Stratigraphy of Paleozoic, Mesozoic rocks in parts of central New Mexico

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STRATIGRAPHY OF PALEOZOIC, MESOZOIC ROCKS IN PARTS OF CENTRAL NEW MEXICO

Introduction

The stratigraphy of Paleozoic and Mesozoic rocks in the vicinity of the Rio Grande Valley of central New Mexico appears to be largely controlled by long existent features, such as the central New Mexico positive area and the Pennsylvanian and Permian positive areas of the Ancestral Rocky Mountains. In contrast, the stratigraphy of Cenozoic rocks appears to be largely controlled by uplifts and basins which developed during the late Cretaceous and early Tertiary Laramide Revolution and subsequent late Tertiary and Quaternary orogenies. Uplifts and basins formed during the earlier orogenies have been greatly modified and in some instances, isolated from the basins and uplifts which developed later. -

In the pages that follow, the sequences of rocks in the areas visited during the conference are described. Such a treatment seems desirable in view of the fact that there are wide variations in the sequences, and hence a standard sequence cannot be established.

Acknowledgements

The data that are presented in the following topics are derived with some modifications from the following sources:

carton, N. H., 1928, Red Beds and associated formations in New Mexico: U. S. Geol. Survey Bull. 794.

Read, C. B., Wilpolt, R. H., Andrews, D. A., Summerscn, C. H., and Wood, G. H., 1944, Geologic map-and-stratigraphic sections of Permian and Pennsylvanian rocks of parts of San Miguel, Santa Fe, Sandoval, Bernelllo, Torrance, and Valencia Counties, north-central New Mexico: U. S. Geol. Survey, Oil and Gas Inves. Prelim. Map 21.

Kelley, V. C. and Wood, G. H. 1946, Lucero Uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Inves. Prelim. Map 47.

Wilpolt, R. H., MacAlpin, A. J., Bates; R. L., and Vorbe, Georges, 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Inves. Prelim. Map 61.

Read, Charles B., and Wood, Gordon H., 1947, Distribution and correlation of Pennsylvanian rocks in late Paleozoic sedimentary basins of northern New Mexico: Jour. Geol., vol. LV, no. 3.

Wilpolt, R. H., and Wanek, A. A., 1951, Geology of the region from Socorro and San Antonio east to Chupadere Mesa, Socorro County, New Mexico: U. S. Geol. Survey, Oil and Gas Inves. Map OM 121 (in 2 sheets).

Kelley, V. C. and Silver, Caswell, 1952, Geology of the Cabello Mountains, Sierra and Dona Ana Counties, New Mexico: Univ. of New Mexico Pub. Geol., No. 4.

Rocks Exposed in the southern Sangre de Cristo, Sandia, Manzanita, and Manzano Mountains

Pre-Cambrian Rocks

Exposures of pre-Cambrian rocks occur in the southern part of the Sangre de Cristo Mountains, in the hills near South Mountain, and in the Sandia, Manzanita, and Manzano Mountains. These rocks consist of red granite, gray granite, granodiorite, gray and brown-red gneiss, quartzite, various types of mica schist, greenstone, and pegmatite. In most places these rocks are overlain unconformably by Pennsylvanian strata, but in parts of the Sandia and Sangre de Cristo mountains, rocks that are probably of Mississippian and Devonian age, intervene.

Paleozoic Rocks

Exposures of Paleozoic rocks are confined, in most cases, to the mountain uplifts. They include strata that are tentatively assigned to the Devonian system, the Mississippian and Pennsylvanian series of the Carboniferous system, and the Permian system.

Devonian rocks

An undetermined part of the lower limestone member of the Sandia formation of the Magdalena group may be of Devonian age. The member, which is discontinuous in outcrop, rests on pre-Cambrian rocks at many places in the Sangre de Cristo Mountains and in the northern part of the Sandia Mountains. The member ranges up to 135 feet in thickness and usually consists of a clastic sequence, which ranges up to 35 feet in thickness, overlain by a limestone sequence, which ranges up to 100 feet in thickness. Paleontologic data bearing on the age of these strata are meager, but it is probable that their age is pre-Pennsylvanian. The clastic sequence probably is correlative with the Elbert formation of south-

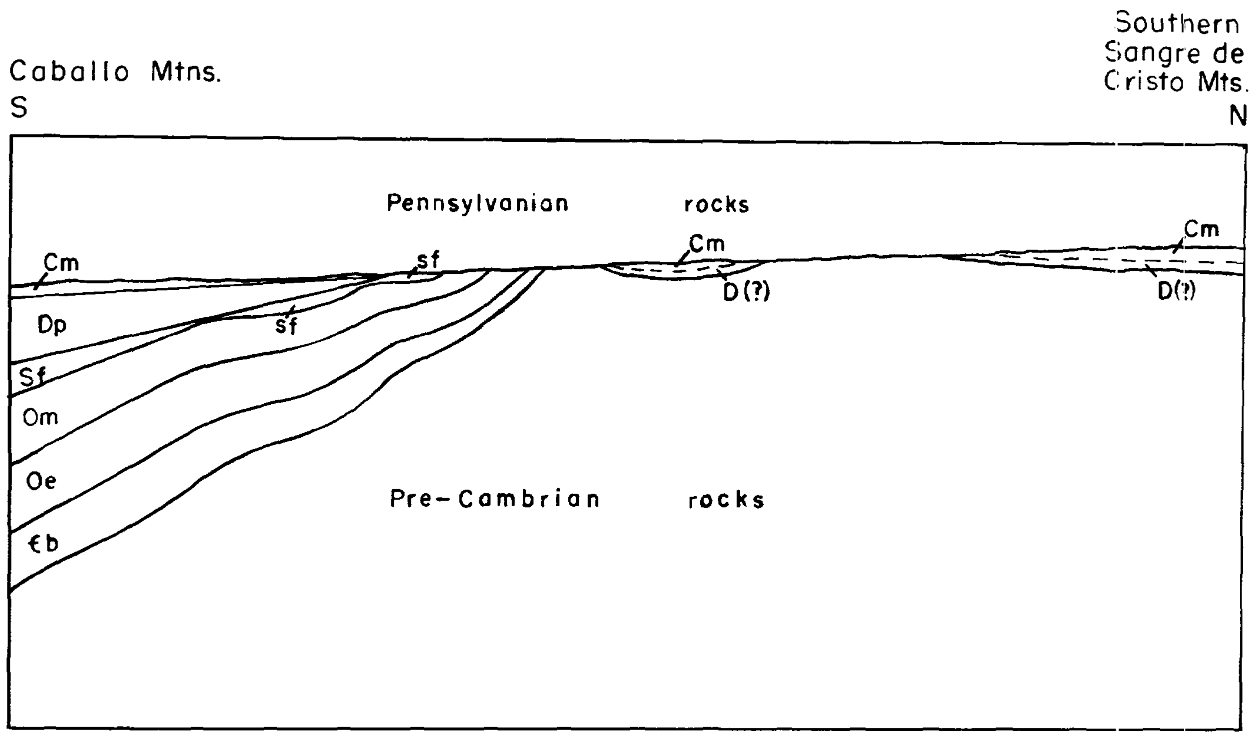


DIAGRAM SHOWING RELATIONSHIP OF MIDDLE AND LOWER PALEOZOIC ROCKS IN PARTS OF CENTRAL NEW MEXICO

Cm — Lake Valley limestone, in south. Mississippian undifferentiated in north
D(?) — Rocks of probable Devonian age
Dp — Perch formation
Sf — Fusselman dolomite
Om — Montoya group
Oe — El Paso group
€b — Bliss formation

western Colorado and with some portion of the Percha shale of southern New Mexico. An unknown part of the limestone beds probably is correlative with the Ouray limeston of southwestern Colorado.

Carboniferous rocks

Rocks of Carboniferous age, dominantly marine in origin, are widespread at the surface in the Sangre de Cristo, Sandia, Manzanita, and Manzano mountains. These rocks are included in the Magdalena group, which in this region has been subdivided into the Sandia formation and the Madera limestone.

The Sandia formation, which forms the lower part of the Magdalena group, is divided into a discontinuous lower limestone member and an upper clastic member. The lower limestone member, as previously outlined under the discussion of Devonian rocks, consists of a few feet of clastics overlain by limestone. The clastic rocks and the lower part of the limestone sequence are probably Devonian. The upper part of the member probably is correlative with the Mississippian Leadville limestone of southern Colorado, and with some parts of the Lake Valley, Kelly, and other recently named Mississippian limestone units of southern New Mexico. The upper clastic member rests unconformably on Devonian and Mississippian beds or on pre-Cambriai rocks. It is a sequence of dominantly clastic beds, many of which are carbonaceous. This member, which in most places forms the greater part of the formation, ranges up to 370 feet in thickness. It shows much variation in detail, but maintains the rather constant characteristic of alternations of irregularly bedded sandstone, thin coal seams, carbonaceous shale, and occasional impure beds of limestone. In terms of midcontinent sequences the upper limits of the member appear to be in the *Fusulinella* zone.

The Madera limestone, of Middle and Upper Pennsylvanian age and of marine origin, rests conformably on the upper clastic member of the Sandia formation. It is subdivided into a lower gray limestone member and an overlying arkosic limestone member. The lower of these members ranges up to 850 feet in thickness, and consists of gray cherty limestone and calcareous shale. It contrasts sharply with the upper member which ranges up to 1,200 feet in thickness and consists of alternations of red or brown arkosic sandstone, arkosic limestone, and gray limestone. The contact between the upper and lower members of the Madera limestone usually is gradational, and there is much interfingering of'beds. Locally there is an unconformity between the two members, and at some places in the Sangre de Cristo Mountains the arkosic limestone member overlaps the lower gray limestone and rests directly on pre-Cambrian rocks.

Permian (?) rocks

Brownish-red arkose and shale of Permian (?) age succeed the Madera limestone. These strata are assigned to the Abo formation in the Sandia, Manzanita, and Manzano mountains, and to the Sangre de Cristo formation in the southern portion of the Sangre de Cristo Mountains. The Abo formation usually is about 900 feet thick, and the Sangre de Cristo formation ranges from 300 to 2,800 feet in thickness. At most places the contact of the Abo or Sangre de Cristo with the underlying arkosic limestone member of the Madera limestone is gradational and there is much interfingering of beds. Locally the Sangre de Cristo formation overlaps the strata of the Magdalena group and rests directly on pre-Cambrian rocks. In the Manzano, Manzanita, and Sandia mountains the base of the Abo formation is usually dated as Wolfcamp, but in the southern part of the Sangre de Cristo Mountains the basal beds of the Sangre de Cristo formation may be of Pennsylvanian age.

