

GEOLOGIC STRUCTURE OF PARTS OF NEW MEXICO.

By N. H. DARTON.

INTRODUCTION.

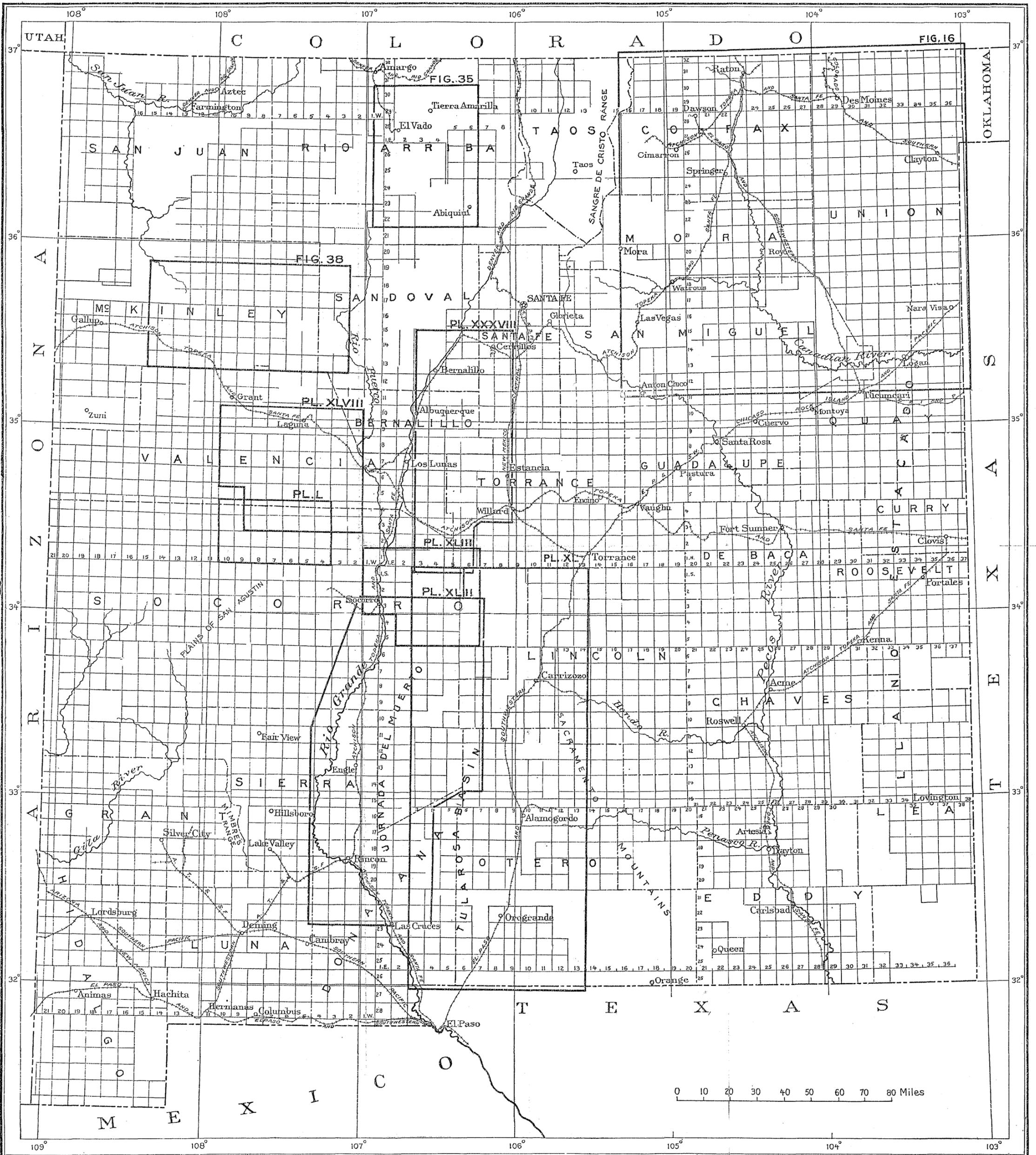
Although New Mexico is not yet producing oil, wide areas of the State are underlain by rocks of the same age as those which yield oil and gas in adjoining States to the east, and in many places the structural conditions are favorable for the accumulation of oil and gas if they are present. So far the only notable discovery of oil has been that made near Dayton, in Pecos Valley, where some artesian wells yield small amounts, but indications of oil have been reported in several parts of the State. Many deep holes have been bored for water and a few for oil, but most of them have been in places where the structure is not favorable for oil or gas or were not deep enough to test the possibilities of all the strata.

This report is published in order to place in the hands of oil and gas geologists the information now in hand as to the structural features of New Mexico. Many of the data are new and are by-products of investigations made with objects very different from those of the geologist in search of new oil fields. During the last four years I have studied the stratigraphy and depositional history of the "Red Beds" region of the Southwest, including a large part of New Mexico, with special reference to the determination of the centers of greatest salt deposition. The principal aim of the work was to discover areas in which potash salts also may have been locally deposited. In the course of these studies reconnaissance was extended over large portions of New Mexico, especially in areas where the stratigraphy and structure were but little known. The results of this work, together with information previously available, are embodied in a forthcoming report on the geology of the "Red Beds" and associated formations of New Mexico, to be accompanied by a colored geologic map on a topographic base founded in large part upon original topographic sketches.

On account of the great number of requests received by the Geological Survey for information relating to the general stratigraphy and structure of New Mexico, it has been decided to publish at this time the data on the character and thickness of the formations and the general structure for the special use of oil geologists in a report with simple maps that may be placed in the hands of the public in advance of the engraving of the more elaborate geologic map of the

State. Emphasis must be laid on the facts that the field examinations were not made for the purpose of finding areas favorable for the occurrence of oil and that the work was done largely by methods less detailed than those required in the search for oil and gas, especially in the recognition and mapping of minor anticlines or domes that might be important centers of oil or gas accumulation. However, it is believed that this report will be of value as a guide to the regions in which the stratigraphy of the formations appears more favorable and as a presentation of the larger structural features. Doubtless it will also indicate some of the areas where minor folds are to be looked for. At the same time many portions of the State are differentiated as offering no encouragement to prospectors for oil.

In general, New Mexico has not been regarded with favor by most of the oil and gas geologists of the country, notwithstanding the fact that surface indications of oil are known at several points in the State and oil in small amounts has been found near Dayton and Seven Lakes. This disfavor is not without some foundation, for there are several adverse considerations, of which the following are perhaps the most important: (1) In New Mexico the Cretaceous formations, which are the sources of most of the oil in the Rocky Mountain States, are present only in relatively small areas, in many of which their position and structure are not favorable for oil; (2) in the many wide areas where the Cretaceous formations are absent, particularly in the central and northern parts of the State, the Paleozoic formations are of no great aggregate thickness, the Carboniferous lying directly on the pre-Cambrian crystalline rocks; (3) the Jurassic, Triassic, and Permian formations in general carry but little carbonaceous matter, the thick succession of these strata being singularly deficient in such organic débris as is generally regarded as the mother substance of petroleum; (4) through the central and southern portions of the State the folding and faulting are relatively pronounced, the pre-Cambrian crystalline rocks are brought up in the axes of the arches, the basins are comparatively narrow, and although minor folds undoubtedly are present, the marginal areas are in some places much faulted and cut by later lavas and many of the catchment areas are very small; and (5) finally, it is likely that in many areas, particularly in the older rocks and toward the southwest, carbonization of the organic débris in the formations has progressed so far as to preclude the survival of oil in commercial pools, though gas in considerable amounts may be present. The data on this fifth point are, however, very meager, so that it is not possible to state at the present time their bearing on the prospects in the different areas. The same condition exists in the Cretaceous rocks in some areas, notably in the Raton and Cerrillos coal fields. For the same reason also it seems probable that the Pennsylvanian rocks in the upper Pecos Valley east of Santa Fe and in a part of Bernalillo County may be too much



MAP OF NEW MEXICO.
Showing areas covered by detailed maps.

altered to encourage the prospector for oil. On the other hand, it is probable that the Cretaceous rocks in the San Juan Basin, except possibly near the Colorado line, and the Carboniferous beds in the eastern third of the State are not too greatly altered. In general the oil geologist may find it advantageous to consider the state of carbonization of the combustible débris of the coals and carbonaceous shales in most areas in advance of testing by the drill.

Although the "Red Beds" are nearly barren of oil-making materials they include sandstones which may be excellent reservoirs for the storage of oil that has migrated from more favorable strata, separated by considerable thicknesses of unproductive beds. The demonstrated presence of oil in the "Red Beds" of the Pecos Valley near Dayton encourages the hope that in some areas the sands in these unpromising rocks may be reservoirs for commercial deposits of oil, even where they are remote from strata rich in carbonaceous matter.

On the whole, the Carboniferous and Cretaceous areas of eastern New Mexico and the Cretaceous areas of the northwestern portion of the State, west of the Nacimiento uplift, probably offer greater encouragement for the discovery of commercial oil fields than other portions of the State. Oil, gas, or asphalt are present in these areas; the sedimentary formations attain considerable thicknesses; some of the associated strata are sufficiently rich in carbonaceous débris; and the presence of stresses, indicated by the major folding, makes it almost certain that examinations in detail will reveal minor anticlines and domes of the type most favorable for oil and gas.

SEDIMENTARY ROCKS OF NEW MEXICO.

GENERAL SUCCESSION.

