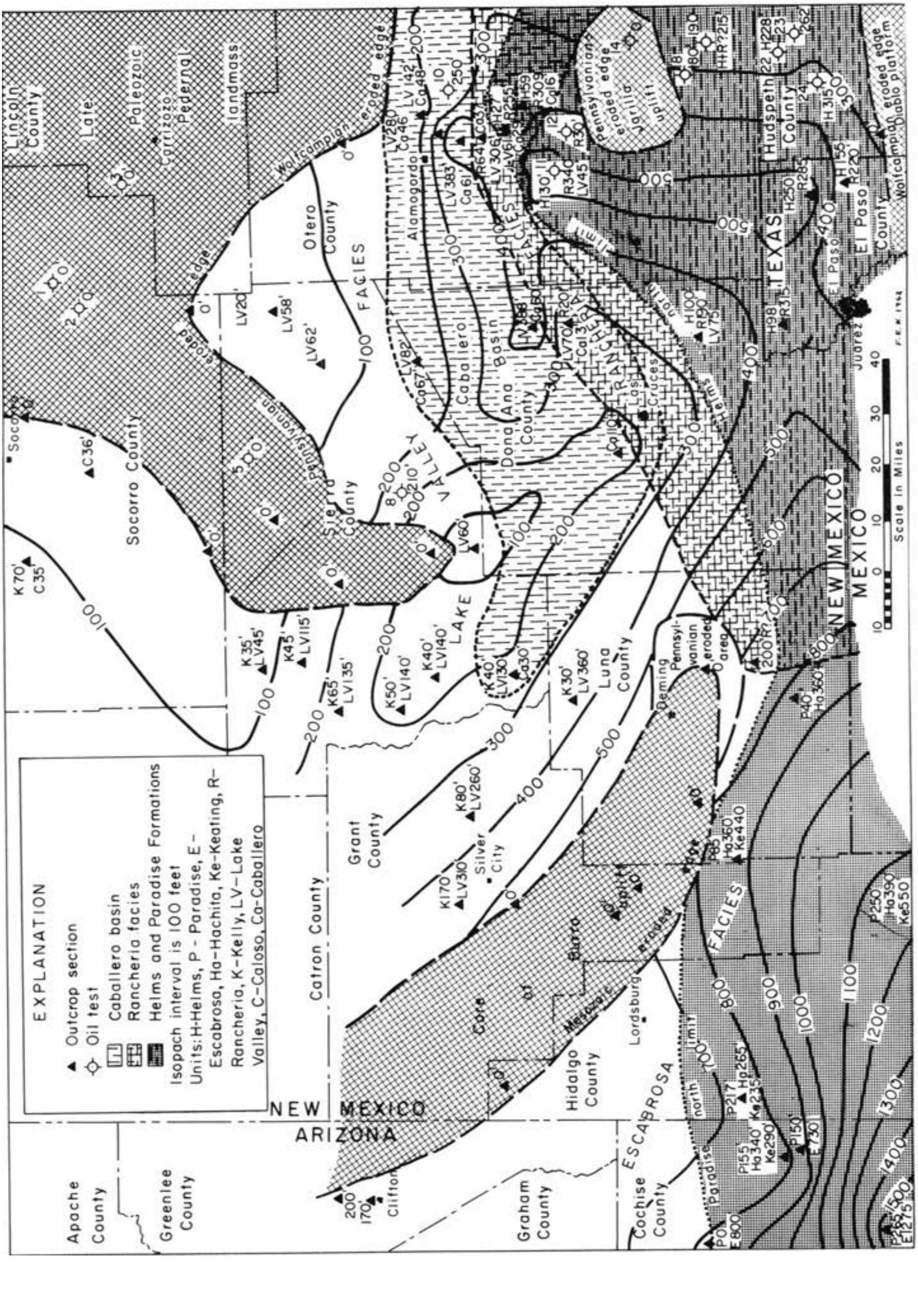

Figure 8

ISOPACH AND FACIES MAP OF MISSISSIPPIAN STRATA IN SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO northeastward thinning due in part to erosion of upper beds but with southward and southwestward thickening, in part due to depositional thickening; truncation during early Wolfcampian time on the Diablo platform in the southeastern corner of the region; extension of the Burro uplift east-southeastward to the northwestern Florida Mountains; and erosion during early Pennsylvanian time in a small area southeast of the Jarilla Mountains. Erosion during early and middle Pennsylvanian time, or during late Pennsylvanian and early Permian time, locally thinned the Mississippian in the Florida Mountains area.

The Caballero Formation of early Mississippian, Kinderhook age occurs only in an east-west-trending basin extending from the Lake Valley area in southwestern Sierra County eastward to the Sacramento Mountains. Sections are present near Lake Valley and in the Robledo Mountains, Sacramento Mountains, and southern San Andres Mountains (fig. 8). This area may have been a local basin in early Mississippian time; Devonian rocks (fig. 7) are relatively thin beneath the Caballero, and the Caballero "basin" is just off the northwest flank of the Jarilla Mountains eroded area where Devonian strata are thin or absent. The Caballero Formation consists of limy clastic rocks—interbedded silty calcareous shale, calcareous siltstone, and nodular lenticular arenaceous silty limestone. Crinoidal calcarenites are reported in the Caballero of the Sacramento Mountains (Pray, 1961); small fossils are abundant in some beds. The formation ranges from 60 to 75 feet in thickness to a knife-edge along the limits of its deposition.

The lower four members of the Lake Valley Limestone are widespread in south-central New Mexico; westward in the Black Range and Silver City area they are overlain by the Kelly Limestone, whereas to the east in the Sacramento Mountains and southern San Andres Mountains the upper two members of the Lake Valley are present. The basal Andrecito Member consists of gray, thin-bedded arenaceous limestone, dark gray, thin-bedded cherty limestone, dark gray, silty, argillaceous limestone, and limy silty shale. Thickness appears to range from a knife-edge to 120 feet; the member pinches out or grades laterally into basal Alamogordo Member limestones northward in the northern San Andres Mountains and southward in the Organ and southern Sacramento mountains. Locally, as in Ash Canyon, there is an apparent angular unconformity between the Andrecito and Alamogordo Members. As Pray (1961) noted, the Andrecito Member is the only member not involved in the extensive biohermal buildups that are typical of the Lake Valley Limestone in the Sacramento Mountains, southern San Andres Mountains, and Black Range.

The Alamogordo Member is a cliff-forming, massive, dark gray, cherty, microcrystalline limestone ranging from 20 to 105 feet in thickness where it is not part of bioherms. The member forms the base from which central biohermal structures rise (Laudon and Bowsher). The Nunn Member consists of interbedded light gray limy shale, friable fossiliferous crinoidal limestone, and dark gray, argillaceous, silty nodular limestone. This member contains most of the prolific "Lake Valley" crinoid fauna; maximum thicknesses are about 100 feet near Santa Rita and 70 feet in San Andres Canyon of the San Andres Mountains. Along with the Tierra Blanca Member, the Nunn Member grades laterally into the biohermal facies. The Tierra Blanca Member consists of massive, light gray crinoidal limestones containing much light gray chert; a maximum of 125 feet in thickness is reported from the Black Range.

The Arcente Member is composed of dark gray calcareous siltstones, lenticular dark gray argillaceous limestones, and dark gray calcareous shale. Maximum thicknesses of more than 200 feet are reported (Pray, 1961) from the Sacramento Mountains where, with the overlying Dona Ana Member, it is a postbioherm unit that tends to level out the topographic relief caused by biohermal growth. The Dona Ana Member is similar lithologically to the gray, massive, crinoidal cherty Tierra Blanca Member and is as much as 175 feet thick in the Sacramento Mountains.

The Lake Valley Limestone, excluding biohermal buildups, is thickest (200 to 390 feet) in the central Sacramento Mountains, Ash and San Andres canyons area of the San Andres Mountains, and near Silver City. Part of the northward thinning in the San Andres Mountains is due to erosion of upper beds, but in part this thinning is depositional. Southward, the Lake Valley Limestone appears to grade laterally into the lower part of the Rancheria Formation, as shown by Armstrong (1962). Southwestward, across the region of lost Paleozoic strata, the Burro uplift, the Lake Valley grades laterally into the lower part of the Escabrosa Limestone.

The Kelly Formation consists of massive, gray, cherty, crinoidal limestones; it overlies the Caloso Formation in the Magdalena Mountains but rests on the Tierra Blanca Member of the Lake Valley Limestone in the Black Range and Silver City area. The formation is 30 to 70 feet thick in the Black Range area but thickens westward to 170 feet northwest of Silver City and must grade westward, across the eroded belt of the Burro uplift, into the middle Escabrosa Limestone.

The Rancheria Formation facies consists of black, cherty, silty, thin-bedded limestones with minor lenses of dark gray limy siltstone, silty, arenaceous, crinoidal calcarenite, and gray calcareous shale. The formation thins northward to a knife-edge in the southern San Andres and southern Sacramento mountains (fig. 8) and is more than 300 feet thick in the northern Franklin Mountains (if underlying similar but relatively noncherty limestones of the Las Cruces Formation are included), southern Sacramento Mountains, and in the Plymouth—Evans oil test. Based chiefly on *Leiorhynchus carboniferum,* Laudon and Bowsher considered the entire formation to be of early Meramec age. They also pointed out that locally the Rancheria rests with angular unconformity upon the Lake Valley Formation. Pray (1961) noted numerous erosional discontinuities, some of which have angular discordances as high as ten degrees, amid the Rancheria beds. He suggested that these breaks are of intraformational origin and not the obvious interformational angular unconformities they appear to be on first inspection. Armstrong (1962, fig. 8) walked out the Lake Valley and Rancheria formations outcrops in the southern Sacramento Mountains from Deadman Canyon southward to Negro Ed Canyon; he reported many penecontemporaneous deformation features in the Rancheria beds and a lateral gradation southward from the Lake Valley facies into the lower part of the Rancheria Formation. Similar facies gradation appears to be present in the southern San Andres Mountains from Ash Canyon southward to Salt Canyon.

Cherty dark gray limestones of the upper Keating Formation, Escabrosa Group, in southwestern New Mexico, appear lithologically similar to the Rancheria facies. This facies probably was deposited in relatively deep and/or stagnant water south of the shelf area of Lake Valley crinoidal deposition; the bituminous silty limestone deposition began in Osage time but continued into Meramec time. If Meramec-age Lake Valley facies were deposited to the north, they were removed by later erosion; crinoidal limestones of Meramec age were deposited to the west, however, where they form the upper part of the Hachita Formation of the Escabrosa Group.

The Escabrosa Limestone or Escabrosa Group facies occurs southwest of the Burro uplift area but is in no way related to that Mesozoic feature. The lower Keating Formation was divided by Armstrong (1962) into two members based on lithology, the lower member A and the upper member **B.** Member A consists of cliff-forming crinoidal limestone, oolitic limestone, and dark gray coral-bearing aphanitic limestone. Member **B** is composed of thin-bedded, highly cherty limestones, the lower beds being dark gray and lithographic, the upper limestones being dark gray fossiliferous crinoidal calcarenites. The Keating Formation is as much as 590 feet thick in the Big Hatchet Mountains and thins northward.

The upper Hachita Formation of the Escabrosa Group is cliff-forming massive crinoidal limestone, containing scattered chert, with the lower two thirds being light gray and the upper one third being gray to dark gray. Armstrong (1962) reports a maximum thickness of 390 feet in the Big Hatchet Mountains with northward thinning. However, in the Pedregosa Mountains of southeasternmost Arizona, Epis (1956) meisured a thickness of 1275 feet for the Escabrosa Limestone; from his description, as much as 800 feet of his section may be equivalent to the Hachita Formation.

The base of the Paradise Formation has been picked at different places by different geologists; Packard (1955) essentially followed Hernon (1935) , but Armstrong (1962) chose a higher horizon, thus grouping part of the type Paradise Formation, beds with a possible Meramec fauna, in the upper part of the Hachita Formation. Lithologically (Armstrong, 1962), "the base of the Paradise Formation is defined . . . as the base of the first 18-inch shale zone which occurs on top of the massive limestone of the Hachita Formation." The contact is a somewhat arbitrary plane, and there appears to have been essentially continuous deposition from Meramec into Chester time. The Paradise Formation consists of cyclic units; impure gray to black calcarenites and calcilutites, black limy siltstone, brown calcareous oolitic fine-grained sandstones, and limy grayish green fossiliferous shales. Plant remains occur in the shales, especially near the top of the formation, along with marine fossils. Many of the limestones are crinoidal coquinas. The unit weathers to a distinctive yellowish brown slope. Sabins (1957a) reported a thickness of 155 feet near the type section in the eastern Chiricahua Mountains, but to the northwest near Apache Pass the formation was either removed by erosion prior to deposition of Pennsylvanian rocks or was not deposited. Gillerman and Packard measured about 217 feet of the Paradise Formation in the central Peloncillo Mountains, Zeller (1958) about 250 feet in the Big Hatchet Mountains, and Armstrong (1962) 85 feet from the Klondike Hills. A possible 20- to 40-foot-thick remnant of the Paradise Formation occurs as far east as the Tres Hermanas Mountains (Armstrong, 1962; Kottlowski and Foster). To the southwest, Epis noted 265 to 290 feet of the formation in the Pedregosa Mountains and suggested that Imlay (1939) found lithologically similar beds to be 375 feet thick in northern Mexico near El Tigre.

In the southeastern part of the region, the Helms Formation encompasses beds of Chester age if restricted, as suggested by Laudon and Bowsher, to the upper part of King and Knight's Helms unit. The Helms (restricted) consists of greenish calcareous silty shales, yellowish brown, limy, silty, fossiliferous sandstones, brown fossiliferous argillaceous limestones, and gray, cherty, crinoidal, oolitic limestone. The lithology and fauna is similar to that of the Paradise Formation. The Helms Formation is about 100 feet thick in the Franklin and southern Organ mountains, thickens southward from a knife-edge to 130 feet in the southern Sacramento Mountains area and is 155 to 250 (?) feet thick in the Hueco Mountains.

Deposition of the Chester-age units appears to follow that of earlier Mississippian strata, with northward thinning partly erosional and partly depositional. The northern limit of the Helms rocks is near the northern limit of the underlying Rancheria facies; the formation represents a shallowing of the Rancheria basin. The Paradise Formation is almost identical to the Helms; where not removed by post-Paradise erosion in the Tres Hermanas Mountains area, it must grade eastward in the subsurface into the Helms Formation. Thickest deposition appears to have been south of the Pedregosa Mountains, with sedimentation essentially continuous throughout middle and late Mississippian time but marked by an upward increase in clastic rocks, as illustrated within the Paradise Formation. Erosion during latest Mississippian and earliest Pennsylvanian time was effective in the northern and central parts of the region but caused only a minor break in the Pedregosa and Big Hatchet mountains area and in the Franklin and Hueco mountains area. Chester-age rocks are overlain by early Pennsylvanian Morrowan beds in these two basinal areas, whereas middle Pennsylvanian strata are unconformable on Chester- to Osage-age rocks of Cooks Peak and the Florida and Tres Hermanas mountains area.

PENNSYLVANIAN STRATA

Pennsylvanian rocks are important reservoirs of oil and gas in southeastern New Mexico and west Texas and in the Four Corners region of northwestern New Mexico and adjoining states. Thus the strata of this system have been much studied in southwestern and south-central New Mexico; many of the studies have been done for or by petroleum companies and are unpublished. Excluding studies of particular areas (such as Pray's, 1961, of the Sacramento Mountains), recent published regional reports have been those by McKee (1951) and Havenor (1959) on Arizona and several on south-central (Kottlowski, 1960c) and southwestern (Kottlowski, 1960b) New Mexico by the writer. Stoyanow (1942) published an early paleogeographic map of the Pennsylvanian in Arizona, and Thompson (1942, 1948, 1954) set the framework for fusulinid zoning of the Pennsylvanian in New Mexico.

Pennsylvanian strata in southwestern and south-central New Mexico range from Morrowan(?) to Virgilian in age, are disconformable to angularly unconformable above Precambrian to Late Mississippian rocks, and are as much as 3000 feet thick, although in most localities they range from 1000 to 2000 feet in thickness. The Pennsylvanian—Permian contact in many areas appears to be gradational, and the boundary is drawn within a zone of indeterminate age between Virgilian and Wolfcampian fossil-bearing beds. Permian rocks at some localities, as well as Cretaceous and Tertiary rocks in other places, are erosionally unconformable on the Pennsylvanian strata. In the southern Hueco Mountains (Diablo platform) and Florida Mountains areas, as well as on the west edge of the Pedernal landmass, all the Pennsylvanian beds apparently were removed by erosion during early Wolfcampian time. Likewise, erosion during early and middle Mesozoic time stripped the Pennsylvanian from the Burro uplift area.

Positive and negative elements effective in pre-Pennsylvanian time were masked or lost during the Pennsylvanian. There is a northward thinning, chiefly depositional, along the New Mexico—Arizona state line toward the Zuni arch (north of the north boundary of fig. 9) and southward thickening into the Pedregosa basin. The other Pennsylvanian elements, in contrast, appear to be aligned roughly north-south; that is, the Pedernal landmass, Orogrande—San Mateo—Lucero basins, and the

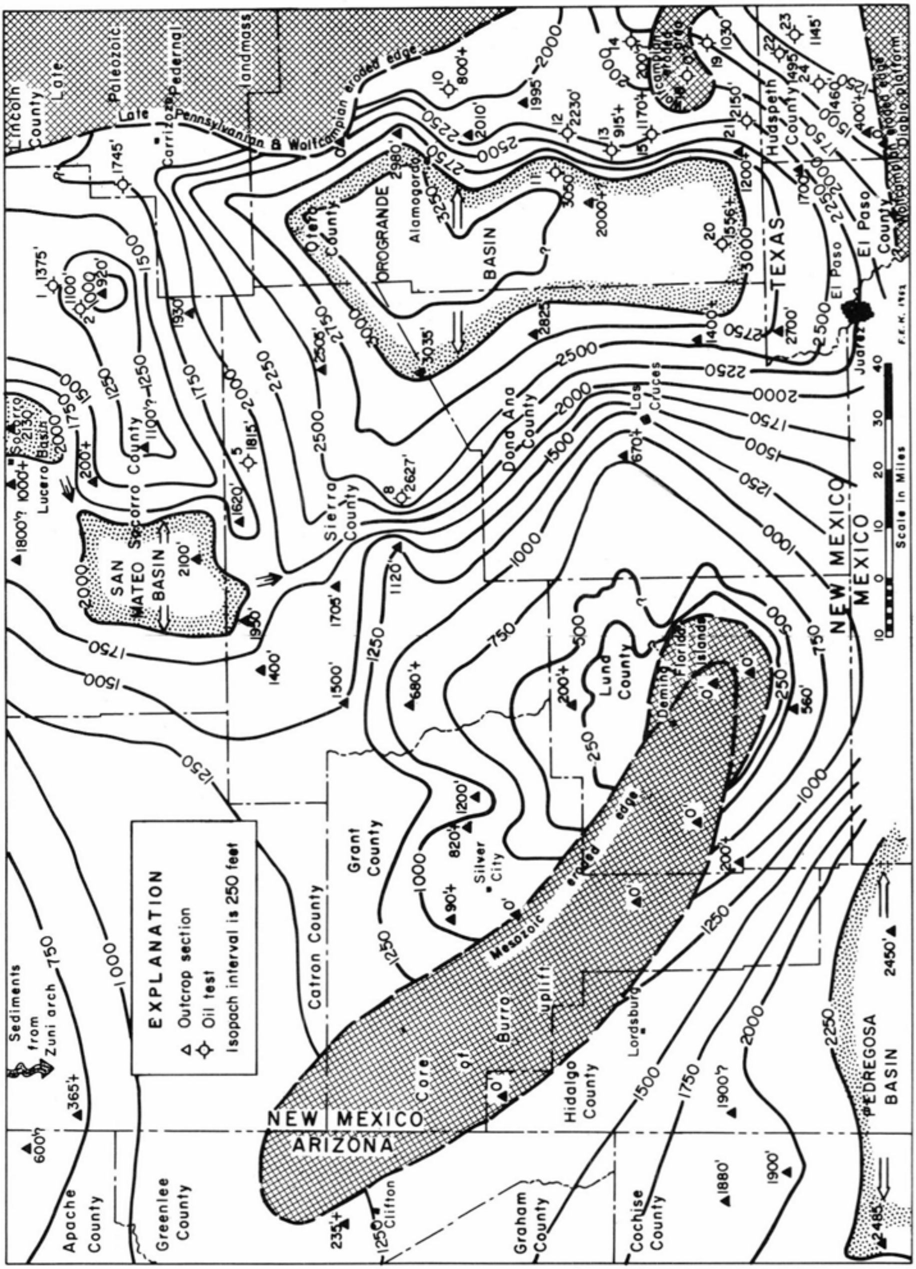

Figure 9

ISOPACH MAP OF PENNSYLVANIAN STRATA IN SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO

Florida islands. The small Wolfcampian-age eroded area southeast of the Jarilla Mountains is near but smaller than the eroded area developed in early Pennsylvanian time (fig. 8). In the southern part of the Orogrande basin, deposition probably was continuous from late Mississippian into early Pennsylvanian time. During late Pennsylvanian and early Permian time, this southern Orogrande basin may have been about on the site of the Rancheria-facies basin, and the resulting deposits have some similar features.