Permian rocks

The sedimentary rocks that are definitely assigned to the Permian are included in the Yeso and San Andres formations. In the southern part of the Sangre de Cristo Mountains and in the Sandia Mountains the Yeso formation is 360 to 600 feet thick, and consists of dominantly fine-grained, light-red sandstone and siltstone with occasional thin limestone. It rests with apparent conformity on the underlying Abo and Sangre de Cristo formations. An indistinct equivalent of the Meseta Blanca sandstone member is present, but is not usually considered to be mappable. Southward from the Sandia Mountains the Yeso lithology gradually changes from a predominantly clastic sequence to an evaporite and clastic sequence. The transition is completed near the northern end of Chupadera Mesa. In the Pedernal Mountains on the eastern side of the Estancia Valley the Yeso overlaps earlier strata and lies on pre-Cambrian rocks.

The San Andres formation conformably succeeds the Yeso formation, and has been divided into three members. The Glorieta sandstone at the base is 70 to 250 feet thick. The limestone member, which is the middle unit, is 50 to 150 feet thick, and the upper member, which consists of fine sandstone and siltstone with occasional limestone beds, ranges up to 150 feet in thickness. At Cerrito del Lobo about 40 miles east of Albuquerque, the Glorieta sandstone member overlaps older strata and rests directly on the pre-Cambrian rocks.

Mesozoic Rocks

Mesozoic rocks in and adjacent to the Sangre de Cristo, Sandia, Manzanita, and Manzano mountains include representatives of the Triassic, Jurassic, and Cretaceous systems.

Triassic rocks

Triassic strata consist of red and gray sandstone, variegated shale, and clay, and are included in the Dockum formation, which is about 600 feet thick. The lower part of the formation contains equivalents of the Santa Rosa sandstone or Shinarump conglomerate, while the upper dominantly shaly part contains an equivalent of the Chinle formation. The Dockum formation at most places rests either on the upper elastic member or the limestone member of the San Andres formation. At Cerrito del Lobo, however, it overlaps the older strata and lies on the pre-Cambrian rocks.

Jurassic rocks

Jurassic strata are usually placed in the Entrada sandstone, the Wanakah, and the Morrison formations. The Entrada sandstone, which commonly is about 100 feet thick, is a massive light-red or gray, cross-bedded sandstone that rests with apparent conformity on the Dockum

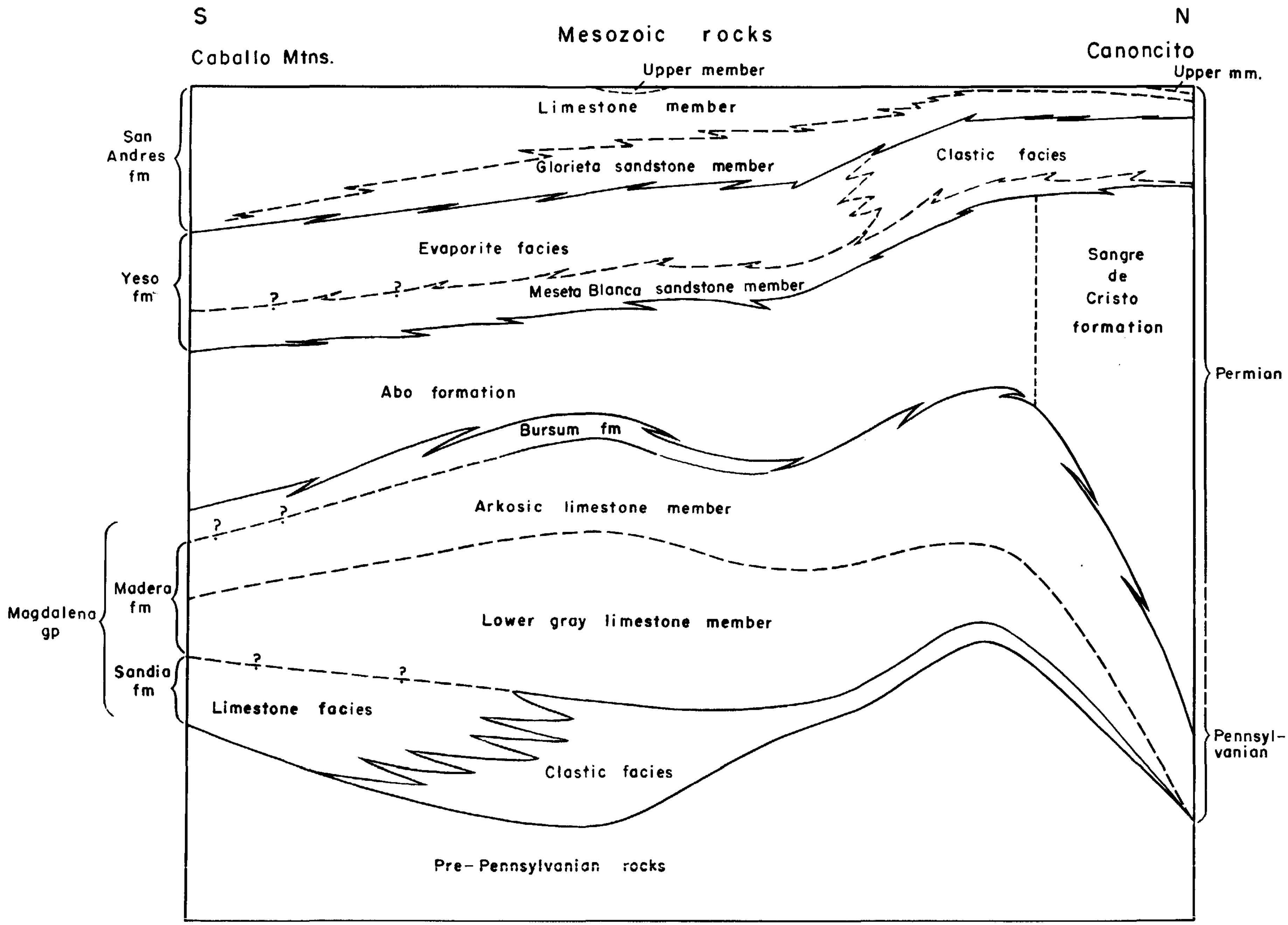


DIAGRAM SHOWING RELATIONSHIP OF UPPER PALOZOIC ROCKS
IN PARTS OF CENTRAL NEW MEXICO

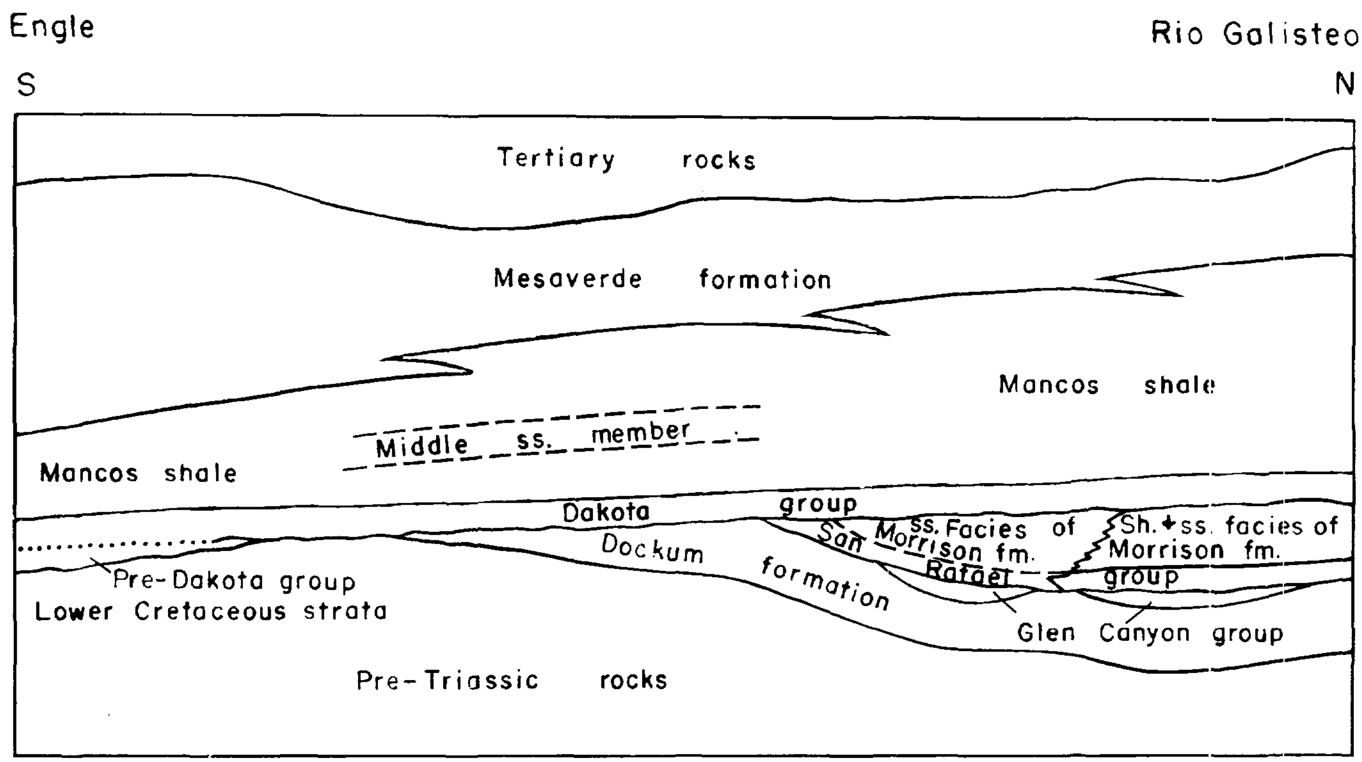


DIAGRAM SHOWING RELATIONSHIPS OF MESOZOIC ROCKS IN PARTS OF CENTRAL NEW MEXICO

formation. The Todilto limestone and gypsum member of the Wanakah formation, which ranges from 50 to 100 feet in thickness, rests conformably on the Entrada sandstone. It consists of a basal thin platy-bedded fetid limestone, a middle massive gypsum, and in some localities an upper sandstone. The Morrison formation, which has an average thickness of 400 feet, rests conformably on the Todilto, and consists chiefly of variegated shale with several beds of sandstone in the lower and middle portion. It is possible that the strata which are usually assigned to the upper part of the Morrison formation may be equivalents of the Lower Cretaceous Purgatoire formation of eastern New Mexico and southeastern Colorado.

Jurassic strata crop out as far south as the Tijeras anticline. To the south of the anticline they are absent and probably were removed by erosion before deposition of the Dakota sandstone. They probably accumulated as a thick wedge in which the proportion of sand-size clastics increased southward toward the central New Mexico positive area. This increase in sand-size material was caused by epeirogenic arching of the central New Mexico area during Jurassic time.

