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STRATIGRAPHY OF THE SAN ANDRES MOUNTAINS IN SOUTH-CENTRAL NEW MEXICO

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The San Andres Mountains, in the central part of southern New Mexico, offer almost unexcelled outcrops for stratigraphic and structural studies. Sedimentary rocks from Precambrian to early Tertiary age are well exposed along the entire 85-mile north-south length of the range and in the major east-west canyons. The range forms a flat north-south arc concave toward the east (Fig. 1) terminated on the north by Mockingbird Gap (altitude 5,260 ft) and on the south side by San Agustin Pass (5,719 ft). San Andres Peak, in the south part of the range, is 8,239 ft above sea level and more than 4,000 ft above the adjoining Tularosa Basin to the east; Salinas Peak near the north end of the range, at an altitude of 8,958 ft, is the highest point. A typical profile cross-section shows an east-facing scarp overlooking the Tularosa Basin and capped by Middle Pennsylvanian limestone that form high ridges at altitudes of 7,000 to 8,000 ft; to the west of this crest of the range are a series of lower west-dipping mesas and north-south strike valleys that have been cut in Upper Pennsylvanian shalt' beds and in Hueco, Abo and Yeso strata. The west margin of the range consists of a prominent cuesta capped by San Andres Limestone, which dips westward beneath the gravel-covered surface of Jornada del Muerto.

About 14 large canyons enter the Tularosa Basin from the range but none have cut completely through to Jornada del Muerto. The drainage divide is near the west edge of the mountains reflecting the lower elevations of the Tularosa Basin as compared to Jornada del Muerto. Along parallels of latitude the lowest points of the Tularosa Basin are 400 to 500 ft below the lowest points of the Jornada. The major canyons are east-west gashes cut perpendicular to the strike, in many places along fault zones, but most of the tributary canyons are north-south strike valleys eroded in less resistant beds such as the Upper Pennsylvanian and Yeso rocks.

At present, and for the foreseeable future, the San Andres Mountains are entirely within White Sands Missile Range and are off bounds to all except federal government personnel. Short escorted trips have been allowed for scientific purposes. The only maintained road through the mountain, other than at Mockingbird Gap and over San Agustin Pass, is the extension of New Mexico Road 52 from Tularosa to Truth or Consequences by way of Rhodes Canyon, Rhodes Pass and Engle.

STRATIGRAPHY

Sedimentary rocks of Precambrian to Tertiary age occur in the San Andres Mountains. The total Cambrian to Cretaceous section is about 7,200 ft thick but in the adjoining basins this section may range from 7,200 ft to 12,700 ft in thickness, north to south. Pre-Pennsylvanian beds thicken southward from 65 ft at Mockingbird Gap to 675 ft on Sheep Mountain, 860 ft along Rhodes Canyon, 1,380 ft in Hembrillo Canyon, and 1,920 ft in Ash Canyon (Fig. 2). Combined Pennsylvanian and Permian strata thin southward from 6,200 ft near Rhodes Pass to 5,200 ft near Ash Canyon, whereas the Pennsylvanian beds thicken and thin from 2,510 ft along Rhodes Canyon, 3,035 ft near Hembrillo Canyon to about 2,825 ft near Ash Canyon (Fig. 2). On the northern edge of the range, about 50 ft of Triassic red beds remain beneath the basal Cretaceous conglomeratic sandstone. Cretaceous rocks consist of the Dakota Sandstone exposed along the northwest margin of the range and the Eagle Ford (Mancos) Formation at the southwest edge. Considerable thicknesses of the Cretaceous Mancos Shale, Mesaverde Formation, and McRae Formation remain in the Jornada del Muerto structural depression to the west but probably do not occur beneath Tertiary sediments of the Tularosa Basin except near Three Rivers. On the southwest flank, outcrops of the Tertiary Love Ranch Formation, 400-2,100 ft thick, rest unconformably on the Cretaceous; to the south in the western part of the Organ Mountains similar rocks overlie eroded Permian and Pennsylvanian strata.

Precambrian Rocks

Precambrian rocks crop out over a large area along the lower part of the east-bounding escarpment of the range. Red to gray granite, including roof-pendants of various schists, gneisses and amphibolites, and cut by pegmatite and diabase dikes, occur in the north and south part of the mountains (see paper by Budding and Condie, this guidebook). From Sulphur Canyon to south of Hembrillo Canyon, a thick series of metamorphic rocks is exposed including mica and quartz-feldspar schist, quartzite, amphibolite, phyllite, talc schist, talc, and dolomite, intruded by diabase and aplite dikes and small masses of granite. Foliation of the metamorphic rocks along Hembrillo Canyon strikes N. 30-45° W. and dips steeply westward. In places this metamorphic series is truncated by a light-gray quartzite with bedding almost parallel to that of the overlying Bliss Sandstone; however, the quartzite is cut by pale-pink aplite dikes that are truncated by basal beds of Bliss Sandstone. The quartzite may be of younger Precambrian age, similar to the pre-Bliss sandstone, siltstone and shale in the Sacramento Mountains (Pray, 1952) and encountered in oil tests east and southeast of Cloudcroft (Foster, 1959).

Cambrian-Ordovician Strata

The Bliss Sandstone, El Paso Group, and Montoya Group are all considered on the basis of faunas (Flower, *in* Kottlowski and others, 1956) to be of Ordovician age in the San Andres Mountains. At the base of the Bliss Sandstone, however, are unfossiliferous beds lithologically similar to those bearing Late Cambrian fossils in the Caballo, Mud Springs, and San Diego Mountains (Flower, 1953, 1955). The Bliss Sandstone crops out as a conspicuous dark-brown ledgy cliff along the eastern front of the San Andres Mountains, overlying the light-brown to reddish concave slopes carved on the Precambrian rocks. The base of the Bliss is an evenly beveled surface in most places where observed relief is on the order of a few inches. In places, however, there are pre-Bliss hills that are