The strata in New Mexico present a great thickness of beds from Cambrian to Recent in age, but portions of some of the geologic periods are not represented by deposits. The classification of most of the formations has been established by the work of several geologists, and this subject will be only briefly treated here, except as it is touched by my own investigations of the Triassic and Permian "Red Beds" and associated formations, for which some new classifications must be introduced. It is necessary to consider these matters briefly at this time, because in this report many new facts are presented in connection with the distribution and structure of the formations of Jurassic, Triassic, and Permian age. A more detailed discussion will be given in the fuller report now in preparation.

The following lists show the stratigraphic position, character, and thickness of the principal formations in different parts of New Mexico. It is not practicable to give them all in one table, because of the regional variations in the character of the deposits in this large State, which has an area of 122,634 square miles.

Formations in northeastern New Mexico.

| Age. | Group and formation. | Character and general relations. | Average thickness (feet). | | |
|-----------------------|----------------------|---|---|--|------|
| Recent. | Alluvium. | Sand, gravel, and clay. | 50± | | |
| Pliocene and Miocene. | Santa Fe formation. | Sand, silt, gravel, and conglomerate. | 150+ | | |
| Eocene. | Raton formation. | Conglomerate and sandstone; local coal beds. | 1,200-1,600 | | |
| Eocene (?). | Galisteo sandstone. | Sandstone and conglomerate. Relations to Raton formation unknown. | 700+ | | |
| Upper Cretaceous. | Montana group. | Vermejo formation. | Sandstone and shale, with coal beds. | 0-375 | |
| | | Trinidad sandstone. | Sandstone, gray to buff. | 0-100 | |
| | | Pierre shale. | Shale, mostly dark colored; upper beds sandy. | (?) | |
| | Colorado group. | Apishapa shale. | Shale, in part limy. | Niobrara formation where not differentiated. | 500 |
| | | Timpa limestone. | Limestone, mostly impure. | | 50 |
| | | Carlile shale. | Shale, with concretions. | Benton shale where not differentiated. | 250 |
| | | Greenhorn limestone. | Limestone, slabby, and dark shale. | | 60 |
| | | Graneros shale. | Shale, dark. | | 150+ |
| | | Dakota sandstone. | Sandstone, gray to buff, hard. | 100 | |
| | Lower Cretaceous. | Purgatoire formation. | Sandstone, overlain by shale. | 140 | |
| Cretaceous (?). | Morrison formation. | Shale, massive, mostly greenish gray, and intercalated sandstones. | 150 | | |
| Jurassic. | Todilto limestone. | Limestone; weathers thin bedded; locally overlain by 60 feet of gypsum. | 0-85 | | |
| | Wingate sandstone. | Sandstone, massive, light gray. | 100 | | |
| Triassic. | Dockum group. | Shales and sandstones, mostly red, containing locally, near the lower part, the Santa Rosa sandstone. | 800+ | | |
| Permian. | Manzano group. | Chupadera formation. | Limestone, sandstone, and gypsum. | 600-1,200 | |
| | | Abo sandstone. | Sandstone, mostly hard, slabby, brownish red. | 600-800 | |
| Pennsylvanian. | Magdalena group. | Limestone, some shale, and sandstone. | 600-1,200+ | | |
| Pre-Cambrian. | | Granite, schist, etc. | | | |

Formations in northwestern New Mexico.

| Age. | Group and formation. | Character and general relations. | Average thickness (feet). | |
|-----------------------|---|--|--|-------------|
| Recent. | Alluvium. | Sand, gravel, and silt of river bottoms, desert floors, and fans. | 0-50 | |
| Pliocene and Miocene. | Santa Fe formation. | Sand, gravel, silt, sandstone, and conglomerate. | 450± | |
| Eocene. | Wasatch formation. | Conglomerate, sandstone, and shale. | 2,000+ | |
| | Torreon formation. | Clay, sandy shale, and sandstones, hard and soft. | 400 | |
| | Puerco formation. | Clay, sandy shale, and sandstones, hard and soft. | | |
| Upper Cretaceous. | Ojo Alamo sandstone. | Sandstone, conglomeratic, with two conglomerate beds and shale lenses. | 65-110 | |
| | Kirkland shale. | Shale. Includes Farmington sandstone member. | 800-1,180 | |
| | Fruitland formation. | Sandstone and shale, with coal, sandy shales, and concretions. | 190-290 | |
| | Pictured Cliffs sandstone. | Sandstone, copper-colored, also yellowish to light gray or brown. | 50-275 | |
| | Lewis shale. | Shale, greenish gray, sandy, with local streaks of yellowish calcareous shale. | 200-1,200 | |
| | Mesaverde group. | Cliff House sandstone. | Sandstone, with some shale beds. | 400+ |
| | | Menefee formation. | Shale, with sandstone and coal beds. | 600-1,200 |
| | | Point Lookout sandstone. | Sandstone, with some shale beds. | 300 |
| | | Mancos shale. | Shale, with sandstone members. | 1,000-2,000 |
| | | Dakota sandstone. | Sandstone, gray to buff, hard, massive. | 75-125 |
| Cretaceous (?). | McElmo formation to west; Morrison formation to east. | Shale, light-colored, and sandstone. | 200 | |
| Jurassic. | La Plata group. | Navajos sandstone. | Sandstone, massive, pink to gray. | 600 |
| | | Todilt limestone. | Limestone, mostly very thin-bedded and 15 feet thick; locally at top a gypsum bed 80 feet thick. | |
| | | Wingate sandstone. | Sandstone, massive, pink. | 80-400 |

Formations in northwestern New Mexico—Continued.

| Age. | Group and formation. | Character and general relations. | Average thickness (feet). | |
|----------------|---|---|---|------|
| Triassic. | Chinle formation. | Shale, largely red, some gray. | 850 | |
| | Shinarump conglomerate to west; Poleo sandstone in Nacimiento uplift. | Sandstone, mostly coarse (Shinarump conglomerate, 50-100 feet); in Nacimiento uplift sandstone, massive gray, hard (Poleo sandstone, 120 feet). | 50-120 | |
| | Moenkopi formation. | Shale, in part sandy, mostly red. | 400-800 | |
| Permian. | Manzano group. | Chupadera formation. | Limestone, gray sandstone, gypsum, and soft red sandstone. | 600+ |
| | | Abo sandstone. | Sandstone, hard, slabby, brownish red; limestone near base. | 700+ |
| Pennsylvanian. | Magdalena group. | Limestone; some shale and sandstone. | 0-200+ | |
| Pre-Cambrian. | | Granite and schist. | | |

Formations in southern New Mexico.

| Age. | Group and formation. | Character and general relations. | Average thickness (feet). | |
|---------------------|--------------------------|---|---|--------------|
| Recent. | Alluvium. | Sand, gravel, and silt of river bottoms, desert floors, and fans. | 0-1,000 | |
| Pleistocene. | Palomas gravel. | Sand, gravel, and conglomerate. | 450 | |
| Eocene (?). | | Conglomerate. | 120+ | |
| Upper Cretaceous. | Mesaverde (?) formation. | Sandstone, with coal beds. | 600 | |
| | Mancos shale (?). | Shale with sandstone layers. | 940-2,000 | |
| Upper Cretaceous(?) | Beartooth quartzite. | Quartzite, with some shale. | 90-125 | |
| Lower Cretaceous. | Sarten sandstone. | Sandstone. | 0-300 | |
| | | Limestones, shales, and sandstones. | 800+ | |
| Triassic (?). | Lobo formation. | Shales, conglomerate, and limestone. | 0-350 | |
| Triassic. | | Red shales. | 0-600 | |
| Permian. | Manzano group. | Chupadera formation. | Limestone, gypsum, and gray and red sandstone. Gym limestone of Deming quadrangle is equivalent to part of Chupadera. | 1,200-3,000+ |
| | | Abo sandstone. | Sandstone, slabby, brown-red. Thins out near Hueco Mountains and to southwest. | 0-900 |

Formations in southern New Mexico—Continued.

| Age. | Group and formation. | Character and general relations. | Average thickness (feet). |
|----------------|------------------------|---|---------------------------|
| Pennsylvanian. | Magdalena group. | Limestone, with some shale and sandstone, especially in lower part. | 1,000-2,500 |
| Mississippian. | Lake Valley limestone. | Limestone. Absent north of latitude 34° 30'. (Combined with Magdalena as Fierro limestone in Silver City region.) | 0-80 |
| Devonian. | Percha shale. | Shale. Absent north of latitude 33° 30'. | 0-300+ |
| Silurian. | Fusselman limestone. | Limestone, massive. Absent north of latitude 33° 30'. | 0-1,000 |
| Ordovician. | Montoya limestone. | Limestone, with cherty members above, dark and massive below. Absent north of latitude 33° 40'. | 0-250 |
| | El Paso limestone. | Limestone, slabby; weathers light gray. Absent north of latitude 33° 40'. | 0-1,000 |
| Cambrian. | Bliss sandstone. | Sandstone, massive to slabby, glauconitic. Absent north of latitude 33° 40'. | 0-300 |
| Pre-Cambrian. | | Granite, schist, etc. | |

OLDER PALEOZOIC ROCKS.

The distribution and classification of formations ranging in age from the Cambrian to the Mississippian have been presented in a previous publication.¹ Since that paper was written it has been found that the full sequence of the limestones and shales of these periods is exposed in the north end of Big Hatchet Mountain and near Gabilan Peak, in Grant County. Their character and relations in the Tularosa Basin, the Sacramento Mountains, the Jornada del Muerto region, and the southwest corner of New Mexico are treated in the sections on those regions in this report. It is rather unlikely that any rocks older than Carboniferous will be found to produce oil in this part of the continent.

MAGDALENA GROUP (PENNSYLVANIAN).