Cretaceous rocks

The Cretaceous sequence consists of the Dakota sandstone, the Mancos shale, and the Mesaverde formation. These formations crop out in the Galisteo basin, in the Hagan basin, and in the Tijeras anticline on the eastern flank of the Sandia Mountains. The Dakota is a conglomeratic ferruginous sandstone which is 50 to 80 feet thick. It overlies the Morrison disconforriably and is conformably overlain by the Mancos shale. The Mancos ranges up to 2,300 feet in thickness and includes near the base the thin Tres Hermanos sandstone member. Above the Tres Hermanos thin equivalents of the Graneros shale and Greenhorn limestone members are locally present. The Mesaverde formation, which ranges up to 1,500 feet in thickness, consists of a sequence of buff and gray sandstone with interbedded gray shale. It contains coal beds of minable thickness at several localities. The formation is progressively beveled in an easterly direction in the Galisteo and Hagan basins, and is overlapped in the vicir ity of Lamy.

Cenozoic Rocks

Strata of Cenozoic age occur as local basin deposits in the Rio Grande depression, in the Galisteo basin, in the Hagan basin, and in the Estancia Valley. The Galisteo formation of Paleocene (?) and Eocene age rests with angular discordance on earlier strata in the

Galisteo and Hagan basins. It consists of about 4,500 feet of conglomeratic sandstone and red shale. Also in the Galisteo basin and in the Hagan basin are from 1,000 to 2,000 feet of sands, gravels, cobbles, and boulders derived largely from igneous rocks. These materials are assigned to the middle Tertiary Espinaso formation. The Espinaso rests unconformably on the Galisteo and is overlain unconformably by Santa Fe or later strata.

The Santa Fe formation of Miocene and Pliocene age crops out over large areas in the Rio Grande Valley and underlies the Santa Fe Plateau. It consists of sediments derived by erosion from the rising mountain masses which flank the Rio Grande depression.

Late Tertiary and Quaternary bolson deposits and pediment veneers are widespread. The Rio Grande Valley contains a great thickness of gravels and sands. The floor of Estancia Valley was the site of a Pleistocene lake, and lacustrine and bolson deposits now obscure bedrock over a large area. In the vicinity of the Santa Fe Plateau, the Ortiz Mountains, and the Jemez Caldera, one or more pediment veneers have been locally named the Ancha formation, the Ortiz gravel, and the Puye gravel.

Rocks exposed in the Joyita Hills, Los Pinos Mountains, Chupadera Mesa, and northern Oscura Mountains

Pre-Cambrian Rocks

Pre-Cambrian granite is exposed in the Joyita Hills, in a small area about 4 miles northeast of the Joyita Hills, in the central Los Pinos Mountains, and in the northern Oscura Mountains. Other pre-Cambrian rocks in the Los Pinos Mountains consist of schist, quartzite, and rhyolite that have been granitized near their contacts with the granite mosses.

Paleozoic Rocks

Paleozoic rocks crop out in the region south of U. S. Highway 60, east of the Rio Grande, and north of U. S. Highway 380. The western_ portion of this large area of outcrop is intricately fractured, and in many localities the stratigraphic relations have been solved as the result of coordinated mapping and stratigraphic work.

Carboniferous rocks

Strata assigned to the Pennsylvanian series are included in the Magdalena group, and are well exposed in the Joyita Hills and Los Pinos Mountains. They rest with an angular unconformity on the pre-Cambrian rocks, and consist largely of gray, moderately fossiliferous limestone with lesser amounts of conglomerate, sandstone, and shale. The lower limestone member of the Sandia formation of the Sangre de Cristo and northern Sandia Mountains is absent and the oldest rocks of the Magdalena group have been assigned to the upper clastic member of the Sandia formation. The member contains numerous fossils which are indicative of a lower Pennsylvanian age. It consists of gray and green sandstone, and locally quartz conglomerate, green, gray and black carbonaceous shale; and dark-gray arenaceous limestone. The thickness ranges from 15 feet in the northern Oscura Mountains to 635 feet in the area to the east of Socorro. The Sandia formation usually forms slopes beneath cliffs of Madera limestone.

The Madera limestone, which conformably overlies the Sandia formation, is divided into the lower gray limestone and arkosic limestone members. The lower gray limestone member consists of massive- to thin-bedded, cherty, medium. to dark-gray limestone with minor amounts of gray and green shale, sandstone, and conglomerate. This member, which usually weathers into a series of cliffs, caps the west escarpment of the Oscura Mountains. It ranges in thickness from 80 feet in the Joyita Hills to 950 feet in the faulted area east of Socorro. It thins to 370 feet in the northern part of the Oscura Mountains, and then thickens rapidly to 700 feet in the central part of the Oscura Mountains.

The arkosic limestone member consists of thin- to thick.bedded, medium- and light-gray limestone that generally contains much less chert than the underlying lower gray limestone member; gray, black and red shale; and green, brown, and gray sandstone, and arkosic sandstone. Fresh, pink feldspars are usually present in the lower sandstone and conglomerate beds of this member. The lower two-thirds to one-half of the arkosic limestone member is arenaceous and argi I laceous, and persistently forms slopes. In contrast, the upper one-third to one-half consists predominantly of cliff-forming limestone. The member is not present in the Joyita Hills, but in the area to the east of Socorro it attains a thickness of more than 700 feet.

Permian (?) rocks

In the Joyita Hills, the Los Pinos Mountains, the area east of Socorro, and the northern Oscura Mountains the youngest formation of the Magdalena group is known as the Bursum. It consists of thick beds of dark purplish-red and green shale separated by thinner beds of arkose, arkosic conglomerate, and gray limestone. A thin, rubbly, nodular, purplish-gray limestone consisting of reworked limestone of the underlying arkosic limestone member of the Madera formation occurs locally at the base. Limestone beds above are 1 to 6 feet thick and carry marine invertebrates. The fusulinid *Schwagerina,* in association with the very obese fusulinid, *Triticites ventricosus,* has been collected from several localities. A massive white-weathering limestone at the top of the formation in the Oscura Mountains has been considered by Thompson to be of Wolfcamp age. Thompson placed the strata below this massive bed and above the massive limestone beds of the arkosic limestone member of the Madera limestone in the Bruton formation. Thompson's Bruton formation is equivalent to all of the Bursum formation, except the uppermost massive ledge and the thin beds of limestone interbedded with red and green shale that lie just above the top of the arkosic limestone member of the Madera in the Oscura Mountains. The Bursum formation ranges from 28 to 250 feet in thickness.

As shown by the fusulinids, the Bursum formation is of Wolfcamp age. According to C. B. Read, these marine strata of Wolfcamp age are the final phase of a cycle of marine deposition, and are therefore logically placed in the Magdalena group, which thus includes Pennsylvanian and possible Permian marine strata. Thompson suggests equivalence of what is here termed Bursum with the Hueco Mountains in southern New Mexico.

The Abo formation rests conformably on and inter-tongues with the Bursum formation. It consists of dark-red shale, dark-red sandstone and arkose, conglomerate, and lime-pellet conglomerate. The continental origin of the formation is shown by the red color, mud cracks, current ripple marks, cross-bedding, tracks of land vertebrates, plant impressions, and the lenticular character of the sandstone beds. The thickness ranges from 300 feet in the Joyita Hills to 910 feet in the type section, which is in Abo Canyon. The shale units erode easily; in contrast, the coarser clastic units are highly resistant and form prominent ridges and cuestas.

The age of the Abo formation is in question. Fossil plants collected and identified by C. B. Read from the upper part of the Abo suggest that at least the upper portion should be correlated with strata of Leonard and not Wolfcamp age.

Permian rocks

Strata that are considered by most geologists to be of Leonard age are divided into the Yeso and San Andres formations. Two subdivisions of the Yeso formation are commonly considered to be mappable in the Los Pinos Mountains, Chupadera Mesa, Oscura Mountains, and the area east of Socorro. These commonly accepted mappable units are the lower or the Meseta Blanca sandstone member, and an upper division that includes in ascending order the Torres member, the Canes gypsum member, and the Joyita sandstone member. The Meseta Blanca sandstone member was named from exposures in the Sierra Nacimientos. The Torres member was named from exposures in a tributary to Agua Torres. Canyon, on the Sevilleta Grant 7 miles due south of Black Butte, Socorro County. The Canas gypsum and Joyita sandstone members were named from exposures in the Joyita Hills and the area east of Scorro. The Torres, Canas, and Joyita members are equivalent to the Los Vallos member of the Yeso formation in the Lucero uplift.

The Meseta Blanca sandstone member of the Yeso formation rests conformably on and intertongues with the Abo formation. It consists of uniformly bedded, red-brown and variegated sandstone and sandy shale. The thickness ranges from 104 to 355 feet. The lower part of the member generally forms a valley on the gently dipping backs lope of the Abo formation, and its upper part forms a slope leading up to the rim of a cuesta which is capped by the lowest limestone bed of the Torres member.

The Torres member which comprises the bulk of the Yeso formation rests conformably on and intertongues with the Meseta Blanca sandstone. It consists of alternating beds of orange-red and buff sandstone and silt-stone, gray limestone, and gypsum. The thickness ranges from 350 to 1,000 feet. The Canas gypsum member intertongues with the Torres and contains some thin gypsiferous siltstone and limestone beds but is chiefly white gypsum. It ranges in thickness up to 190 feet. The Joyita sandstone member intertongues in turn with the Canas and consists of orange-red, buff and yellow sandstone, silty sandstone, and siltstone, and ranges in thickness from 30 to 150 feet.

The San Andres formation is divided into the Glorieta sandstone member, the limestone member, and the upper clastic member. The Glorieta sandstone member consists of white, light-yellow, and light-gray, medium- and coarse-grained, cross-bedded sandstone, ranging from 33 to 200 feet in thickness. It is the prominent cliff-former in the steepest part of the Chupadera Mesa escarpment. In the southern part of Chupadera Mesa easily eroded beds are present in the middle of this member, giving the Glorieta portion of the cliffs a double-ledged character. The Yeso intertongues upward into the Glorieta, and gradually replaces it to the south; the Glorieta, in turn, intertongues upward into the limestone member, and replaces it gradually to the north.

The limestone member consists of dark-gray, thin- and medium-bedded, slightly petroliferous limestone with beds of white gypsum and sandstone. It ranges from 270 to 396 feet in thickness in the Los Pinos and Oscura mountains, and probably becomes thicker and more gypsiferous in the Chupadera Mesa area where the upper part has been removed by erosion. The lower resistant beds of this member generally form the cap rock of the steep cliffs of Chupadera Mesa.

The upper member which rests conformably on the limestone member is orange-red, silty sandstone with local thin beds of dark-gray limestone. The member ranges from 5 to 36 feet in thickness in the Joyita Hills and in the area east of Socorro.