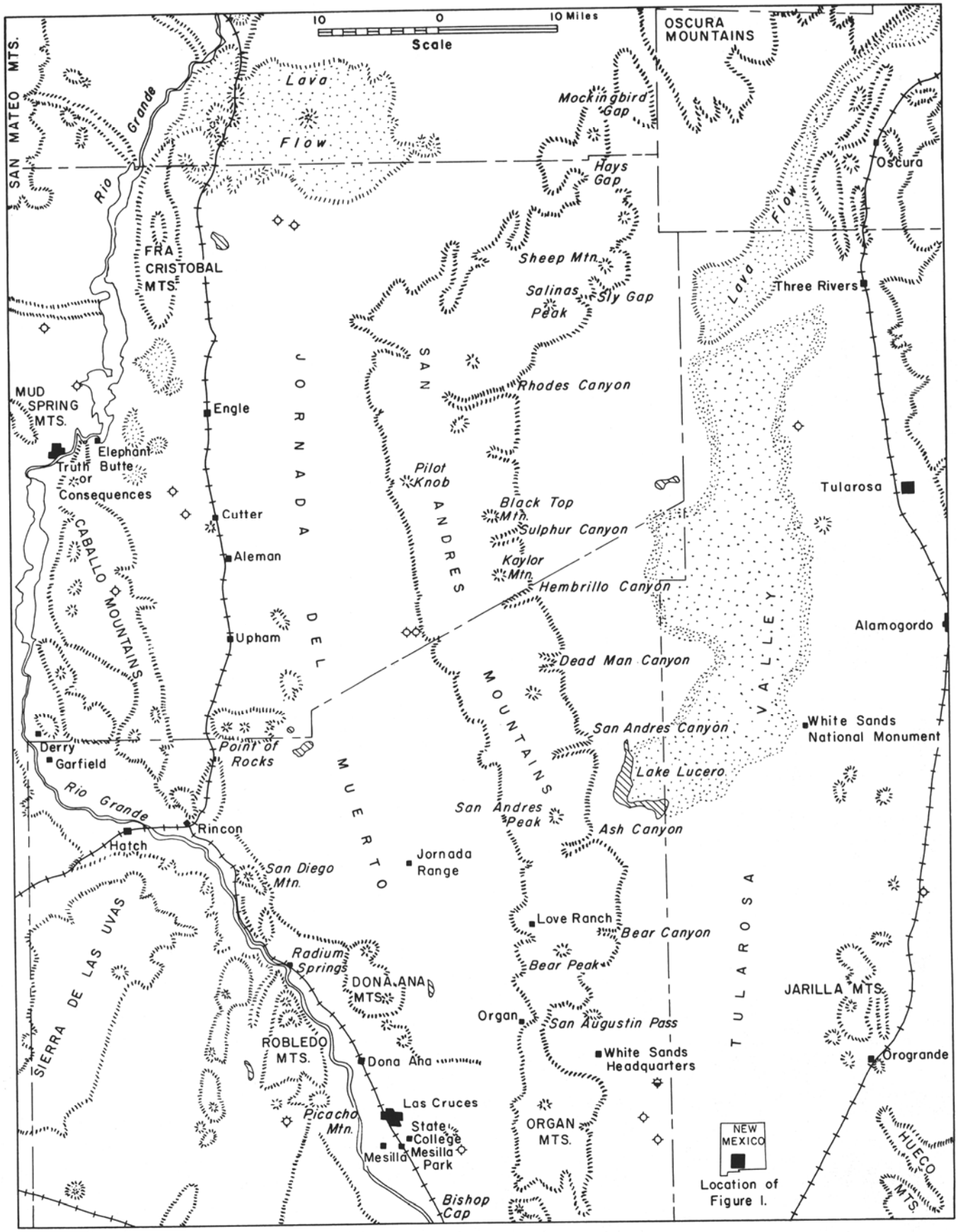

Figure 1. Index map of San Andres Mountains.

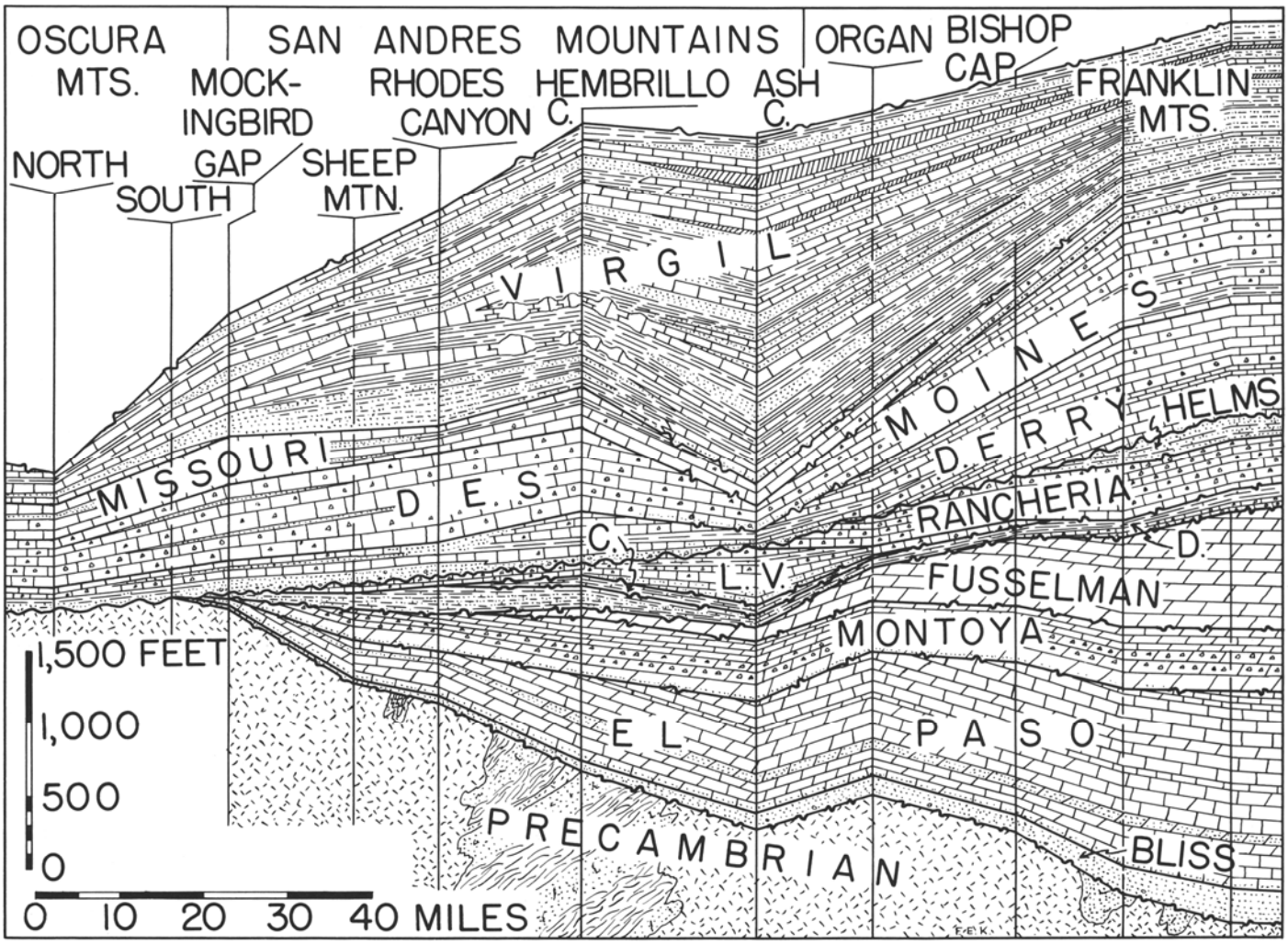

Figure 2. Diagrammatic section of the pre-Permian strata in the San Andres Mountains and adjacent areas.

overlapped by the basal Bliss conglomeratic units. Contact with the overlying El Paso Group is gradational and is picked at different places by different geologists, depending on whether the top of the Bliss Sandstone is placed on the uppermost arenaceous bed, below the lowest limy bed, or (as suggested here) at the top of a dominately arenaceous sequence.

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 of oolitic hematite and pebbly siliceous hematitic sandstone. The beds are various shades of red, green, brown, or gray depending on mineral content; the beds vary considerably in thickness but are mostly thin and cross laminated. The Bliss Sandstone thickens southward in the range as follows: Mockingbird Gap 8 ft, Sheep Mountain 17 ft, Rhodes Canyon 46 ft, Hembrillo Canyon 46 to 90 ft, and Ash Canyon 105 ft. The type section of the Bliss Sandstone at the south Franklin Mountains totals 240 ft in thickness.