Pennsylvanian rocks in southeasternmost Arizona are mapped as the Horquilla Formation and lower part of the Earp Formation of the Naco Group. In southwesternmost New Mexico, the upper part of the Horquilla Formation is younger than in Arizona and includes Wolfcampian beds. Pennsylvanian strata in central New Mexico generally have been referred to the Sandia and Madera formations of the Magdalena Group by the U.S. Geological Survey or to faunal equivalents of the Morrow, Derry (Atoka), Des Moines, Missouri, and Virgil series. Lithic mappable units have been named from outcrops in isolated mountain ranges, such as the Gobbler, Beeman, and Holder formations in the Sacramento Mountains (Pray, 1961), the Red House, Nakaye, and Bar B formations in the Caballo Mountains (Kelley and Silver), and the Panther Seep Formation in the San Andres Mountains.

Clastic sediments were derived mainly from the Pennsylvanian-age Pedernal landmass to the east and locally from the Florida and Zuni positive-trending areas. Four basinal downwarps, where thick sections were deposited, stand out on the isopach map (fig. 9): (1) the Orogrande basin, containing as much as 3000 feet of clastic Pennsylvanian rocks and limestones, of which more than two thirds was deposited in late Pennsylvanian time; (2) the Pedregosa basin, in which Pennsylvanian strata, chiefly limestones, are almost 2500 feet thick; (3) the Lucero basin (Wengerd, 1959), with as much as 2700 feet of sediments; and (4) the San Mateo basin with more than 2100 feet of blackish limestones and associated strata. The Orogrande, San Mateo, and Lucero basins are aligned along a curved north-south trend that probably marks a channelway northward to the Paradox basin; the Pedregosa and Orogrande basins probably joined south of the Florida islands and connected eastward, in northern Chihuahua and westernmost Texas, with the Marfa and Delaware basins. Local areas bordering these basins were favorable spots for the development of patch reefs, such as near Alamogordo (Pray, 1961), Hembrillo Canyon (fig. 10) in the San Andres Mountains (Kottlowski, 1960c), northern Hueco Mountains (King and Knight), and Big Hatchet Mountains (Zeller, 1960).

The Pennsylvanian sequence is a limestone lithofacies (clastic ratio less than 0.25) throughout most of the southern part of the area. Northward it grades into lime-shale and then into shale-lime lithofacies of interbedded red beds and nodular limestone southwest of the Zuni arch, but of interbedded grayish calcareous shale and fossiliferous limestone

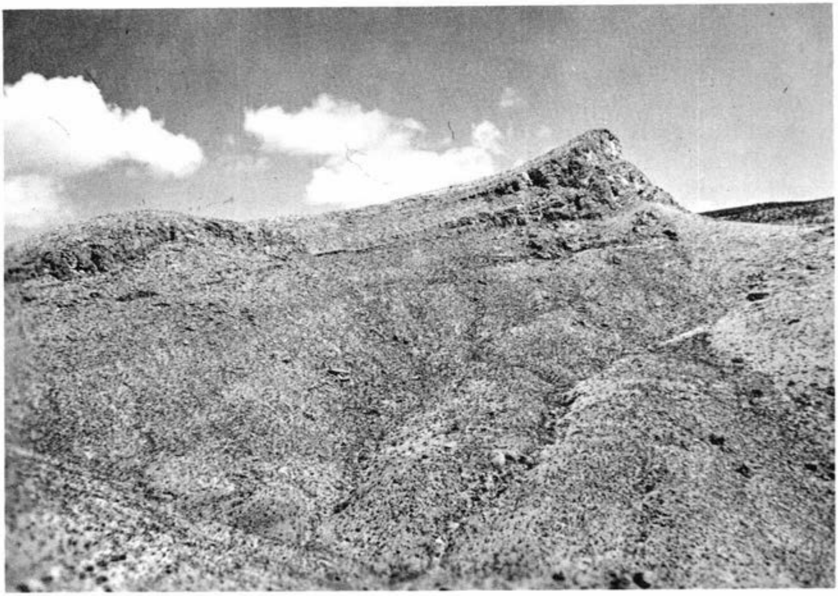

Figure 10
PATCH REEFS IN HEMBRILLO CANYON AREA, SAN ANDRES MOUNTAINS

west of the Pedernal landmass. Deposits in the Pedregosa basin are mainly of limestone and lime-shale; those in the Orogrande basin are shale-lime at the south and sand-lime lithofacies on the north. In a small area near the Florida islands lime-sand lithofacies dominate; the thick San Mateo section is of dark lime-shale lithofacies.

In south-central New Mexico, the dominant source of clastic sediments was the Pedernal landmass, as is shown by the concentration of arkosic and feldspathic sandstones within 60 miles west of the landmass (fig. 11). An isopach map (fig. 11) of the shale (and shaly siltstone) thicknesses exhibits forms similar to the isopach map of the entire Pennsylvanian (fig. 9), with the thicker sections of shale being on the west side of the Orogrande basin. Gypsum beds in the uppermost Pennsylvanian (or lowest Permian ?) appear to have been deposited only in the southwestern part of the Orogrande basin (Seager, 1961). The actual southern limits of the Orogrande basin may never be known, as erosion during early Wolfcampian time (and during latest Virgilian time ?) truncated older beds in the Hueco Mountains and Diablo Plateau area; in the Hueco Mountains the basal Powwow Conglomerate of the Hueco Formation rests southward on progressively older strata ranging in age from early Virgilian down to Ordovician.

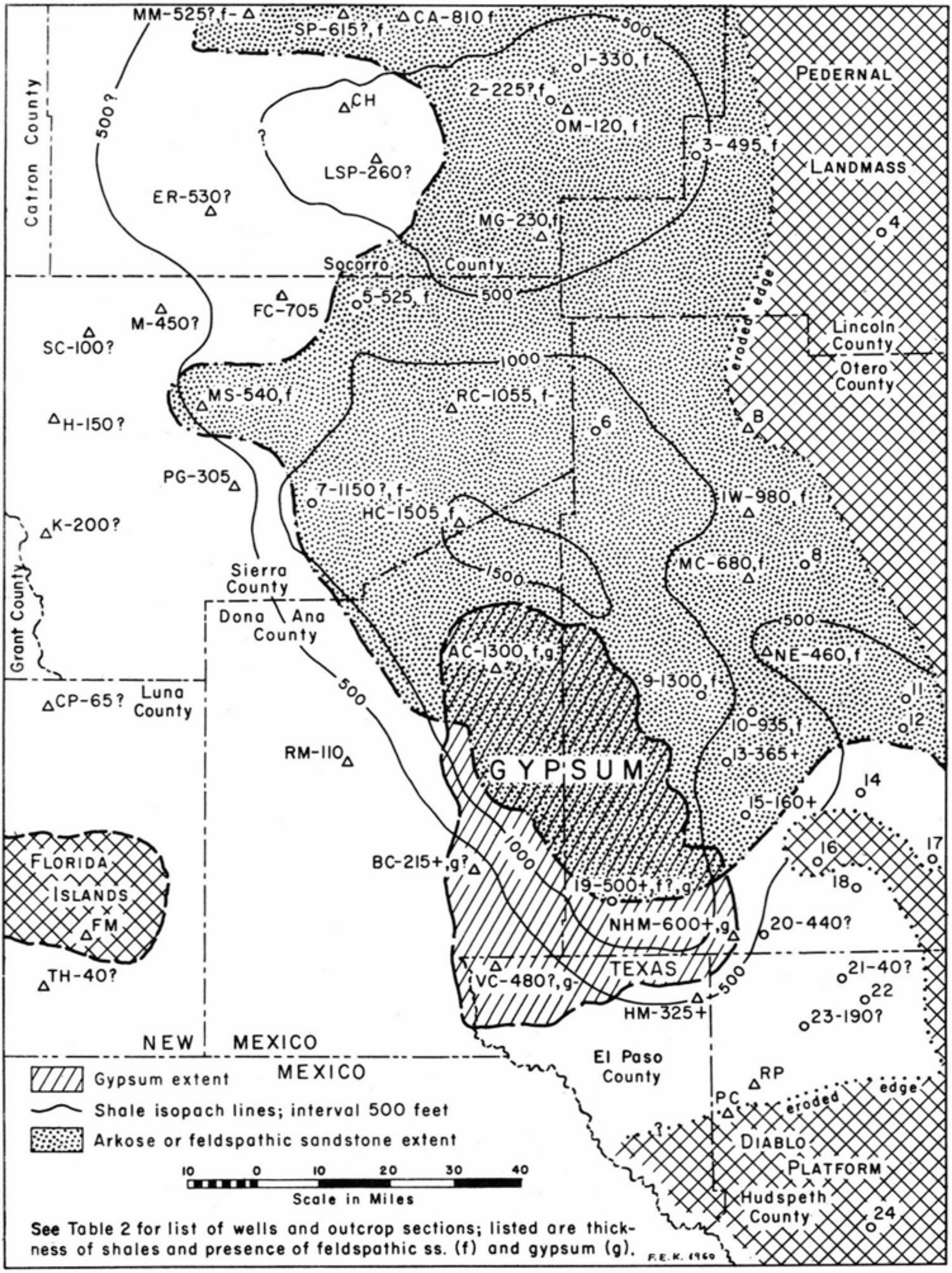

Figure 11

"GSA" MAP FOR PENNSYLVANIAN OF SOUTH-CENTRAL NEW MEXICO. GYPSUM EXTENT, SHALE ISOPACH, ARKOSIC SANDSTONE EXTENT

TABLE 2. OUTCROP SECTIONS AND OIL TESTS SHOWN IN FIGURE 11

OUTCROP SECTION OR OIL TEST	PENNSYLVANIAN *(thickness in feet)*
Socorro County:	
MM—Magdalena Mountains	1185*(1845?)
SP—Socorro Peak	1000*(1800?)
CA—Cerros de Amado	2130
OM—Oscura Mountains (northern)	920
CH—Coyote Hills	200*
LSP—Little San Pascual Mountain	1100?
MG—Mockingbird Gap	1930
ER—Eaton Ranch	2100(*?)
Sierra County:	
FC—Fra Cristobal Mountains	1620
M—Monticello	1950?
SC—Sierra Cuchillo	1400*
MS—Mud Springs Mountains	1705
H—Hermosa	1500?
RC—Rhodes Canyon	2505
PG—Palomas Gap	1120
HC—Hembrillo Canyon	3035
K—Kingston	680*
Otero County:	
B—Bent	0
IW—Indian Wells–La Luz	2980
MC—Mule Canyon	2010
NE—Nigger Ed Canyon	1995
NHM—Northern Hueco Mountains	1200*(2800?)
Dona Ana County:	
AC—Ash Canyon	2825
RM—Robledo Mountains	670*
BC—Bishop Cap	1400*(2900?)
Luna County:	
CP—Cooks Peak	200*
FM—Florida Mountains	0
TH—Tres Hermanas Mountains	635
Westernmost Texas:	
VC—Vinton Canyon area	2700
HM—Hueco Mountains (central)	1700(*?)
RP—Rancheria Peak	400* (eroded)
PC—Padre Canyon	0 (eroded)
Oil tests:	
1—Lockhart No. 1 oil test	1375
2—Sun Oil Co. No. 1 Bingham State	1100
3—Standard Oil Co. Texas–Heard test	1745
4—Capoco Corp. No. 1 Spencer test	0?
5—Sun Oil Co. No. 1 Victorio test	1815
6—Tularosa Basin oil test	400?*
7—Sunray Midcontinent Oil Co. No. 1-M Federal oil test	2627
8—Southern Production Co. No. 1 Cloudcroft	800*(eroded)
9—Plymouth Oil Co. No. 1 Evans test	3050
10—Sun Oil Co. No. 1 Pearson test	2230
11—Zapata Petroleum Corp. No. 1 Federal	2000?
12—Stanolind No. 1 Thorn Unit test	1800*?

* Indicates "plus."

TABLE 2. OUTCROP SECTIONS AND OIL TESTS SHOWN IN FIGURE 11
(continued)

OUTCROP SECTION OR OIL TEST	PENNSYLVANIAN (thickness in feet)
13—Otero Oil Co. No. 1 McGregor test	9I5*(eroded?)
14—Turner No. 1 Everett oil test	200?*(eroded?)
15—Kinney 0. & G. Co. No. 1 State test	1170*?(eroded?)
16—E. P. Campbell No. 1 Federal test	0?(eroded?)
17—Flynn, Welch, & Yates—Donahue test	400*?
18—Union Oil Co. No. 1 McMillan test	1030*(eroded)
19—Ernest No. 1 Located Land Co. test	1556*(3000?)
20—Seaboard Oil Co. No. 1 Trigg	2150?
21—Magnolia No. 1-39881 oil test	1495
22—Seaboard & Shamrock No. 1 C University oil test	1145
23—California Co. No. 1 University Theisen oil test	1460
24—Oil tests on north flank of Finlay Mountains	0(eroded?)

* Indicates "plus."

PERMIAN STRATA

The recent Permian correlation chart (Dunbar et al., 1960) listed the Permian rocks of southwestern and south-central New Mexico as they were known in 1954. Whereas the units thus presented are generally correct, significant details are not shown, such as the southward intertonguing of the Abo Redbeds with the Hueco limestones and gray shales and the local occurrence of possible Leonardian floras in the uppermost Abo Redbeds (Charles B. Read quoted in Bachman and Hayes, 1958). The Permian section in this region ranges from the predominantly marine, middle and upper parts of the Naco Group of southwesternmost New Mexico eastward into the Abo—Hueco, Yeso, and San Andres units of south-central New Mexico, and hence eastward to the classic back-reef strata of the western Guadalupe Mountains. North-south variation is from the Abo Redbeds, Yeso sandstone-gypsum-limestone, Glorieta Sandstone, and San Andres Limestone of the Abo Pass area (northeast of Socorro) southward to the marine Hueco and Bone Spring rocks of the Hueco Mountains area.

WOLFCAMPIAN ROCKS

Earliest Permian rocks are within the Bursum Formation in the Socorro County area; the unit consists of interbedded red beds and marine limestones bearing a fusulinid fauna that has both Pennsylvanian and Permian aspects; that is, *Triticites* and *Schwagerina*. The mixed lithologies of the Bursum appear to grade downward into similar Virgilian strata and upward into the Abo Redbeds; local erosional unconformities have been noted, of course, at the base of all the clastic lenses within the upper Virgilian strata, Bursum Formation, and Abo Red-beds. This transition zone, consisting of intertongued red beds and marine limestones, appears between the dominantly marine Pennsylvanian strata and the overlying Abo Redbeds throughout south-central New Mexico. It has its lithic counterpart in the Earp Formation of southwestern New Mexico and adjoining parts of Arizona, but the Earp Formation is between the marine limestones of the Horquilla Formation and the overlying marine limestones of the Colina Limestone; no true lithic Abo Redbed correlative is present except as thin red beds within the Earp Formation.

In the Sierra Cuchillo area, Jahns found only Virgilian fusulinids within the Bursum-like transition zone. The Earp Formation, a similar lithic unit, rises in age eastward, being of Virgilian age in central Cochise County, Arizona (Gilluly, Cooper, and Williams, 1954), and of Wolfcampian age in the Big Hatchet Mountains (Zeller, 1958). In the Robledo Mountains, Thompson (1954) reported a Bursum fauna from massive marine limestones that are conformable and apparently gradational on Virgilian limestones. Similar faunas should occur in the upper Horquilla Limestone of the Big Hatchet Mountains, as it is of earliest Permian age.

In the northern Sacramento Mountains, Otte walked out the bed-by-bed relationships of the Bursum Formation, his Laborcita Formation, and showed that deposition was essentially continuous from late Pennsylvanian into early Permian time; his Laborcita Formation contains basal beds of late Virgilian age and upper beds of early Wolfcampian age. In the northern Sacramento Mountains, the Bursum—Laborcita Formation intertongues upward into the Abo Redbeds, but a few miles southeastward the Laborcita Formation wedges out into an unconformity where Abo Redbeds overlie rocks as old as the Mississippian. The Laborcita strata are nearshore deposits laid down on the west edge of the Pedernal landmass and near Tularosa include huge algal bioherms. The fauna in the middle of the formation is mixed, with the brachiopods and fusulinids being of Wolfcampian types, whereas the ammonoids and gastropods are of early Late Pennsylvanian forms (Otte).

The Bursum is a nebulous unit in the San Andres Mountains where, indeed, the Pennsylvanian—Permian boundary is not everywhere clearly defined. The type section of the Bursum Formation occurs near the Oscura Mountains just north of the San Andres range; it consists of lower, interbedded, dark purplish red and grayish green shale, pinkish gray arkose, and gray to greenish gray limestones, capped by a thick, massive, light gray biostromal limestone; thickness totals about 130 feet but is variable. In Mockingbird Gap, Thompson *(in* Kottlowski et al., pl. 1) measured 325 feet of Bursum (or Hueco in part ?), with basal arkosic conglomerates unconformable on Virgilian limestones and overlain by interbedded argillaceous limestones, greenish, reddish, and purplish arkosic sandstones, and greenish shales. Lower beds contain Bursum fusulinids. Red beds increase proportionally upward, the base of the Abo Redbeds being chosen at the top of the highest limestone. Near Rhodes

Canyon, the Bursum Formation (Thompson, 1954; Kottlowski et al.) is about 265 feet thick and includes lower limestone-pebble conglomerate, calcarenite, and limy sandstone; middle gray calcareous silty shale, silty limestone, and olive to reddish purple shale; and upper massive light gray biostromal limestone. The basal limestone-pebble conglomerate is unconformable on underlying Virgilian strata near Rhodes Canyon. Locally, the upper massive limestone is channeled deeply, and the channels are filled by at least 40 feet of limestone-pebble conglomerate; however, in nearby sections the massive 65-foot-thick limestone is overlain conformably by algal calcarenite in the basal beds of the Hueco Formation. No Bursum-age (earliest Wolfcampian) fusulinids were found in the Rhodes Canyon Bursum unit. The overlying Hueco Formation, of green and red-purple shales and fossiliferous arenaceous calcarenites, intertongues upward into the Abo Redbeds.