Mesozoic Rocks

Mesozoic rocks crop out in the region south of U. S. Highway 60, east of the Rio Grande, north of U. S. Highway 380, and west of Chupadera Mesa.

Triassic rocks

Maroon, light-green, and light-gray sandstone, silt-stone, and shale beds which are assigned to the Dockum formation rest disconformably on strata of the San Andres formation. Local limestone-conglomerate lenses are present. The maximum thickness is approximately 500 feet. Owing to the paucity of clean exposures and complex structural relationships, it is difficult if not impossible to measure a complete stratigraphic section. The outcrops are limited to the area west of the southern Los Pinos Mountains, the Torres syncline, and the area north of the Carthage coal field. Correlatives of the Santa Rosa sandstone, Shinarump conglomerate, and the Chinle formation are probably included in the Dockum.
In the Joyita Hills all but the lower 80 feet of the Dockum formation was removed by pre-Baca erosion.

Cretaceous rocks

The Dakota sandstone rests directly on beds of the Dockum formation. The Dakota consists of 71 to 112 feet of medium- to coarse-grained, locally conglomeratic sandstone, with yellowish-green and grayish-black shale at the base.

Near the Joyita Hills the overlying Mancos shale rests conformably on the Dakota sandstone and consists of up to 700 feet of buff and black shale and yellow, buff, and brown sandstone. In the Carthage coal field the Mancos shale is locally differentiated into three members; the lower, which is 295 to 340 feet thick, includes a dark-gray, friable, calcareous shale with several thin beds of flaggy limestone near the middle. The middle member consists of 240 feet of medium- to fine-grained medium-bedded light-buff sandstone interbedded with light-gray, red, and lavender beds of shale. A conspicuous bed of brown sandstone occurs at the top of the unit. The uppermost member, which is 225 to 290 feet thick, consists of dove-gray to blue-gray, friable, calcareous shale. The formation was entirely removed from the Joyita Hills and partly removed from the Agua Torres area by pre-Baca erosion.

The Mesaverde formation rests conformably on and intertongues with the Mancos shale. The formation consists of gray to buff and brown sandstone and gray to buff calcareous shale, and two coal beds. The upper limit of the formation is an erosional surface. It is probable that the original thickness of the formation was much greater than the 200 to 987 feet that remain.

Cenozoic Rocks

Rocks of Cenozoic age crop out principally in the Rio Grande depression, in the faulted areas near the Joyita Hills and Socorro, and in the down-warped or synclinal Jornada del Muerto.

Tertiary rocks

The Tertiary sequence is divided into the Baca formation, the Datil formation, and the Santa Fe formation.

The Baca formation was named from exposures in Baca Canyon. in Secs. 4, 5, 8, and 9, T. 1 N., R. 4 W., north Bear Mountains, Socorro County, where it is 694 feet thick. In the Joyita Hills, in the area east of Socorro, and in the Carthage coal field, it consists of coarse conglomerate, red and white sandstone, and red clay. The conglomerate contains an abundance of pebbles, cobbles, and boulders derived from pre-Cambrian quartzite, Madera limestone, and the Abo formation. The thickness ranges from 80 to 1,023 feet. The pre-Cambrian fragments are chiefly granite. Because of folding and erosion prior to its deposition, the Baca formation truncates all the Cretceous formations, and rests on the lower 80 feet of the Dockum formation in the Joyita Hills. It is absent in the Magdalena mining district and in Socorro Mountain.

Near Carthage the Baca formation was mapped and a thickness of 1,023 feet was measured by Gardner, who collected a mammal tooth near the base. The tooth was identified by Gidley as *Palaeosyops,* probably of Bridger (Eocene) age.

Near Elephant Butte dam, a thick conglomerate sequence composed of pre-Cambrian and volcanic fragments, sandstone, and shale (McRae formation of Kelley and Silver) above Mesaverde strata is somewhat similar in lithology with the Baca formation. According to Lee these beds carry *Triceratops.* It is possible that the bones of this late Cretaceous dinosaur were exhumed and reworked into these beds. Abundant fossil wood also is present near the base of the formation. Dunham describes strata in the Organ Mountains consisting of conglomerate containing large boulders of limestone from the Magdalena group, with subordinate amounts of sandstone and shale. These strata are a few feet to almost 100 feet thick. They rest unconformably on the Magdalena group and underlie a thick volcanic unit similar to the Datil formation.

It is quite possible that the Baca formation is correlative with the Galisteo sandstone of the Gal isteo basin and the McRae formation of Elephant Butte. All were apparently basin deposits.

Although Winchester took the name Datil formation from the Datil Mountains, the only published stratigraphic section was measured in the north Bear Mountains. The type section of the Baca formation, as defined in this report, occupies the lower 694 feet of Winchester's stratigraphic section. The restricted Datil formation in that area is 1,140 feet thick, the upper beds having been removed by erosion. It consists of latite, rhyolite, and andesite flows, agglomerate, tuff, conglomerate, and sandstone. Purple is the dominant color, but there are some reds and grays. The thickness has not been measured in the Joyita Hills, in the area east of Socorro, and in the Carthage coal field, but is estimated to be about 2,000 feet.

The Datil formation truncates several older formations. In the Magdalena mining district, Loughlin and Koschmann observed that a sequence of effusive igneous rocks (Datil (?) formation) rests on the eroded edges of the Sandia formation, the Madera limestone, and the Abo formation. In Socorro Mountain, west of Socorro, the Datil rests on the Madera limestone.

The age of the Datil formation is in doubt. It is younger than the Baca formation and older than the Popotosa or Santa Fe formations which are generally considered to be Miocene (?) and Pliocene. If the Baca formation is Eocene, the Datil may be Eocene or younger.

The Santa Fe formation consists of red, brown, and gray gravel, sand, and silt cemented locally with calcareous material. It is not known whether the thickness of these deposits is very great, since no more than a few hundred feet are exposed at any one place. The formation is bevelled and covered by Quaternary pediment deposits. The associated Popotosa formation is difficult to delimit, although some of the Santa Fe sediments to the west of the Joyita Hills are similar to the Popotosa formation of Denny. Denny mapped the Tertiary rocks and structure of the Joyita Hills area, and did not recognize Popotosa sediments there.

Quaternary rocks

The Quaternary sediments consist of pediment gravel and valley alluvium. The gravel commonly includes some caliche. Deposits of this material cover several levels, such as the Llano de Albuquerque and Llano de Sandia which bevel the underlying rocks.

Rocks exposed in the northern Ladron Mountains and Lucero uplift

Pre-Cambrian Rocks

Exposures of pre-Cambrian rocks are almost entirely confined to the Ladron Mountains, although small patches of granite are present on the eastern flank of the Lucero uplift along the Comanche thrust on the southeast side of Gray Mesa. The pre-Cambrian is dominantly red granite along the north and west sides of the Ladron Mountains. In the higher parts of the mountains some quartzite and schist occur as large roof pendants in the granite. In most places, as along the Ladron fault, the Paleozoic rocks are in faulted contact with the pre-Cambrian rocks. At the northwest corner of the mountains, however, the Sandia formation locally lies in normal contact on the granite.

Paleozoic Rocks

Rocks of Paleozoic age crop out in a north-south trending belt of varying width which extends from the eastern flank of the Lucero uplift, across Los Vallos into the lower and middle slopes of Sierra Lucero

Devonian rocks

The lower limestone member of the Sandia formation of the Magdalena group may contain a few feet of strata that are Devonian in age. These strata crop out at the base of the hogback which trends northwest from the Ladron Mountains. The thickness of strata which may be Devonian is less than 15 feet and may not exceed 10 feet. These strata consist of a fine clastic non-fossiliferous sequence overlain by limestone. Just as in the Sandia and Sangre de Cristo mountains, the clastic sequence probably is correlative with the Elbert formation, and possibly the lower part of the limestone sequence is correlative with the Ouray limestone.

Carboniferous rocks

The Magdalena group is well exposed in the south and central parts of the area. Magdalena strata are dominantly gray marine limestone although some shale, sandstone, granulitic quartz conglomerate, and limestone conglomerate likewise occur.. The best and most complete exposures of the group are in the hogback that extends northwestward from the Ladron Mountains and in Monte de Belen. The Magdalena group is divided into the Sandia formation and the overlying Madera limestone.

The only complete exposure of the Sandia formation is in the northwest-trending hogback of the Ladron Mountains where it is divided into a thin, 15-foot thick, lower limestone member and a 400-foot thick upper clastic member. There is little or no paleontologic evidence concerning age of the lower limestone member, but it is believed that it is pre-Pennsylvanian in age. As described in the section devoted to Devonian rocks, an indefinite part probably is of Devonian age and the remainder probably is of Mississippian age. The upper part of the member has a somewhat different I ithology than the Kelly limestone, but the two may be correlative.

The upper clastic member of the Sandia formation is disconformable on the limestone member. It erodes into covered or gullied slopes below the Madera limestone. At the foot of Monte de Belen the upper clastic member is partly exposed. About 100 feet of coarse sandstone crops out in a small area at the foot of Gray Mesa. The member is not exposed north of this point in the Lucero area. However, the log of the well on South Suwanee dome shows about 200 feet of the Sandia formation.

In the Lucero area the Madera limestone is divided into three members which have been named the Gray Mesa, the. Atrasado, and the Red Tanks members.

The Gray Mesa member, which is 850 to 900 feet thick, rests conformably on the upper clastic member of the Sandia formation. It extends in continuous outcrop from Comanche Arroyo along the steep east face of Gray Mesa and southward past Monte de Belen. Another prominent belt of outcrop extends from Red Tanks Arroyo near Salado Ranch southeastward into the west slopes of the Ladron Mountains. The most completely exposed section lies in the steep east face of Monte de Belen. North of Monte de Belen the basal part of the member is involved in close folding or faulting along the Comanche thrust. Ledgy gray to dark-gray limestone predominates in the member. One or more massive ledges are prominent above the middle of the member in the east face of Monte de Belen, and one of these attains a thickness of 60 feet. The Gray Mesa member is markedly cherty, and this feature aids in distinguishing it from the overlying, only slightly cherty, Atrasado member. Locally, however, the chert may be less abundant, as it is at Gray Mesa. The upper limit of the Gray Mesa member is the top of a rather conspicuous thin-bedded, tan-weathering limestone. This unit lies about 150 feet stratigraphical ly below beds that contain abundant *Triticites* and about 200 feet above the prominent ledges described above. The Gray Mesa member is correlative with the lower gray limestone member of the Sangre de Cristo, Sandia, Manzanita, Manzano, Los Pinos, and Oscura mountains.