Beds of the El Paso Group crop out as a light-brown ledgy concave slope below the Montoya cliffs and above the dark-weathering Bliss Sandstone. The upper contact below the Cable Canyon Sandstone of the Montoya Group is a distinct regional unconformity, although lacking much local angularity. The change is abrupt from dolomite and limestone of the El Paso to the coarse-grained pebbly Cable Canyon Sand stone, or in places, a basal sandy zone of the Upham Dolomite; locally karst topography developed prior to and during deposition of the basal arenaceous unit of the Montoya. The rocks of the El Paso are chiefly limestone that have been vertically and laterally dolomitized and in places silicified; color ranges from light to dark gray on fresh surfaces, with dark gray most common, but weathering to light brown or light gray. Beds average 6 to 12 inches in thickness but in the south part of the mountains the upper part of the El Paso consists of massive cliff-forming beds.

The El Paso Group can be divided into seven lithologic units in the south part of the San Andres Mountains (Foster, *in* Kottlowski and others, 1956); northward the units successively cut out, from the top downward, due to erosion during pre-Montoya time. These lithic units are roughly correlative with Flower's *(in* Kottlowski and others, 1956; also Flower 1953, 1955, 1957) faunal zones of the Canadian which have been given formational names in the Franklin Mountains area. The most easily recognized units are the basal arenaceous glauconitic carbonate rocks of the Gasconade zone, and the fourth lithic unit above the base, an arenaceous oolitic sequence. The El Paso Group thins northward in the range as follows: Ash Canyon 760 ft, Hembrillo Canyon 580 ft, Rhodes Canyon 360 ft, Sheep Mountain 285 ft, and Mockingbird Gap 40 ft. The type section in the south Franklin Moun-

tains is about 1,400 ft thick and includes younger beds than the uppermost part of the El Paso at Ash Canyon.

The Montoya Dolomite crops out as a lower dark-weathering cliff and an upper lighter colored !edgy slope. The basal arenaceous beds truncate the El Paso Group northward. The upper contact is an erosional surface which shows only slight local relief beneath the Fusselman Dolomite, but abrupt ragged contacts where overlain by Devonian strata. Near the north end of the San Andres Mountains, the Montoya Dolomite was completely cut out by erosion prior to deposition of Upper Devonian rocks. The Montoya Group has been variously subdivided in southern New Mexico. In the range there are four lithologic units: (1) a basal dolomitic sandstone or arenaceous dolomite, the Cable Canyon Sandstone, (2) the massive dark-gray cliff-forming dolomite, the Upham Dolomite, (3) a cherty dark-gray dolomite, the Aleman Dolomite, and (4) an upper medium-bedded, light-gray-weathering, calcic dolomite, the Cutter or Valmont Dolomite. These carbonate rock units have been highly dolomitized in the San Andres Mountains, but Flower (1958) reported that to the southwest limestone dominates some of the sections.

Thickness of the Montoya Group decreases northward in the range owing chiefly to erosion before deposition of the Upper Devonian strata. Thicknesses are: Ash Canyon 425 ft, Hembrillo Canyon 400 ft, Rhodes Canyon 260 ft, Sheep Mountain 205 ft, and at Mockingbird Gap the Devonian rests on the lower part of the El Paso Group. The Cable Canyon Sandstone, as a distinct dolomitic sandstone beneath arenaceous dolomite of the Upham, is 21 ft thick in Ash Canyon, but in most parts of the range it is only 8 to 2 ft thick and grades laterally into arenaceous dolomite. Combined thickness of the Upham and Aleman Dolomites thins slightly to the north from 235 ft at Ash Canyon to 203 ft on Sheep Mountain; individual thicknesses of the two lithic units, however, vary in reverse position, i.e., the Upham thickens where the Aleman thins. The Cutter Dolomite is 165 to 185 ft thick where overlain by Silurian rocks, but thins erratically northward beneath the Devonian strata.

Silurian Rocks

The Fusselman Dolomite, of Silurian age, crops out as a prominent dark-brown weathering cliff. Where debris from the overlying shaly Devonian beds has been removed exposing the upper contact, the top of the Fusselman is an undulating, knobby, ridged and channeled, silicified surface of considerable relief. This erosional surface bevels the Fusselman Dolomite, as well as older strata, from south to north in the San Andres Mountains. Below this erosional surface, the Fusselman Dolomite thickens from a knife edge 6 miles south of Rhodes Canyon to 60 ft in Hembrillo Canyon, 95 ft in Ash Canyon, and to the south in the central Franklin Mountains, to 608 ft (Pray, 1958). The dolomite is relatively pure, medium dark gray and massively bedded. Chert occurs as scattered to numerous nodules, lenses, and silicified laminae; some of the lower beds contain many vugs partly filled with quartz crystals.

Devonian Formations

The Devonian units in the San Andres Mountains, as in most of south New Mexico, are relatively thin, are shaly, and in most localities form a covered slope between underlying Silurian and Ordovician dolomites, and overlying Mississippian beds. Actual outcrops may be miles apart, and only in a few places can the beds be traced more than a few tens of feet laterally. Where exposed, most of the beds are fossiliferous, and there have been numerous formational names applied to thin lithic-faunal units. How much the variation of the faunas is due to facies control is not known, especially as correlative faunas occur as far away as Montana, Iowa, and New York.

Devonian units in the San Andres Mountains (Flower, *in* Kottlowski and others, 1956) as revised by Flower (1957) upon continuing study of the faunas, are in ascending order: °hate Formation, Sly Gap Formation, Contadero Formation, Thoroughgood Formation, and Rhodes Canyon Formation.

As noted above, the lower contact is on a pronounced erosion surface carved during Late Silurian and Early and Middle Devonian times. This surface truncates northward all pre-Devonian strata, and the overlying Devonian beds are a significantly different facies of silt-clay-limestone rock as compared to the pre-Devonian carbonate-rock sequences. Contact with the overlying Mississippian beds appears to be one of slight erosion but not much angular unconformity; locally the contact between the uppermost shaly Devonian strata and the shaly limestone of the Early Mississippian Caballero Formation appear almost gradational.

The (Nate Formation is dominantly siltstone, dolomitic, thin- to medium-bedded, with lenses of light-brown-weathering silty dolomite, weathering to olive-gray, yellowish-brown and yellowish-orange ledges. Thicknesses average 15 to 32 ft, except for the thick type section of 86 ft in San Andres Canyon and southward thinning to about 10 ft at Ash Canyon. Pronounced local variations are the rule, as near Rhodes Canyon where thicknesses vary from 9 to 30 ft owing chiefly to filling of low spots on the pre-Onate surface. There is an upward lithic transition into overlying Sly Gap beds, and there may be a similar lateral transition, with the (Mate being merely a basal facies of the Sly Gap.

The Sly Gap Formation consists of alternating fossiliferous calcareous silty shale, silty limestone, and calcareous siltstone, yellowish gray to dark gray, in thin lenticular beds. Thicknesses range from 30 to 75 ft, with the thicker sections in the south part of the range. Southward also there appears to be a gradational facies change from the type calcareous Sly Gap beds on Sheep Mountain into the dark-gray to black fissile shale units lithologically similar to the Ready Pay Member of the Percha Shale. The prolific Sly Gap fauna is of early Late Devonian age.