Southward in the San Andres Mountains, beds tentatively assigned to the Bursum underlie a massive biostromal limestone at the base of the Hueco Formation and consist of basal limestone-pebble conglomerates and conglomeratic sandstones, and upper interbedded argillaceous limestone, limy shale, and limy silty sandstone; there are no red beds at this horizon south of Rhodes Canyon. These strata are conformable with the overlying massive limestone placed at the base of the Hueco; this 50-foot-thick biostromal limestone contains a typical Hueco fusulinid fauna of *Schwagerina* and *Pseudoschwagerina* and it appears to be lithologically similar, and at the same stratigraphic position, as the massive limestone at the top of the Rhodes Canyon Bursum Formation. The writer would not be surprised if future studies in this range found that the Bursum fusulinid fauna, typified by *Triticites creekensis* and *Schwagerina* sp., was a nearshore facies fauna partly equivalent to the more normal marine facies fauna of *Schwagerina* and *Pseudoschwagerina* typical of the Hueco Formation.

The transition zone, of interbedded red beds and nearshore limestones, becomes younger southward in the Oscura and San Andres mountains. **In** the northern Oscuras, the zone is of Virgilian and early Wolfcampian age; near Rhodes Canyon, the main part of the zone is within early Wolfcampian beds at the gradational contact between a thin Hueco Formation and a thick Abo Redbed sequence; in Ash Canyon, the transition zone is between a thick Hueco Formation and a thin Abo unit; whereas to the south in the Franklin Mountains, Harbour (1960b) reported only a few red-bed lenses within a thick Hueco sequence.

The age of the continental Abo Redbeds is a complex problem. Locally, as in the Black Range and Sierra Cuchillo area, the basal Abo may be of late Pennsylvanian age. At the type section near Abo Pass (35 miles northeast of Socorro), the Abo is underlain, gradationally, by fossiliferous Bursum beds of early Wolfcampian age. Southward in the Oscura, San Andres, and Franklin mountains chain-of-ranges, the Abo inter-tongues with the Wolfcampian Hueco Formation. In the Sacramento

Mountains, the lower Abo intertongues with the early Wolfcampian Laborcita Formation at the north end of the range, and southward the the upper Abo intertongues with the Hueco Formation (Pray, 1961; Bachman and Hayes). In the Robledo Mountains (Kottlowski, 1960a), Abo-like red beds are a northeastward-thickening tongue in the upper part (but not at the top) of the Hueco Formation. In the areas where the Abo intertongues with the Hueco, the red beds appear to be of Wolfcampian age.

There is confusion as to the exact age of the type Hueco Formation in the Hueco Mountains. The upper part of this type Hueco bears a slightly different fauna from the middle and lower Hueco. At the type locality of the Wolfcamp Series in the Glass Mountains, the upper beds of the Wolfcamp have been removed by erosion, but the remaining part contains fusulinids similar to those of the lower and middle Hueco of the Hueco Mountains. The fusulinids in the upper type Hueco are "more similar to subjacent Hueco faunas than to younger Permian faunas," according to Thompson (1954), and he redefined the Wolfcamp Series to include this younger Hueco fauna. This fauna appears to be older than the oldest fauna of the type Leonard Series and is thus more reasonably placed below the pronounced unconformity at the base of the type Leonard. Dunbar and Skinner (1937) noted that *Pseudoschwagerina* is a guide fusulinid of the Wolfcampian of Texas; Thompson (1954) collected *Pseudoschwagerina* from the upper part of the type Hueco Formation.

Williams (1962) studied fusulinids from the type Hueco Formation in the Hueco Mountains and found *Pseudoschwagerina* throughout all but the uppermost part of the formation. In this upper part, he identified a *Schwagerina crassitectoria—Schwagerina franklinensis* fauna, without *Pseudoschwagerina,* and considered that part of the Hueco to be Leonardian in age. Wendell Stewart, Texaco, Inc., comments (letter dated November 2, 1962),

> I have collected from the highest exposures of limestone in the Hueco Mountains, such as Alacran Mountain, Deer Mountain, the Caprock scarp, and the interfingering dolomites and limestones immediately to the east, and I found *Pseudoschwagerina* present in all. I have not found *Schwagerina crassitectoria,* but have found *S. franklinensis.* There is no question that *S. franklinensis* is Wolfcamp, but I am not sure about *S. crassitectoria.* I feel perhaps there is some misidentification possible. The type locality of *S. franklinensis* is well within the zone of *Pseudoschwagerina* in the Franklin Mountains. *S. crassitectoria* is present in the type Leonard, but I have never found or heard of others finding *S. franklinensis* in the type or any other Leonard.

Garner L. Wilde, Humble Oil and Refining Company, also comments (letter dated November 8, 1962),

> Generally, I agree with Wendell, for our highest Hueco material in the Hueco Mountains is Wolfcampian; but it is always possible that Williams has found a higher fossiliferous zone which carries lower Leonardian forms. . . . I would be interested to know exactly where Williams made his collections. Also, I need verification on the occurrence of *S. crassitectoria* and *S. franklinensis* together. I'm not saying it could not happen, but we have never found the two together anywhere. . . . The *S. eolata-neolata-elkoensis* forms are somewhat similar to the *S. crassitectoria-gumbeli* forms, for instance; and I'm sure there are gradations of all kinds.

The Hueco Formation in the Hueco Mountains proper, as measured by King and Knight, appears to be entirely of Wolfcampian age. Directly east of the Hueco Mountains, on the west edge of the Diablo Plateau and separated by normal faults from the Hueco units mapped in the Hueco Mountains, King and Knight mapped a dolomite and limestone unit. This they correlated with the Hueco but noted it probably contained upper beds of Leonardian age. Dolomitization of this unit is erratic; the unit is much broken by faults and poorly exposed. Locally, beds of the Yeso—Bone Spring Formation have been identified in this unit. Either the Hueco grades without appreciable break up into these Leonardian beds of the Yeso Formation or there is an unconformity between the two units which has not been recognized on the west edge of the Diablo Plateau because of dolomitization, faulting, and burial by alluvium. Farther east on the Diablo Plateau, the Bone Spring Limestone is unconformable on the Hueco Formation, and there the Hueco contains Wolfcampian fossils.

Charles B. Read *(in* Bachman and Hayes; *in* King, 1942) reported elements of the *Gigantopteris* and *Supaia* floras from uppermost beds of the Abo Sandstone in the Sacramento, Oscura, and San Andres mountains, near Abo Pass, and from Otero Mesa. These two floras do not occur together but they are thought to be lateral or facies equivalents (Read, 1957) of *Glenopteris* flora of Kansas. *Gigantopteris* has been found in the Belle Plains Formation of north Texas, the basal Leonardian unit of that area. The *Gigantopteris* zone is underlain by beds bearing a *Callipteris* flora which Read believed to be of lowermost Permian (Wolfcampian) age. However, Otte reported that Read's *Callipteris* flora of the northern Sacramento Mountains was collected from basal beds of the Laborcita Formation which are of late Virgilian age, as dated by fusulinids. Read's statement *(in* Bachman and Hayes) that "Inasmuch as the *Gigantopteris* flora is underlain by the *Callipteris* flora both in New Mexico and Texas, it is an established fact that the *Gigantopteris* flora can not be older than uppermost Wolfcamp and most paleobotanists regard it as lower Leonard in age" would seem to be in some doubt, as the *Callipteris* flora appears to be able to straddle the Pennsylvanian—Permian boundary.

To further confuse the use of *Callipteris* as an index flora for the earliest Permian, *Callipteris arizonae,* only known previously from the

Hermit Shale (lower Leonard ?) of the Grand Canyon area, was found by J. P. D. Hull, Jr., and Garner L. Wilde (letter dated February 4, 1963) 298 feet above the Kriz lens and in the Leonardian Bone Spring Limestone of Sierra Diablo (westernmost Texas), and was identified by Chester A. Arnold. Thus species of *Callipteris* appear to occur in beds ranging in age from late Pennsylvanian through Leonardian.

Charles B. Read *(in* Bachman and Hayes) collected a *Supaia* flora from uppermost beds of the Abo Redbeds from the Otero Mesa area; these beds are regarded by Bachman and Hayes as their Otero Mesa Member of the Yeso Formation. However, Pray (1961) and the writer *(in* Weber and Kottlowski, 1959) believe this Otero Mesa Member to be the upper tongue of the Abo Redbeds, underlain gradationally by the Hueco Formation. If the *Supaia* and *Gigantopteris* floras are contemporaneous, one wonders why they occur separately in uppermost beds of the Abo from the Sacramento Mountains and Otero Mesa area within outcrops only 36 miles apart.

Read collected the *Supaia* flora from "just beneath . . . a persistent bed of light-colored sandstone . . . at the top of the Abo in the San Andres and Oscura Mountains" (King, 1942) . There are some olive sandstones in the Meseta Blanca Member of the basal part of the Yeso Formation in these ranges, but no light-colored sandstones are reported within the Abo Redbeds (Wilpolt and Wanek, 1952; Kottlowski et al.) . The Meseta Blanca Member of the Yeso is a calcareous, reddish orange, silty sandstone and sandy siltstone more or less transitional from the dark reddish brown and dusky red shales, siltstones, and sandstones of the Abo up into the olive, light red, and gray sandstones, interbedded with limestone and gypsum, of the middle members of the Yeso Formation. Perhaps the *Supaia* flora and its correlatives are most typical of the basal Yeso and suggest a Leonardian age for that unit. All the three floras, the *Supaia, Gigantopteris,* and *Glenopteris,* appear to be areally limited facies floras and probably are environment indicators rather than strict guide fossils.

Langston (1953) collected vertebrate fossils from the Abo Redbeds in New Mexico, chiefly from localities near Socorro and northward, and concluded that "evidence from the amphibian and fish faunas of New Mexico seems to point to a rough age equivalence between these and assemblages from the lower and middle Wichita (Moran—Admiral) beds of Texas." The Moran and Admiral formations are of Wolfcampian age (Dunbar et al.).

Bachman and Hayes commented on their upper unit of the Abo Redbeds in the southern Sacramento Mountains as follows: "Most of the Lee Ranch Tongue grades and intertongues southward into the Hueco Limestone. . . ." They believed the Lee Ranch Tongue of the Abo to be of Leonardian age because Read collected *Gigantopteris* from its uppermost beds 20 miles to the north; however, if the red-bed tongue grades laterally into the Hueco Limestone it should be of Wolfcampian age.

Based on Bachman, Hayes, and Read's work, Hill (1961) stated that "the upper Abo is definitely placed in the Leonard by plant and vertebrate fossil evidence." Based on Thompson's (1954) fusulinid studies of the type Hueco Formation, and Langston's vertebrate identifications, the writer concludes that the upper Abo of south-central New Mexico is more likely to be of Wolfcampian age than Leonardian. Be that as it may, however, the bulk of the Hueco Formation is of Wolfcampian age, and the bulk of the Abo Redbeds grade southward into the Hueco Formation in the Sacramento and San Andres mountains; therefore, the *main part* of the Abo is of Wolfcampian age.

Along the east border of the region, the Abo rests unconformably on Precambrian rocks in the area of the Pedernal landmass (fig. 12). As shown by the coarse-grained sandstones and pebble to cobble conglomerates of the Abo (and Laborcita) near Alamogordo, a high part of the early Permian Pedernal landmass lay to the northeast, perhaps in the vicinity of the present mountainous Sierra Blanca. In much of northeastern Otero County and adjoining parts of southern Lincoln and southwesternmost Chaves counties, Abo Redbeds were deposited on a surface of considerable relief, locally as much as 1000 feet, carved into Precambrian rocks (Foster, 1959); this is the buried core of the Pedernal landmass where Abo Redbeds fill valleys and overlap hills that resulted from uplift and erosion during late Pennsylvanian and early Permian time. Uppermost red beds of the Abo probably were derived from emergent areas far to the north, since Foster (1959) reported from subsurface studies that the Yeso Formation is nowhere in contact with the Precambrian in this area. To the north in the Pedernal Hills area of central New Mexico and to the south in the small Pump Station Hills area of western Texas, the Yeso fills valleys and overlaps hills cut into Precambrian rocks. Foster (1959) noted that the Yeso and younger Permian formations were deposited as blanketlike units on an even surface left by Abo deposition over the Pedernal landmass east of Alamogordo.

Considering correlations in the area east of the Pedernal landmass, Hill commented that the red and green shales of the Leonard of the Permian Basin in southeastern New Mexico and west Texas obviously seem to correlate with the Abo Redbeds of the eastern flank of the "Pedernales" uplift. This reasoning is shown on the Roswell Geological Society's (1956) cross section, generalized herein as Figure 13, and based on the scattered oil tests in southwestern Chaves and northeastern Eddy counties. A 200-foot-thick Abo Redbed section on the top of the Pedernal landmass is shown thickening eastward in about 15 miles into a lower 1400-foot-thick red-bed tongue, a middle 400-foot-thick dolomite, and an upper 200-foot-thick red-bed tongue. About 30 miles farther eastward, the lower red-bed tongue is shown splitting into an upper red-bed lens that grades eastward into "Abo" dolomite of Leonardian age and into a lower lens that intertongues with the Hueco Limestone. The upper red-bed tongue is shown grading westward into green "Abo"

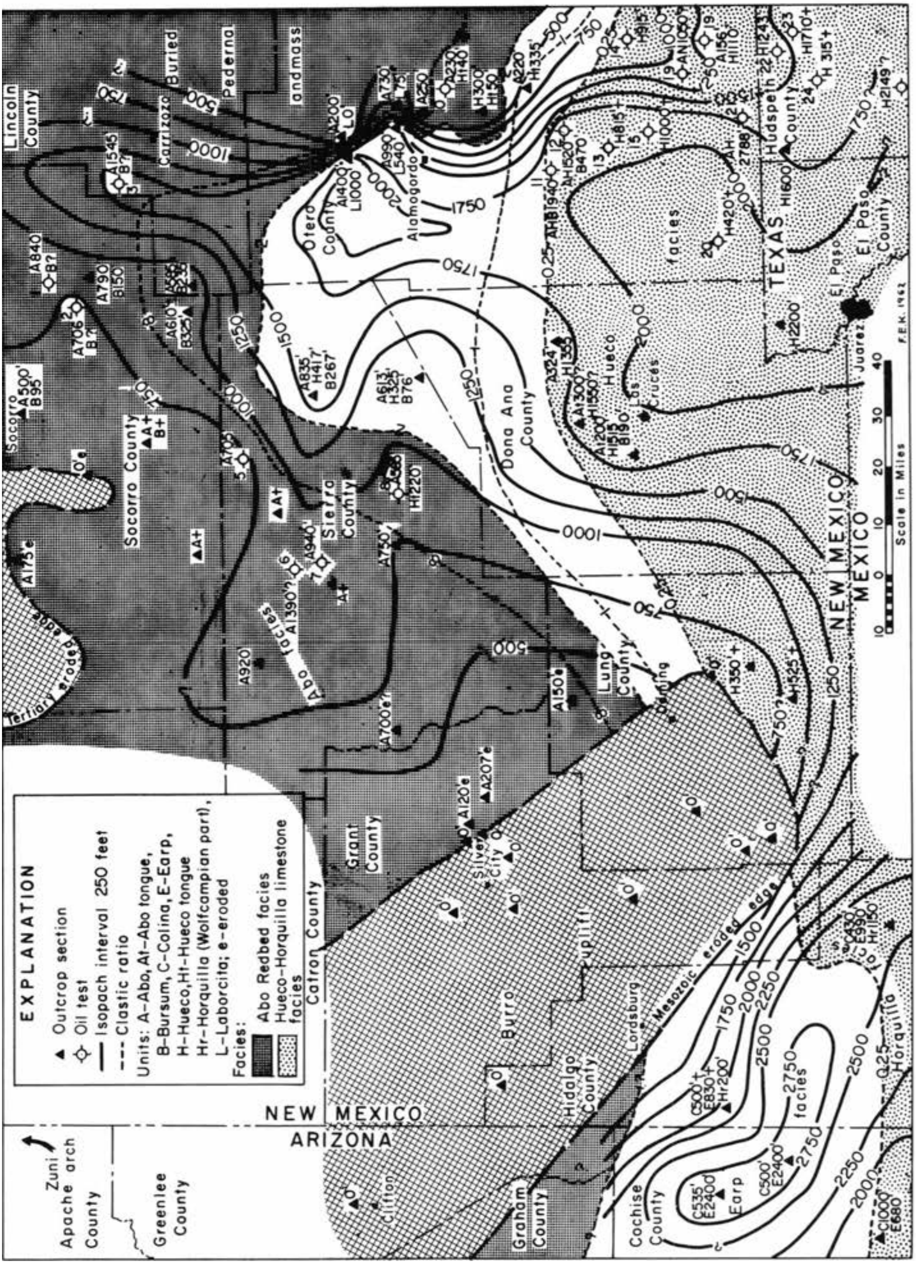

Figure 12

Isopach and facies map of Wolfcampian strata in southwestern and south-central New Mexico

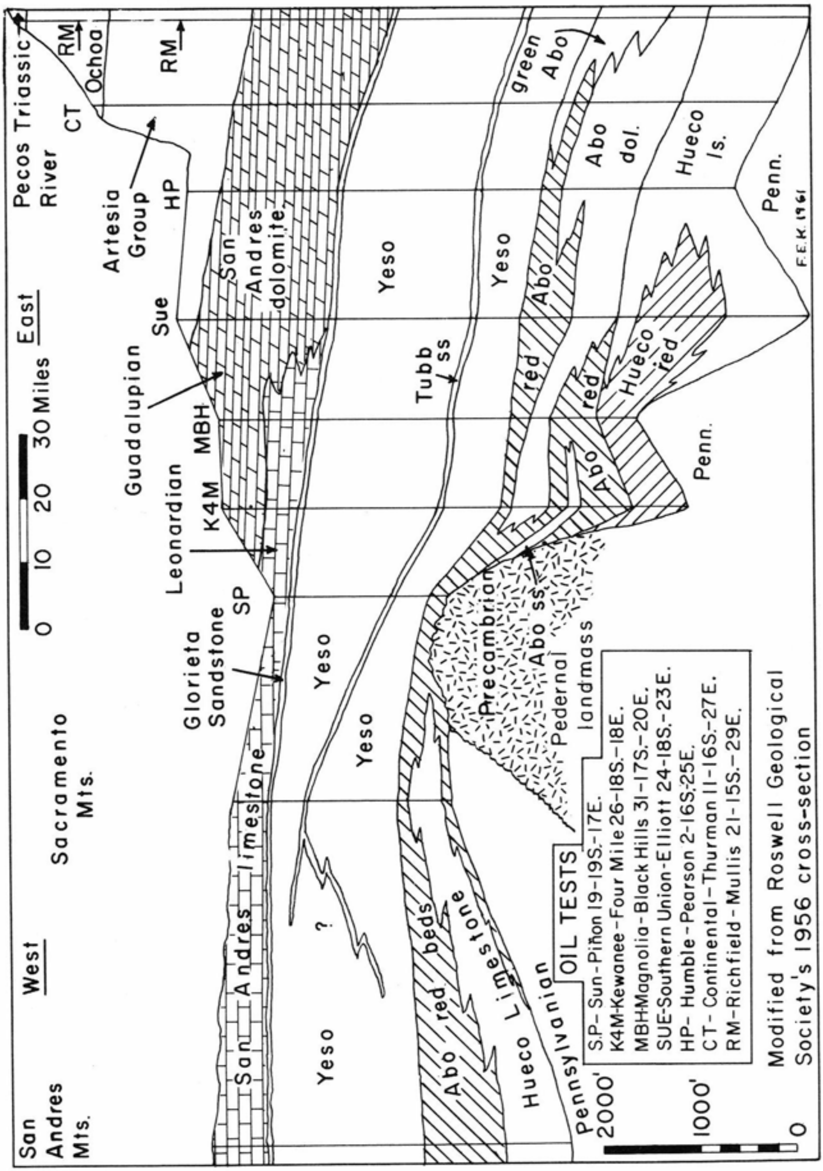

Figure 13

West to east diagrammatic section of Permian units across the Pedernal landmass; conventional correlations shales and then into "Abo" dolomite, gradationally with the medial dolomite.