The Atrasado member, conformably overlies the Gray Mesa member and its outcrop is nearly coextensive with it. The Atrasado member, however, extends a few miles farther north to Carrizo Arroyo. Although the section west of the Ladron Mountains is the thickest, measurement there is complicated by faulting. The thickness ranges from 550 to 800 feet. The Atrasado member crops out in the upper slopes and underlies the tops of Gray Mesa and Monte de Belen. It differs from the Gray Mesa member in having a greater proportion of shale, somewhat more sandstone and red beds, and far less chert in the limestone. The contact with the overlying Red Tanks member is at the top of the uppermost massive limestone in the sequence. This horizon is topographically at the west bases of Monte de Belen and Gray Mesa and commonly marks the eastern edge of Los Vallos. The Atrasado member is correlative with the arkosic limestone member in the Joyita Hills, Los Pinos Mountains, and the area east of Socorro, and is correlative with an indefinite portion of the lower part of the arkosic limestone member in the Sandia and Sangre de Cristo mountains.

The Red Tanks member rests conformably on and grades into the Atrasado member. It forms a continuous belt, 200 to 300 feet thick, along the eastern side of Los Vallos from Breach Canyon on the north, to the west foot of Monte de Belen on the south. North of Breach Canyon it is covered for a short distance by the basalt cap of south Mesa Lucero, but comes to the surface again in a wide fork extending south from Carrizo Arroyo where the most complete section of the member is exposed. West of the Ladron Mountains the member is covered by pediment gravels, but it crops out in several places in the tributaries of Red Tanks Arroyo. The Red Tanks member also crops out in Comanche Arroyo. The lower part of the member consists of dark red-brown siltstone, sandstone, and shale. Locally, as in Carrizo Arroyo, the base contains buff sandstone and limestone conglomerate. The upper part consists mostly of cement-gray, thin-bedded, nodular limestone and gray shale. The limestone is marine and contains an abundant, well preserved fauna, which is indicative of an upper Virgil age. The most prominent limestone bed generally lies at the top of the member. In east Los Val los this limestone forms a line of low disconnected hills which commonly lie in the middle of the valley. There is some inter-tongu• ing of the marine sediments of the Red Tanks member with the continental beds of the overlying Abo formation. The contact with the Abo formation is at the top of the uppermost marine limestone in the member. The Red Tanks member is in the same stratigraphic position as the Bursum formation in the Joyita Hills, the Los Pinos, and 'Oscura mountains, and the area east of Socorro. The Bursum as previously shown is of Wolfcamp age. It is probable that Red Tanks strata grade and intertongue laterally, and become progressively younger to the south and east, toward the area of Bursum outcrop, and progressively older to the north and west.

Permian (?) rocks

The red-brown shale, siltstone, and sandstone of the continental Abo formation contrast markedly with the dull-gray of the underlying Magdalena group and the light-brown and white of the overlying Yeso formation. The Abo rests conformably on and intertongues with the Red Tanks member of the Madera limestone. The principal outcrop belt of the Abo formation is a line of cuestas and low hills which divide the east and west Los Vallos. This belt extends from the southwest corner of the Lucero area northward a distance of about 13 miles and then passes beneath the basalt cap of south Mesa Lucero. To the north of the cap in Carrizo Arroyo, exposures of the Abo are prominent. Several incomplete sections of the Abo formation are exposed along Red Tanks Arroyo south and east of Monte de Belen, and several small patches of Abo occur in the Comanche thrust belt in and near Comanche Arroyo. Soft red-brown shale and occasional thin, fresh-water limestone or limestone conglomerate and thin sandstone or siltstone make up the lower half of the formation. In the upper half, red-brown, cross-bedded, massive, cuesta-forming sandstone beds alternate with shale. In Los Vallos the lower half of the soft shale unit is generally covered in the broad valley floor. The thickness of the formation ranges from 870 to 900 feet.

Permian rocks

Two members are recognized in the Yeso formation of the Lucero uplift, the lower or Meseta Blanca sandstone member, and the upper or Los Vallos member. In the northern part of the Lucero area the Meseta Blanca sandstone member, about 250 feet thick, is coextensive with outcrops of the upper part of the Abo formation. The member thins to the south and is not generally mappable south of Monte de Belen. Its bold, rounded, and picturesque ledges contrast with the somber angular outcrops of the Abo formation. Lentils of sandstone similar to the Meseta Blanca sandstone member occur locally in the top few tens of feet of the Abo formation. These lentils suggest intertonguing between the Abound Meseta Blanca. The upper few feet of the member generally consists of friable white sandstone.

The Los Vallos member constitutes the bulk of the Yeso formation, and probably is correlative with the Torres, Canas, and Joyita members in the Joyita Hills, Los Pinos, and Oscura mountains, and in the area to the east of Socorro. It underlies west Los Val los, and forms the lower slopes of the east face of Sierra Lucero in a long broad belt extending from the west edge of the area in T. 5 N. into the head of Carrizo Arroyo. Still farther north it forms the floor and slopes of the wide inner valley of Santa Fe Arroyo and the head of Garcia Arroyo. Small outcrops occur in the south tributaries of Red Tanks Arroyo near Monte de Belen. The member is severely deformed in the Comanche thrust belt near Carrizo Arroyo, and beds of this unit are the rocks most commonly exposed immediately east of the 25-mile extent of the thrust. The thickness ranges from 820 to 1,020 feet. The lower part of the member is dominantly a clastic unit, but contains several persistent thin limestone and thicker gypsum beds. In the upper part of the Los Vallos member, gypsum comprises about 50 percent of the section. This part of the member probably is correlative with the Canas gypsum, but it is so much thicker that the correlation has been made-in only a general way. No sandstone comparable to the Joyita sandstone occurs in the Lucero area.

The San Andres formation consists of three members, which are, from the base up, known as the Glorieta sandstone member, the evaporite member, and the limestone member. The most prominent and complete exposures of the formation are in Sierra Lucero. The bold east face of the sierra is largely due to the resistance of this formation to erosion. The Glorieta sandstone member, 180, to 220 feet thick, crops out as a double cliff; the middle evaporite member, 300 to 350 feet thick, as a series of steep slopes and ledges; and the upper limestone member, which ranges from 100 to 120 feet thick, caps parts of the Sierra Lucero and crops out widely in the gentle dip slope on the west side. The Glorieta rests conformably on and intertongues with the Los Vallos member of the Yeso formation. The sandstone and shale which alternate with the gypsum in the evaporite member are generally white to buff, in contrast with the tan-brown color of the Yeso formation. The lower part of the San Andres formation is exposed beneath the Mesa Lucero basalt cap along the south and east side, and it arches across the North Lucero anticline near the head of Garcia Arroyo. From Carrizo Arroyo northward for about 6 miles the formation dips steeply east in the prominent hogback west of the Santa Fe fault. The middle and upper members are much deformed by compression and possible sedimentary thinning along this zone. The top of the San Andres formation is an erosional unconformity of low relief.

Mesozoic Rocks

Strata of Mesozoic age crop out in the higher parts of Sierra Lucero, on the western slopes of Sierra Lucero, beneath and to the north of Mesa Lucero, and locally to the east of the Comanche thrust belt.

Triassic rocks

The Shinarump conglomerate is principally exposed along the top and east slope of Sierra Lucero. It underlies the Mesa Lucero basalt cap in a considerable belt and is exposed in small patches along the east limb of the North Lucero anticline west of Garcia Arroyo. It also crops out locally beneath extensive spring deposits along the west side of the Santa Fe fault. The Shinarump rests disconformably on the limestone member of the San Andres formation. Little or no conglomerate is present in the Lucero area, and the formation more nearly resembles the equivalent Santa Rosa sandstone east of the Rio Grande Valley than the Shinarump conglomerate of western New Mexico and Arizona. The top of the formation is either eroded or covered throughout the Lucero area; however, the thickness is inferred to be about 300 feet.

The Chinle formation in the Lucero area is divided into a red shale member and the Correo sandstone member. The red shale member, which is about 1,000 feet thick, is the unit most susceptible to erosion in the area. Most of the estimated section is covered by alluvium and landslide material. It appears, however, to underlie the northwest half of Mesa Lucero and the broad San Jose Valley from near Lucero Spring northward to the base of Mesa Gigante. Probably it is present also in many isolated outcrops along the Comanche thrust and the Santa Fe faults, but in such occurrences positive identification can not be made because of the presence of similar shale in the Shinarump conglomerate.

The Correo sandstone member, which ranges from 90 to 120 feet in thickness, crops out along the lower bench at the south edge of Mesa Gigante. The upper contact of this member is slightly uneven owing to erosion prior to deposition of Jurassic strata.

Jurassic rocks

Locally in the southern slopes of Mesa Gigante the Correo sandstone is overlain by thin lentils which are probably best correlated with the Glen Canyon group. Resting disconformably on these lentils is the Entrada sandstone.

The Entrada is best exposed as a tan-brown, friable, massive, cross-stratified sandstone, 160 to 220 feet thick, in the south side of Mesa Gigante where it appears to thin gradually to the west. A few feet of the top of the sandstone are exposed locally in the flats between Mesa Redonda and the Garcia fault and in an interrupted strip in the valley east of the Santa Fe fault.

The Wanakah formation in the Lucero uplift is divided into the lower Todilto limestone and gypsum member and the upper buff shale member. The Todilto limestone and gypsum member, 90 to 110 feet thick, rests with apparent conformity on the Entrada sandstone. The member crops out in the southern slope of Mesa Gigante, in Mesa Redonda, and in the southern part of the area north of the Rio San Jose. It is poorly exposed in the interrupted strip in the valley east of the Santa Fe fault. The buff shale member, 60 to 120 feet, crops out in the same general area as the Todilto.

The Morrison formation is divided into a basal brown and buff sandstone member, 100 to 140 feet thick; a middle white sandstone member, 160 to 175 feet thick; and an upper variegated shale member, 50 to 260 feet thick. These members are distinguished readily in nearly all exposures of the formation in the Lucero area; however, the best exposures are in the south slopes of Mesa Gigante. Complete, sections are exposed also in Mesa Redonda and in the highly faulted area north of the Rio San Jose. The brown-buff member which forms the prominent brown cliff along the south side of Mesa Gigante gradually becomes buff in an easterly direction toward the Correo fault, and in the southern outcrops, as -in Mesa Redonda, it is white or buff.

Jurassic strata become sandier and are progressively bevelled by the pre-Dakota sandstone erosion surface to the southwest in the drainage basin of the Rio Colorado. Near the southern end of the Rio Colorado drainage basin most of the Jurassic shales and the Todilto limestone and gypsum have been replaced by sandstone. Still farther to the south the entire Jurassic sequence is overlapped by the Dakota sandstone.