The Contadero Formation, as restricted by Flower *(in* Kottlowski and others, 1956; and Flower, 1957), consists of dark-gray to pale-olive, fissile silty shale, interbedded with dark gray to dark brownish-gray siltstone, and an upper nodular silty limestone. The unit is 20 to 45 ft thick in the north part of the mountains from Sheep Mountain to Rhodes Canyon but is believed to be absent in Hembrillo and Ash Canyons. Contact relationships and faunas suggest only a minor sedimentation break, if any, with the underlying Sly Gap beds.

Strata above the Contadero Formation 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 units by Flower (1957). The older unit, the Thoroughgood Formation, consists of tan blocky, silty, fine-grained sandstone and shaly calcareous siltstone, and thins from 12 ft on Sheep Mountain to 24 to 6 inches in Rhodes Canyon. The

upper unit, the Rhodes Canyon Formation, consists of 50 ft of interbedded white- to dark-gray silty fissile shale and dark-gray to brownish-gray micaceous siltstone with some thin tan sandstone beds in Hembrillo Canyon (called Contadero in 1956), and 75 ft 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 (called Percha in 1956). 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 shale of lower Percha Shale aspect.

Total thickness of the Devonian beds appears to thin both north and south from Rhodes Canyon (185 ft) to 105 ft on Sheep Mountain and to 85 ft in Ash Canyon. This thinning appears due to both: (1) mild pre-Mississippian truncation and (2) local basinal deposition.

Mississippian Rocks

Mississippian rocks in the San Andres Mountains are divisible into two distinct units, the lower Caballero Formation of Kinderhook, Early Mississippian age, and the Lake Valley Formation of Osage, early Middle Mississippian age. In the extreme southern part of the range the Rancheria Formation forms the upper beds of the Mississippian. The Caballero Formation overlies the Devonian rocks with slight unconformity and crops out as the upper part of the slope developed on Devonian beds. The formation consists of olive- to tan-weathering silty calcareous shale with some lenses of calcareous siltstone and silty, gray to dark-gray limestone. The Caballero is about 65 ft thick in Hembrillo Canyon (tentatively called Percha in 1956) and 60 ft thick in Ash Canyon, but pinches out to the south and north.

Basal beds of the Lake Valley Formation are distinctly unconformable on the Caballero Formation where it is present and on the various Devonian units north of Hembrillo Canyon and south of Bear Canyon. The Lake Valley consists of alternating and intertonguing members of ledge- or cliff-forming crinoidal bioclastic cherty limestone and slope-forming shalt' fossiliferous marl, in ascending order called: Andrecito, Alamogordo, Nunn, Tierra Blanca, Arcente, and Dona Ana Members. Thicknesses of the individual members vary abruptly in short distances. The total thickness of the Lake Valley Formation, however, thins fairly consistently northward from 390 ft in Ash Canyon, 80 ft in Hembrillo Canyon, 60 ft near Rhodes Canyon to absent at Mockingbird Gap. Southward from Ash Canyon the formation thins abruptly to only 70 ft in Bear Canyon and is absent in the Franklin Mountains. This southward thinning coincides with a southward thickening of the Rancheria Formation which is 200 ft thick in Bear Canyon and 315 ft in the Franklin Mountains.

The Rancheria Formation is of grayish-black, argillaceous to cherty limestone believed to be of early Meramec age by Laudon and Bowsher (1949). The Rancheria Formation thins northward from 255 ft in Vinton Canyon to 195 ft in Bear Canyon and to remnants near Ash Canyon. Jones (1953) suggested that these dark cherty limestones are a southern facies that grades northward into the crinoidal limestone facies of the Lake Valley Formation. Meyers (1974), however, has shown that there is an unconformity at the base of the Rancheria Formation on top of the Lake Valley units.

Pennsylvanian Rocks

The Pennsylvanian strata range from 1,925 to 3,035 ft in thickness in the San Andres Mountains, thickening southward from Mockingbird Gap to Hembrillo Canyon and then slightly thinning southward to Ash Canyon. The three lower faunal zones, Atokan, Desmoinesian, and Missourian, are 1,000 to 1,200 ft thick in the northern and central parts of the range to south of Hembrillo Canyon, but thin southward to only 435 ft near Ash Canyon. The upper series, Virgilian, thickens southward from about 825 ft at Mockingbird Gap to 2,390 ft near Ash Canyon. The geologic history is much more complex than a total generalized lithic picture would suggest.

The cherty Desmoinesian limestone caps most of the higher east-facing eastern escarpment of the mountains and numerous strike valleys are eroded along the less-resistant Virgilian beds. Atokan strata overlie Mississippian rocks, and at the extreme north end of the range, pre-Mississippian beds, with pronounced erosional unconformity. At some localities deep pre-Atokan channels were cut, and the channels filled by Pennsylvanian chert-pebble-conglomerate. The Atokan beds were deposited on a very irregular surface and therefore vary greatly in thicknesses in short distances; they average about 220 ft thick from Mockingbird Gap to Rhodes Canyon, thicken to 345 ft in Hembrillo Canyon and thin to 110 ft near Ash Canyon. The thick Hembrillo Canyon section may have Morrowan beds at the base, whereas the thin Ash Canyon section lacks upper Atokan strata, the lower Atokan being overlain unconformably by Desmoinesian beds.

Basal beds of the Pennsylvanian are chiefly chert-pebble-conglomerate and conglomeratic sandstone north of San Andres Canyon but to the south are more calcareous and less arenaceous suggesting the dominance of marine deposition as compared to a northern nearshore environment. Upper Atokan beds at Mockingbird Gap are chiefly dark limestone, contrasting with the calcareous sandstone and arenaceous limestone of the upper beds near Rhodes Canyon. Along Hembrillo Canyon the upper Atokan is chiefly of silty limestone and carbonaceous shale. To the west in the Caballo, Fra Cristobal and Robledo Mountains, the upper Atokan is chiefly limestone, thus the spatial and lithic relationships indicate a clastic-source landmass east-northeast of Rhodes Canyon, probably near the present site of Sierra Blanca, east of Three Rivers (Fig. 1).

Desmoinesian beds are mainly massive- to medium-bedded cherty bioclastic limestone, with arenaceous calcarenite near the base and argillaceous limestone near the top. Thicknesses are 540 to 620 ft for the northern and central parts of the San Andres Mountains but thin to 185 ft near Ash Canyon where strata of late Desmoinesian age are absent according to fusulinid data. There is a conglomeratic sandstone/arenaceous calcarenite unit in the upper part of the Desmoinesian of the northern part of the range and similar clastic beds at the base of the series in Rhodes and Ash Canyons. Desmoinesian sections to the west lack any appreciable clastic strata but to the east in the Sacramento Mountains Pray and Graves (1954) described a deltaic sequence between Fresnal and Alamo Canyons (an area east-southeast of Hembrillo Canyon). If this deltaic material was carried as far west as the San Andres Mountains, it probably is reflected in sections between Hembrillo and Ash Canyons, and probably is related to the truncation of Atokan strata and lack of upper Desmoinesian beds near Ash Canyon.