Another interpretation is possible (fig. 14). The lower 1400-foot-thick red-bed tongue may grade eastward into the Hueco Limestone, as a similar 1400-foot-thick red-bed tongue of the northern Sacramento Mountains does southwestward toward the San Andres Mountains. The medial 400-foot-thick dolomite and the upper 200-foot-thick red-bed tongue may be eastern equivalents of the pale red Meseta Blanca Sandstone, the basal Yeso to the west of the Pedernal landmass.

These various formations and facies, both east and west of the buried Pedernal landmass, intertongue laterally and are in gradational contact; the writer doubts that any of the facies are time synchronous units throughout all of southern and central New Mexico. If the Abo—Yeso contact, or even that of the Hueco—Bone Spring, is exactly at the Wolfcampian—Leonardian boundary in any part of the region, it is probably due to coincidence rather than to collusion of geologic forces.

Locally, the uppermost part of the Abo Redbeds may be of Leonardian age, just as locally (for example, in Sierra Cuchillo ?) the lowermost red beds may be of late Pennsylvanian age. However, to interpret the regional thicknesses and facies (fig. 12), all of the Bursum, Laborcita, Hueco, Abo, and Colina formations are considered to be of Wolfcampian age, along with parts or all of the Earp Formation and some upper parts of the Horquilla Limestone in southwesternmost New Mexico. The parallelism of the isopach lines drawn on the Pennsylvanian strata (fig. 9) and on the Wolfcampian beds (fig. 12) is noteworthy. The Pennsylvanian-age Orogrande basin in western Otero County was also the site of thick Wolfcampian deposition. The Wolfcampian deposits in the Orogrande basin, however, change lithologically southward in three steps. First, on the northeast edge of the basin, the 1000 feet of nearshore, reefy, marine Laborcita beds are overlain gradationally by 1400 feet of Abo Redbeds near Tularosa. Secondly, southward there are more than 1990 feet of Wolfcampian beds in the Sun—Pearson oil test (Kottlowski, 1960b, fig. 27) which consists of a lower 470 feet of dark gray, greenish, and brownish limestone, oolitic and algal, arenaceous calcarenite, calcareous shale, laminae of bone coal, and limy feldspathic sandstone of "Bursum" age. This is overlain by a lower Hueco sequence, 240 feet thick, of algal oolitic limestones with basal interbeds of red to gray arkosic sandstone, gray shale, black silty limestone, and gray calcarenite. Above is an Abo Redbed tongue, 380 feet thick, mainly of red shale and red calcarenite, silty to arenaceous, but with interbeds of brown, green, and dark gray limestone, limy shale, and feldspathic micaceous sandstone. The upper 900 feet penetrated in the oil test beneath alluvium is of typical Hueco; dark gray to brown limestone, algal in part, and some interbedded green, gray, and black pyritic shale and dark gray to red calcareous shale. Selenite flakes occur within the upper part of this fossiliferous upper Hueco sequence; these may be basinward depositional

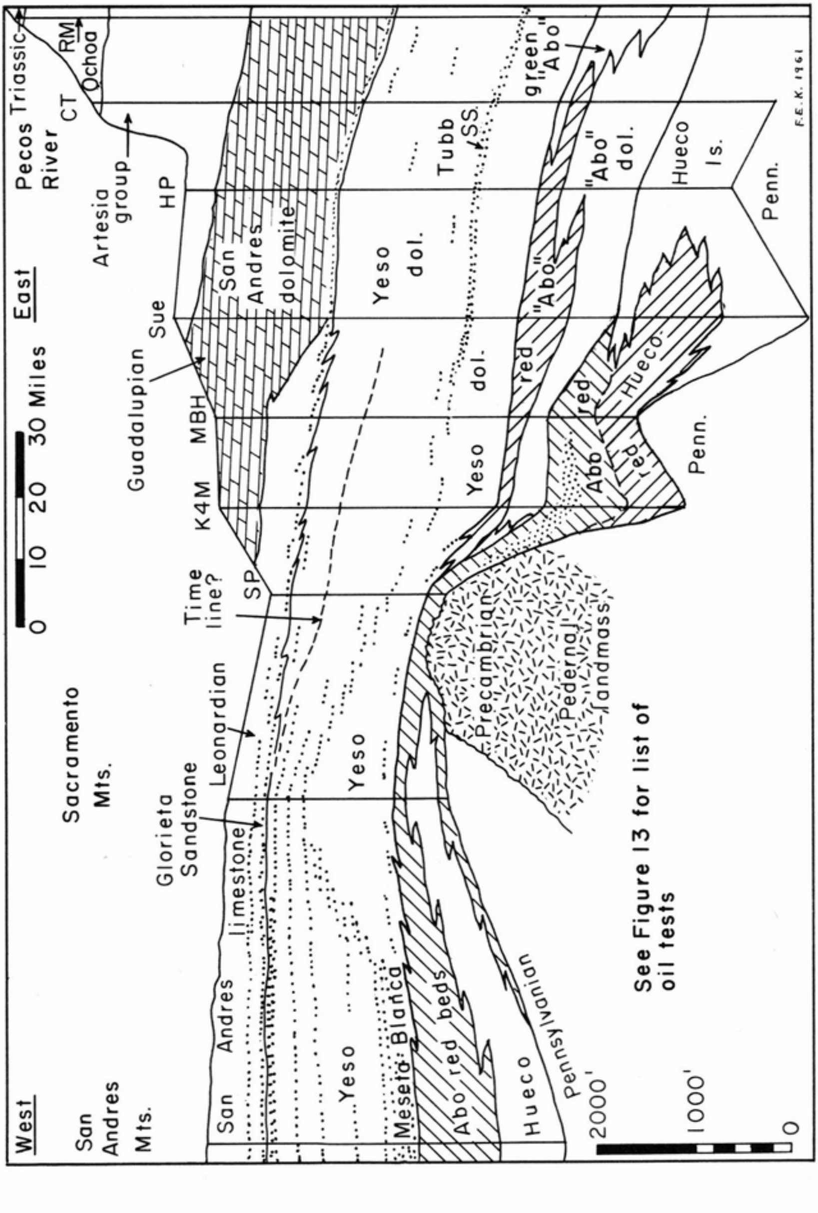

Figure 14

West to east diagrammatic section of Permian units across the Pedernal landmass; alternate correlations remnants of the thin gypsum beds in the upper Hueco outcrops a few miles to the southeast which Bachman and Hayes placed in the basal unit of their Yeso Formation, the Otero Mesa Member.

Thirdly, farther to the southwest in the northern Franklin Mountains, Harbour (1958) described 2200 feet of the Huceo Formation, gradationally overlying Pennsylvanian strata and truncated by recent erosion; the Hueco consists of gray to dark gray, fossiliferous, partly cherty, medium-bedded limestone, with thin persistent interbeds of yellowish siltstone and shale and some thin red siltstone in the upper part of the formation. This Franklin Mountains section of the Wolfcampian strata is similar to that of the type Hueco, although the Hueco of the Hueco Mountains is thinner and includes a larger percentage of shaly beds, as well as more red-bed elastic rocks. The type Hueco, as described in the central Hueco Mountains by King and Knight, is about 1600 feet thick, rests with marked angular and erosional unconformity on older rocks down to the Ordovician, and forms the crest of the Hueco Mountains. To the east and southeast on the Diablo Plateau, the Hueco Limestone is overlain unconformably by either the Leonardian Bone Spring Limestone or by Cretaceous rocks (King, 1934). As a result, the Hueco Limestone is much thinner eastward and southeastward. In the Hueco Mountains, the Hueco Limestone was divided into three lithic units, the upper and lower divisions consisting chiefly of gray, thick-bedded limestones and the middle division of thinner-bedded, darker gray, and more shaly limestones. Locally, a limestone conglomerate and red-bed unit, the Powwow Conglomerate Member, fills basal depressions cut into underlying rocks. Near the New Mexico—Texas state line, the Deer Mountain Red Shale Member, 150 to 200 feet thick, occurs in the upper part of the Hueco Limestone. *Above* this red shale unit, Thompson (1954) collected several species of *Pseudoschwagerina*. Yochelson's (1956, 1960) studies of some of the gastropod families from the type Hueco Limestone confirm its Wolfcampian age and its correlation with the Colina Limestone of southeastern Arizona, whereas Batten's (1958) studies of other gastropod families from the type Hueco suggest a general resemblance to the gastropods of the "Magdalena" Limestone; that is, Pennsylvanian gastropods.

The contact between the Abo—Hueco (chiefly of Wolfcampian age) and the Yeso—Bone Spring (Leonardian age) lithic units appears to be gradational in the outcrops areas in the southern San Andres Mountains, southern Sacramento Mountains, western Otero Mesa, Hueco Mountains, and northwesternmost Diablo Plateau. The Hueco Limestone of the Hueco and Franklin mountains may represent the longest extent of "Wolfcampian" time in the Southwest, with uppermost beds being of youngest Wolfcampian time, a short period of time not preserved in the type Wolfcamp Formation of the Glass Mountains section. Perhaps the lower series of the Permian should be called the Huecoan (way-co-an) rather than the Wolfcampian!

The major uplift of the Pedernal landmass along the northeast edge of the region appears to have occurred during late Pennsylvanian and early Permian time. Debris from this erosional period forms part of the Virgilian, Bursum, and Abo red beds in the areas near Alamogordo and westward. Southward, however, coarse-grained, post-Pennsylvanian, clastic rocks and red beds occur mainly in the lower part of the Wolfcampian beds (Bursum(?) equivalents and Powwow Conglomerate) or in the upper part of the Wolfcampian strata (the Deer Mountain Red Shale) or in the Abo tongues and lenses. Southeastward from the region, uplift during early Wolfcampian time (and late Virgilian time ?) occurred in the Diablo Platform (King, 1942) area, but the clastic materials derived from this uplift, and deposited in westernmost Texas (area in southeastern corner of fig. 12), are merely basal limestone conglomerates and red beds, the Powwow Conglomerate, which are of local extent. The bulk of the Abo Redbeds must have been brought in from the north, as the belt of gradation from the red-bed facies into the Hueco Limestones appears to be roughly aligned east-west (fig. 12).

This facies change, from red beds southward into limestones, as shown in Figure 12, is locally abrupt. It occurs within 30 miles between Cooks Peak and the Florida Mountains, and between the southern Caballo Mountains and the Dona Ana Mountains, whereas in the southern Sacramento Mountains the transition facies is merely 10 to 15 miles wide. The "mean" shoreline of the Wolfcampian seas probably stood near the 8:1 ratio (red beds to carbonate rocks) line in Figure 12, although early Wolfcampian marine limestones of the Bursum Formation were deposited far north of Socorro. Clastic rocks were derived from the Pedernal landmass to the northeast, from the Zuni landmass to the northwest (beyond the limits of fig. 12), and from other uplifts in northern New Mexico and Colorado. Between the floods of detritus from these positive areas, a narrow, northward-projecting seaway was maintained in early and middle Wolfcampian time, its marine deposits recorded in the Bursum and Hueco formations of the San Andres Mountains. In late Wolfcampian time, this seaway was filled by northward-derived masses of red beds that pushed the shoreline as far south as Ash Canyon and the southern Sacramento Mountains, and at the same time overwhelmed and buried most of the Pedernal landmass in this region. Wolfcampian bioherms occur near the ancient shoreline in the Tularosa and Rhodes Canyon areas. Complications are suggested by the 30- to 50-foot tongue of Hueco Limestone in the upper part of the Abo Redbeds penetrated in the Sunray Mid-Continent 1-M Federal oil test (fig. 1, no. 8). This limestone tongue and the overlying 170 feet of red beds probably grade southward into the upper limestones of the Hueco in the Robledo Mountains (Kottlowski, 1960a) where the main red-bed tongue is above the middle of the Hueco Formation but not at the top.

In the southwestern part of the region, erosion during the Mesozoic removed much of the Permian strata. Permian rocks appear to be absent in the Cedar Mountains (Bromfield and Wrucke, 1961) and Klondike Hills beneath Cretaceous(?) conglomerates. Near Clifton and Morenci (Lindgren), the Late Cretaceous Pinkard Formation in some places unconformably overlies the Modoc Limestone (Mississippian in age), and the only Pennsylvanian strata in the area are erosional remnants with no known Permian preserved. The eroded edge of the Mesozoic-age Burro uplift is expanded on the Wolfcampian isopach map (fig. 12) as compared with its extent on isopach maps of older systems (figs. 3-9). Thickest sections of the Wolfcampian beds appear to be in the northeastern Chiricahua Mountains area and not southward beyond the border of the region—as had been the case for most of the older systems. The ratio lines (fig. 12) of red beds as compared to carbonate rocks, however, suggest that although the shoreline was far to the north, carbonate-rock deposition dominated only along the southern border of the region in southwesternmost New Mexico.

The Abo Redbeds near Santa Rita and Cooks Peak contain much coarse-grained clastic material. In the Santa Rita area, Spencer and Paige (1935) and Lasky (1936) reported 50 to 207 feet of the Abo Redbeds, truncated westward by the basal Cretaceous conglomerate and sandstone and consisting of intertongued limestone-pebble conglomerate, red shale, and argillaceous algal limestone with minor lenses of chert conglomerate and arenaceous red shale. In the Cooks Range, Jicha mapped 80 to 150 feet of the Abo Redbeds, unconformably overlain by the Early Cretaceous Sarten Sandstone and consisting of a lower conglomeratic unit and upper red to brown arenaceous shale and silty sandstone. The conglomeratic beds are of limestone- and chert-pebble conglomerate, with some limestone and chert cobbles. The pebbles and cobbles are mostly angular to subangular in a matrix of gray to red calcarenite. Silicified limestone and reddish siltstone form some of the pebbles, as do minor amounts of schist, gneiss, and chloritized granite (Kottlowski, 1958). These rocks appear to have been deposited east, but near the shoreline, of the Wolfcampian-age "Florida islands." This postulated, partly emergent area probably lay west and southwest of Cooks Peak, perhaps extending from the present southern tip of the Burro Mountains to the vicinity of the present Vittorio Mountains. Stripping of the pre-Permian rocks in that area may have occurred in late Pennsylvanian and Early Permian time and was accentuated during the Mesozoic. Thus the Florida islands may have been the forerunner of the much larger positive feature of Mesozoic age that was called the Burro uplift by Elston (1958), a "Mesozoic continent" by Paige, and the source of Early Cretaceous-age detritus made up of pre-Permian carbonate rocks and Permian red beds (Lasky, 1947).

The Early Cretaceous(?) Lobo Formation of the Florida Mountains unconformably overlies rocks ranging from the Hueco Limestone down to Precambrian granites and schists. Permian beds are exposed only on the southeast margin of the range where they unconformably overlie early Mississippian limestones. Basal beds of the Hueco, poorly exposed amid a 20-foot-thick slope, are (1) black calcarenites with some fragments and thin lenses of chert-limestone-granule conglomerate, clasts angular to subrounded, (2) black fossiliferous limestones separated by purplish fossiliferous shale partings, and (3) upper lenses of light brown limy cross-laminated silty sandstone and pinkish purple limy fossiliferous sandstone. Above are the medium- to thick-bedded dark gray fossiliferous limestones typical of the Hueco, about 350 feet thick beneath the pre-Lobo erosion surface. The contact between the lower clastic Hueco beds and the early Mississippian limestones is relatively conformable, but locally 10 to 20 feet of relief occurs on top of the Mississippian.

In the northwestern part of the Florida Mountains, the Lobo Formation of Early Cretaceous(?) age unconformably overlies eroded hills cut in the El Paso Limestone, Montoya Dolomite, and Precambrian rocks. Most of the basal beds of this type Lobo are brown to buff, limy conglomeratic sandstone and conglomerate, pink to gray limy siltstone, and pink to purple shale. Local pockets in the pre-Lobo surface, however, are filled by lenses of limestone nodules in a reddish to purplish calcareous silty shale matrix; basal beds of these lenses are purplish, medial beds pale reddish brown, and upper beds yellowish brown. Angular cobbles of pre-Lobo rocks and numerous sand-size grains of chert, quartz, and limestone are scattered through the matrix. These scattered pockets of nodular limestone and red shale may be of Permian age based on lithologic similarity to parts of the Abo Redbeds near Cooks Peak.

The Hueco Formation in the Tres Hermanas Mountains includes many more basal clastic beds than the Hueco of the southeastern Florida Mountains; thus, the Tres Hermanas Mountains section probably was deposited nearer the shoreline of the late Pennsylvanian and Early Permian Florida islands. The basal beds of this section (Kottlowski and Foster) consist of reddish brown chert-pebble and chert-cobble conglomerate, 10 to 15 feet thick, unconformable on the underlying middle Pennsylvanian limestones. Next above are siliceous microcrystalline limestones, algal in part, about 85 feet thick, overlain by 70 feet of lower cross-laminated chert-pebble conglomerates and upper limestone-pebble conglomerates with interbeds of brown to olive, siliceous microcrystalline limestone. The upper 355 feet of the Hueco consists of dark gray limestones, oolitic in part, containing many gastropods, much crinoidal debris, and some fusulinids. The total thickness of the Hueco Formation may be much greater than the 525 feet measured, since the highest units are in fault contact with volcanic rocks.