Cretaceous rocks

The Dakota sandstone rests with a slight angular unconformity on the variegated shale member. The formation consists of 75 to 100 feet of medium- to coarse-grained cross-stratified, locally conglomeratic sandstone. The Dakota is locally absent to northwest and south of the Lucero area. Strata which are assigned to the Mancos shale rest conformably on the Dakota and grade into it. These strata have an aggregate thickness of 550 to 750 feet, and the lower 350 feet contains two sandstones, which are marine in part. The upper sandstone is considered by some to be the upper part of the Dakota sandstone. The upper beds of the Mancos intertongue with the lower beds of the Mesaverde formation which has an aggregate thickness of about 1,700 feet. The Mesaverde is divided into five members in the vicinity of the Lucero uplift. These members are, in ascending order, the Gallup sandstone member, 50 to 100 feet thick; the Dilco coal member, 75 to 100 feet thick; the Mulatto tongue, 250 to 400 feet thick; the Dalton sandstone member, 75 to 100 feet thick; and the Gibson coal member, 1,000 to 1,300 feet thick.

Cenozoic Rocks

Rocks of Cenozoic age are primarily confined to the area of the Lucero uplift in the Rio Grande depression. Small outliers of Tertiary rocks are locally involved in what appears to be late Tertiary and Quaternary structural complications.

Tertiary rocks

The Tertiary sedimentary rocks are included in the Santa Fe formation. These are of great thickness and locally may include rocks equivalent to the Popotosa formation as described by Denny. The Santa Fe formation is widely exposed in the northeastern quarter of the area. The best and largest exposures of the Santa Fe formation are in and south of Los Cerros. The top of the Santa Fe formation is undetermined, and deformed strata of the Santa Fe are widely bevelled and covered by Quaternary pediment gravels in the Llanos del Rio Puerco.

Quaternary rocks

The oldest Quaternary deposits are pediment gravels, and they are preserved most extensively in the Llanos del Rio Puerco. East of Major's ranch they are present on a small upper surface, which appears to have once merged with the Mesa Lucero surface, and on a much larger surface which forms most of the Llanos del Rio Puerco. Pediment gravels also crop out beneath the Mesa Lucero basalt cap near Branch Canyon and west of the Lucero crater.

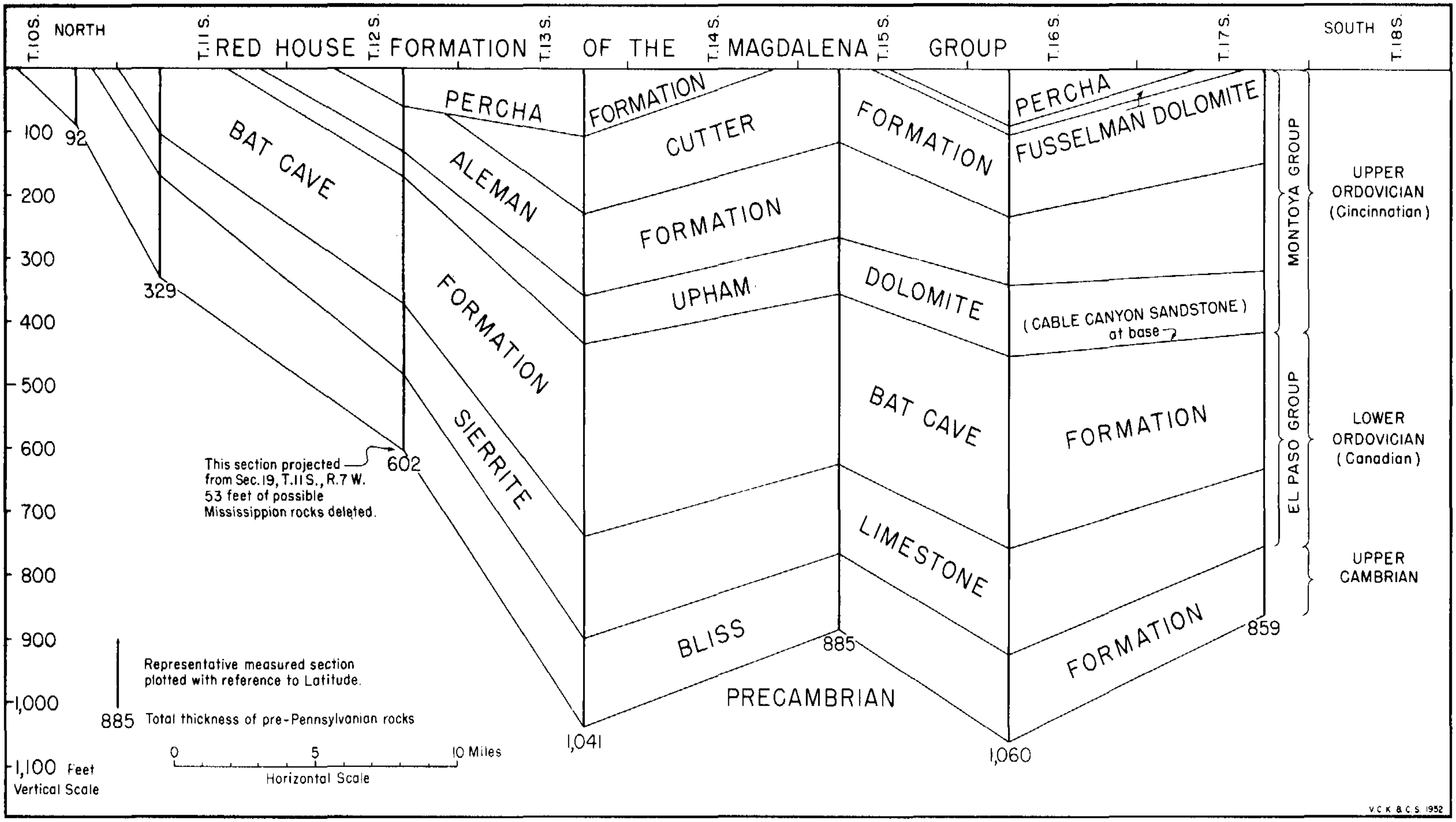
Large and extensive spring deposits lie along the Comanche thrust and the Santa Fe fault. The deposits form a continuous strip $^{1}/4$ to 1/2 mile wide for 10 miles between Monte de. Belen and Gray Mesa. Most of the springs along the extent of the deposits are inactive, though a few springs still flow. Along the Comanche thrust at Monte Largo Arroyo, spring deposits, 75 to 100 feet thick, are exposed in a small gorge. These grade eastward in part into pediment gravels of the Llanos del Rio Puerco. In many places travertine occurs on broad surfaces with little or no gravel and this material is termed caliche.

Rocks exposed in the Caballo Mountains*

Pre-Cambrian Rocks

The principal outcrops of pre-Cambrian rocks are along the base and in the lower slopes of the bold west escarpment of the mountains. The outcrop.-is essentially continuous beneath the Bliss formation in the escarpment for some eleven miles between Palomas Gap on the north and Apache Canyon on the south. Pre-Cambrian rocks occur in the lower part of the Mud Springs Mountains.

* Stratigraphy abstracted from: "Geology of the Cabello Mountains, Sierra and Dona Ana Counties, New Mexico:" by V. C. Kelley.and Caswell Silver, University of New Mexico Pub. Geol. 4, 1952


T.10S.
NORTH
T.11S.
RED HOUSE
T.12S.
FORMATION
T.13S.
OF THE
T.14S.
MAGDALENA
T.15S.
GROUP
T.16S.
T.17S.
SOUTH
T.18S.
100
200
300
400
500
600
700
800
900
1,000
1,100 Feet
Vertical Scale
92
329
602
1,041
885
1,060
859
BAT CAVE
FORMATION
SIERRITE
PERCHA
ALEMAN
FORMATION
CUTTER
FORMATION
UPHAM
BLISS
PRECAMBRIAN
FORMATION
DOLOMITE
BAT CAVE
LIMESTONE
PERCHA
FUSSELMAN DOLOMITE
(CABLE CANYON SANDSTONE)
at base
FORMATION
FORMATION
MONTOYA GROUP
EL PASO GROUP
UPPER
ORDOVICIAN
(Cincinnatian)
LOWER
ORDOVICIAN
(Canadian)
UPPER
CAMBRIAN
This section projected
from Sec.19, T.11S., R.7 W.
53 feet of possible
Mississippian rocks deleted.
Representative measured section
plotted with reference to Latitude.
885
Total thickness of pre-Pennsylvanian rocks
0
5
10 Miles
Horizontal Scale
V.C.K & C.S. 1952

Several small patches of pre-Cambrian rocks occur in the North Red Hills a few miles south of Truth or Consequences. A rather large and prominent mass of pre-Cambrian rock crops out in the South Red Hills southeast of Caballo dam and a very small patch is exposed in the bottom of a small tributary of Mol Inas Canyon in the southern part of the mountains. Pre-Cambrian rocks are only a few feet below the surface in some of the small gulches along the west face of Red House Mountain.

The dominant rock of the pre-Cambrian is a pinkish coarse-grained granite. In most outcrops the rock is gneissoid. Small dikes of simple granite pegmatite and silexite afe fairly common. Small lamprophyric dikes are occasionally present. Here and there small patches of mica schist, metadiorite, and greenstone crop out. Between Granite Wash and Burbank Canyon along the central part of the Caballo escarpment several square miles are underlain by pre-Cambrian rocks. These rocks are composed mostly of mica schist, but granite gneiss, metadiorite, and greenstone are common. The metamorphic series is intruded by pink coarse-grained granite.

Cambrian racks

The Cambrian rocks of the Caballo Mountains are represented by the Bliss formation of late Cambrian age. It is one of the more distinctive and conspicuous formations of southern New Mexico owing to unusual mineralogy and prominent color. The Bliss formation is probably the most widespread of the lower Paleozoic formations in southern New Mexico.

In the Caballo Mountains the outcrop of the Bliss formation is nearly everywhere darker in color than the underlying pre-Cambrian rocks and the overlying Sierrite limestone, but in most places the topographic expression is the same as the underlying pre-Cambrian. Nearly everywhere the top of the Bliss formation is marked by a niche above which the sheer cliffs or the abrupt ledgy slopes of the Sierrite limestone begin.

Except for a few basal medium- to thick-bedded ledges of coarse-grained sandstone and oolitic hematite, the Bliss is thin-bedded and commonly laminated. Cross-bedding up to about one foot in thickness occurs locally in the basal sandstone. The lowermost part of the Bliss formation in the Caballo area is generally characterized by coarse textured beds which consist of conglomerate, sandstone, coarse and often feldspathic sandstone, and oolitic hematite. Above the lowermost coarse clastic part the Bliss consists of alternating thin beds and laminae of gray, commonly glauconitic limestone, ferru ginous quartzose, fine-grained sandstone and siltstone, glauconite, and non-a6litic hematite.