Missourian strata vary considerably in thickness in the

range, from 345 ft near Mockingbird Gap, 195 ft at Rhodes Canyon, 270 ft in Hembrillo Canyon, to 145 ft near Ash Canyon. The rocks are interbedded argillaceous limestone and calcareous shale, with medial massive cherty limestone, although at Mockingbird Gap many beds of green micaceous sandstone occur. The greater thickness of the Mockingbird Gap section is due chiefly to the addition of the sandstone beds, whereas the thick Hembrillo Canyon section appears merely an expansion of limestone-shale sequence. The thin Missourian sequence near Ash Canyon, again as in older series, is mainly lower units, and upper Missourian beds seem to have been eroded, with the upper surface locally undulating, silicified, and iron-stained beneath Virgilian shale. The Mockingbird Gap section (along with the Missourian of the Oscura Mountains to the north) indicates a source of clastics to the south-southeast, perhaps (as in Atokan time) near the present site of Sierra Blanca. Missourian sections from Rhodes Canyon southward suggest shale and limestone deposition of marine shelf or restricted basinal types, west of the thicker (500 ft) and more clastic Missourian beds in the Sacramento Mountains.

Virgilian beds were considered lithologically distinct enough from typical beds of similar age in the rest of New Mexico to be mapped as a formational unit from Mockingbird Gap southward into the Franklin Mountains, and were therefore labeled the Panther Seep Formation from the type section near Panther Seep on a tributary of Rhodes Canyon (Kottlowski and others, 1956). The formation consists of cyclic deltaic- to brackish water clastic rocks and limestone, ranging from silty brownish shale and dark carbonaceous shale, dark-gray argillaceous limestone and laminated calcilutite, silty calcarenite, and silty calcareous sandstone, to thick lenses of massive biostromal limestone. Several gypsum beds are close to the top of the formation near Ash Canyon, and numerous biohermal or patch reefs occur at two horizons near Hembrillo Canyon and as far north as Sulphur Canyon. The Panther Seep beds thicken southward as follows: Mockingbird Gap 825 ft, Rhodes Canyon 1,460 ft, Hembrillo Canyon 1,820 ft and Ash Canyon-Love Ranch area 2,390 ft.

Panther Seep sediments were deposited in the north-south basin extending southward beyond the Texas-New Mexico line and eastward to the Sacramento and northern Hueco Mountains. This basin was called the Orogrande basin by Pray (1959) and had been noted by Thompson (1942) and others. Basin is here used in the sense that it was an area that received a thick section of deposits, and implies a continued sinking beneath a continuous supply of clastic sediments flushed westward from the Pennsylvanian-aged (and early Permian) Pedernal Mountains. Most of the Panther Seep rocks seem to have been deposited in shallow marine waters although some are stream or shoreline sediments. The black carbonaceous shale and fetid carbonaceous calcilutite were deposited in anaerobic waters that may have been shallow compared to the deep anaerobic Permian Delaware basin. Shallow depth and hypersaline environment is suggested by the interlamination of gypsum and carbonaceous calcilutite. Gypsum beds occur in the formation, near the upper limits, from San Andres Canyon south to the Franklin Mountains and southeastward to the northern Hueco Mountains (Hardie, 1958), and may outline the late stage area of the basin.

There is some doubt as to the age of the upper part of the Panther Seep Formation, as Virgilian fusulinids are sparse, not found, or occur in calcarenite and calcareous sandstone. Permian strata appear to overlie the Panther Seep beds unconformably in areas near Mockingbird Gap, from Rhodes Canyon to Hembrillo Canyon, and from Ash Canyon to Love Ranch but must be mapped in the entire range before exact relationships can be determined.

Besides the southern thickening of the formation in the San Andres Mountains, the proportion of coarse clastic rocks decreases southward, reef-like limestone and associated grayish-black carbonaceous shale occur chiefly in the central part from Rhodes Canyon to Hembrillo Canyon, and gypsum beds with argillaceous calcilutite are the characteristic feature of the strata south of San Andres Canyon. The biohermal-like limestone masses near Hembrillo Canyon may encircle the deeper part of the Orogrande basin, connecting as a reef-zone eastward with the Virgilian reefs in the Sacramento Mountains and arced south-southwest, south, and then southeastward to join the Virgilian reefs in the northern Hueco Mountains.

Permian Formations

During the early phase of geologic investigations in New Mexico, the Pennsylvanian-Permian contact was placed at the obvious break between the Magdalena limestone and the overlying Abo red beds. To the happy delight of lovers of controversy, upper limestone of the Magdalena was found in places to bear Wolfcampian fusulinids; examinations of the upper Pennsylvanian-lower Permian zone by many geologists has resulted in complex and, depending on the individual observation, contradictory ideas of the contact relationship. An example of an excellent way to solve local, as well as regional, problems was Carel Otte's (1959) bed-by-bed field mapping and collection of all available fossils in the La Luz-Tularosa area of the northwestern Sacramento Mountains.

Permian rocks in the San Andres Mountains thin southward from 3,700 ft near Rhodes Pass to 2,385 ft around Love Ranch (Fig. 2). This thinning is mainly due to erosional and depositional thinning of the Yeso and San Andres Formations, with the Bursum-Hueco-Abo thickening southward from 910 ft east of Mockingbird Gap to 1,680 ft near Love Ranch. Beds believed of early Wolfcampian age overlie eroded strata of the Panther Seep Formation throughout the range but the truncation may be a local feature. In some places Virgilian beds may grade up into Wolfcampian strata, particularly in the southern part of the range. The upper surface of the Permian is an erosional one, cut during early and middle Mesozoic times. North of Rhodes Canyon a thin sequence of Triassic red beds overlies the San Andres Formation. Southward to Ash Canyon the San Andres is unconformably overlain by the Dakota Sandstone of Late (?) Cretaceous age. Near Love Ranch, the Lower Cretaceous Sarten Formation rests on a thin San Andres(?)-Yeso sequence. Relief of the surface beneath the Cretaceous rocks exceeds 20 ft vertically within a short horizontal distance.

The type Bursum Formation, near Bursum Ranch in the western foothills of the Oscura Mountains (Wilpolt and Wanek, 1951), consists of intertongued red beds and marine limestone. The type section included beds of late Virgilian and early Wolfcampian age, until restricted by Thompson (1954) to the early Wolfcampian beds. The typical lithology, as emphasized by the type section, may vary in age in central and south-central New Mexico from entirely Virgilian to entirely middle Wolfcampian. In Sierra Cuchillo and the Black Range, inter-