Southwest of the eroded edge bordering the Burro uplift, the Wolfcampian beds are as much as 2935 feet thick and are mapped as part of the Horquilla Limestone, Earp Formation, and Colina Limestone. In the Big Hatchet Mountains, Zeller (1958) reported that the upper 1150 feet of the Horquilla Limestone is of Wolfcampian age; it is overlain gradationally by 990 feet of the interbedded red beds and limestones of the Earp Formation, which in turn is beneath 430 feet assigned to the Colina Limestone. The Wolfcampian rocks of the central Peloncillo Mountains (Gillerman; Quaide, 1953) are involved in complex faulting but are more than 1530 feet thick. The upper 200 feet of the Horquilla Limestone is assigned to the Early Permian, the Earp Formation is at least 830 feet thick, and the Colina Limestone is more than 500 feet thick. In the northeastern Chiricahua Mountains, Sabins (1957a) assigned the entire Horquilla Limestone and the lower part of the Earp Formation to the Pennsylvanian, based on fusulinids. Even then, he measured about 2400 feet of the Earp Formation which he placed in the Wolfcampian, overlain by 500 to 535 feet of the Colina Limestone. To the south-southwest in the Pedregosa Mountains, Epis (1956) considered only the upper 680 feet of the Earp Formation to be of Wolfcampian age, but the Colina Limestone is about 1000 feet thick. No fusulinids have been reported from the Colina Limestone, but the gastropod faunas are believed identical with those of the Hueco by Yochelson (1956, 1960). Sabins (1957a), however, collected species of the cephalopod *Perrinites* from the upper part of the Colina, a genus believed (Dunber et al.) confined to Leonardian rocks. As the upper part of the Colina Limestone in some places appears to be of Leonardian age, based on the cephalopods, the thickness of Wolfcampian strata may be overestimated in Figure 12 in southeasternmost Arizona.

The red beds in these southwestern Wolfcampian sections appear to be marine deposits. Conglomeratic units, as noted by Gilluly, Cooper, and Williams, are mainly of intraformational types, but some of the conglomerates in the upper part of the Earp Formation appear to have been derived by erosion of large areas of pre-Permian sedimentary rocks. As the Wolfcampian strata seem to become more clastic northward, the source of this debris is assumed to be northward, toward the area of the Zuni landmass, or perhaps more likely, northwestward toward the Mazatzal landmass of McKee in central Arizona.

LEONARDIAN ROCKS

Admitting some confusion and much uncertainty as to which "formations" are entirely or partly of Wolfcampian age, dating of the formations does not become more precise as one ascends the Permian sections. Most of the Yeso Formation of south-central New -Mexico appears to be of Leonardian age, but there are problems as to which beds are in the Yeso and which beds are in the Hueco of the Otero Mesa area. The type San Andres Limestone is dated as Leonardian in age, based on cephalopods and brachiopods (Flower *in* Kottlowski et al.), but the thicker San Andres Limestone of southeastern New Mexico is believed to be mainly of Guadalupian age based chiefly on fusulinids. **In** southwesternmost New Mexico, the Colina Limestone appears to straddle the Wolfcampian—Leonardian boundary, the Epitaph Dolomite and Scherrer Formation are of Leonardian age, and the Concha Limestone is of Leonardian and Guadalupian(?) age. At the type section of the Wolfcamp and Leonard in the Glass Mountains area and westward into the Diablo Plateau country (at the extreme southeast corner of fig. 12), Leonardian beds, the Bone Spring Limestone of the Diablo Plateau, unconformably overlie Wolfcampian strata, the Hueco Limestone. Farther westward in the Hueco and Franklin mountains, the Hueco includes beds that are younger than the uppermost strata of the type Wolfcamp formation but (apparently) older than the lowermost units of the type Leonard. In southwesternmost New Mexico and southeasternmost Arizona, the Colina Limestone probably includes these youngest Wolfcampian horizons, and here there appears to be a complete Permian section without notable breaks, deposited continuously from Wolfcampian through Leonardian into Guadalupian time. In this Pedregosa basin area, as well as in the Orogrande basin, the Pennsylvanian—Permian boundary seems indecipherable amid a sequence of continuously deposited sediments.

Thicknesses and lithofacies of the middle and late Permian strata, therefore, are depicted on two "formational" maps that show the extent and changes of the Yeso Formation and Epitaph Dolomite (fig. 15), and those of the Glorieta, San Andres, Scherrer, and Concha formations (fig. 16). The contacts of these formations with contiguous units, for the most part, appear to be gradational, so that the units shown on each map are only approximately correlative.

In the Hidalgo and Cochise counties area, the black limestones of the Colina grade upward into either the Epitaph Dolomite or the Scherrer Formation. To the west in central Cochise County (Gilluly, Cooper, and Williams), the base of the type Epitaph Dolomite is arbitrarily taken at the base of the first massive dolomite above the zone of partially dolomitized limestone at the top of the Colina Limestone. Here the Epitaph Dolomite is about 785 feet thick with upper beds including much intercalated red shale, sandy limestone, and limy sandstone. These upper beds bear a marine fauna, but features such as cross-bedding, ripple marks, and sedimentary breccias suggest deposition in shallow water. In the Pedregosa Mountains, Epis (1956) noted that the contact between the Colina Limestone and Epitaph Dolomite is gradational through a 50-foot-thick dolomitic limestone sequence. He measured 1350 feet of the Epitaph, the lower 800 feet being of gray, thick-bedded, cherty dolomite and the upper 550 feet consisting of thin-bedded, sandy dolomite and limestone interbedded with red calcareous shale, siltstone, and sandstone in which cross-bedding is prominent. The upper contact is placed at the top of a sandy dolomite which grades upward into the dolomitic quartz sandstone of the Scherrer Formation.

In the northeastern Chiricahua Mountains, however, Sabins (1957a) reported that the Colina Limestone is overlain directly (and conform-

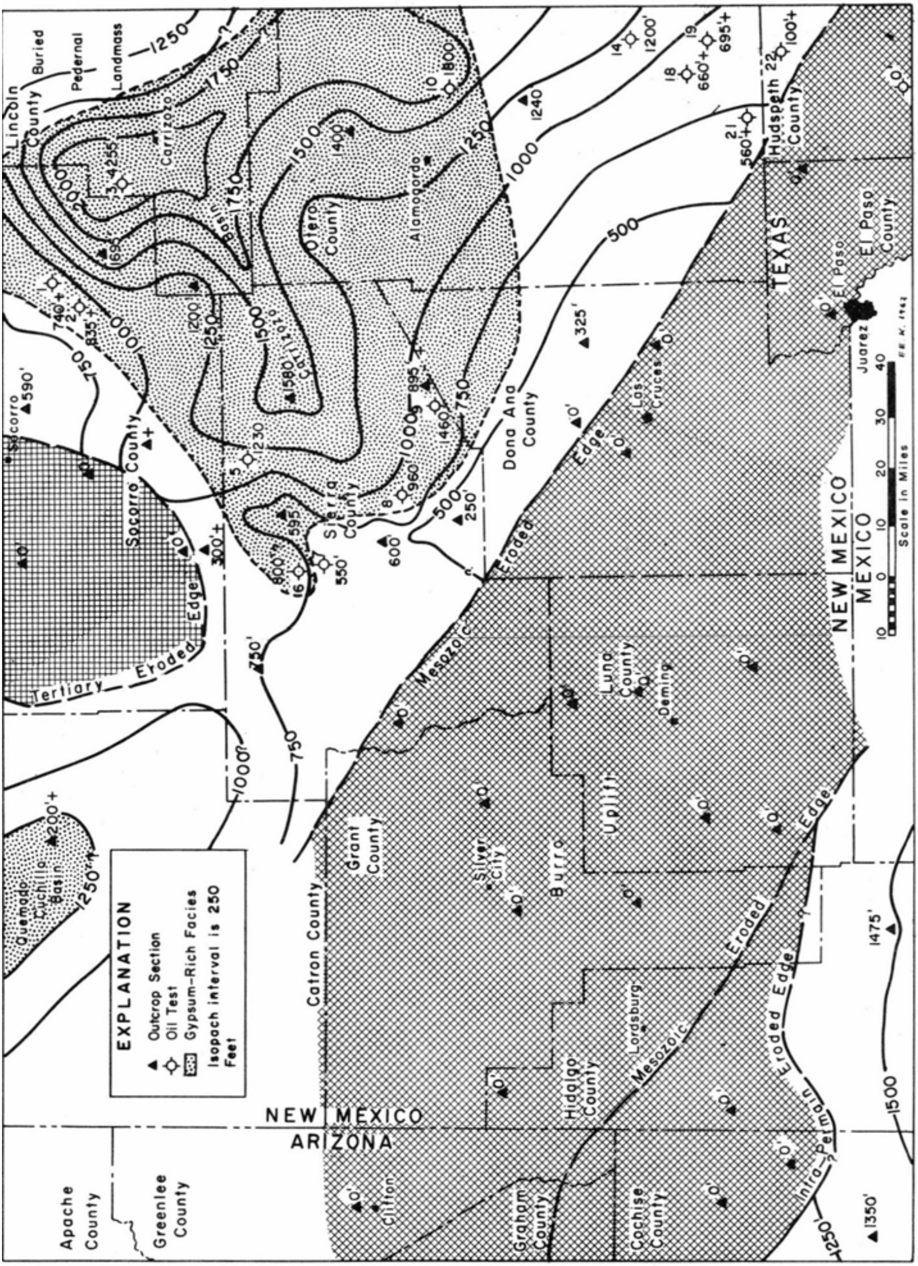

Figure 15
Isopach and Facies Map of Yeso Formation and Epitaph Dolomite in Southwestern and South-Central New Mexico

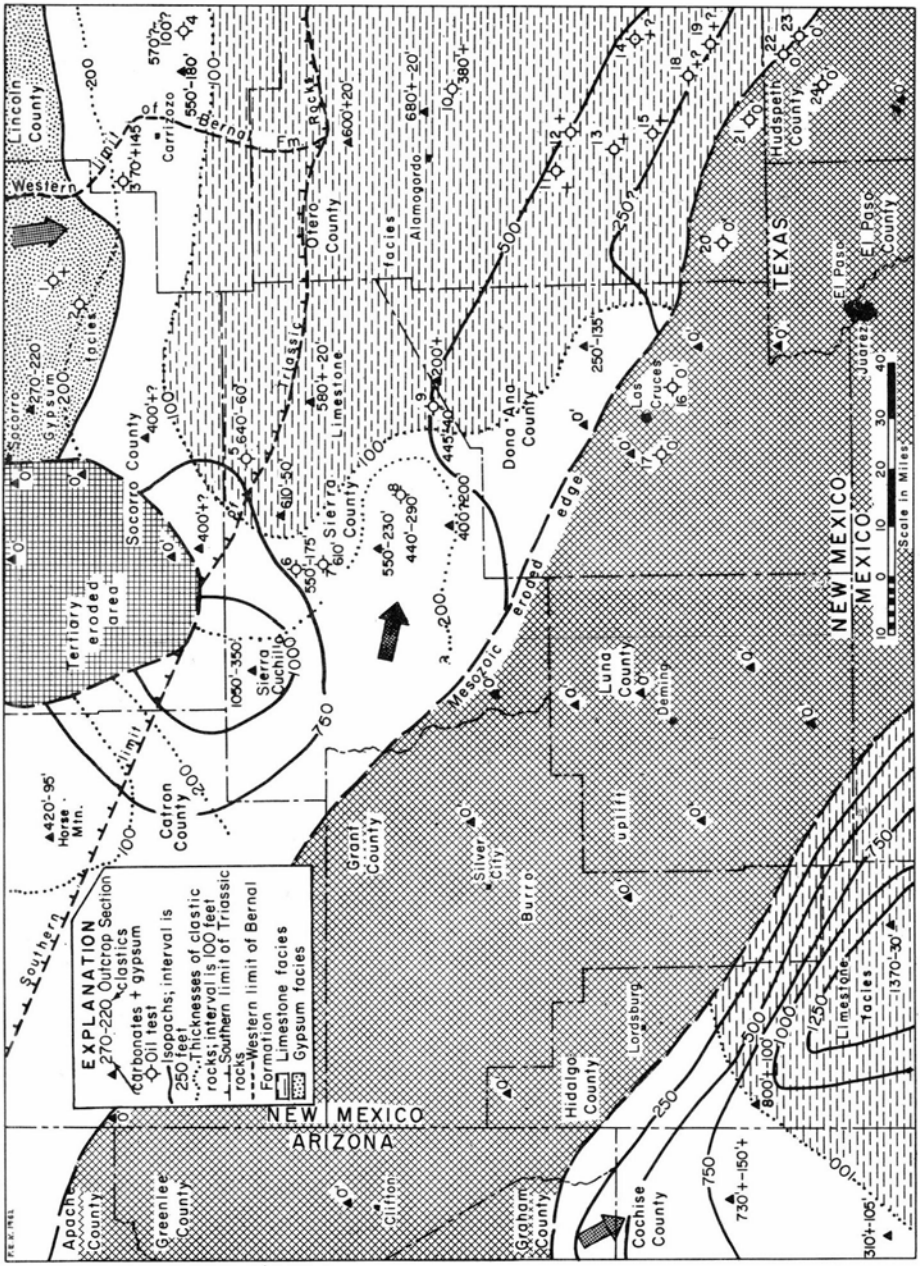

Figure 16

ISOPACH AND FACIES MAP OF GLORIETA, SAN ANDRES, SCHERRER, AND CONCHA (INCLUDES RAINVALLEY) FORMATIONS IN SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO ably) by the Scherrer Formation, with no recognizable part of the Epitaph Dolomite present. He suggested that the Epitaph Dolomite of the central Cochise County area may be a twofold unit, the lower part a dolomitized equivalent of the upper part of the Colina Limestone of other areas and the upper part of the Epitaph equivalent to part or all of the Scherrer Formation. Gillerman did not find any Epitaph Dolomite between the Colina Limestone and the thin Scherrer Formation of the central Peloncillo Mountains. In contrast in the Big Hatchet Mountains, Zeller (1958) measured 1450 to 1500 feet of the Epitaph Dolomite grading downward into the Colina Limestone and upward into a thin Scherrer Formation. The upper part of the Epitaph Dolomite is mostly medium-bedded to massive dolomite, whereas the lower 400 feet includes interbeds of siltstone—the reverse of the lithology of the type Epitaph.

The upper part of the Colina (that part with a Leonardian fauna ?), the Epitaph Dolomite, and the Scherrer Formation appear to be intertonguing facies consisting of a lower, dominantly carbonate-rock sequence and an upper sequence of interbedded carbonate rocks and fine-grained clastic strata. The middle part of these units seems to be an approximate equivalent of the Yeso Formation, deposited in shallow but open marine water, whereas much of the Yeso was laid down in the highly saline waters of partly restricted lagoons.

If the Epitaph Dolomite is merely a facies of parts of the Colina Limestone and Scherrer Formation, one might expect the total thicknesses of these post-Earp and pre-Concha formations to be roughly equal within the small area of the Chiricahua, Pedregosa, Big Hatchet; and central Peloncillo mountains. However, these units total only 700 feet in the northeastern Chiricahua Mountains (Sabins, 1957a) and about 600 feet in the central Peloncillo Mountains (Gillerman), but 1925 to 2455 feet in thickness in the Big Hatchet (Zeller, 1958) and Pedregosa (Epis, 1956) mountains. Either beds equivalent to the bulk of the Epitaph Dolomite of the Pedregosa and Big Hatchet mountains were not deposited to the north or these equivalents were removd by erosion (fig. 15) prior to or during deposition of the Scherrer Formation clastic rocks.

Post-Wolfcampian strata were removed by erosion during early Mesozoic time along a broad (75 to 85 miles wide) northwest-trending belt (figs. 15, 16). The outcrop area of the Epitaph Dolomite is isolated from that of the Yeso Formation by this eroded belt which appears to be the maximum expansion of the Burro uplift with its projection to the southeast to join areas in westernmost Texas where Early Cretaceous conglomerates rest on Wolfcampian beds. This eroded area was an upland source of clastic materials deposited during Early Cretaceous time and may have been controlled by some deep-seated "'lineament" that was later reflected in the late Cretaceous and Cenozoic deformation and igneous activity that marks the "Texas lineament" (Mayo, 1958;

Turner, 1962). The trend of the Texas lineament, a 150-mile-wide belt of transverse structures, however, is more nearly west-northwest.

Only the upper 150 to 200 feet of the Yeso Formation is exposed on Horse Mountain in central Catron County, where the formation is overlain conformably by the Glorieta Sandstone. About .40 miles to the north-northwest, however, the Huckleberry—Federal oil test (north of fig. 15) penetrated 1450 feet of the Yeso, including much anhydrite and gypsum (Foster, 1957). To the southeast in Sierra Cuchillo, Jahns measured only 750 feet of the Yeso, but the overlying San Andres Limestone is unusually thick (1400 feet) suggesting that part of this San Andres unit is equivalent to the upper part of the Yeso Formation elsewhere. The Yeso (and San Andres) of the Sierra Cuchillo is a carbonate-rock facies with only subordinate amounts of greenish and pale red sandstone and siltstone. Gypsum occurs only as laminae and veinlets. On the southeast edge of the San Mateo Mountains in Nogal Canyon, the upper part of the Yeso Formation is chiefly of pinkish, fine-grained elastic rocks and much dolomitic limestone; again, gypsum is present in only minor amounts. In the Gartland—Brister (fig. 1, no. 6) and Summit—Mims (fig.l, no. 7) oil tests northeast of the Mud Springs Mountains, the Yeso is •550 to 800(?) feet thick, includes a high percentage of fine-grained elastic rocks and only small amounts of calcium sulfate. Northwestern and central Sierra County was an area where Yeso sedimentation was mostly of carbonate rocks and interbedded, subordinate, fine-grained elastic strata with almost no gypsum deposition. To the northwest, thick sections of the Yeso, including much gypsum and anhydrite, were deposited in the northwest-trending "Quemado—Cuchillo" basin (Foster, 1957).

Erosion during early Tertiary time removed all the post-Wolfcampian strata in a circular area of southwestern Socorro County (fig. 15). East of this eroded area, east and southeast of Socorro, the Yeso also is thin and contains but little gypsum (Wilpolt and Wanek). The Yeso appears to be thin and relatively nongypsiferous in the southern Caballo Mountains (Kelley and Silver) and Ash Canyon areas where, however, the unit ascribed to the overlying San Andres Limestone may be equivalent to the upper Yeso of adjoining areas. The Yeso is thin (600 feet thick) in the central Caballo Mountains and contains only a few thin (5 to 20 feet thick) gypsum beds, whereas to the north in the Fra Cristobal Mountains (Thompson, 1955) gypsum beds are more numerous within a 595-foot-thick section.

Gypsum makes up only seven percent of the 1240-foot-thick Yeso section in the southern Sacramento Mountains (Pray, 1961). To the south on Otero Mesa, the Yeso crops out over large areas so that complete sections are not reported. Northward in the Sacramento Mountains the Yeso thickens and includes a larger percentage both of gypsum and of pale red elastic rocks. In the San Andres Mountains, the Yeso thickens from 325 feet near Ash Canyon to more than 1000 feet west of

Hembrillo Canyon and to 1580 feet west of Rhodes Canyon; much of this northward thickening is due to an increase in the number and thickness of the gypsum units. Sharp folds, contorted bedding, slumping, and local brecciation of the thicker Yeso sections may indicate removal of halite beds at and near the surface. Whereas the Yeso is thinner and less gypsiferous near Mockingbird Gap, the formation is about 1695 feet thick in the southeastern Oscura Mountains (Wilpolt and Wanek), and as much as 4255 feet of the formation was penetrated in the Standard of Texas—Heard oil test (fig. 1, no. 3). This well was drilled on the Carrizozo dome. The apparent section encountered is in part thickened by steep dips, but it includes many halite beds which are not reported from outcrops. For example, a 1600-foot interval of the Yeso Formation drilled through was almost 75 percent salt.