The Magdalena group is conspicuous at many places in New Mexico, notably in the Rocky Mountains, the Sandia, Manzano, and Pinos mountains, the Nacimiento uplift, the Magdalena, Mimbres, San Andres, and Sacramento mountains, and the Silver City and El Rito districts. It underlies a large part of the State and will be found in many well borings, although in the eastern part of the State it lies very deep. Limestone is the most conspicuous feature of the group,

¹ Darton, N. H., A comparison of Paleozoic sections in southern New Mexico: U. S. Geol. Survey Prof. Paper 108, pp. 31-55, 1917.

but interbedded sandstones and shales occur in all sections; along the east side of the Rocky Mountains in the northern part of the State the Magdalena consists mainly of a thick body of gray to red sandstone. In the Sandia Mountains the group has been divided into the Sandia formation below and the Madera limestone above. Although the lower part of the Magdalena generally contains much sandstone the stratigraphic position of the sandstone beds and the transition from one member to the other differ at different localities. Locally the group can be divided into three or four formations, some of them separated by apparent unconformities. No faunal distinctions have been established in these formations, although eventually the fossils may indicate desirable subdivisions.

In the uppermost portion of the Magdalena group, or perhaps the basal portion of the overlying Abo sandstone, near Rio Salado, west of the Ladrone Mountains, D. E. Winchester² found plants which David White regards as probably Permian. The material is fragmentary but includes *Odontopteris* probably *O. obtusa* Brongniart, *Neuropteris* aff. *N. gleichenoides*, *Sphenopteris* sp., *Callipteris* cf. *C. lyratifolia*, *Taeniopteris*, *Saportaea?*, *Walchia pinnaeformis*, *Walchia gracilis*, *Gomphostrobus bifidus*, *Araucarites*, *Trigonocarpon* sp., and other fragments less clearly identifiable. Mr. White says: "Notwithstanding the insufficiency of much of the material for the specific and in part the generic identification of the types, the evidence in hand points very strongly to the Permian age of the flora, and there is little room for doubt that the collection of material more adequate for satisfactory determination will prove conclusively that the containing shale is Permian."

In the overlying bed of limestone, 4 feet thick, presumably at the base of the Abo sandstone, though not certainly, as the overlying beds are hidden by terrace deposits, fossils were collected which were it not for the evidence of the fossil plants G. H. Girty would regard as Pennsylvanian. They are as follows:

| | |
|----------------------------|----------------------------|
| Lophophyllum profundum. | Pustula semipunctata? |
| Fistulipora sp. | Pustula nebraskensis. |
| Crinoid stems. | Pugnax osagensis. |
| Fenestella sp. | Dielasma bovidens. |
| Pinnatopora sp. | Spiriferina kentuckyensis. |
| Polypora sp. | Spirifer cameratus. |
| Stenopa carbonaria. | Spirifer rockymontanus. |
| Derbya robusta. | Squamularia perplexa. |
| Productus nebraskensis. | Ambocoelia planiconvexa. |
| Productus cora. | Cliothyridina orbicularis? |
| Productus semireticulatus. | Platyceras parvum? |
| Marginifera? | Griffithides? sp. |
| Composita subtilita. | Fish tooth. |
| Chonetes verneuillanus. | |

² Personal communication.

PERMIAN "RED BEDS" (MANZANO GROUP).

Abo sandstone.—The Abo sandstone, differentiated by W. T. Lee,³ is the basal formation of the Manzano group. It has been found to be continuous throughout New Mexico but apparently thins out near the Texas line, in the south-central part of Otero County. It has very distinctive characteristics at most places and a uniform stratigraphic position between the Magdalena group and Chupadera formation. These features are both lost, however, in the Chama Basin and along the Rocky Mountain uplift north of Mora, where the formation may perhaps be undistinguishable from the adjoining red strata. In most places the Abo formation appears to be unconformable to the Magdalena, but in other places there is an apparent gradation between them. The few data available on which to class the formation place it in the Permian. It lies immediately on or includes at its base the 4-foot limestone member overlying the plant-bearing beds of supposed Permian age west of the Ladrone Mountains referred to on page 180. Plants obtained by Lee, Stanton, and White near Canyoncito and Glorieta are regarded by David White as Permian, and there can be no question that the beds yielding them belong to the Abo. Fossils collected by me in 1902 in the basal beds of the formation in the axis of the Lucera anticline, in sec. 36, T. 6 S., R. 3 W., were identified by G. H. Girty as follows:⁴

| | |
|--|--|
| <i>Myalina permiana.</i> | <i>Bakewellia?</i> sp. |
| <i>Myalina perattenuata.</i> | <i>Bulimorpha</i> near <i>B. nitida.</i> |
| <i>Aviculipecten</i> cf. <i>A. whitei.</i> | <i>Spirorbis</i> sp. |

Mr. Girty regards these fossils as indicating the Permian age of the beds.

Chupadera formation.—The name Chupadera is here introduced for the upper part of the Manzano group, which Lee⁵ divided into the Yeso formation and San Andreas⁶ limestone. In mapping these deposits it was found that while Lee's subdivisions were discernible in places, it was impracticable to separate them generally. Although limestone is the conspicuous feature of the San Andres limestone, much of that subdivision consists of thick beds of gypsum and sandstone which are not well exposed in the type localities. In the future, wherever Lee's subdivisions can be recognized they will be treated as members of the Chupadera formation, instead of as distinct formations. The new name is taken from Chupadera Mesa, in central

³ Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande valley, N. Mex.: U. S. Geol. Survey Bull. 389, p. 12, 1909.

⁴ Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 37, 1910.

⁵ Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande valley, N. Mex.: U. S. Geol. Survey Bull. 389, pp. 12-17, 1909.

⁶ Now spelled San Andres.

New Mexico, a prominent topographic feature consisting of a very extensive capping of the formation 1,500 feet or more thick. (See Pl. XXXIX, *B*, p. 220.)

The limestones of the formation carry many fossils of the well-known Manzano fauna described by G. H. Girty,⁷ originally regarded as late Pennsylvanian but now believed to be Permian. The Chupadera formation overlies the Abo sandstone, which as above shown also presents evidence of Permian age, and I have traced it continuously southward into the Capitan and Delaware Mountain limestones of the Guadalupe Mountains of Texas, which are unquestionably Permian. The Gym limestone⁸ of the Luna County region represents a part of the Chupadera formation.

In the Nacimiento uplift and Chama Basin it has not been practicable to recognize the Chupadera formation in the succession of red beds lying between the Magdalena group and the Poleo sandstone (Triassic), so that for the present at least these beds in that region are treated as "Permian undivided," although they doubtless include a representative of the Triassic Moenkopi formation. Bones of Permian animals, however, occur a short distance below the Poleo sandstone near Coyote.

TRIASSIC "RED BEDS."

In a previous report⁹ I mapped the red shales in the northwestern part of New Mexico as the Moenkopi formation, Shinarump conglomerate, and Leroux formation, the last capped by the Wingate sandstone of Dutton, of supposed Jurassic age. Later work by Gregory¹⁰ extending into part of the same region showed the desirability of changing the name Leroux to Chinle. The Moenkopi was supposed to be Permian, but fossils found by B. S. Butler¹¹ in its probable extension into Utah are of Triassic age.

The recognition of these subdivisions farther east in New Mexico has not been entirely satisfactory so far. The Shinarump conglomerate appears to be represented in the Nacimiento-Chama-Cobre region by a massive sandstone which Huene¹² has called the Poleo sandstone, from Poleo Mesa, of which it forms the surface; and although to me this sandstone strongly suggests the sandstone of Glorieta Mesa (which belongs to the Chupadera formation), it contains Triassic plants at the old Cobre copper mine, near Abiquiu, as

⁷ Lee, W. T., and Girty, G. H., *op. cit.*, pp. 41-136.

⁸ Darton, N. H., *Geology and underground water of Luna County, N. Mex.*: U. S. Geol. Survey Bull. 618, p. 35, 1916.

⁹ Darton, N. H., *A reconnaissance of parts of northwestern New Mexico and northern Arizona*: U. S. Geol. Survey Bull. 435, p. 12, 1910.

¹⁰ Gregory, H. E., *Geology of the Navajo country*: U. S. Geol. Survey Prof. Paper 93, pp. 42-48, 1917.

¹¹ Emery, W. B., *The Green River Desert section, Utah*: *Am. Jour. Sci.*, 4th ser., vol. 46, p. 560, 1918.

¹² Huene, F. von, *Kurze Mitteilung über Perm, Trias und Jura in New Mexico*: *Neues Jahrb., Beilage Band 32*, pp. 730-739, 1911.

described by Newberry¹³ and by Fontaine and Knowlton.¹⁴ Triassic bones near Coyote have been described by Williston and Case.¹⁵ Above this Poleo sandstone, as I shall term it in this paper, are red shales supposed to belong to the Chinle formation, extending to the base of what is unmistakably the Wingate sandstone. Underlying the Poleo are red shales and sandstones about 1,000 feet thick, which doubtless include strata representing the Moenkopi, Chupadera, and Abo formations but in which so far I have not found distinctive features in this region to enable me to separate them.