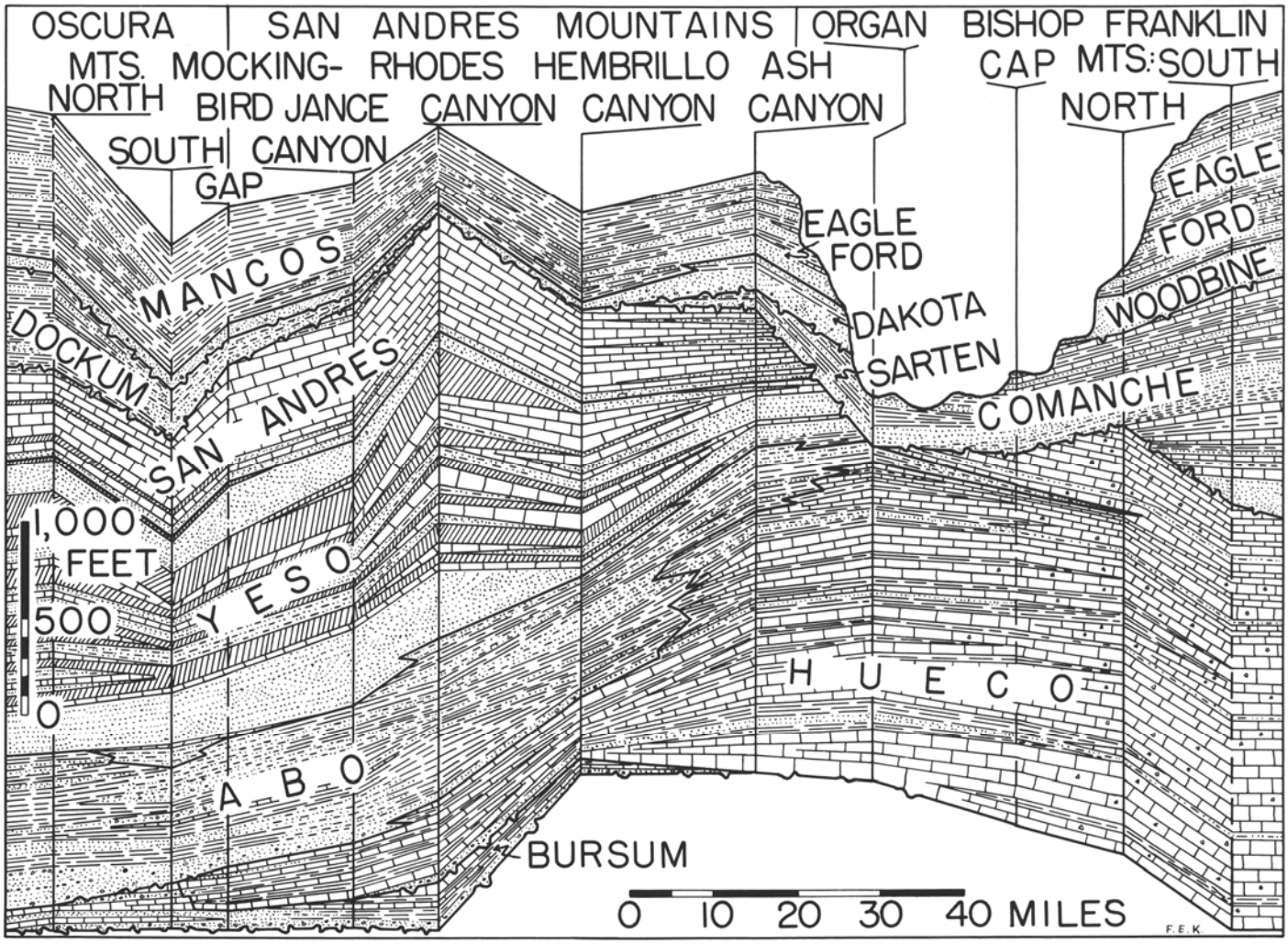

Figure 3. Diagrammatic section of the Permian and Mesozoic strata in the San Andres Mountains and adjacent areas.

bedded red beds and limestone above the main bulk of the Magdalena limestone and below the Abo red beds appear to be of Virgilian age. Near Rhodes Canyon, the main sequence of interbedded red beds and gray limestone is between the Hueco Limestone and the Abo.

Bursum has also been used extensively as a label for the early Wolfcampian faunal zone, whose main guide fossils are primitive forms of *Schwagerina,* and advanced species of *Triticites.* There is some formational basis for this usage, as a fairly widespread erosional period appears to have separated the Bursum from the middle and upper Wolfcampian Hueco.

The uppermost bed of the Bursum Formation in the Oscura Mountains is a massive gray limestone. This bed was correlated by Thompson (1954) with a similar massive limestone, along with thinner bedded limestone, gray clastic strata, and minor lenses of grayish red-purple shale, as the Bursum Formation in Rhodes Canyon. A similar sequence can be traced, at least intermittently, the length of the San Andres Mountains, but the writer does not know of any diagnostic fossils collected from the unit. Thicknesses range from 265 ft to a knife edge. Basal beds are arkosic to calcareous limestone-pebble-conglomerate or conglomeratic sandstone that exhibits striking cut-and-fill deposition upon upper beds of the Panther Seep Formation. North of Rhodes Canyon, the upper beds labeled as Bursum are locally deeply channeled and the basal Hueco rocks range from limestone-cobble-conglomerate filling the channels to conglomeratic algal calcarenite.

The Hueco Formation thickens southward from 415 ft near Rhodes Canyon to 1,355 ft near Love Ranch. The upper contact in the mountains is in a transitional zone of red beds and limestone grading upward into the Abo red beds and intertonguing northward with the Abo. The Hueco consists of argillaceous limestone, cherty fossiliferous limestone, silty calcarenite, and gray fossiliferous shale. Upper beds are reddish shale, reddish to purple calcareous siltstone, and thin gray limestone, with the top picked on the highest persistent limestone. Near the base, in the central and southern parts of the range, is a massive cliff-forming biostromal limestone. Most of the intertonguing with the Abo takes place between San Andres Canyon and Love Ranch. West-southwest of Love Ranch in the Robledo Mountains, Abo-like red beds are a series of tongues just above the middle of the Hueco Formation.

Fusulinid faunas of the Hueco are characterized by primitive *Pseudoschwagerina* and by more advanced species of *Schwagerina* than those of the Bursum.

The Abo red beds thin southward in the San Andres Mountains by downward intertonguing into the Hueco Formation.

A thin (20-80 ft ?) red bed sequence appears to be present above the Hueco near San Agustin Pass at the southern tip of the range. In the central Franklin Mountains, Harbour (1972) reported red siltstone in the upper part of the 2,200-ft thick Hueco limestone and suggested its correlation with the Deer Mountain Red Shale Member of the Hueco in the Hueco Mountains. Similarly, the red siltstone appears to be the feather edge of the thicker Abo red beds in the southern San Andres and Robledo Mountains.

In the San Andres Mountains, the Abo consists of dusky-red to dark reddish-brown shale and calcareous siltstone, with a few lenses of silty fine-grained sandstone. The rocks are much finer grained than the type Abo red beds to the north. Southward in the range, olive-gray, light-brown, and greenish-gray clastic beds are common and grade laterally into silty calcareous Hueco beds (Bachman and Myers, 1969). The Abo is 835 ft thick near Rhodes Pass, thinning to 325 ft near Love Ranch. The red beds intertongue with the middle and upper Wolfcampian Hueco limestone and are therefore considered to be of Wolfcampian age, although it is possible that the uppermost red-bed elastics in the northern part of the mountains may have been deposited in early Leonardian time.

The contact of the Abo and the overlying Yeso is gradational, although relatively sharp, a change from hard, dark reddish-brown, ledge-forming siltstone of the Abo into friable orange, light-gray, or light-brown sandstone of the Yeso. In the northern part of the range the Yeso can be divided into four lithic units, in ascending order: 1) light-red, orange-pink and light-gray friable sandstone, silty and shaly, 355 ft thick, 2) interbedded gypsum, silty limestone, light-red to orange, friable sandstone and light-gray siltstone, 935 ft thick, 3) gypsum with some intercalated limestone and siltstone, 235 ft thick, 4) pale reddish-brown friable calcareous sandstone, 55 to 110 ft thick. Southward to Hembrillo Canyon, the Yeso, 1,580 ft thick north of Rhodes Pass, thins to 890 ft, and contains much less gypsum. Outcrops of the Yeso and San Andres Formations are covered by eolian sand along the west side of the San Andres Mountains from Dead Man Canyon south to Ash Canyon, so these formations cannot be traced directly to those near Love Ranch. Beds picked as the Yeso Formation south of Love Ranch are 325 ft thick and consist chiefly of tan, yellowish, and reddish-orange calcareous sandstone with some upper argillaceous limestone. Overlying limestone with some interbedded siltstone that are labeled the San Andres Formation near Love Ranch may be equivalent to the calcareous middle part of the Yeso near Hembrillo Canyon.