About 30 miles to the east-southeast of the Standard—Heard oil test, the Capoco—Spencer oil test apparently penetrated a thin clastic section of the Yeso formation, and to the north (north of fig. 15) in the Gallinas Mountains and southern Pedernal Hills, the Yeso also is thin and consists chiefly of clastic rocks. The thicker sections outline an inverted mushroom-shaped "Carrizozo" basin in which large amounts of gypsum were deposited with the thickest Yeso reported from the Carrizozo dome; possible persistent arms of the basin, suggested by thick deposits, extended southwestward toward Rhodes Canyon and south-southeastward toward the east-central Sacramento Mountains.

The youngest Permian strata remaining in most of this region are the Glorieta Sandstone and San Andres Limestone of south-central New Mexico and the Scherrer Formation and Concha Limestone of southwestern New Mexico and southeastern Arizona. Bryant and McClymonds' (1961) Rainvalley Formation is included as the upper part of the Concha Limestone in the Chiricahua, Peloncillo, and Big Hatchet mountains area merely as a matter of convenience. Only the Concha Limestone (as restricted by Bryant and McClymonds) remains in the Pedregosa Mountains beneath the erosion surface cut during Mesozoic time. In the Peloncillo Mountains, this post-Scherrer Permian unit has been metamorphosed (Gillerman) so that the Concha Limestone and Rainvalley Formation have not been differentiated. In the Chiricahua and Big Hatchet mountains the thick-bedded cherty Concha Limestone could be mapped separately from the overlying thin-bedded limestone, dolomite, and minor sandstones of the Rainvalley Formation.

In this southwestern part of the region, erosion during Mesozoic time truncated the upper Permian strata. Thicknesses, therefore, are remnant thicknesses and do not necessarily reflect original deposition. Southeastward toward the Big Hatchet Mountains, however, these remnant thicknesses are greater, and the basal clastic rocks in the Scherrer Formation and lower part of the Concha Limestone thin (fig. 16) from about 150 feet in the northeastern Chiricahua Mountains (Sabins, 1957a) to less than 30 feet in the Big Hatchet Mountains (Zeller, 1958). This combination suggests that the main marine basin in the southwestern part of the region was near and south of the Big Hatchet Mountains during Scherrer and Concha "time." These outcrops of the upper Naco Group are cut off from the Glorieta—San Andres outcrops by the expanded Burro—Diablo uplift as noted previously in the discussion of the Yeso and Epitaph formations.

The Glorieta Sandstone is a prominent light gray, yellowish brown-weathering, quartzose sandstone in the Chupadera Mesa area and northward. To the south in the San Andres and Sacramento mountains, possible equivalents of the Glorieta Sandstone are lenses of friable, poorly cemented, yellowish brown sandstones which grade down into the reddish sandstones of the Yeso Formation and are interbedded with lower limestones of the San Andres Limestone. The Glorieta Sandstone is 150 to 200 feet thick east of Socorro; southeastward to the southern part of Chupadera Mesa, the unit thins to 25 to 50 feet because of intertonguing of lower sandstones with upper beds of the Yeso Formation (Wilpolt and Wanek). On Horse Mountain to the west, the Glorieta is a discrete 95-foot-thick unit.

Near Rhodes Canyon at the type section of the San Andres Limestone (Lee and Girty, 1909; Needham and Bates, 1943), the Glorieta(?) Sandstone appears to be represented by a 30- to 35-foot-thick unit of interbedded sandstone and dolomitic limestone. This unit is gradational with both the overlying San Andres Limestone and underlying reddish sandstones of the Yeso Formation. In the Sacramento Mountains, Pray (1961) prefers to call a similar unit the Hondo Sandstone Member of the San Andres Limestone following the usage of Lang (1937). This member consists of several beds of clean, quartz sandstone with rounded frosted grains occurring within limestones typical of the San Andres Limestone and 60 to 120 feet above the top of the Yeso Formation. The Glorieta(?) Sandstone of south-central New Mexico appears to be a well-washed, yellowish, marine sandstone differing from pinkish sandstones of the underlying Yeso Formation merely in the amount of ferruginous coating on grains and in containing a much smaller fraction of clay and fine-grained silt. These yellowish sandstones probably are not at the same stratigraphic position throughout the region. They may be isolated lenses that may become younger in age eastward (fig. 14) and older southward.

The San Andres Limestone is about 600 feet thick at its type locality near Rhodes Canyon in the north-central San Andres Mountains (Kottlowski et al.). Here the limestone consists of almost monotonous, gray to dark gray, medium-bedded to massive, fetid fossiliferous petroliferous limestones. Dolomitic limestones and some dolomites occur within the lower and upper-middle beds. Even in this section dominated by carbonate rocks, there are lenses of arenaceous calcarenites and very limy quartz sandstones. Many of the limestones contain scattered quartz grains and laminae of calcareous siltstone; most of the limestones show much scattered quartz silt in thinsections. In the Sacramento Mountains, Pray (1961) reports a similar dominance of carbonate rocks above the basal Hondo Sandstone Member. The extent of this limestone lithofacies is shown in Figure 16. To the north, west, and southwest, the amount of clastic beds in the Glorieta and San Andres formations increases. The northward increase is due to the thickening of the Glorieta Sandstone and northward thinning of the San Andres Limestone. Westward and southwestward, however, the increase in clastic rocks is due to an increase in interbeds of siltstone and sandstone within the San Andres Formation. The sections in Sierra Cuchillo (Jahns) and the Caballo Mountains (Kelley and Silver) contain 25 to 35 percent of clastic rocks, aggregating 200 to 350 feet thick, with a possible source to the west-northwest. Perhaps part of the Burro uplift was an active eroded area in northwestern Grant County during deposition of the San Andres Formation.

The lower part of the San Andres Formation includes thick beds of gypsum northeast and east of Socorro. These gypsum beds appear to mark the southeastern limit of an evaporite basin that extended northwestward to the Lucero Mesa area (Kelley and Wood, 1946). A narrow belt of clastic lithofacies separated this evaporite basin from the site of predominant carbonate-rock deposition to the south. Allen and Jones's (1951) section of the San Andres Formation east of Carrizozo (near Capitan) is typical of this clastic-rock belt; limestones and minor dolomites make up 60 to 80 percent of the unit but quartz sandstones and silt-stones are interbeds throughout the formation. Scattered in the lower 350 feet of the San Andres Formation near Capitan are at least three thick Glorieta-like sandstones, each 15 to 30 feet thick.

The combined thicknesses of the Glorieta and San Andres formations (fig. 16) are between 500 and 750 feet in most of south-central New Mexico. Thinning to the south in northeastern Dona Ana County is a reflection of erosion during Mesozoic time along the flanks of the Burro—Diablo uplift. The San Andres Formation is about 1400 feet thick in the Sierra Cuchillo (Jahns); if this thickness is not exaggerated by inclusion of upper Yeso beds in the lower part of the San Andres, it represents one of the thickest known sections of the formation. Upper beds are erosional remnants that may have been deposited over most of south-central New Mexico but apparently were removed from all parts of the region outside of Sierra Cuchillo during Mesozoic time. This thick section of the San Andres Formation is overlain unconformably by Cretaceous(?) clastic rocks, but a short distance to the north the feather edge of Triassic strata occurs. The northward-thickening Triassic rocks occur above the San Andres Formation and below Cretaceous strata north of a line drawn (fig. 16) south-southeastward through Horse Mountain, SunVictorio oil test, north of Rhodes Canyon, and south of Sierra Blanca.

The age of the San Andres Limestone is a complex problem. At the type locality in the San Andres Mountains, Flower *(in* Kottlowski et al.)

identified the brachipod *Dictyoclostus bassi (Peniculauris bassi* of Muir-Wood and Cooper, 1960) and the ammonoid *Perrinites* from upper beds of the 600-foot-thick section. These are guide fossils of the Leonard Series (Dunbar et al.) and are considered with the rest of the brachiopod-molluscan fauna from the type section; the formation there is of Leonardian age. In southeastern New Mexico, however, the thicker back-reef section of the San Andres Limestone lying west of the Permian Basin appears to inch de a lower sequence of Leonardian age, and an upper, thicker sequel* of Guadalupian age (Skinner, 1946; Newell et al., 1955; Boyd, 1958; Hayes, 1959). Thus the San Andres Limestone in south-central New MeXico may be merely the lower Leonardian part of the thicker San Andres to the southeast (fig. 13). This Leonardian San Andres unit, however,, is overlain by the Bernal Formation near Carrizozo (Dane and BachMan, 1958), a probable red-bed equivalent of the Grayburg Formation (and younger Guadalupian formations) that overlies the thick Leonardian—Guadalupian San Andres Limestone of southeastern New Mexico.

A theoretical alternative is that the Pedernal landmass may have acted as a buried but relatively positive feature and that the entire Permian section changes facies going from west to east across this late Paleozoic mountain range (fig. 14). The type Abo Redbeds thin across the roots of the Pedernal landmass and may intertongue eastward into the subsurface Hueco Limestone. The basal pinkish Meseta Blanca Sandstone Member of the eso Formation in central New Mexico may grade eastward, and basinw rd, into the "Abo" red-bed tongues and "Abo" dolomite of southeast rn New Mexico. The type San Andres Limestone may grade almost imp rceptibly eastward into the upper Yeso dolomites of the Delaware Basin back-reef section. But what about the Glorieta Sandstone and the Drinkard or Tubb sandy member of the Yeso Formation? The Glorieta Sandstone of the Carrizozo, western Sacramento Mountains, and San Andres Mountains area may be merely one of several sandstone lenses within the gradational contact zone of the Yeso and San Andres formations, and is therefore of doubtful time-stratigraphic value. Likewise, the subsurface tracing of the Tubb sandstone from southeastern N w Mexico into the outcrops of the Sacramento Mountains area is bas d on choosing one sandstone from several within the Yeso Formation p netrated in the widely scattered oil tests of western Chaves and western Eddy counties. Whether the Glorieta (Hondo) and Tubb are extensive time-line sand sheets covering at least 40,000 square miles in south-central New Mexico or are local lenticular bodies of erratic lateral extent is yet to be determined by detailed studies of the outcrop and of s bsurface samples. The Glorieta Sandstone does intertongue with the eso Formation southward from Chupadera Mesa to the San Andres M untains, and possibly the thick Yeso Formation of the Rhodes Canyon rea is the equivalent of the thin Yeso Formation and most of the thin San Andres Formation to the south near Hembrillo and Ash canyons, as well as correlative to the similar thin sections to the southwest in the southern Caballo Mountains.

GUADALUPIAN ROCKS

In the northeast corner of the region (fig. 16), the Bernal (Artesia, Chalk Bluff, Whitehorse) Formation of probable Guadalupian age unconformably overlies the San Andres Limestone. As described by Allen and Jones and Smith and Budding (1959) for the area east and northeast of Carrizozo, the Bernal rests on an eroded karsted surface cut on the San Andres Limestone and ranges from less than 200 to about 355 feet in thickness within short distances. The formation consists of red to buff, fine- to medium-grained, limy sandstones with silty partings and some shale beds. This lithic unit is more similar to the type Bernal Formation (Bachman, 1953) of north-central and central New Mexico than to the Chalk Bluff Formation (Lang) near Artesia or the equivalent Grayburg, Queen, and younger formations of the Artesia (Whitehorse) Group of the Pecos Valley area (Murphy and Helmig, 1954; Tait et al., 1962). These latter formations do contain reddish sandstones and siltstones but have many interbeds of dolomite and gypsum. The Bernal Formation is absent west of a north-south line drawn roughly through Carrizozo, but northeast of Socorro equivalent beds have been mapped as the upper clastic member of the San Andres Formation (Wilpolt and Wanek). This unit is only 5 to 36 feet thick and includes some thin beds of dark gray argillaceous limestone amid the dominant orange-red silty sandstone. The western limit of the Bernal Formation shown in Figure 16 is in part due to abrupt truncation of the unit beneath the overlying Triassic rocks. Erosion during Recent time has stripped the post-San Andres Limestone strata from Chupadera Mesa and removed the precise western limit of the Bernal; however, Triassic rocks rest unconformably on the San Andres Limestone in the northern San Andres Mountains and just west of the northwestern Oscura Mountains. The Bernal red-bed facies grades eastward into the Artesia red-bed and evaporite facies of the Pecos Valley area. The source of the Bernal clastic rocks may have been to the west and northwest.

Mesozoic Strata

Triassic beds, the *1:,* ockum Formation, or the Santa Rosa Sandstone overlain by the Chinle Formation have been left beneath an erosion surface only in the northe n part of the region. No Jurassic rocks are known from this area. Early C etaceous rocks are thick to the southwest but thin or absent in the north rn part of south-central and southwestern New Mexico, whereas Late Cretaceous strata, where left after Cenozoic erosion, are thick in the n rthern part of the region but absent to the southwest. Both Early and ate Cretaceous sequences locally include thick masses of volcanic detr tus.

TRIASSIC STRATA

Triassic rocks occ r only along the north edge of the region. On Horse Mountain the remnant of the Triassic(?) strata in fault contact with Tertiary volcanic and sedimentary rocks consists of light gray, grayish orange, and light ed, cross-laminated pebbly sandstone above the San Andres Limestone In the Sun—Victorio oil test (fig. 1, no. 5), the Triassic is about 180 feet thick, with the upper 120 feet of red claystone, siltstone, and sandston - perhaps an equivalent of the Chinle Formation, and the lower 60 feet if gray to red silty sandstone representative of the Santa Rosa Sandstone In the northern San Andres Mountains, the Triassic is referred to the Dockum Formation and consists of 50 to 100 feet of red to gray, calcare o us, micaceous claystone and siltstone with laminae of feldspathic san I stone. East of Socorro, Wilpolt and Wanek estimated 500 feet of the Dockum, whereas north of Carrizozo, Smith and Budding mapped 200 eet of the Santa Rosa Formation, a red micaceous sandstone containing pper lenses of quartz and chert-pebble conglomerates, overlain by the Chinle Formation consisting of red to lavender sandstone and mudst a ne about 400 feet thick.

The southern limi of Triassic strata (fig. 16) reflects some southward thinning but is due m: inly to truncation beneath basal Cretaceous conglomerates and sandst o nes. Southwestern New Mexico and southeastern Arizona, however, see l to have been a low, broad, uplifted source of the early and middle Mesozoic clastic rocks deposited to the north in central New Mexico and cent al Arizona. No Jurassic rocks are known from the region, the Jurassic s. ndstones, limestone, and gypsum of central and northern New Mexico being abruptly cut out along an east-west line 40 to 60 miles north of So orro.

I RETACEOUS STRATA

Late Cretaceous ri cks remain as erosional remnants in the northern part of the region an I appear to be thin or absent above the thick sequence of Early Cre aceous strata of southwesternmost New Mexico (fig. 17). Near D-Cross Mountain, along the Socorro—Catron county line west-northwest of Socorro, typical central New Mexico Cretaceous rocks crop out. Here Givens (1957) noted that the Dakota Sandstone is about 20 feet thick and unconformably overlies the Triassic Chinle Formation. Above is the Mancos Shale consisting of a lower 105-foot-thick shale member, a middle 25-foot-thick Tres Hermanos Sandstone Member, and an upper 165-foot-thick shale member. The shales are sandy, fossiliferous, calcareous, gypsiferous, and carbonaceous. The overlying Mesaverde Group consists of the lower La Cruz Peak Formation (Tonking, 1957) and the upper Crevasse Canyon Formation. The La Cruz Peak Formation contains a basal marine sandstone 40 to 100 feet thick, a middle fossiliferous, sandy, calcareous shale 190 feet thick, and an upper 70-foot-thick marine sandstone. The Crevasse Canyon Formation is made up of quartzose sandstones interbedded with mudstones, nonmarine shales, and coals, about 600 feet in thickness. The Late Cretaceous rocks are about 1275 feet thick beneath the early Tertiary Baca Formation. The same units were recognized by Dane, Wanek, and Reeside (1957) along the north edge of the Datil—Mogollon plateau, but they used a slightly different terminology.

On Horse Mountain, Triassic(?) sandstones appear to underlie early Tertiary(?) sediments and volcanic rocks. In the northwestern Magdalena Mountains, the basal Tertiary rests unconformably on the Abo Redbeds (Loughlin and Koschmann, 1942), but east of the Rio Grande, east of Socorro, the Dakota, Mancos, and Mesaverde formations total 1010 to 1930 feet in thickness beneath the Baca Formation. On the southeast edge of the San Mateo Mountains, Tertiary rocks rest unconformably on Permian strata. In the northern Sierra Cuchillo, Jahns reported only 200 feet of Late Cretaceous(?) clastic beds above the San Andres Limestone and below Tertiary rocks. A thin remnant sandstone and black shale unit above the Abo Redbeds was noted by Kuellmer near Kingston in the Black Range and may be of Late Cretaceous age. Cretaceous rocks, however, appear to have been removed by erosion during early Tertiary time from much of the Datil—Mogollon plateau area (fig. 17).

North of Silver City and Santa Rita, Paige mapped Tertiary rocks unconformable above Cretaceous and Paleozoic strata. North of Silver City, the Tertiary appears to overlap pre-Tertiary beds in descending order, suggesting that Cretaceous strata may not be present beneath the volcanic rocks in southern Catron County. West of the region shown in Figure 17, Tertiary sedimentary and volcanic rocks overlie pre-Cretaceous strata in an east-west belt between westward projections of the Grant—Catron county line and the Apache—Greenlee county line. To the north and west of Escudilla Mountain, thin (500 feet ?) Late Cretaceous sediments occur beneath the Tertiary rocks and thicken rapidly northward.