Farther east in the State, east of Glorieta Mesa and the Hills of Pedernal, the strata overlying the Chupadera formation consist of 800 feet or more of red shales and sandstones representing the Dockum group, including near the bottom a resistant massive sandstone which is prominent in the mesas of Guadalupe County and along Pecos River at Santa Rosa. This sandstone appears to occur at about the horizon of the Shinarump conglomerate, but no definite correlation is possible, and I here propose for it, tentatively at least, the name Santa Rosa sandstone. Case¹⁶ has found in it, as well as in overlying strata, bones of Triassic age. I found supposed *Unios*¹⁷ in beds immediately above it 1 mile north of Santa Rosa. The underlying shales are of undetermined age and may be either Triassic or Permian. Near Carthage and 17 miles northeast of Socorro shales at about this horizon carry Triassic vertebrates,¹⁸ and 12 miles northeast of Socorro some red conglomerate just above the Chupadera formation yielded Permian bones.¹⁹ It appears likely, however, that most of the shales overlying the Chupadera formation are of Triassic age. In the Pecos Valley region in Eddy and Chaves counties the overlying series is several hundred feet thick, and its outcrop extends from the east bank of Pecos River to the edge of the Staked Plains. No satisfactory evidence has been found as to the age of these beds. This question has been discussed by Beede,²⁰ who showed that they are above the Guadalupe group of limestones (Permian), which near Carlsbad are in places uplifted and bared in broad, low anticlines. These overlying beds are probably of Lower Triassic age.

¹³ Newberry, J. S., Geological report, in Report of expedition from Santa Fe, N. Mex., to the junction of the Grand and Green rivers in 1865 under Capt. J. N. Macomb, 1876.

¹⁴ Fontaine, W. M., and Knowlton, F. H., Notes on Triassic plants from New Mexico: U. S. Nat. Mus. Proc., vol. 13, No. 821, pp. 281-285, pls. 22-26, 1890.

¹⁵ Williston, S. W., and Case, E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20, pp. 1-12, 1912; Permo-Carboniferous vertebrates from New Mexico: Carnegie Inst. Pub. 181, 81 pp., 1913.

¹⁶ Case, E. C., The Red Beds between Wichita Falls, Tex., and Las Vegas, N. Mex., in relation to their vertebrate fauna: Jour. Geology, vol. 22, pp. 243-259, 1914.

¹⁷ Determined by T. W. Stanton.

¹⁸ Case, E. C., Personal letter; also Science, new ser., vol. 44, pp. 708-709, 1916.

¹⁹ Case, E. C., Science, new ser., vol. 44, p. 709, 1916.

²⁰ Beede, J. W., The correlation of the Guadalupian and the Kansas sections: Am. Jour. Sci., 4th ser., vol. 30, pp. 131-140, 1910.

LA PLATA GROUP (JURASSIC).

Wingate sandstone.—The Wingate sandstone, the lowest formation of the La Plata group, with all its highly characteristic features, relations, and associates, has been found to continue eastward across northern New Mexico, being unmistakable at least as far east as the longitude of Las Vegas.

Todilto formation.—The characteristic very thin bedded Todilto limestone, in places very sandy, overlies the Wingate sandstone in northern New Mexico as far east as this formation was traced, to longitude 105°. In the Nacimiento and Sandia uplifts it is well exposed, with characteristic outcrops, as far east as points 8 miles east of Canjilon and 2 miles northwest of Abiquiu. It appears near Lamy and 5 miles southeast of Galisteo and extends along the south face of the Canadian escarpment southeast of Las Vegas. It is also prominent around the Zuni uplift and in the central eastern part of Valencia County.

A thick deposit of gypsum overlies the limestone of the Todilto formation in the Chama Basin and Nacimiento uplift, the San Jose Valley southwest of Albuquerque, the Sandia uplift east of Albuquerque, and the uplift west of Cerrillos. As this gypsum bed is overlain by the Navajo sandstone, which also overlies the typical Todilto limestone, the gypsum is regarded as a local development of the upper part of the Todilto limestone.

Navajo sandstone.—The Navajo sandstone of Gregory, the upper formation of the La Plata group, extends for some distance eastward in New Mexico and is conspicuous in the eastern part of Valencia County, where the massive gray sandstone that constitutes much of it is widely exposed about Laguna, Acoma, the Mesa Gigante, and the west side of Cebolleta Mesa. Its outcrop zone extends around the Zuni uplift. It was not recognized east of the Rio Grande, and if present in the Nacimiento uplift it is represented by chocolate-colored sandstone between the gypsum bed in the top of the Todilto formation and the greenish-gray clays that are believed to represent the Morrison formation.

MORRISON FORMATION (CRETACEOUS?).

Light-colored massive shales with local sandstone members underlying the Dakota sandstone in northern New Mexico are believed to represent the Morrison formation, of supposed early Cretaceous age. The McElmo formation, in part at least equivalent to the Morrison, has been mapped by Gregory in the northwestern part of the State, and the typical Morrison beds of Colorado have been traced far southward in the eastern counties. The pale greenish-gray clays near Laguna, in the Nacimiento uplift northwest of Albuquerque, west of Cerrillos, near Lamy and Las

Vegas, in San Miguel, Union, Mora, and Quay counties, and near Fort Stanton probably will all prove to be Morrison.

LIMESTONES AND SANDSTONES OF COMANCHE (LOWER CRETACEOUS) AGE.

In Grant and Luna counties and at Las Cornudas, northeast of El Paso, occur limestone, shale, and sandstone that contain Comanche fossils. The Sarten sandstone, north of Deming, is also of Comanche age. Similar sandstone with Comanche fossils crops out along the north edge of the Staked Plains and in the outlying mesas to the north, and the Purgatoire formation, underlying the Dakota sandstone in the northeastern part of the State, is of Comanche age.

DAKOTA SANDSTONE (UPPER CRETACEOUS).

The sandstone at the base of the Upper Cretaceous series is regarded as Dakota, and in places it yields plants of that age. In Union and Mora counties it is spread out widely in a great plateau which terminates to the south in the high Canadian escarpment.

MANCOS SHALE AND CONTEMPORANEOUS UPPER CRETACEOUS FORMATIONS.

The thick body of shale lying between the Dakota sandstone and the coal-bearing sandstones in northwestern New Mexico is called the Mancos shale, for apparently it is a stratigraphic unit. It comprises part of the Pierre shale of the Montana group and all of the Colorado group, which to the east is differentiated into the Niobrara formation and the Benton shale. In the north-central and northeastern parts of the State these Upper Cretaceous deposits are still further subdivided, as shown in the table on page 176. Sandstones occur at several horizons in the Mancos, differing in position in different regions and locally carrying coal beds. Without detailed study it is difficult to separate the upper coal-bearing sandstones from the overlying Mesaverde group. I offer no new light on this problem. It was found that coal-bearing sandstones of Mancos age extend far south in the Rio Grande valley, the southernmost point being on the east line of T. 20 S., R. 3 E., 20 miles northeast of Las Cruces. The composition of the Mancos is favorable for the generation of oil.

MESAVERDE GROUP AND CORRESPONDING AND YOUNGER CRETACEOUS ROCKS.

The thick series of sandstones with coal beds that make up the Mesaverde group, of Montana age, is well represented in northwestern New Mexico, especially in the San Juan Basin, west of the Nacimiento uplift, where it is divided into three formations, named, in

ascending order, the Point Lookout sandstone, Menefee formation, and Cliff House sandstone. Coal-bearing rocks of Mesaverde and Mancos age are also present in the Cerrillos Basin and in the broad, shallow basin extending southward from Gallup, past Zuni, to the head of the Salado and Alamosa drainage basins, also in the small basins of Carthage, Tijeras, the White Mountains, and Engle.

In northeastern New Mexico the Montana group is divided into three formations, known, in ascending order, as the Pierre shale, Trinidad sandstone, and Vermejo formation. The relations of the Trinidad sandstone and Vermejo formation to the Mesaverde have not been definitely determined. The fossil plants of the Vermejo formation suggest correlation with the Mesaverde, but the invertebrates and some of the stratigraphic data indicate that the Vermejo is younger than the Mesaverde and probably corresponds more closely with the Fox Hills.

The thick body of marine shale of Montana age (Lewis shale) that overlies the Mesaverde group in southern Colorado extends far southward in New Mexico but in some places diminishes greatly in thickness.

The succession of latest Cretaceous rocks in the San Juan Basin formerly designated "Laramie" has been subdivided into the Pictured Cliffs sandstone, Fruitland formation, Kirtland shale, and Ojo Alamo sandstone. Details regarding these formations, which overlie the Lewis shale, are given by Bauer.²¹

EARLY TERTIARY (EOCENE) DEPOSITS.

In the San Juan Basin there is a broad area filled with a succession of clays and sands comprising, in ascending order, the Puerco, Torrejon, and Wasatch formations. These beds lie unconformably on a somewhat uneven surface of Upper Cretaceous formations and overlap southward into the west slope of the Nacimiento uplift. The Galisteo sandstone, a reddish sandstone overlying the coal measures in the Cerrillos coal field, is thought to be early Tertiary. The Raton formation, which occupies the Raton coal basin, is also of that age.²² Early Tertiary sandstones or conglomerates overlie the Upper Cretaceous rocks in the Valle de la Parida, northeast of Socorro; along the west side of Miller Arroyo southeast of Socorro, about Carthage, in the Elephant Butte region; and in T. 20 S., R. 3 E., 20 miles northeast of Las Cruces.

LATER TERTIARY DEPOSITS.

The later Tertiary deposits in New Mexico comprise great accumulations of volcanic materials, including tuff, volcanic ash, agglomerate,

²¹ Bauer, C. M., Stratigraphy of part of the Chaco River valley: U. S. Geol. Survey Prof. Paper 98, pp. 269-278, 1916.

²² Lee, W. T., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, pp. 56-61, 1917.

and lava flows, and also the Santa Fe formation, a deposit of loam, silt, sand, and gravel of Miocene and Pliocene age, occupying the Rio Grande basin in Taos, Rio Arriba, Santa Fe, Sandoval, and Bernalillo counties and extending southward for an unknown distance. These deposits cover a very large area in the State and conceal the structure of the sedimentary rocks, which no doubt underlie them in greater part. Some of these recent beds are tilted in various directions, but the structure which they might indicate should not be expected to continue downward in the underlying older rocks.