A prolific fauna of brachiopods and molluscs collected from Yeso near Rhodes Pass consists largely of undescribed species that are considered by Rousseau Flower as Leonardian in age. Fusulinids were not found in the Yeso Formation, nor in the San Andres limestone.

The type locality of the San Andres Formation is just west of Rhodes Pass (Lee and Girty, 1909) where the formation is more than 600 ft thick, its top an erosion surface. Northeast of the San Andres Mountains, the Glorieta Sandstone is a prominent mappable unit between the Yeso and San Andres Formations, and is distinguished by light-gray to yellowish color and siliceous cement. In the San Andres Mountains, there are lenses of friable yellowish-brown sandstone interbedded with the lower San Andres limestone and grading downward into the pale reddish-brown uppermost Yeso sandstone. This yellowish arenaceous unit is treated as a basal member of the San Andres Formation, roughly correlative to the Glorieta Sandstone.

The San Andres Formation in the northern and central parts of the San Andres Mountains, above the basal arenaceous beds, consists of gray to dark-gray, medium-bedded to massive, fetid, fossiliferous, petroliferous limestone. The San Andres Formation near Love Ranch includes many thick beds of yellowish to pale-red sandstone and siltstone, and may be equivalent to the middle calcareous units of the Yeso Formation west of Hembrillo Pass. A large fauna, mostly of undescribed types, was collected from the San Andres limestone. On the basis of cephalopods from upper beds in the type section, Rousseau Flower believes the formation to be of Leonardian age.

Northwest of Rhodes Pass, oil tests encountered 650 to 700 ft of the San Andres Formation beneath Triassic red beds, and a few miles west of the measured section near Hembrillo Pass the formation in subsurface is only 485 ft thick beneath the Dakota Sandstone. Near Love Ranch, the sequence referred to the San Andres Formation is 380 ft thick beneath the Sarten Formation.

Triassic Rocks

North of Rhodes Pass, along the northwest edge of the mountains, the San Andres Formation is overlain by poorly exposed, pale reddish-brown calcareous siltstone, claystone, and shale believed correlative with the Dockum Formation. Ten miles west of Salinas Peak, these red beds are 50 ft thick beneath an irregular erosional surface overlain by the Dakota Sandstone. To the northwest in the Sun Oil Company Victorio Land and Cattle Company oil tests, 100 to 180 ft of these red beds were penetrated. These Triassic beds are absent from Rhodes Pass southward.

Cretaceous Formations

Cretaceous rocks in and near the San Andres Mountains are the Sarten (?) Formation of Early Cretaceous age, the Dakota Sandstone of Late (?) Cretaceous age and the Eagle Ford-Mancos and Mesaverde formations of Late Cretaceous age.

Near Love Ranch, unconformably on the San Andres limestone and unconformably beneath the Dakota Sandstone, is a sequence of intercalated yellowish-brown to purple silty sandstone, gray sandy fossiliferous shale, brown fossiliferous calcareous sandstone, olive glauconitic sandstone, and black carbonaceous shale. These beds are referred to the Sarten Formation in the sense of a generalized term for Early Cretaceous clastic beds as used by Darton (1928) and because of resemblance to some lithic parts of the type Sarten near Cookes Peak. The sequence near Love Ranch is 65 to 100 ft thick, and contains many fragmentary fossils that appear to be of late Early Cretaceous age.

The Dakota Sandstone is exposed in scattered outcrops on the northwest and southwest margins of the range. This light-colored quartzitic, crossbedded, resistant sandstone is lithologically identical to the sandstone called the Dakota in the Caballo Mountains, near Capitan, and east and northwest of Socorro. No fossils were found in the unit and although the lithology is similar to some of the upper beds of the type Sarten Sandstone which contain Early Cretaceous fossils, the Dakota of the San Andres Mountains is labeled Late (?) Cretaceous, following the San Juan basin usage. The sandstone is 50 to 70 ft thick northwest of Rhodes Pass and thickens to

185 ft west of Love Ranch. A similar lithic unit described by Bose (1906), from outcrops southwest of El Paso, is over 200 ft thick, and was called the Woodbine Sandstone by Adkins (1932). In the southwestern part of the range, basal shale of the overlying Eagle Ford Shale appears unconformable on the Dakota Sandstone.

Northwest, west, and east of the San Andres Mountains, black carbonaceous shale above the Dakota is called the Mancos Shale, but no outcrops of the Mancos occur within the northern and central parts of the range. Near Love Ranch, intercalated olive-gray calcareous subgraywacke, sandstone, and black carbonaceous shale, with some beds of fossiliferous calcarenite, silty limestone, and coal overlie the Dakota Sandstone and contain an abundant fauna of molluscs of Benton age. These shaly arenaceous beds, 425 ft thick northwest of Love Ranch, are not a facies similar to the correlative Mancos Shale, but closely resemble the shale, sandstone, and arenaceous limestone called the Colorado Shale near Cookes Peak and the Eagle Ford Shale near El Paso, and are therefore referred to the Eagle Ford Shale. A few miles west of Hembrillo Pass two oil tests drilled 455 ft of the Mancos Shale with arenaceous beds confined to the lower part of the formation. Southward change from black shale and argillaceous limestone of the Benton Mancos facies and to the arenaceous nearshore Benton Eagle Ford facies takes place between the latitudes of Hembrillo and Ash Canyons.

No outcrops of the Mesaverde Formation are known to occur in the San Andres Mountains but incomplete sections have been drilled by oil tests in Jornada del Muerto. Kelley and Silver (1952) estimated the Mesaverde to be about 2,500 ft thick near the northern Caballo Mountains and Bushnell (1955) measured about 3,200 ft of Mesaverde strata west of Engle. There the Mesaverde consists of olive-brown intercalated sandstone, conglomerate siltstone, and shale with some local coal beds. In the structurally low area between the Caballo and Fra Cristobal Mountains, the Mesaverde Formation is overlain, locally unconformably, by the McRae Formation (Kelley and Silver, 1952) which may be as much as 3,300 ft thick (Bushnell, 1955). The clastic nonmarine McRae beds include much volcanic detritus and contain Late Cretaceous vertebrate and plant fossils in their lower part; they probably do not occur more than a few miles east of Engle.

Cenozoic Sedimentary Rocks

Near Love Ranch as much as several thousand feet of interbedded boulder conglomerate and reddish siltstone overlies the Eagle Ford Shale with pronounced erosional unconformity. Similar conglomerate and red beds occur to the south in the Organ Mountains, resting unconformably on steeply dipping Pennsylvanian and Permian limestone; to the southwest in the general Robledo Mountains area, limestone-boulder-conglomerate, red beds, and gypsum lenses occur at the base of the Tertiary sequence unconformable on the Hueco Formation. These basal Tertiary clastic rocks in the San Andres and Organ Mountains are a mappable unit called the Love Ranch Formation. Poorly preserved plants were the only fossils seen, so the formation is referred to the Tertiary by stratigraphic position, by similarity to the lower Tertiary beds in other parts of south-central New Mexico, and because they rest unconformably on strata ranging in age from Pennsylvanian to Late Cretaceous.