Along the east margin of the region, outliers of Late Cretaceous

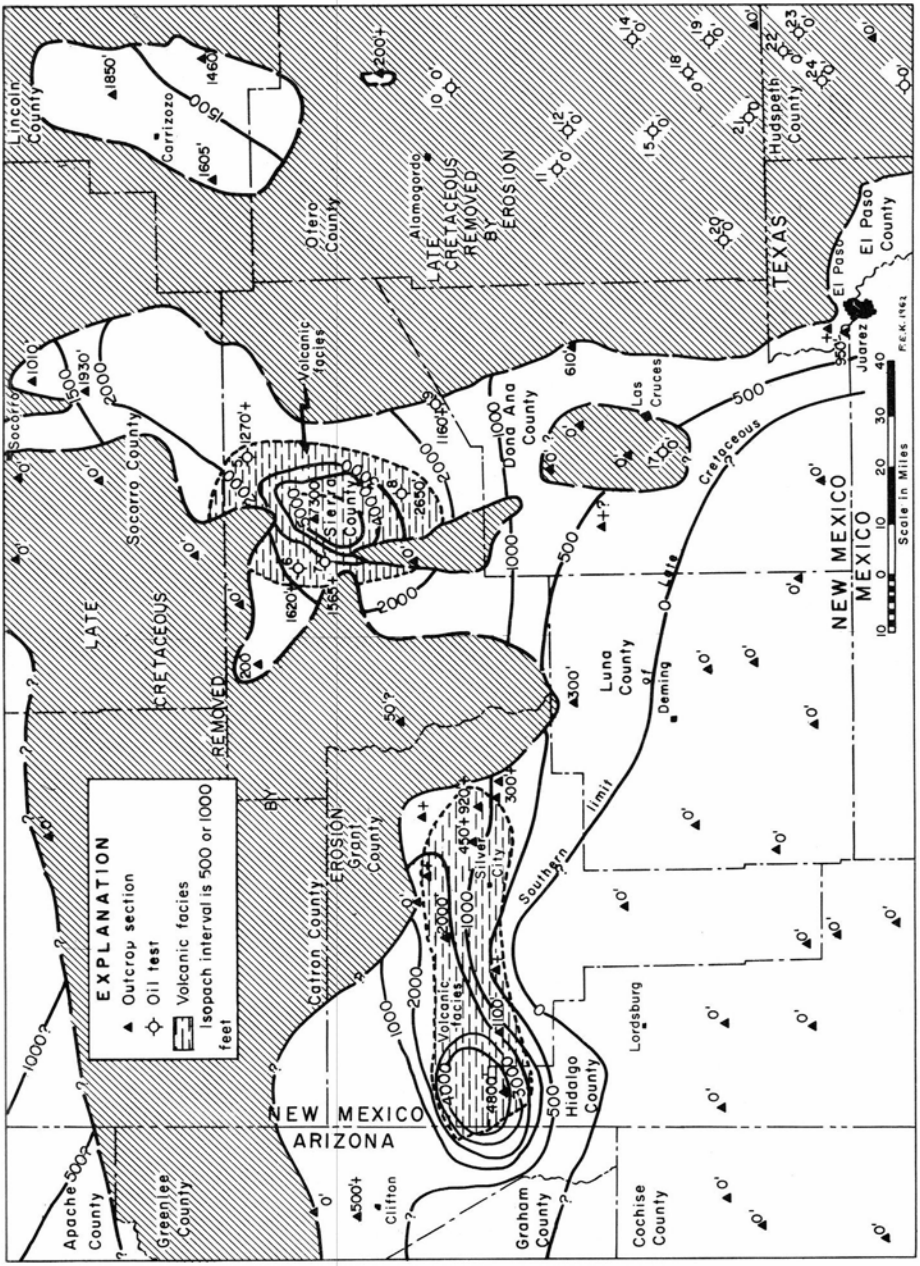

Figure 17

Isopach and facies map of Late Cretaceous strata in southwestern and south-central New Mexico strata occur on the crest of the Sacramento Mountains east of Tularosa and from Sierra Blanca northward to the Jicarilla Mountains bordering the Carrizozo synclinorium. Near Capitan, Allen and Jones measured 135 feet of Dakota Sandstone, 390 feet of Mancos Shale, and more than 535 feet of the Mesaverde Formation. In the Capitan coal field, Bodine (1956) placed 510 feet of sandstones, shales, and coals in the Mesaverde Formation and noted that it is overlain by the Cub Mountain Formation. This formation may be of late Cretaceous or of early Tertiary age; it is about 500 feet thick, and consists of yellow sandstone, quartzitechert-pebble conglomerates, and reddish shales and siltstones. A thicker section of the Late Cretaceous strata was reported by Wegemann (1912) on the southern flanks of the Jicarilla Mountains. To the south on the crest of the Sacramento Mountains, Pray and Allen (1956) measured a 200-foot-thick remnant of the Dakota Sandstone, disconformable on the San Andres Limestone. Thick sections of the Dakota, Mancos, and Mesaverde formations probably were deposited across the region stretching eastward from the San Andres Mountains toward the Pecos Valley but were removed by erosion during Cenozoic time.

Late Cretaceous strata are 1010 to 1930 feet thick beneath the Tertiary Baca Formation in the northern part of Jornada del Muerto southeast of Socorro (Wilpolt and Wanek). About 1270 feet of Late Cretaceous strata were penetrated in the Sun—Victorio oil test (fig. 1, no. 5) beneath a thin valley fill; thicknesses penetrated in other oil tests in central Sierra County range up to 2650 feet. In the structurally low area between the Caballo and Fra Cristobal mountains, Bushnell (1955) and Kelley and Silver measured 245 feet of the Dakota Sandstone, 350 to 450 feet of the Mancos Shale, and as much as 3300 feet of the Mesaverde Formation. The upper 100 to 200 feet of this thick Mesaverde section at the north end of the Caballo Mountains includes beds of coarse-grained sandstone and quartz-pebble conglomerate; this distinctive unit contains the coarsest material known from outcrops of the Mesaverde Formation in south-central New Mexico. The Mesaverde Formation of the northern Caballo and Fra Cristobal is overlain by the McRae Formation; in places the basal beds of the McRae are angularly unconformable on the Mesaverde, whereas in other places the contact appears gradational.

Bushnell divided the McRae Formation into the lower Jose Creek Member and an upper Hall Lake Member. The Jose Creek Member, about 395 feet thick, consists of a lower brown to greenish shaly sequence and upper tan to dark brown sandstones with a few intercalated tan siliceous siltstones—quite similar to Mesaverde strata, except that the sandstones have a higher percentage both of chloritic and ferruginous silt and of lithic fragments and feldspars. Conglomeratic lenses in the Jose Creek Member contain many pebbles and cobbles of andesite not found in the Mesaverde Formation. At several localities, such as near Elephant Butte dam, the Jose Creek Member appears to grade into ventagglomerates and associated intrusive-extrusive volcanic rocks and volcanic sediments.

In places at the base of the Hall Lake Member, there are distinctive conglomerates which continue as lenses up into the lower half of the member. The conglomerates consist mainly of rounded to subangular cobbles of quartzite, with lesser amounts of granite, quartzose schist, and scattered andesite, in a matrix of light gray friable arkosic tuffaceous sandstone. The bulk of the Hall Lake Member, which is about 2900 feet thick, is purplish, purple-brown, and chocolate-brown tuffs, tuffaceous siltstones, and argillaceous siltstones with lenses of hard, light olive, purplish gray, and light gray arkosic volcanic graywackes (Kottlowski et al.).

Triceratops is reported from the lower part of the Hall Lake Member; plant fossils collected by Hugh Bushnell from the Jose Creek Member suggest a Late Cretaceous age according to Roland W. Brown (U.S. Geological Survey; personal communication, 1956). The source of the quartzite, granite, and schist cobbles is unknown, but they indicate that an uplift with considerable vertical relief was present nearby during latest Cretaceous time; an uplift on which Precambrian rocks were exposed to erosion. Kelley and McCleary (1960) reported a small outcrop of the McRae Formation resting unconformably on Precambrian granite gneiss at the northern tip of the Fra Cristobal Mountains. Within a few miles of this outcrop, as much as 4000 feet of Paleozoic strata overlie the Precambrian rocks, and within ten miles, the pre-McRae Late Cretaceous section may be 4000 feet thick. Thick sections of Paleozoic beds occur above Precambrian rocks in almost all directions within 2 to 17 miles from this northern Fra Cristobal Mountains outcrop of the McRae Formation; thus, the uplift appears to have been small.

Near Eaton Ranch on the southeast edge of the San Mateo Mountains, about 14 miles northwest of the McRae outcrops in the northern Fra Cristobal Mountains, andesite of presumed Tertiary age overlies and was intruded into Precambrian granite and gneiss (Kottlowski, 1960b, fig. 34). Whether the andesite cobbles and boulders of the northern Fra Cristobal outcrops were derived from the Eaton Ranch area or from the McRae volcanic centers 24 miles to the south near Elephant Butte dam is a matter of speculation.

The McRae Formation appears to be limited to north-central Sierra County; southward toward the southern Caballo Mountains the unit seems to be overlapped by the Palm Park Formation which is somewhat similar lithologically but is believed to be of Tertiary age (Kelley and Silver). Cretaceous rocks have been removed by erosion from the Dona Ana and Robledo mountains area, where Tertiary(?) latites and gypsiferous red beds are unconformable on the Hueco Formation. On the southwest side of the San Andres Mountains southwest of Ash Canyon, Kottlowski et al. measured about 610 feet of Late Cretaceous strata unconformable on 95 feet of the Early Cretaceous Sarten Sandstone, and unconformably overlain by the limestone-boulder conglomerate and red beds of the Tertiary(?) Love Ranch Formation. Here the Dakota(?) Sandstone is unfossiliferous, about 185 feet thick, and consists of brown, quartzose, cross-bedded sandstones interbedded with greenish gray glauconitic silty sandstones and minor grayish black shale. Above are fossiliferous Benton-age rocks, equivalent to the Mancos Shale of the Caballo Mountains but more similar lithologically to the Eagle Ford Formation near El Paso. The unit, about 425 feet thick, consists of intercalated olive, calcareous subgraywacke, sandstone, and black bituminous shale, with some interbeds of fossiliferous calcarenite, silty limestone, and coal.

These shaly arenaceous beds are a facies similar to the shale, siltstone, and arenaceous limestone called the Colorado Shale near Cooks Peak and the Eagle Ford near El Paso. The Mancos Shale penetrated in the Western—Guame Federal oil test (fig. 1, no. 9), just west of Hembrillo Canyon, was 455 feet thick with arenaceous beds confined to the lower part of the formation. The southward change from black shale and argillaceous limestone of the Benton Mancos facies into the arenaceous nearshore Benton Eagle Ford facies takes place between the latitudes of Hembrillo and Ash canyons—somewhere near the north feather edge of the Early Cretaceous strata.

The 95-foot-thick clastic sequence sandwiched unconformably between the San Andres Formation and the Dakota(?) Sandstone near Ash Canyon consists of interbedded yellowish brown to purplish silty sandstone, gray sandy fossiliferous shale, brown fossiliferous limy sandstone, olive glauconitic sandstone, and black carbonaceous shale. These beds are referred to the Sarten Sandstone in the sense of a generalized term for Early Cretaceous clastic beds as used by Darton (1928) and because of some lithic resemblance to the type Sarten Sandstone near Cooks Peak.

Cretaceous strata in the Cooks Peak area, about 600 feet thick, consist of the Sarten Sandstone overlain conformably by the Colorado Shale. The Colorado Shale contains fossils of Benton age and is a dark gray to black, calcareous silty shale with interbeds of thin buff sandstone, brown sandy siltstone, and dark gray, brown-weathering, fossiliferous silty limestone; maximum thickness is about 300 feet. The Sarten Sandstone, 300 feet thick, consists of light gray, fine- to medium-grained quartz sandstone. The quartz grains are well sorted, subangular, and cemented by silica, although some beds have a small to large amount of calcite cement. Bedding planes are marked by hematite-rich laminae; the bedding is thin to massive and even. Near the middle of the sandstone, Darton (1917) found an Early Cretaceous fauna (Fredericksburg or Trinity ?) in manly sandstones. To the northwest along the west side of the Mimbres Valley, Elston (1957) noted a few lenses of unfossiliferous limestone within the Sarten (Beartooth ?) Sandstone and commented that cross-bedding is commonplace—in contrast to the dominance of even bedding near Cooks Peak.

In the Santa Rita—Silver City area, the basal Cretaceous sandstone was named the Beartooth Quartzite (orthoquartzite) by Paige. It appears to be lithologically similar to the type Sarten Sandstone and in many respects to the Dakota(?) Sandstone of south-central New Mexico. Whereas many mining geologists consider the Beartooth Quartzite to be of Late(?) Cretaceous age, the writer (as well as Darton, 1928) believes the unit is more likely to be of Early Cretaceous age and correlates directly with the Sarten Sandstone. However, time and faunal breaks are not necessarily wedded to lithologic changes; perhaps the Sarten Sandstone, Beartooth Quartzite, and Dakota(?) Sandstone of the area from Silver City eastward to the Sacramento Mountains are all roughly correlative units with either (1) a lower part of Early Cretaceous age and an upper part of Late Cretaceous age or (2) a time-transgressive unit grading from Early Cretaceous age at the south into Late Cretaceous age to the north.

Near Santa Rita, the Beartooth Quartzite is 60 to 140 feet thick, and consists of an upper massive sandstone and lower interbedded fine-grained sandstone, gray to black carbonaceous shale, and gray sandy shale (Spencer and Paige). Thin lenses of chert conglomerate occur at or just below the top of the unit. Near Fort Bayard, Lasky (1936) found rounded quartzite and chert pebbles at this upper conglomeratic horizon. Farther to the west near Silver City and in the Burro Mountains, basal beds are thin lenses of chert-quartz-pebble conglomerate, containing black and white silica pebbles in a kaolinized feldspathic quartz sand matrix (Paige). In the Burro Mountains area, the Beartooth Quartzite rests unconformably on Precambrian rocks but basal beds contain few fragments larger than pebbles and most of these pebbles are rounded to subrounded. In the northwestern Burro Mountains, Hewitt noted basal beds of hematite-stained angular-grained arkose grading up into chert-quartz-pebble conglomerate with rounded pebbles.

The Colorado Shale of the Silver City—Santa Rita area contains fossils of Benton and younger ages and appears to be a southwestern equivalent of the Mancos and Mesaverde formations of south-central New Mexico. Near Santa Rita the Colorado Shale includes three units, a lower 200-foot-thick dark carbonaceous shale with thin interbeds of sandstone and fossiliferous sandy limestone, a middle 520-foot-thick light gray calcareous fossiliferous sandstone, and an upper 220-foot-thick unit of intercalated green shale, sandy shale, and sandstone. To the west near Silver City, Paige estimated a maximum thickness of 2000 feet for the Colorado Shale; the threefold lithic divisions seem to occur west of Santa Rita but with each unit thickened. Farther west near Redrock, Hewitt reported a maximum thickness of 1100 feet and noted that the formation is mostly of blue-black carbonaceous shale with only a few beds of dark gray limestone and gray arenaceous shale.

South of Steeple Rock Peak, in northernmost Hidalgo County, Elston (1960) noted 60 feet of Beartooth Quartzite overlying Precambrian granite and overlain conformably by 800 feet of fossiliferous Colorado Shale. At one locality, the Colorado Shale is overlain unconformably by the Virden Formation, whereas a few miles to the east Late Cretaceous(?) andesites or Tertiary volcanic rocks are unconformable above the shale. Southwest of Steeple Rock Peak, the Virden Formation is unconformable on andesites, dacites, and some rhyolites dated as Late Cretaceous in age because they are beneath the Virden Formation. This formation is a thick (maximum 4000 feet according to Elston, 1960), local unit consisting of fanglomerate, conglomerate, tuffaceous sandstone, and gray shale; it contains boulders of the underlying andesite and plant fossils tentatively dated as Late Cretaceous in age. The field relationships are most remarkable, being similar in some respects to those of the McRae Formation; in one area the Virden Formation overlies the Colorado Shale, whereas two miles to the west-northwest it rests on the thick (4000 feet ?) andesite-dacite-rhyolite sequence which apparently overlies the Colorado Shale in the subsurface.

In the Santa Rita area, several hundred feet of andesite breccia, tuff, and interbedded volcanic sandstone and shale are unconformable on the Colorado Formation (Hernon, Jones, and Moore, 1953) and have been placed tentatively in the Upper Cretaceous with no particular proof other than that they are intruded by Cretaceous(?) intrusive rocks. The andesites near Steeple Rock beneath the Virden Formation may be similar to those near Santa Rita and would suggest a Late Cretaceous age. However, in the Cooks Peak area, Jicha's Macho andesites, which he considered to be of Early(?) Tertiary age, also are similar to the andesite breccias near Santa Rita and include interbeds of green sandstone and red conglomerate.

Near Clifton in eastern Arizona, Paleozoic rocks are overlain unconformably by the Late Cretaceous Pinkard Formation (Lindgren), a 200-to 500-foot-thick sequence of lower black shales and upper interbedded shales and light gray sandstones. This appears to be the Silver City Late Cretaceous Colorado Formation sequence with the basal Beartooth Quartzite absent. The Pinkard Formation was intruded by the quartz monzonite of the Clifton—Morenci mining district, but both the Late Cretaceous sediments and the quartz monzonite are unconformable beneath thick sequences of Tertiary (Tertiary ?) rhyolite (dacite), basalt, and andesite. The andesite and dacitic rhyolite may be traceable into the andesite, dacite, and rhyolite of the Steeple Rock area.

South of the Clifton, Steeple Rock, Silver City, and Cooks Peak areas, Late Cretaceous strata seem to be absent, having been removed by erosion during Tertiary time, and thick marine and shoreline Early Cretaceous sections occur. Near El Paso on the southwestern flanks of the Franklin Mountains and surrounding Cerro del Muleros, Late Cretaceous strata, including the Woodbine Sandstone and Eagle Ford Formation, are about 950 feet thick. They are underlain by at least 1165 feet of Early Cretaceous beds placed in the Washita, Fredericksburg, and

Trinity Groups (Adkins, 1932; Bose, 1906). To the east, along the New Mexico—Texas state line, shales, limestones, marls, and basal sandstones of the Washita Group crop out in the Cornudas Mountains unconformably on Yeso strata. On Sand and Molesworth mesas in the southeast corner of the region, older beds of the Fredericksburg and Trinity Groups cap these westernmost parts of the Diablo Plateau. Basal beds, unconformable on the Hueco Limestone, are in the Campagrande Conglomerate of calcareous limestone-chert-pebble conglomerate with interbeds of red and brown sandy limestone; above is the Cox Sandstone, about 250 feet thick, consisting of coarse-grained cross-bedded sandstone with interbeds of fossiliferous limestone. These Trinity-age beds are overlain by the Finlay (Edwards) Limestone, which caps the higher mesa remnants (King and Knight). Southward, the Finlay Limestone underlies younger Fredericksburg strata and the Washita Group, the Early Cretaceous beds thickening rapidly southward into northern Mexico. These relationships suggest onlap of the early Cretaceous seas onto a large landmass that has been postulated as occupying most of southwestern and south-central New Mexico. However, the northern limits (fig. 18) of Early Cretaceous rocks, rocks that are mainly nearshore or shoreline sediments, lie near the *northern* edge of the Mesozoic-age Burro—Diablo uplift in the El Paso, Hudspeth, and Otero counties area. Perhaps most of the clastic strata in this Early Cretaceous sequence are sediments deposited by longshore currents and were derived from the west-northwest, from the heart of the Burro uplift.

An arkose of uncertain age occurs in the southern Burro Mountains, forming a thin bed above the Precambrian granite, and overlain by Tertiary(?) volcanic rocks (Ballman, 1960). The arkose, medium- to coarse-grained, includes abundant cobbles of granite, schist, and vein-quartz in a silica matrix. Ballman tentatively dated the unit as Cretaceous in age and correlated it with the type Lobo Formation of the Florida Mountains. However, the arkose is similar to that described by Hewitt in the northwestern Burro Mountains, where it grades up into the Beartooth Quartzite.