QUATERNARY DEPOSITS.

Sand, gravel, and clay of Quaternary age constitute the surface in many parts of New Mexico, especially in the river valleys and wide desert basins. Their thickness varies greatly, but in the wide area west of El Paso, about Deming, and in other similar valleys farther west they aggregate several hundred feet. Other broad areas are in the Tularosa Basin, the Jornada del Muerto, and the Plains of San Agustin. The "White Sands" west of Alamogordo consist of granular gypsum of Quaternary age, and other deposits of loose sand, mostly silica, occur in the same and other basins. Alluvial deposits occur along most of the streams, notably in the broad flood plain of the Rio Grande. Some of the valleys are also occupied by Quaternary lava flows, mostly lying on sand and gravel. The "Malpais" (badland) in Tularosa Basin west of Carrizozo is an example.

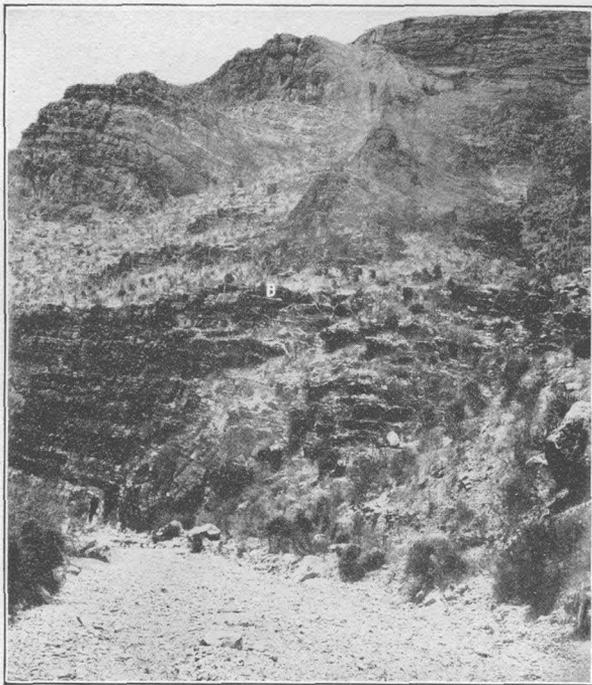
GENERAL STRATIGRAPHIC CONDITIONS.

Petroleum occurs in rocks only under certain favorable conditions of origin and storage, and naturally there are in New Mexico many districts in which the conditions are wholly unfavorable. The entire State is underlain by a basement of granite, gneiss, quartzite, and similar crystalline rocks which are barren of oil. These rocks in which it is hopeless to look for oil are uplifted to the surface in several areas, such as the Rocky Mountains, the San Andres Mountains, the Sierra Nacimiento, and the Hills of Pederal. At other places they are overlain by limestones, sandstones, shale, red beds, volcanic rock, sands, and gravels, locally 5,000 feet thick. In texture, composition, and organic contents some of these strata are likely to be favorable for the development of oil, but although some porous beds are suitable for oil storage many such beds are far removed from any promising source of oil. Oil is believed to be produced from organic matter laid down with sands and clays in the original deposition, and in some of the beds in New Mexico there was never sufficient organic matter to produce any notable amount of oil. The "Red Beds," with thick bodies of red sandstone and shale and with deposits of gypsum, are nearly barren of organic matter and are not regarded by geologists as likely to contain oil unless the oil has migrated into

them and there found a suitable porous reservoir. In the very thick series of red beds the sandstones, however porous they may be, are thought generally to be too far above or below the mother rocks to have been reached by such oil as may have been generated in the beds containing more carbonaceous matter. Texture is a most important condition controlling oil accumulation, and the shales consisting of fine clay, the compact limestones, and some of the finer-grained sandstones have but little capacity for oil. Sand and gravel of the younger formations, valley fill, and slope talus are naturally very unfavorable materials. The volcanic rocks which cover a wide area in New Mexico should not be expected to carry oil, but in most areas these rocks are underlain by sedimentary strata of various kinds which may be reached by the drill.

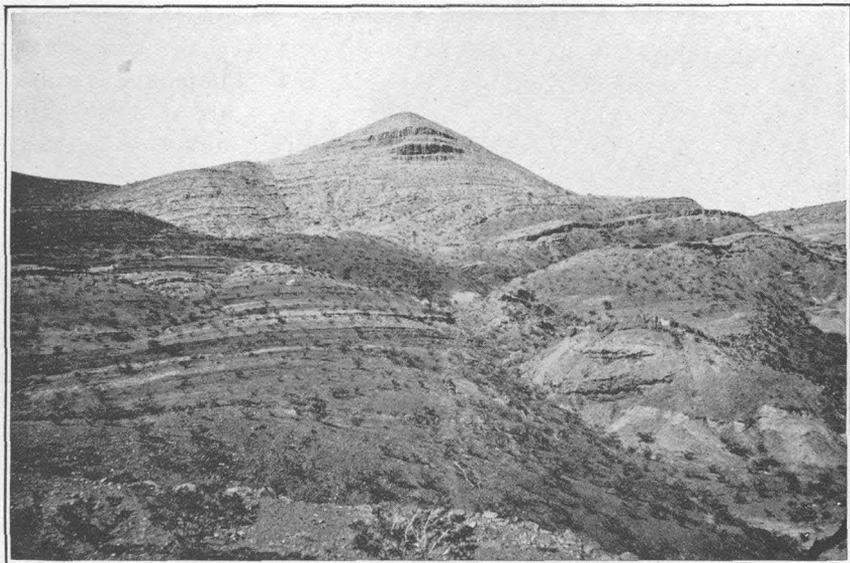
Of the sandstones in New Mexico those believed to be most likely to yield oil are members in the Mesaverde, Mancos, Chupadera, and Magdalena formations. The Bliss sandstone (see Pl. XXXI, *A*), 50 to 150 feet thick, at the base of the sedimentary succession, underlies the southern third of the State and does not contain much organic matter. Moreover, it is probably too much altered to contain oil. Sandstones in the Magdalena group, especially those in the lower part, are enveloped by strata that teem with remains of organic life and are not far removed from other beds that contain considerable carbonaceous matter. Some of the oil in Oklahoma and Kansas occurs in the eastward extension of this group. The sandstones in the Chupadera formation (see Pls. XXXI, *B*; XXXII, *A*; XXXIII, *B*) present stratigraphic conditions somewhat similar to those in the Magdalena group, though carbonaceous beds are but little in evidence. The oil at Dayton occurs in beds of the Chupadera far above the base of the formation. These sandstones are of wide extent under New Mexico, especially its eastern part, but to the north the amount of organic material in the associated strata is less, and in some of the central eastern area the formation is probably too near the surface to retain oil.

The red sandstones of the Navajo and Abo formations (see Pls. XXXI, *B*; XXXII, *B*; XXXIV) and the Wingate sandstone (Pl. XXXIII, *A*) carry very little organic matter and are not closely associated with carbonaceous strata. The Dakota sandstone (see Pl. XXXV, *B*, p. 196) where it lies under a cover of the Benton or Mancos shales, which contain much organic matter, appears to be favorable as a reservoir but has never been definitely proved to be oil-bearing in any region. In many portions of the State it lies at too shallow a depth, and in most areas it is saturated with water. The sandstones of the Mancos and Mesaverde formations are included in strata containing a very large amount of organic matter of various kinds, including coal. The oil at Seven Lakes is probably in the



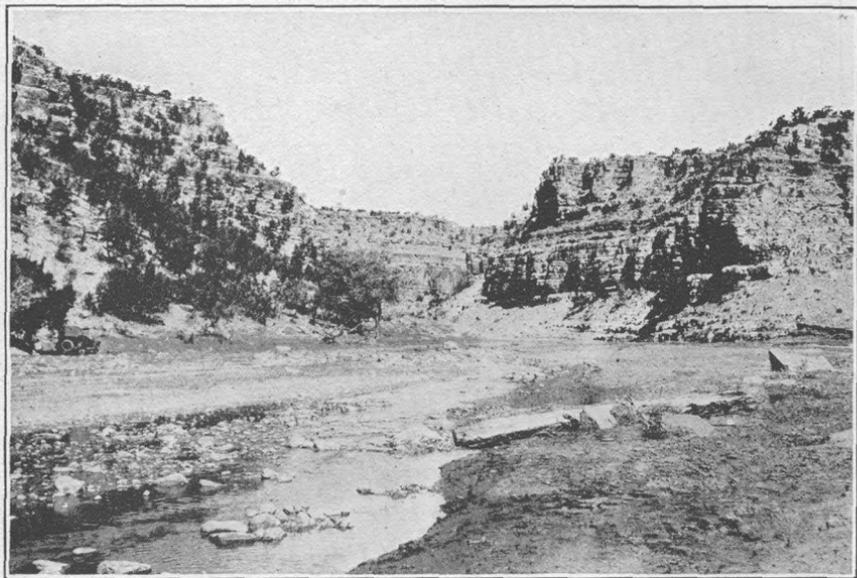
A. BLISS SANDSTONE, SAN ANDRES MOUNTAINS, IN BENNETT CANYON, NORTHEAST OF LAS CRUCES, N. MEX.