Thick piles of Tertiary volcanic rocks occur in some of the neighboring mountain ranges but only one area of such outcrops, occupying about one square mile, is present in the San Andres Mountains. North of Organ on the west flank of the range, andesitic rocks are faulted against Hueco limestone.

Cenozoic rocks, principally of the Santa Fe Group, are described in other articles in this guidebook, particularly for the area to the west of the San Andres Mountains. Sediments resembling the Santa Fe Group occur east of the San Andres Mountains in the Tularosa Basin but are predominantly clay with much gypsum. These Cenozoic deposits thicken erratically southward from about 750 ft northwest of Tularosa to more than 5,000 ft east of El Paso.

REFERENCES

Adkins, W. S., 1932, The Mesozoic systems in Texas, *in* The geology of Texas, v. I, Stratigraphy: Texas Univ., Bur. Econ. Geol. Pub. 3232, p. 239-518.

Bachman, G. 0., and Harbour, R. L., 1970, Geologic map of the northern part of the San Andres Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map 1-600.

Bachman, G. 0. and Myers, D. A., 1969, Geology of the Bear Peak area, Dona Ana County, New Mexico: U.S. Geol. Survey Bull. 1271-C, 46 P.

Bose, E., 1906, Excursion au Cerro de Muleros: Internat. Geol. Cong. 10, Guide Exc. 20, 24 p.

Bushnell, H. P., 1955, Stratigraphy of the McRae formation, Sierra County, New Mexico: Compass, v. 33, p. 9-17.

Darton, N. H., 1928, "Red Beds" and associated formations in New Mexico, with an outline of the geology of the state: U.S. Geol. Survey Bull. 794, 356 p.

Entwistle, L. P., 1944, Manganiferous iron-ore deposits near Silver City, New Mexico: New Mex. Bur. Mines and Min. Res. Bull. 19, 70 p.

Flower, R. Fl., 1953, Paleozoic sedimentary rocks of southwestern New Mexico, *in* Southwestern New Mexico: New Mex. Geol. Soc. Guidebook 4, p. 106-112.

Flower, R. H., 1955, Pre-Pennsylvanian stratigraphy of southern New Mexico, *in* South-Central New Mexico: New Mex. Geol. Soc. Guidebook 6, p. 65-70.

----, 1957, Studies of the Actinoceratida: New Mex. Bur. Mines and Min. Res. Mem. 2, 101 p.

----, 1958, Cambrian-Mississippian beds of southern New Mexico, *in* The Hatchet Mountains and the Cookes Range-Florida Mountains areas: Roswell Geol. Soc. Guidebook 11, p. 61-78.

----, 1965, Early Paleozoic of New Mexico, *in* Southwestern New Mexico II: New Mex. Geol. Soc. Guidebook 16, p. 112-140.

Foster, R. W., 1959, Precambrian rocks of the Sacramento Mountains and vicinity, *in* Sacramento Mountains: Roswell Geol. Soc. Guidebook 12.

Harbour, R. L., 1972, Geology of the northern Franklin Mountains: U.S. Geol. Survey Bull. 1298, 129 p.

Hardie, C. H., 1958, The Pennsylvanian rocks of the northern Hueco Mountains, *in* Franklin and Hueco Mts.: W. Tex. Geol. Soc. Guidebook, 1958 Field Trip, p. 43-45.

Jones, T. S., 1953, Stratigraphy of the Permian Basin of west Texas: W. Tex. Geol. Soc., 63 p.

Kelley, V. C., and Silver, C., 1952, Geology of the Caballo Mountains: New Mex. Univ. Pub. Geol. Ser., n. 4, 286 p.

Kottlowski, F. E., 1960, Summary of Pennsylvanian sections in southwest New Mexico and southeast Arizona: New Mex. Bur. Mines and Min. Res. Bull. 66, 187 p.

----, 1963, Paleozoic and Mesozoic strata of southwest and south-central New Mexico: New Mex. Bur. Mines and Min. Res. Bull. 79, 100 p.

Kottlowski, F. E., Flower, R. H., Thompson, M. L., and Foster, R. W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mex. Bur. Mines and Min. Res. Mem. I, 132 p.

Laudon, L. R., and Bowsher, A. L., 1949, Mississippian formations of southwestern New Mexico: Geol. Soc. America Bull., v. 60, p. 1-87.

Lee, W. T., and Girty, G. H., 1909, The Manzano group of the Rio Grande Valley, New Mexico: U.S. Geol. Survey Bull. 389, 141 p.

LeMone, D. V., 1969, Lower Paleozoic rocks in the El Paso area, *in* The Border Region: New Mex. Geol. Soc. Guidebook 20, p. 68-79.

Meyers, W. J., 1974, Carbonate cement stratigraphy of the Lake Valley Formation, Sacramento Mountains, New Mexico: Jour. Sed. Pet., v. 44, p. 837-861.

Needham, C. E., and Bates, R. L., 1943, Permian type sections in central New Mexico: Geol. Soc. America Bull., v. 54, p. 1653-1667.

Otte, C., 1959, Late Pennsylvanian and Early Permian stratigraphy of the northern Sacramento Mountains, Otero County, New Mexico: New Mex. Bur. Mines and Min. Res. Bull. 50, 111 p.

Pray, L. C., 1952, Stratigraphy of the escarpment of the Sacramento Mountains, Otero County, New Mexico (Ph.D. thesis): Pasadena, Calif. Inst. Technology.

----, 1958, Stratigraphic section, Montoya group and Fusselman formation, Franklin Mountains, Texas: *in* Franklin and Hueco Mts.: W. Tex. Geol. Soc. Guidebook, 1958 Field Trip, p. 30-42.

----, 1959, Stratigraphic and structural features of the Sacramento Mountain escarpment, New Mexico, *in* Sacramento Mountains: Roswell Geol. Soc. Guidebook 12, p. 87-130.

----, 1961, Geology of the Sacramento Mountains Escarpment: New Mex. Bur. Mines and Min. Res. Bull. 35, 144 p.

Pray, L. C., and Graves, R. W., 1954, Desmoinesian facies of the Sacramento Mountains, New Mexico (abs.): Geol. Soc. America Bull., v. 65, p. 1295-6.

Pray, L. C., and Otte, C., 1954, Correlation of the Abo formation of south-central New Mexico (abs.): Geol. Soc. America Bull., v. 65, p. 1296.

Seager, W. R., 1973, Geologic map and sections of Bishop Cap-Organ Mountains Area: New Mex. Bur. Mines and Min. Res. Geol. Map 29.

Thompson, M. L., 1942, Pennsylvanian system in New Mexico: New Mex. Bur. Mines and Min. Res. Bull. 17, 92 p.

----, 1954, American Wolfcampian fusulinids: Kans. Univ. Paleont. Contr., n. 14, Protozoa, art. 5, 226 p.

Wilpolt, R. H., and Wanek, A. A., 1951, Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, New Mexico: U.S. Geol. Survey Oil & Gas Inv., Prelim. Map OM 121.