In the Caballo area the Bliss ranges in thickness from 110 to 160 feet. In general the Bliss formation increases in thickness from zero points in the northern part of the Era Cristobal Mountains and in the southern part of the Oscura Mountains to nearly 300 feet in the southern and southwestern parts of the State.

Ordovician rocks

The El Paso limestone at its type locality consists of gray magnesium limestone, which is locally sandy at the base. In the Cabello Mountains the formational relations are somewhat more complicated than they are at the type locality; therefore the El Paso limestone has been expanded to the El Paso group. The group is divided into the Sierrite limestone and the Bat Cave formation.

The Sierrite limestone crops out along the west face of the Cabello Mountains, in the west face of the Mud Springs Mountains, in the west face of South Red Hills, at the south end of Nakaye Mountain, and in the west face of the Red House Mountain. In most places the medium-gray to brown outcrops of the Sierrite clearly contrast with the dark& underlying Bliss formation and the lighter, slope-forming lower beds of the Bat Cave formation, which lies above it. It is essentially conformable with the confining formations and is 127 feet thick at Molinas Canyon, 167 feet at Cable Canyon, 140 feet near Palomas Gap, and 150 feet in the Mud Springs Mountains. Although the Sierrite limestone is characteristically thin-bedded to laminated it presents a massive outcrop in most places owing to the firm bonding of the layers. On fresh surfaces the Sierrite limestone is medium-gray to dark-gray with a slight brownish cast. Although most of the beds are microgranular, fine- to medium-grained textures are common, and locally the texture is distinctly crystalline in appearance. The limestone is almost entirely calcite at the type locality, but it is expectable that it may be a dolomitic limestone in some places. Glauconite and choloritic materials are sparingly present in some of the lowermost beds. The chert is light-gray to white on fresh surfaces.

The Bat Cave formation comprises the upper and major part of the El Paso group in the Caballo Mountains. The formation rests conformably upon the underlying Sierrite limestone and is overlain with marked erosional unconformity by the Cable Canyon sandstone of the Montoya group. It crops out boldly along most of the west escarpment of the Caballo Mountains. It is also exposed in the escarpment of the Mud Springs Mountains, at the south end of Nakaye Mountain in Molinas Canyon, and at Flat Top and Red House mountains. The lower part of the formation is light-gray in general appearance and generally forms slopes. It contains many irregularly distributed biostromes and bioherms which are predominantly stromatolitic. Surrounding and interspersed with the stromatolitic masses is much detrital limestone. The upper part of the formation is somewhat darker than the lower, is banded in general appearance, and is generally cliff-forming. The thickness of the Bat Cave formation ranges from 216 feet at Molinas Canyon to 305 feet in the Mud Springs Mountains. The irregular variation is mostly due to pre-Montoya erosion.

The upper beds of the formation are strikingly exposed in the cliffs on the north side of the Cable Canyon. Their highly banded outcrop is typical of this part of the formation. They consist of medium- to thick-bedded dolomitic limestone, and some dolomite. Most of the beds are very fine-grained and dense. Beds of calcarenite and calcirudite are commonly intercalated with the normal limestone. Cherty beds or units are occasionally present. A few of the beds in the upper unit are biostromal and contain isolated small stromatolites. One of the most outstanding features of the Bat Cave formation is the presence of large masses of collapse breccia in the upper part of the formation.

The Montoya group in the Caballo Mountains is divided into the following formations from the base up: the Cable Canyon sandstone, Upham dolomite, Aleman formation, and Cutter formation.

The Cable Canyon sandstone is a coarse granulitic sandstone that appears as a dark band above the I ightcolored cliffs of the Bat Cave formation. With a few exceptions it is a ledge or cliff. The sandstone is medium-gray on fresh exposure and contains grains of white, gray, pale-rose, smoky and blue-gray quartz. The texture ranges from medium sand to small pebbles. Cement ranges from calcitic to dolomitic. Fresh exposures of the sandstone are always highly cemented and appear to have low porosity.

Resting comformably upon the Cable Canyon sandstone in the Cabal lo Mountains is the massive, medium-gray to brownish-gray weathering Upham dolomite. In many exposures it is a cliff or ledge for its full thickness of 50 to 80 feet. The dolomite is a medium-gray to dark-gray micro-crystalline to fine-grained, arenaceous rock. Detrital quartz grains are scattered in thin lentils, and in irregular vertical streaks.

The most distinctive formation of the Montoya group is the Aleman formation. It consists of alternations of chert and dolomite beds which are strikingly banded medium-gray to dark-gray brown. The chert weathers white, brown, and black, and contrasts strongly with the general color of the carbonate beds. The dolomite is medium-to dark-gray or brownish-gray on fresh exposures and microcrystalline to finely granular. The chert is mottled light- and dark-gray on fresh exposure and is often a replacement of fossils.

Overlying the Aleman formation in the Cabal lo Mountains with apparent conformity is a sequence of light-gray weathering, generally unfossiliferous limestone and dolomite beds which are designated as the Cutter formation. This formation usually crops out as a steep slope beneath the Fusselman. The Cutter has the same general distribution as the other formations of the Montoya group except where it has been locally removed in part or entirely by pre-Pennsylvanian erosion in the southeast end of the Nakaye Mountains. South of Palomas Gap in the central part of the Cabal lo Mountains the formation ranges in thickness from about 50 to 115 feet in a distance of two miles, and then to thicken to about 130 feet at Granite Wash. These rather abrupt changes in thickness may be attributed to pre-Fusselman truncation. The dolomitic limestone is light-gray to brown ishgray on fresh surfaces. The dolomite is medium-gray to dark-gray. Both weather light-gray or light-tan. Only a few of the dolomite beds are finely crystalline. The limestone is generally microgranular to sublithographic.

Silurian rocks

The Fusselman dolomite overlies the Montoya group in most places in the Caballo Mountains, but in some localities Percha or Magdalena strata rest directly on the Montoya and the Fusselman is absent. The Fusselman is a dark-colored gray to brownish-gray cherty dolomite which often forms a cliff or ledge beneath the Percha or lower Magdalena beds. It is less than 50 feet in thickness, and throughout much of its extent is less than 20 feet.

Devonian rocks

In most places the Percha formation rests upon the Fusselman, in other places it rests upon dolomite of the Montoya group. It is most often overlain by beds of the Magdalena group, but in the southern end of the mountains the Lake Valley formation intervenes. The general topographic expression is that of a back-slope. The formation is always soft, thin-bedded, and ranges in thickness from a thin edge to 105 feet. It consists predominantly of gray-weathering calcareous claystone, olive-drab-weathering shale, and rusty-weathering fine-grained sandstone and siltstone. The claystone is light-gray to medium-gray on fresh exposures, somewhat gritty, and contains limestone nodules in sizes ranging from pebbles to boulders. Thin limestone lentils and beds are irregularly distributed. The shale is fissile and breaks into shiny olive-green chips which form a distinctive float. Limonite concretions are common.

Mississippian rocks

The Lake Valley formation, which consists of the Alamogordo and Nunn members in the Caballo Mountains, crops out as isolated patches between the basal beds of the Magdalena formation and the top of the Percha formation. Strata that are definitely assigned to the Mississippian system crop out only in the southeastern part of the Caballo Mountains.

The Alamogordo member is a massive-bedded, dark-gray weathering, ledge-forming limestone, up to 31 feet thick, which contains lense-shaped chert masses. The limestone is light-gray to medium-gray on fresh exposure and finely crystalline. The chert masses weather pink in many localities, but are medium-gray to white on fresh exposure.

The Nunn member is a thin-bedded, nodular light-gray to pinkish-gray weathering concoidal fracturing limestone and shale unit as much as 30 feet thick. It rests u ['conformably upon the Percha shale or the Alamogordo member. It is overlain unconformably by the basal beds of the Magdalena group.

Pennsylvanian: rocks

In the Caballo Mountains the Magdalena group crops out as a gray or tan-gray !edgy sequence of considerable prominence. The thickness of the Magdalena ranges from about 1,000 feet in the northern part of the mountains to nearly 1,500 feet in the southern part of the-mountains.. Local variations in thickness are caused by irregularities of erosional surfaces, at both the bottom and top of the formation, but there is a gradual increase in thickness southward along the range.

The uppermost beds of The Magdalena locally intertongue with red beds of probable continental origin through a stratigraphit interval of as much as 50 feet.

Limestone beds are commonly 10 to 20 feet in thickness and are usually separated by shale beds of several feet or more in thickness. The limestone of the Magdalena is almost entirely calcitic. The texture of the limestone ranges from very fine-grained to medium-grained and crystalline. Chert in the Magdalena occurs on bedding planes, in bands and is irregularly distributed through beds. Many limestone beds contain a lacey intergrowth of light-gray chert with the calcite, and others contain much very fine-grained to clay-like particles of chert.

Most limestone beds of the Magdalena group are dense and lack porosity. It is probable that fluids migrate much more readily on bedding planes or fractures than within the beds of the Magdalena.

The clastic rocks of the Magdalena consist of shale, clastic limestone, and sandstone. The shale is medium-gray to black and generally moderately fissile. It is commonly calcareous, and limestone nodules, lenses, or thin beds are intercalated with the shale. Limestone conglomerate beds are thin, discontinuous, and of minor occurrence. A few sandstone and siltstone beds mark the transition zone at the top. These are usually red and arkosic.

Permian (?) and Permian rocks

The Permian (?) and Permian rocks of the Caballo Mountains consist of the Abo, Yeso, and San Andrei formations, and their aggregate thickness is about 2,000 feet in the central part of the mountains.

The base of the Abo is poorly exposed and although the formation appears generally conformable with the. underlying Magdalena group there may be some local divergence or irregularity at the contact. The deep reddish-brown appearance of the Abo is distinctive. The formation ranges from about 550 to 1,100 feet in thickness in the Caballo Mountains, and is chiefly thin- to medium-bedded. Individual beds of sandstone and siltstone are lenticular and occur in a wide range of geometric shapes and dimensions. Sandstor4 beds are often cross-bedded. Claystone is the dominant rock of the formation, but siltstone and sandstone are abundant. Lenses, nodules, and thin beds of gray-brown limestone are scattered in the red-brown claystone.

The belt of outcrop of the Yeso formation underlies a nearly continuous valley between the Abo and San Andres hogbacks along almost the entire eastern foothills of the mountains. The formation ranges in thickness from 189 feet in the southwestern part of the Caballo area to 600 feet in the northern part. The thin section in the southwestern area may be due to nondeposition or erosional truncation of the upper beds of the formation. Yeso strata range from thin- to thick-bedded, and laminated bedding occurs in the gypsum units. They consist dominantly of sandstone and gypsum with lesser amounts of siltstone, limestone, and claystone. The sandstone is mostly tan to pale-red although buff to white beds are common. Gypsum beds occur throughout the formation, but appear to be more abundant in the upper part. In many places gypsum beds are only a few feet thick and alternate with thin beds of sandstone. Elsewhere beds of gypsum are 20 to 30 feet thick. Light-gray to dark-gray very fine-grained limestone beds up to 20 feet thick are sparingly scattered through the section.