B. Contact of Bliss sandstone and El Paso limestone.

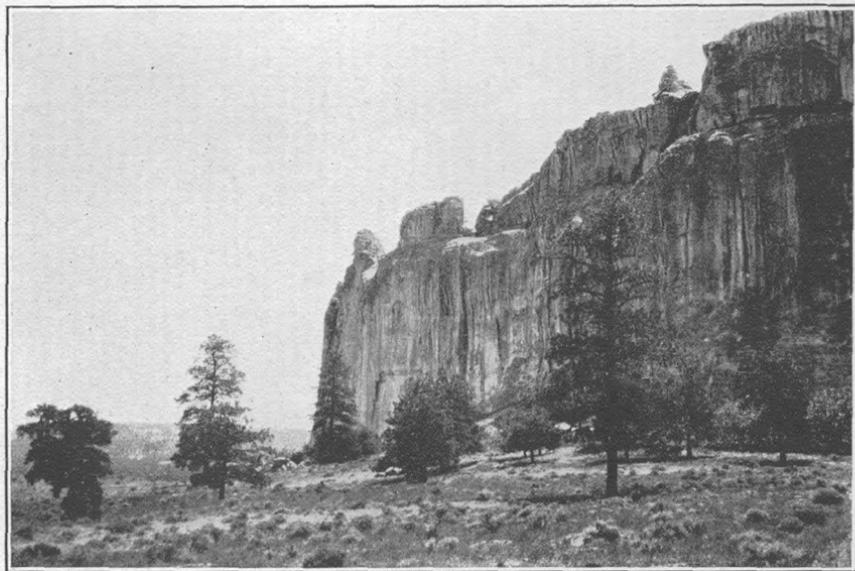


B. COYOTE BUTTE, 12 MILES NORTHEAST OF SOCORRO, N. MEX.

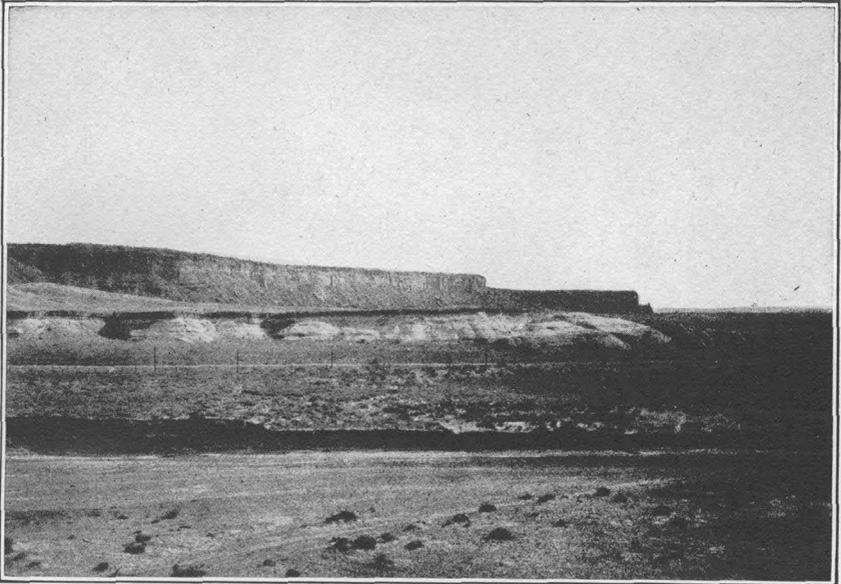
Limestone, sandstone, and gypsum of Chupadera formation.



A. BLUEWATER CANYON, N. MEX.
Limestone and sandstone of Chupadera formation.

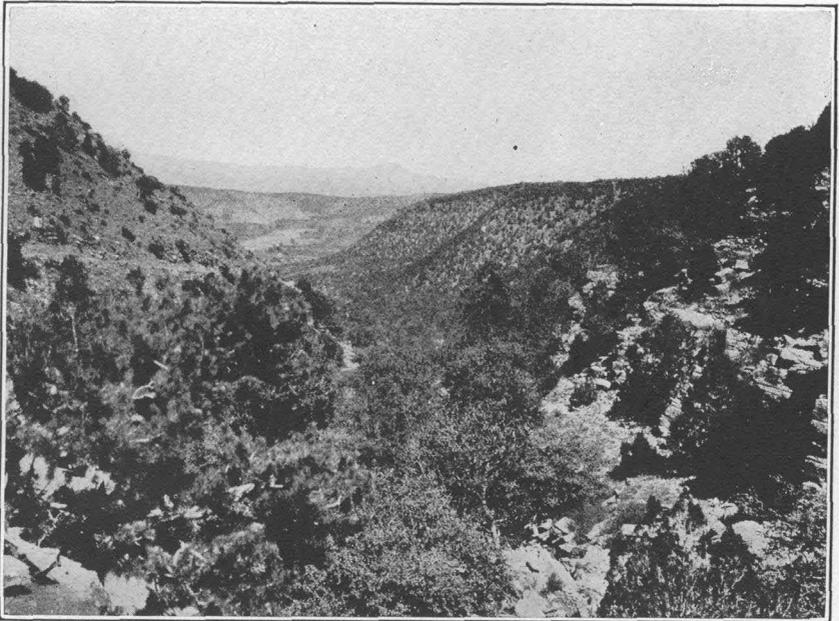


B. INSCRIPTION ROCK, N. MEX.
Navajo sandstone on southwest slope of Zuni Mountains.

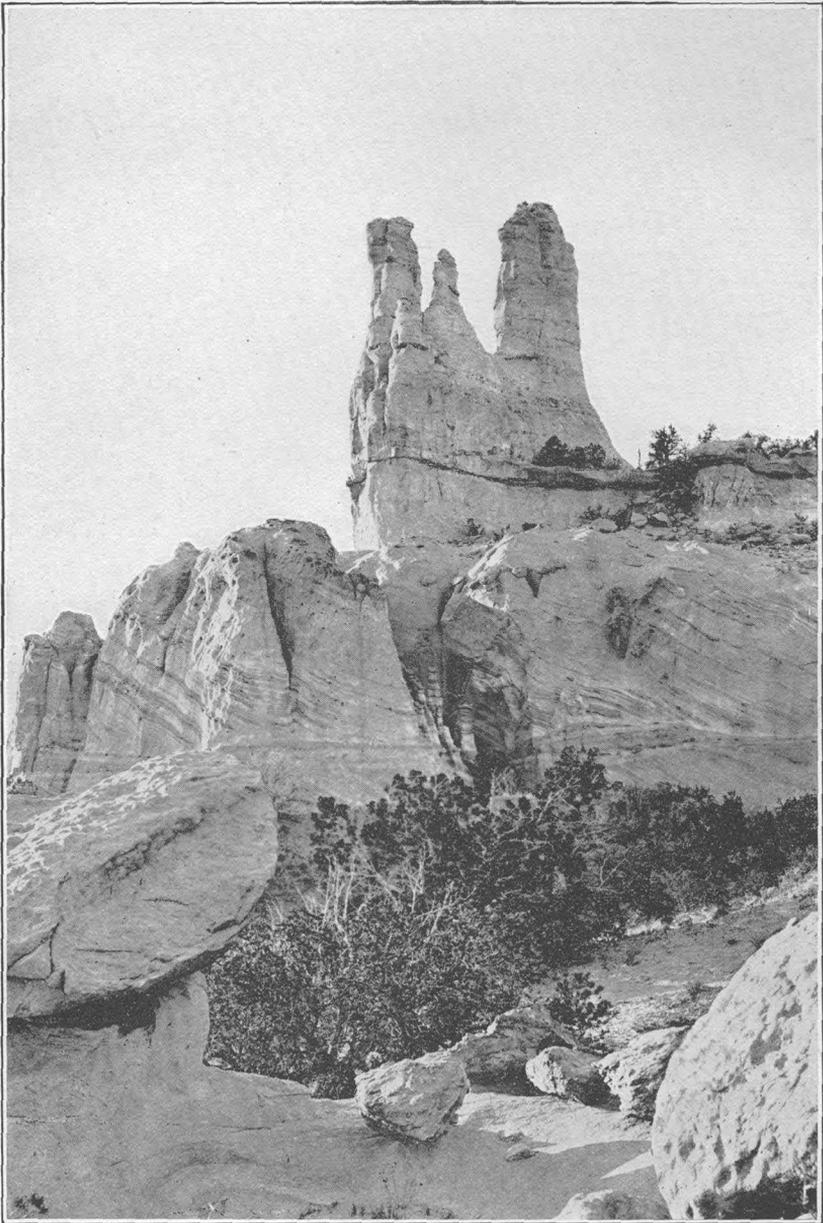


A. WINGATE SANDSTONE AT RITO, N. MEX.

Shows limestone and gypsum of Todilto formation; Navajo sandstone in the background.



B. SANDSTONE OF GLORIETA MESA, NEAR LA CUESTA, N. MEX.



SANDSTONES AT NAVAJO CHURCH, N. MEX.

Mesaverde formation. The capabilities of the Cretaceous sandstones above the Lewis shale as oil reservoirs can only be surmised. Some of the associated shales carry considerable organic matter.

STRUCTURAL AND STRATIGRAPHIC RELATIONS.

NORTHEASTERN COUNTIES.

GENERAL RELATIONS.