About 25 miles southeast of these outcrops of arkose, Early Cretaceous strata unconformably overlie the Montoya and Fusselman Dolomites in the Victorio Mountains (Kottlowski, 1960b, pl. 13). This Cretaceous sequence also had been called the Lobo Formation by Darton (1928); it is 600 to 800 feet thick and consists of interbedded conglomerates, siltstones, sandstones, and fossiliferous limestones, overlain unconformably by Tertiary(?) andesitic agglomerates, breccias, tuffs, and sandstones. Minor lenses of feldspathic sandstone occur amid the Cretaceous sequence but most of the detrital fragments are of quartz, chert, silicified limestone, limestone, and dolomite. Locally, lenses of andesite breccia and andesite conglomerate occur near the base of this Early Cretaceous section. The overlying Tertiary(?) andesite units contain rounded boulders and pebbles of andesite, early Paleozoic dolo-

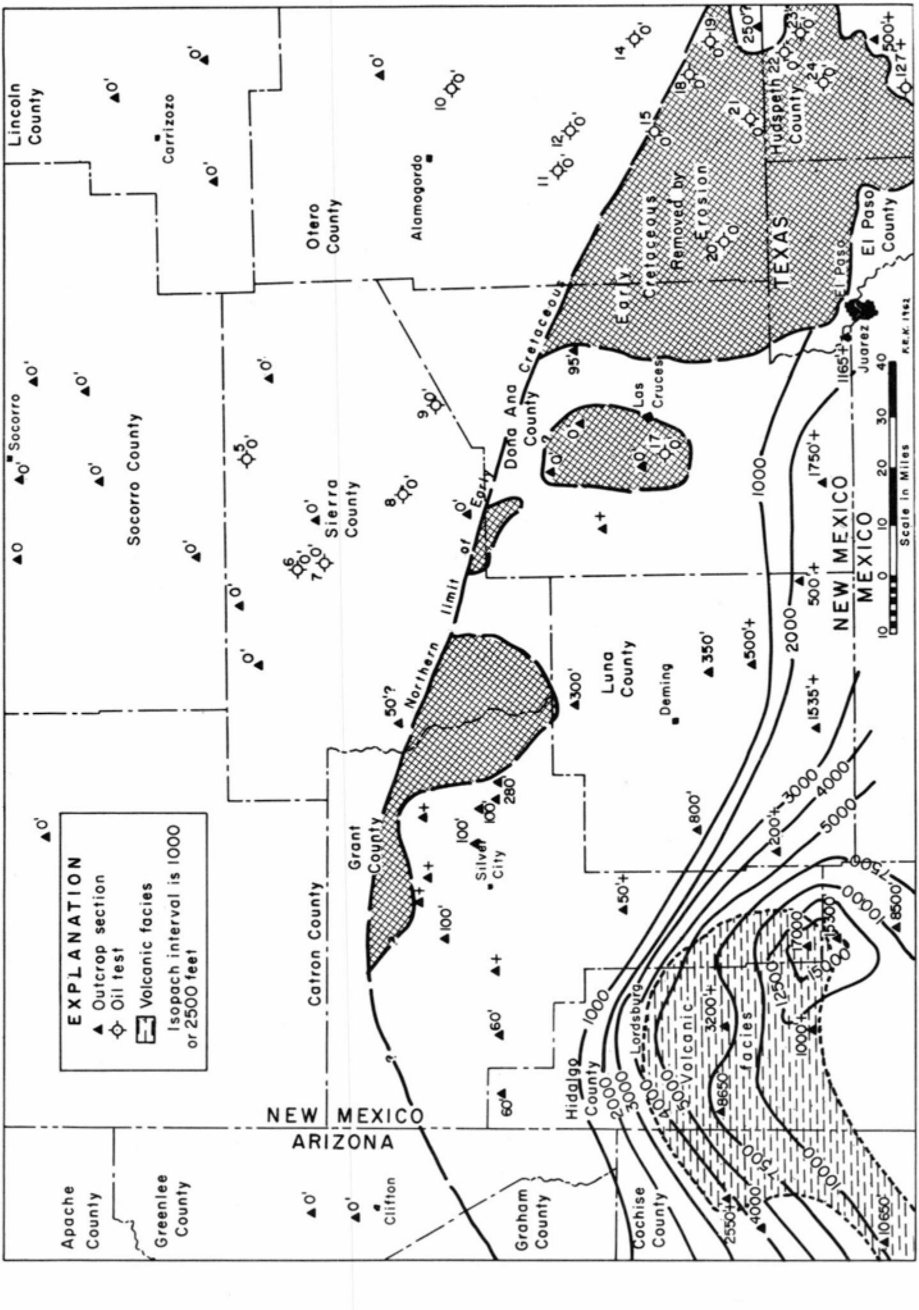

Figure 18

ISOPACH AND FACIES MAP OF EARLY CRETACEOUS STRATA IN SOUTHWESTERN AND SOUTH-CENTRAL NEW MEXICO mites, various Early Cretaceous rocks, and minor amounts of schist, granite, and pegmatite (Precambrian ?).

This Early Cretaceous sequence of the Victorio Mountains is a lenticular, relatively thin, nearshore deposit that contains all the lithic types present in the thick sections to the southwest in the Little Hatchet and Big Hatchet mountains but contains a higher percentage of non-carbonate rocks. The type Lobo Formation of the Florida Mountains is an enigma but most closely resembles the nearby Early Cretaceous strata of the Victorio, Cedar, and Tres Hermanas mountains, except it lacks any considerable percentage of carbonate rocks. Most of the type Lobo, above pockets filled by basal nodular impure limestones, is of interbedded pink to gray limy siltstone and very silty limestone, pink, gray, and purple shale, and yellowish brown to light gray limy conglomeratic sandstone and conglomerate. Even in the fine-grained beds there are numerous angular sand-sized grains of quartz, chert, and carbonate rocks. The larger fragments, of pebble to boulder size, are chiefly chert, early Paleozoic carbonate rocks, and Precambrian quartzite where the Lobo overlies Ordovician strata but include much basal brown granitic debris where the formation is unconformable on Precambrian granite. In the upper third of the Lobo Formation are coarse-grained conglomerates marked by the appearance of reddish granite. Above the type Lobo are Tertiary(?) volcanic and sedimentary rocks whose basal beds are conglomerates composed of rounded cobbles and boulders of chert, limestone, dolomite, red granite, gray latite, and purple andesite; these rocks are similar to the basal Tertiary in the Victorio Mountains.

On the southeast edge of the Florida Mountains, beds as young as the Hueco Limestone were preserved beneath the early Mesozoic erosion surface and are unconformably overlain by red claystone, limestone conglomerate, and red pebbly arkose. These red beds seem to grade up into gray to pale red conglomerates and calcareous conglomeratic sandstones that contain angular pebbles and cobbles of carbonate rocks, chert, and Precambrian rocks. The red beds and conglomerates appear to be a facies of the type Lobo Formation.

On the southwest edge of the Tres Hermanas Mountains (Balk; Kottlowski and Foster), Early Cretaceous strata are about 1535 feet thick, but both the lower and upper contacts are fault zones so that the actual sequence is probably much thicker. The structure is complex, and there is a possibility of repeated parts in the measured section. The lower 375 feet consist of chert conglomerate, arkosic to quartzose sandstone, pale red siltstone, and gray siliceous limestone. Above is 395 feet of gray, coarsely crystalline massive limestone, overlain by 425 feet of chert-limestone-cobble conglomerate with interbeds of red arkosic sandstone and gray limy sandstone. The upper 340 feet is sparsely fossiliferous gray limestone that is highly cherty near the top.

To the west in the Cedar Mountains, Griswold (*see* also Bromfield and Wrucke) noted several hundred feet of Early Cretaceous limestone-cobble conglomerates interbedded with gray limestones and unconformable on Mississippian and Pennsylvanian strata. To the east, several isolated outcrops of Early Cretaceous limestones and sandstones occur on the west side of the West Potrillo Mountains, and a relatively thick sequence of Early Cretaceous rocks crops out in the East Potrillo Mountains. Some of the units in the West Potrillo Mountains resemble the lower clastic unit of the Tres Hermanas Mountains, and in one locality, near Eagle Nest, lenslike masses of massive fossiliferous limestone may mark a nearshore reef trend. Bowers (1960) reported a maximum of 1550 feet of Early Cretaceous strata in the East Potrillo Mountains unconformable on the Hueco(?) Limestone. His lower unit consists of limestone-pebble conglomerates, sandy limestone, and calcareous sandstone similar to the third highest unit of the Tres Hermanas Mountains Cretaceous sequence; this lower unit is overlain by massive limestone that grades up into sandy limestone and calcareous sandstones, then into fossiliferous limestone and silty shaly limestone. At the base of the section, Bowers' unfossiliferous Hueco(?) Limestone, about 200 feet thick, consists of gray limestone and marble that resembles the second highest unit of the Early Cretaceous strata in the Tres Hermanas Mountains.

The Early Cretaceous section in the East Potrillo Mountains consists chiefly of limestone and limestone-conglomerate and contrasts greatly with the Early Cretaceous rocks 25 miles to the east near El Paso which include much marl, dark gray shale, and quartzose sandstone. However, a thick Early Cretaceous section, cut by faults, occurs in the Juarez Mountains southwest of Juarez; there the marls and sandstones may be underlain by a thick carbonate-rock sequence.

The Early Cretaceous sequence of southwesternmost New Mexico and southeastern Arizona is somewhat similar to the partial sections exposed in southern Luna and southwestern Dona Ana counties but is much thicker. The classic sections are near Bisbee, west of Figure 18, and in the Little Hatchet Mountains. Near Bisbee, as named by Ransome and redefined by Stoyanow (1949), the Early Cretaceous Bisbee Group consists of the following units in ascending order: (1) Glance Conglomerate, as much as 500 feet thick, containing chiefly angular pebbles of schist and limestone; (2) Morita Formation, 1800 feet thick, consisting of buff and red sandstone and dark red shale; (3) Lowell Formation, 350 feet thick, of thin-bedded arenaceous fossiliferous limestone; (4) Mural Limestone, 300 feet of thick-bedded fossiliferous limestone; and (5) Cintura Formation, 1800 feet thick, consisting of red nodular shale and cross-bedded buff sandstone. The Bisbee Group is of Trinity and possibly of early Fredericksburg age and contains larger detritus and thicker clastic-rock units toward the south in northern Sonora. As Imlay suggested, the increase in clastic material and the large amount of schist and gneiss debris indicate a landmass source to the south. Also, west of Bisbee in the Tombstone area, the Lowell and Mural limestones pinch out and the Early Cretaceous section consists of the Glance Conglomerate and the undifferentiated Morita and Cintura formations which Gilluly (1956) called the Bisbee Formation and suggested a shoreline area and a landmass to the west (Fergusson, 1959).

In the structurally complex Pedregosa Mountains, Epis (1956) measured about 8000 feet of Early Cretaceous strata. His lithic units are generally similar to those of the type Bisbee Group. The Glance Conglomerate, only 30 to 150 feet thick, contains clasts of Paleozoic rocks but none of granite or schist. The Morita Formation is somewhat thinner than near Bisbee, 1350 feet, and includes much feldspathic sandstone. The Lowell Formation is not recognizable, its position being occupied by a 3120-foot-thick sequence of fossiliferous limestone, red to buff feldspathic sandstone, and red shale; oyster, rudistid, and coral biostromes are notable. The Mural Limestone, 200 feet thick, is marked by abundant *Orbitolina;* the Cintura Formation is 3200 feet thick, similar to the Morita lithology, and contains some feldspathic sandstone. Disconformably on the Bisbee Group is a thick conglomerate (2350 to 4000 feet thick) containing thin flows of propylitized andesite near the top. This unit is conformably overlain by a thick sequence of andesitic volcanic rocks. Epis (1956) suggested these latter two units are of Upper Cretaceous age; they may be correlative with the Early Cretaceous andesites of the Little Hatchet and Pyramid mountains. The andesites (and older strata) of the Pedregosa Mountains are overlain with marked unconformity by the Chiricahua Rhyolite of Tertiary(?) age.

The Bisbee Group is similar in the Chiricahua Mountains (Sabins, 1957a). The Glance Conglomerate, locally absent, thickens to as much as 1000 feet and consists mainly of limestone conglomerate but includes a quartzite conglomerate facies near Apache Pass and an andesite conglomerate facies along the northeast edge of the mountains. The upper part of the Bisbee Group, more than 2550 feet thick, consists of a lower reddish purple siltstone with some conglomeratic sandstone interbeds, a middle limestone unit, and an upper green to brown, cross-bedded orthoquartzite and olive siltstone unit. This upper unit, comprising about two thirds of the Bisbee Group, contains much andesitic detritus along the east edge of the mountains near Portal where the Bisbee Group is overlain unconformably by the Nipper Formation (Sabins, I957b), a unit of volcanic conglomerate, flows, and graywacke. The clasts range in composition from altered andesite to augite basalt. In the rest of the northern Chiricahua Mountains, the Bisbee Group is overlain unconformably by rhyolitic rocks.

Gillerman introduced four new formational names for parts of the Bisbee Group in the central Peloncillo Mountains. His basal McGhee Peak Formation, 370 to 600 feet thick, is characterized by limestone-pebble conglomerate; quartzite, chert, and locally granite clasts also occur in the conglomerate. Interbeds are of sandstone and minor limestone. The overlying Carbonate Hill Limestone, about 200 feet thick, consists of fossiliferous arenaceous calcarenite. Above is the Still Ridge

Formation, about 600 feet thick, containing silty arenaceous limestone with interbeds of limy sandstone and limestone conglomerate. The youngest unit of the Bisbee Group is the Johnny Bull Sandstone, more than 1050 feet thick, composed of light gray orthoquartzite and brown subgraywacke. These formations of the Bisbee Group are overlain unconformably by a local, altered quartz latite, a local thick (up to 1140 feet) limestone-andesite conglomerate, and by widespread, much altered andesite (as much as 5000 feet thick). Much of the andesitic debris appears to have come from the east and may be related to the Cretaceous andesites of the Pyramid Mountains, as well as part of the source of the andesite fragments in the Bisbee Group and andesite conglomerate of the eastern Chiricahua Mountains to the west.

The oldest rocks exposed in the Pyramid Mountains are altered augite basalts (Flege, 1959) traceable (Lasky, 1938) southeastward into Early Cretaceous rocks of the Little Hatchet Mountains and at least 2000 feet thick. These basalts are unconformably overlain by augite andesite agglomerates, flows, and breccias, about 1200 feet thick, which in turn are unconformable beneath a thick sequence of rhyolitic pyroclastic rocks. The base of the andesite sequence is locally marked by rounded boulders and blocks of augite basalt, Precambrian granite, and Paleozoic limestone. Flege believed the andesite to be of Tertiary age, but it is lithologically similar to other nearby andesites of possible Cretaceous age, actually being only slightly more silicic than the underlying augite basalt, and would be classed as a basalt by some petrographers.

The thick section of Early Cretaceous strata in the Little Hatchet Mountains ranges from 15,300 to about 21,000 feet in thickness (Lasky, 1947). Units are (1) basal Broken Jug Limestone, 3400 to 5000 feet thick, limestone and interbedded sandstone, shale, and limestone conglomerate; (2) Ringbone Shale, 0 to 650 feet thick, fresh-water shale and sandstone with local basal conglomerate and upper basalt and andesite; (3) Hidalgo Formation, 0 to 5000 feet thick, andesite and basalt flows and pyroclastic rocks; (4) Howells Ridge Formation, 1100 to 5200 feet thick, lower red shale, mudstone, limestone, sandstone, and conglomerate, middle andesite, and upper massive reefoid limestone; (5) Corbett Sandstone, 1500 to 4000 feet thick; (6) Playas Peak Formation, 800 to 3000 feet thick, local basal conglomerate overlain by fresh-water shale and sandstone, and upper massive reefoid limestone; and (7) upper Skunk Ranch Conglomerate, 0 to 3400 feet thick, red conglomerate and red shale with a local augite basalt flow. The entire section appears to be of Trinity age and was envisioned by Lasky (1947) as being deposited within 15 to 20 miles of the shoreline and at times even north of the shore. Detrital fragments of pre-Cretaceous rocks were found only in the upper part of the Skunk Ranch Conglomerate, and these fragments are mainly of only Pennsylvanian and Permian strata.

To the south in the Big Hatchet Mountains, Zeller (1958) mapped the Early Cretaceous strata, about 8500 feet thick, in three units. The lower unit, about 1300 feet thick, consists of red beds, gypsum, and some andesite, unconformable on Permian limestones. The middle unit, the U-Bar Formation, is about 1900 feet thick and is mainly massive and thin-bedded fossiliferous limestone with minor brown shale. The upper Mojado Formation, about 5300 feet thick, is mostly of quartz sandstone with some shale and a few limestone interbeds near the base and near the top. These three units may range from Trinity through Fredericksburg and into Washita age, a considerable contrast with the thicker Little Hatchet Mountains section.

Thick sections of Early Cretaceous rocks are concentrated in southwestern New Mexico (fig. 18), more or less centered on the Little Hatchet Mountains area but also extending southwestward into northern Sonora. The Hatchet Mountains basin appears to have been a local, rapidly sinking trough of only Trinity age on the southern shores of the Burro uplift but north of the main Sonoran geosyncline. Large shield volcanos, centered in the area just northwest of the Little Hatchet Mountains, contributed much silicic basalt and andesitic debris. The northern limit (fig. 18) of the Early Cretaceous seas, and of related nearshore and shoreline deposition, was probably farther north than has generally been realized, being near or north of the Silver City area and perhaps as far north as the southern Caballo Mountains.

Late Cretaceous rocks have been stripped irregularly from much of the region by erosion during Cenozoic time so that any isopach lines drawn are but estimates. Fossiliferous Late Cretaceous strata are absent in the southwest part of the region (fig. 17), but remnants occur near El Paso and northward. The Benton-age units, the Mancos Shale, Eagle Ford Formation, and lower part of the Colorado Shale, change from a black shale and argillaceous limestone facies southward into an arenaceous, calcareous, clastic facies containing coal beds, and thus suggest fluctuating shorelines along the southern margin of the region. Thick, preserved sections of Late Cretaceous rocks occur near Steeple Rock in northern Hidalgo County and in north-central Sierra County near the Caballo and Fra Cristobal mountains. In both areas the Mesaverde Formation, or its equivalents in the upper Colorado Shale, are unconformably overlain by thick, clastic, local deposits containing much andesitic material. In both areas, the dating based chiefly on plant fossils suggests latest Cretaceous age. Nearby uplifts of relatively small size but with much vertical throw provided the detritus, and their movement was accompanied by eruptions of andesitic rocks. These sediments and volcanic rocks may mark the beginning of Laramide deformation, as suggested by Kelley and McCleary. The local, apparent gradation of the Mesaverde Formation into the McRae near the Caballo Mountains and the coarse-grained conglomeratic sandstones of the upper Mesaverde there suggest that this deformation in some localities began during late Mesaverde time.

Petroleum Possibilities

Almost all the Paleozoic and Cretaceous units of south-central and southwestern New Mexico are marine deposits containing potential source beds of oil and gas. Possible traps are as follows: (1) porous sandstone lenses in Bliss Sandstone, Cable Canyon Sandstone, Helms and Paradise formations, Pennsylvanian sequences, Yeso Formation, Glorieta Sandstone where present, Scherrer Formation, Early Cretaceous sequence, Dakota—Beartooth—Sarten Sandstone, and in the Mesaverde Formation; (2) porous calcarenite lenses and bioclastic banks in the El Paso, Montoya, Lake Valley, Escabrosa, Pennsylvanian, Hueco, and Early Cretaceous formations; (3) porous dolomite zones in the El Paso, Montoya, Fusselman, Horquilla, Yeso, Epitaph, San Andres, and Concha formations; (4) secondary porosity zones in the carbonate rocks of the El Paso, Montoya, Fusselman, Mississippian, Pennsylvanian, Hueco, Colina, Yeso, Epitaph, San Andres, Concha, and Early Cretaceous formations; (5) bioherms and other reefoid masses in the El Paso, Montoya, Lake Valley, Escabrosa, Pennsylvanian, Bursum, Laborcita, and Early Cretaceous formations; (6) porous lenses within the inter-tonguing areas of units such as the Abo Redbeds and Hueco Formation; and (7) at, beneath, or above the truncating unconformities below the Cable Canyon Sandstone, Devonian strata, Pennsylvanian sequence, Early Cretaceous rocks, and Dakota—Sarten—Beartooth Sandstone.

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