The San Andres formation crops out in a nearly continuous band along the eastern edge of the Cabal lo Mountains. The thickness ranges from 550 to nearly 1,000 feet.

The formation is thin- to medium-bedded and generally even- or parallel-bedded. It consists of about 75 percent limestone which is slightly dolomitic in places. The limestone is light- to dark-gray on both weathered and fresh surfaces although some weathered surfaces have a light olive-drab appearance. The texture is chiefly very fine-grained. In general, the limestone is not cherty.

Thin units of thin-bedded limestone, claystone, or sandstone alternate with thicker units of limestone. The sandstone is mostly fine-grained and yellowish-brown or buff. Some lentils of claystone and siltstone are pale-red, and these in places include thick to massive beds of gypsum.

Cretaceous rocks

The Dakota group, about 220 feet thick, rests disconformably on the San Andres formation. The basal unit is a medium-bedded, white siltstone about 26 feet in thickness. Above the basal siltstone is a unit which resembles the rocks generally referred to as Dakota sandstone in other parts of New Mexico. It is a thick ledged, often laminated, pink to white sandstone which weathers medium-brown.

The Mancos shale, which ranges up to 500 feet in thickness and may rest disconformably on the Dakota group, is divided into two units. The lower shale unit is 42 feet thick, thin-bedded, and contains several limestone beds which are from 1 to 4 inches thick. The upper unit consists of medium- to dark-gray shale containing olive-drab siltstone and shale. A few limestone beds 1 to 6 inches thick and a few light-gray bentonitic beds 1/2 to 1 inch thick occur in the unit.

The Mesaverde formation rests on the Mancos shale. The change from marine shale to interbedded and lenticular conglomerate, siltstone, shale, and coal is locally abrupt where scour and fill relations at the base of the Mesaverde cut downward into the upper beds of the Mancos, but in most places there is a thin transition zone between the two. Shale beds of the Mesaverde are light-gray to medium-gray and weather to olive-gray or olive-brown hues. They are more continuous than the interbedded sandstone beds which are light-gray to buff and weather to buff, olive-brown, and dark-brown. The upper part of the Mesaverde consists largely of interbedded sandstone, shale, and conglomerate. The conglomerate beds contain pebbles of chert, quartzite, sandstone, and fragments of petrified wood.

Cenozoic Rocks

Cenozoic rocks in the Caballo Mountain area are confined to the flanks of the mountain uplifts, to the Rio Grande depression, and to the Jornada del Muerto.

Tertiary rocks

The McRae formation of early Tertiary and possibly of late Cretaceous age probably is generally correlative with the Baca and Galisteo formations farther to the north. Rough estimates indicate that the formation exceeds 3,000 feet in thickness. It crops out at the north end of the Caballo Mountains around the base of Elephant Butte and along most of the shoreline of the Elephant Butte reservoir for several miles to the north of the dam. The upper limits of the formation have not been determined, and the lower contact appears to be transitional, disconformable, or sharp in different places. At the base there is usually one or two hundred feet of conglomerate consisting dominantly of assorted intermediate volcanic rocks. These beds are interbedded with shale or siltstone which is fairly typical of the shale and siltstone in the Mesaverde. Above the conglomerate unit the formation consists of many hundreds of feet of alternating purplish shale and buff sandstone beds. Conglomerate beds above the basal unit are unusual and generally thin.

At the south end of the Cabal lo Mountains a thick sequence of reddish-brown clastic rocks, which are probably younger than the McRae formation, crop out. These clastic rocks are known as the Palm Park formation. Palm Park strata have a high content of volcanic detritus and are interbedded with a few rhyolitic to basaltic flows. The relationship of the Palm Park sequence to the McRae sequence is unknown; however, the Palm Park beds probably are younger and probably are equivalent to some part of the Datil formation of the Socorro region.

Resting unconformably on the Palm Park formation and on the San Andres formation in the southern part of the Cabal lo Mountain area is a sequence known as the Thurman formation. This formation consists of white to light-buff rhyolite tuff breccia, pinkish sandy clay, water-laid tuff, and tuffaceous sandstone. The stratigraphic position and lithology of the Thurman is similar to parts of the Datil, Espinaso, and Abiquiu formations to the north.

The Thurman formation appears to be overlain unconformably by strata of the Santa Fe formation. Santa Fe strata consists of alluvial fan and playa deposits which range from fanglomerate beds to sand, silt, and claystone. The color of the formation ranges from purplish-brown to buff. The upper beds of the Santa Fe formation are bevelled by several levels of Quaternary erosion surfaces and stream terraces in the Rio Grande depression adjacent to the Cabello Mountains.

Selected References.

Baker, A. A., Dane, C. H., and Reeside, J. A., Jr., 1947, Revised correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: Am. Assoc. Petroleum Geologists Bull, Vol. 39, No. 9, pp. 1664-1668.

Bryan, Kirk, 1938, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico: Regional Planning Pt. 6, Upper Rio Grande, pp. 197-225., Washington, Nat. Res. Comm.

___________ and McCann, F. T., 1938, The Ceja del Rio Puerco, a border feature of the Basin and Range Province in New Mexico; Jour. Geology, Vol.'45, pp. 801-828.

Cape, E. D., 1882, Geological age of the Lake Valley mines of New Mexico: Eng. and Min. Jour., Vol. 34, p. 214.

Darton, N. H., 1928, Red beds and associated formations in New Mexico: U. S. Geol. Survey Bull. 794.

Denny, C. S. 1940, Tertiary geology of the San Acacia Area, New Mexico: Jour. Geology, Vol. 48, pp. 73-106.

Dunham, K. C., 1935, The geology of the 01-gan Mountain's: New Mexico School of Mines Bull. 11, 272 pp.

Entwistle, L. P., Manganiferous iron-ore deposits near Silver City, New Mexico: New Mexico School of .Mines Bull. 19, 70 pp.

Gardner, J. H., 1910, The Carthage coal field, New Mexico: U. 5. Geol. Survey Bull. 381, pp. 452-460.

Gordon, C. H., 1907, Notes on the Pennsylvanian formations in the Rio Grande Valley, New Mexico: Jour. Geology Bull., Vol. 15, pp. 805-816.

_____________ and Groton, L. C., 1906, Lower Paleozoic formations in New Mexico: Amer. Jour. Sci. Bull., Vol. 21, pp. 390-395.

Hayden, F. V., 1869, Preliminary field report of the United States Geological Survey of Colorado and New Mexico: U. S. Geol. and Geog. Survey Terr. Third Ann. Rep., 155 pp.

Herrich, C. L., 1904, Laws of formation of New Mexico mountain ranges: Am. Geol., Vol. 33, pp. 301-312, 393.

Hunt, C. B., 1936, The Mount Taylor coal field, Pt. 2 of Geology and fuel resources of the southern part of the San Juan Basin, New Mexico: U. S. Geol. Survey Bull. 860-B, pp. 31-80.

Kelley, V. C., 1951, 0Olitic iron deposits of New Mexico: Amer. Assoc. Petroleum Geologists, Vol. 35, pp. 2199-2228.

__________ and Silver, Caswell, 1952, Geology of the Cabello Mountains, Sierra and Dona Ana Counties, New Mexico: Univ. of New Mexico Pub. Geol. No. 4.

_________ and Wood, G. H., 1946, Lucero Uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Inves., Prelim. Map 47.

Laudon, L. R. and Bowsher, A. L., 1949, Mississippian formations of southwestern New Mexico: Geol. Soc. America Bull., Vol. 60, pp. 1-88.

Loughlin, G. F. and Koschmann, A. H., 1942, Geology and ore deposits of the Magdalena mining district, New Mexico: U. 5. Geol. Survey, Prof. Paper 200, 168 pp.

Lee, W. T., 1917, Geology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey, Prof. Paper 101, pp. 9-221.

_________ and Girty, G. H., 1909, The Manzano group of the Rio Grande Valley, New Mexico: U. S. Geol. Survey, Bull. 389, pp. 5-40.

Needham, C. E. and Bates, R. L., 1943, Permian type sections in central New Mexico: Geol. Soc. America Bull.,- Vol. 54, pp. 1653-1657.

Read, C. B., Wilpolt, R. H., Andrews, D. A., Summerson, C. H., and Wood, G. H., 1944, Geologic map and stratigraphic sections of parts of San Miguel, Santa Fe, Sandoval, Bernalillo, Torrance, and Valencia Counties, north-central New Mexico: U. S. Geol. Survey, Oil and Gas Inves., Prelim. Map 21.

__ and Wood, Gordon H., 1947, Distribution and correlation of Pennsylvanian rocks in late Paleozoic sedimenatry basins of northern New Mexico: Jour. Geology, Vol. LV.

Richardson, G. B., 1904, Report of reconnaissance in. Trans-Pecos Texas, north of the Texas and Pacific Railway: Texas Univ., Mineral Survey Bull. 9.

______________ 1909, U. S. Geological Survey Geol. Atlas, El Paso Folio (No. 166).

Reiche, Parry, 1949, Geology of the Manzanita and north Manzano Mountains, New Mexico: Geol. Soc. America Bull., Vol. 60, pp. 1183-1212.

Rothrock, H. E., Johnson, C. H., and Hahn, A. D., 1946, Fluorspar resources of New Mexico: New Mexico Bur. Mines and Min. Res., Bull. 21, 239 pp.

Silver, Caswell, 1948, Jurassic overlap in western New Mexico: Amer. Assoc. Petroleum Geologists Bull., Vol. 32.

Stark, J. J. and Dapples, **E.** C., 1946, Geology of the. Los Pinos Mountains, New Mexico: Geol. Soc. America Bull., Vol. 57, pp. 1121-1172.

Stearns, C. E., 1943, The Galisteo formation of north-central New Mexico: Jour. Geol., Vol. 51, pp. 301-319.

Thompson, M. L., 1942, Pennsylvanian system in New Mexico: New Mexico School of Mines Bull. 17, 90 pp.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, Georges, 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Inves., Prelim. Map 61.

__________________ 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 and Gas hives., Map Om 121 (in 2 sheets).

Winchester, Dean E., 1921, Geology of the Alamosa Creek Valley, Socorro County, New Mexico, with special reference to the occurrence of oil and gas: U. S. Geol. Survey, Bull. 716.

Wood, G. H. and Northrop, S. A., 1946, Geology of the Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Inves., Prelim. Map 57.

Wright, H. E., Jr., 1946, Tertiary and Quaternary geology of the lower Rio Puerco area, New Mexico: Geol. Soc. America Bull., Vol. 57, pp. 383-456.