In the northeast corner of New Mexico, east of the Atchison, Topeka & Santa Fe Railway, in Union County and the eastern parts

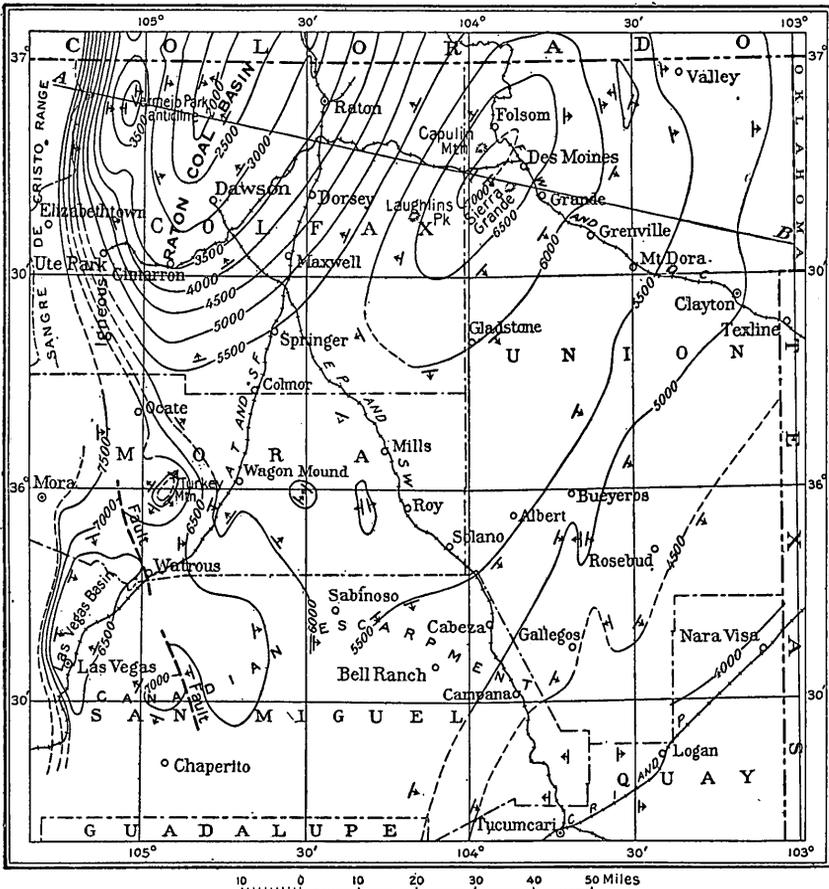


FIGURE 16.—Map showing the major structure of northeastern New Mexico by contours at the surface of the Dakota sandstone in Colfax, Union, Mora, and San Miguel counties. Contour interval, 500 feet. As but little of the area has been surveyed topographically, many of the elevations are only approximate. A-B, Line of section in figure 17.

of Colfax and Mora counties, the sedimentary rocks are uplifted in a broad dome or elongated arch with its highest part near Capulin Mountain and the Sierra Grande. To the west in Colfax County is the deep basin of the Raton coal field, from which the strata rise steeply to the Rocky Mountain front range, beyond. The broader features of the structure of this region are shown in figures 16 and 17.

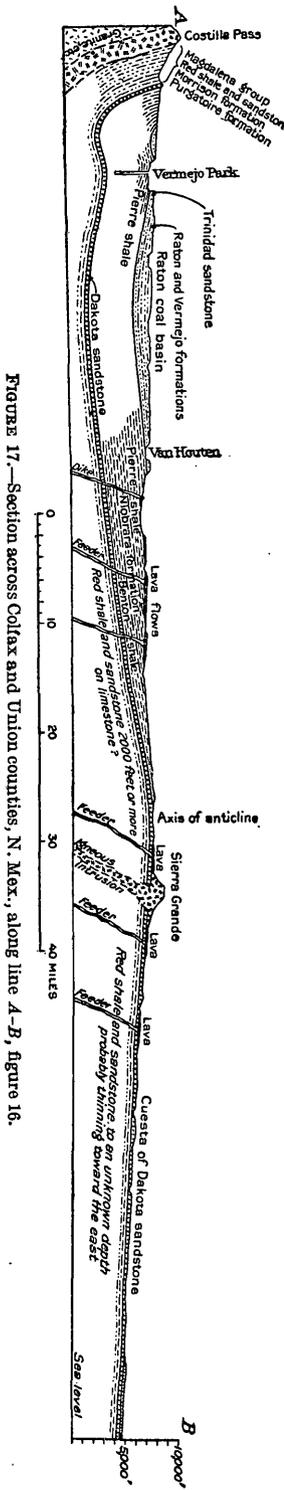


FIGURE 17.—Section across Colfax and Union counties, N. Mex., along line A-B, figure 16.

Doubtless a detailed investigation of the region will reveal many minor irregularities of structure, such as local domes, anticlines, or terraces of the types in which oil and gas are found in other regions. Those situated on the crest or slopes of the broad arch are probably more promising than those farther down in the basins.

A large part of the surface of Union County consists of the Dakota sandstone, sloping eastward, covered to the east by Tertiary sands and gravels and to the north and west by sheets of lava. The deeper canyons cut through to underlying red beds. In Colfax and Mora counties the Dakota sandstone passes beneath the Benton and overlying shales, and in the Raton coal basin it is covered by several thousand feet of Cretaceous and early Tertiary beds. To the south, however, the strata rise somewhat, and the deep canyons of Canadian and Mora rivers reveal Triassic red shale (Dockum group).

STRATIGRAPHY.

The succession of rocks beneath the Dakota sandstone in northeastern New Mexico comprises sandstones and shales of Lower Cretaceous age and a thick body of red shales and sandstone (Triassic and Permian), probably including limestones in their lower part. In most places the Dakota is about 100 feet thick and the underlying gray shales and brown sandstones 125 feet thick. The deeper canyons cut through these rocks and also through a white to gray massive sandstone (Wingate sandstone) that underlies the area. Only the upper parts of the Triassic red sandstones and shales (Dockum group) are revealed in the walls of such canyons as the Dry Cimarron and Canadian, so that the deeper underground conditions can be judged only from exposures of the upturned edges of the rocks in the front range of the Rocky Mountains. These exposures are so distant that there may be considerable change in the

character of the materials in the interval. A section measured by Lee²³ not far north of the Colorado State line is as follows:

Geologic section measured on the south fork of Purgatoire River in southern Colorado.

| | Feet. |
|--|---------|
| Sandstone (Dakota) massive, quartzitic..... | 95 |
| Shale, fine grained, sandy, dark (Purgatoire formation)..... | 3 |
| Sandstone, conglomerate (Purgatoire formation)..... | 50 |
| Not exposed..... | 50 |
| Shale and sandstone (Morrison formation), variegated; red agates near base..... | 150 |
| Not exposed [probably gray and red sandstones and red shale—N. H. D.]..... | 632 |
| Sandstone, conglomeratic with some shale (red beds); many coarse conglomerate, pebbles up to 8 inches or more in diameter, of crystalline and metamorphic rocks..... | 11, 537 |
| Sandstone, dark red, more or less quartzose, much harder than the red beds above. Small pebbles and conglomerate in places.... | 2, 508 |
| Crystalline rocks [pre-Cambrian]. | 15, 025 |

Ten miles farther north Lee found shale and limestone at the base of this series, and several limestone and dark shale members were included. As these beds are represented by limestone and dark shale in Kansas, probably in Union County a considerable amount of this material will be found when the formation is penetrated by wells. The total thickness of beds below the Morrison formation will probably prove to be less than 4,000 feet.

In the Raton coal field the Dakota sandstone is overlain by 5,000 feet or more of shale and sandstone of later Cretaceous age (Benton to Pierre) and by the Raton formation, of early Tertiary age. That the shales from the Benton to the Pierre are more than 2,500 feet thick is shown by the failure of deep holes at Raton and Vermejo Park to reach their base. A 3,000-foot hole at Raton began about 300 feet below the top of the Pierre shale and was entirely in shale, apparently not reaching the base of the formation. A hole at the Bartlett ranch, in Vermejo Park, began about 230 feet below the top of the Pierre shale and penetrated about 2,300 feet of shale, apparently all Pierre. The Niobrara and Benton shales are doubtless more than 1,000 feet thick and include two thin beds of limestone. A small amount of sandstone may also be included, possibly the equivalent of beds which carry oil in Colorado, Wyoming, and some other States. These shales are absent in Union County except for a few small thin outliers in some of the western townships and a small area at Moses. In Mora County they cap the ridge east of the Canadian Canyon and occupy a basin west of that canyon which

²³ Lee, W. T., *Geology of the Raton Mesa and other regions in Colorado and New Mexico*: U. S. Geol. Survey Prof. Paper 101, p. 41, 1917.

may be 600 to 800 feet deep west of Nolan. The north end of another basin enters the county south of Golondrinas, but it does not contain more than 450 feet of the shales.

The stage of carbonization (incipient alteration) of the lower group of coals in the Raton coal field makes it appear probable that oil in commercial amounts will not be found in the Vermejo coal-bearing formation or in underlying formations near Fishers Peak and possibly not in Vermejo Park, though gas is likely to be found in the local domes and anticlines. Information is lacking as to the degree of carbonization of the carbonaceous matter of the rocks farther south toward Turkey Mountain and Las Vegas.

LOCAL STRUCTURE.

The main anticlinal fold is a broad dome elongated to the northeast and southwest, whose axis passes a short distance east of Folsom and which flattens out in the northeastern part of Mora County. To the north it extends some distance into Colorado, with relations that have been shown in a previous report.²⁴ In the highest part of the dome, near Folsom, the surface of the Dakota sandstone reaches an altitude of about 7,200 feet. From this place westward the dips are to the west at a very low angle and, as shown in figure 17, the Dakota sandstone passes under shales which at Raton are more than 3,000 feet thick.

To the southwest the shale covering decreases in thickness, owing to erosion, and the Dakota sandstone is exposed in the Canadian Valley as far north as Taylor. Near Springer it is only a few hundred feet below the surface. The sandstone comes up again in Ocate Park, apparently in a low, flat anticline, and it is sharply upturned in the Turkey Mountain dome, which reveals the "Red Beds."

The Vermejo Park anticline or dome, as shown in figures 16 and 17, rises on the west slope of the Raton coal basin. At Vermejo Park, which is on its eroded crest, the Pierre shales are exposed, and the cliffs encircling the park consist of Trinidad sandstone and overlying strata. The uplift amounts to several hundred feet.

A small uplift in the "Red Beds" under the Exeter sandstone is revealed in the canyon of the Dry Cimarron, 6 miles east of Valley. An anticline of considerable prominence extends northward across the valleys of the Dry Cimarron and Travesser Creek, in R. 32 E. During 1919 the United Oil Co. has been boring a test well on this anticline. The record to a depth of 2,725 feet is given on pages 193-194.

DEEP BORINGS.

A number of deep holes have been bored in northeastern New Mexico, mostly for water. A 2,530-foot hole at the Bartlett ranch,

²⁴ Darton, N. H., The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, pp. 19-21, pl. 1, 1918.

in Vermejo Park, was entirely in shale, probably all Pierre, because the Timpas and Greenhorn limestones were not reported. The Dakota sandstone may be several hundred feet below the bottom of this hole.

A 2,700-foot hole at Raton had a similar record.

It was reported in 1918 that a test hole for oil or gas had been started north of Des Moines and another one on the Dry Cimarron, in the extreme northeast corner of the State, but no reports of progress have been received. The latter hole was on or near the crest of a local anticline or dome in the "Red Beds."

At Solano, on the El Paso & Southwestern Railroad, a hole was bored to a depth of 926 feet by the railroad company for water, without success. The record showed brown sandstone to 221 feet, sand and shale from 221 to 276 feet, and hard rock and white sandstone from 276 to 307 feet, below which there is blue clay and doubtless several hundred feet of "Red Beds."

The boring of the United Oil Co. in T. 31 N., R. 33 E., has a depth of 2,725 feet. Samples of drillings to a depth of 2,337 feet were furnished by R. S. Shannon and aid somewhat in interpreting the record.

Record of boring of United Oil Co. in NW. ¼ sec. 6, T. 31 N., R. 33 E., Union County, N. Mex.

| | Feet. |
|--|---------|
| Sand and sandy shale, blue..... | 0-68 |
| Sandstone..... | 68-108 |
| Shale, blue or brown..... | 108-159 |
| Shale, sandy, red..... | 159-179 |
| Sandstone, coarse..... | 179-193 |
| Sandstone, red..... | 193-227 |
| Shale, red; some limestone..... | 227-259 |
| Limestone and sandstone, red..... | 259-271 |
| Shale, red, sandy..... | 271-293 |
| Limestone, red, and blue shaly sandstone..... | 293-319 |
| Shale, red, and limestone..... | 319-363 |
| Limestone..... | 363-383 |
| Limestone and red shale..... | 383-400 |
| Shale, red, sandy; some limestone near 470 feet..... | 400-574 |
| Limestone, sandy, hard..... | 574-595 |
| Shale, red, and limestone (dolomite)..... | 595-615 |
| Shale, blue; some gray dolomite and sandstone..... | 615-652 |
| Sandstone, shale, and limestone..... | 652-680 |
| Sandstone..... | 680-700 |
| Sandstone and blue shale; some dolomite..... | 700-720 |
| Sandstone, mostly gray..... | 720-760 |
| Shale, blue, sandy..... | 760-778 |
| Limestone and sandstone alternating..... | 778-847 |
| Sandstone; some red sandy shale..... | 847-880 |
| Sandstone, mostly red; some limestone..... | 880-945 |
| Sandy shale, red..... | 945-960 |

| | Feet. |
|--|---------------|
| Sandstone, red..... | 960-970 |
| Sandy shale, red..... | 970-990 |
| Sandstone, red; some dolomite near 995 feet..... | 990-1, 015 |
| Sandy shale, red..... | 1, 015-1, 053 |
| Limestone, red, hard..... | 1, 053-1, 121 |
| Sandstone, soft..... | 1, 121-1, 161 |
| Sandstone, red, and sandy clay, red..... | 1, 161-1, 205 |
| Limestone, hard, and sandstone..... | 1, 205-1, 211 |
| Limestone, red..... | 1, 211-1, 240 |
| Sandstone, limestone, and shale, red..... | 1, 240-1, 260 |
| Sandy shale, mostly red..... | 1, 260-1, 312 |
| Sandstone, red, and limestone..... | 1, 312-1, 342 |
| Sandstone, red, hard..... | 1, 342-1, 357 |
| Sandy shale, red, and limestone..... | 1, 357-1, 372 |
| Limestone, hard..... | 1, 372-1, 398 |
| Limestone, hard, and sandstone..... | 1, 398-1, 430 |
| Sandy shale, red..... | 1, 430-1, 513 |
| Red rock, hard..... | 1, 513-1, 700 |
| Sandstone, red, coarse..... | 1, 700-1, 760 |
| Red rocks..... | 1, 760-1, 960 |
| Limestone, hard, sandy, red..... | 1, 960-2, 040 |
| Limestone, hard, sandy, white..... | 2, 040-2, 080 |
| Limestone, hard, sandy, red..... | 2, 080-2, 104 |
| Sandstone, red, soft; water..... | 2, 104-2, 123 |
| Sandstone, red, hard..... | 2, 123-2, 597 |
| Limestone, sandy..... | 2, 597-2, 647 |
| Sandstone, gray..... | 2, 647-2, 654 |
| Sandstone, pink..... | 2, 654-2, 670 |
| Sandstone, red..... | 2, 670-2, 725 |

It is said that granite was found at the bottom.

A hole drilled for oil in the NW. $\frac{1}{4}$ sec. 32, T. 20 N., R. 31 E., penetrated red beds to a depth of about 2,200 feet. It found nothing but a strong flow of noncombustible gas.

CENTRAL EASTERN COUNTIES.

GENERAL RELATIONS.

The area comprising Guadalupe, De Baca, and Quay counties and the part of San Miguel County lying below the Canadian escarpment is mostly in the valleys of Canadian and Pecos rivers. To a large extent the strata in this area dip eastward, but the inclination is so slight that it is imperceptible to the eye. Several shallow basins and low arches or domes²⁵ have been found in this area, and it is probable that careful scrutiny will reveal others.

The general structural relations are shown in the accompanying cross section (fig. 18).

²⁵ Attention was called to some of these domes in U. S. Geol. Survey Press Bulletin 413, June 26, 1919.

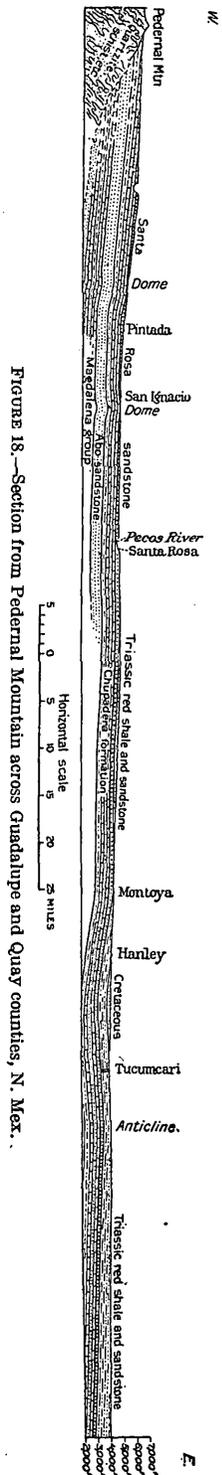
STRATIGRAPHY.

The rocks that crop out in the area are red shales and sandstones of Triassic age (Dockum group) in the lower lands and the Purgatoire and Dakota formations in the adjoining mesas. Just west of Tucumcari these sandstones descend into a structural basin and occupy its center for some distance.

The Triassic red shales and sandstones are about 800 feet thick and include near their lower part a prominent bed of gray sandstone which comes to the surface at Santa Rosa and is exposed widely in plateaus to the west, north, and south of that place. Small amounts of asphalt or dried-up petroleum occur in ledges of this sandstone on the banks of Pecos River 8 miles north-northwest of Santa Rosa, and it is possible that oil will be found in the sandstone east of this place, where it is from 50 to 550 feet below the surface. Next below this sandstone are some red shales, and then limestones, sandstones, and gypsum deposits of the Chupadera formation, which crop out in the southwestern part of Guadalupe County, the eastern part of Torrance County, and the southwestern part of San Miguel County. This formation, which is 1,000 to 1,200 feet thick, contains beds of sandstone that may yield oil in places where the structural conditions are favorable. The red sandstones of the Abo formation underlying the Chupadera formation are probably 800 feet thick and are not likely to be oil bearing. They are underlain by limestones and shales of the Magdalena group, which is 1,200 feet or more thick in the Rocky Mountain and Sandia uplifts and which lies on a floor of pre-Cambrian granite, schist, and other crystalline rocks. The 2,013-foot hole sunk in the Esterito dome, 25 miles northwest of Santa Rosa, apparently found but little if any of the Magdalena group lying on the granite.

LOCAL DOMES.

One of the most marked structural features in central eastern New Mexico is the Esterito dome (fig. 19), just east of Dilia, in the middle



of the Anton Chico grant, about 25 miles northwest of Santa Rosa. It is in a region of "Red Beds" and brings to the surface on its eroded crest the top limestone and upper sandstone of the Chupadera formation. (See section, fig. 20.) The area of exposure of these beds is only about 3 square miles. The upturned edges of the red beds crop out on the flanks of the dome. Further details of this dome are shown by figure 19, constructed from a contour map kindly furnished by Mr. J. R. Gardner, of Tulsa, Okla., based on a detailed survey by Messrs. Newby, Garrett, Crabtree, and Wright. In 1918-19 a hole was bored by the Gypsy Oil Co. in sec. 30, T. 11 N., R. 19 E., to test

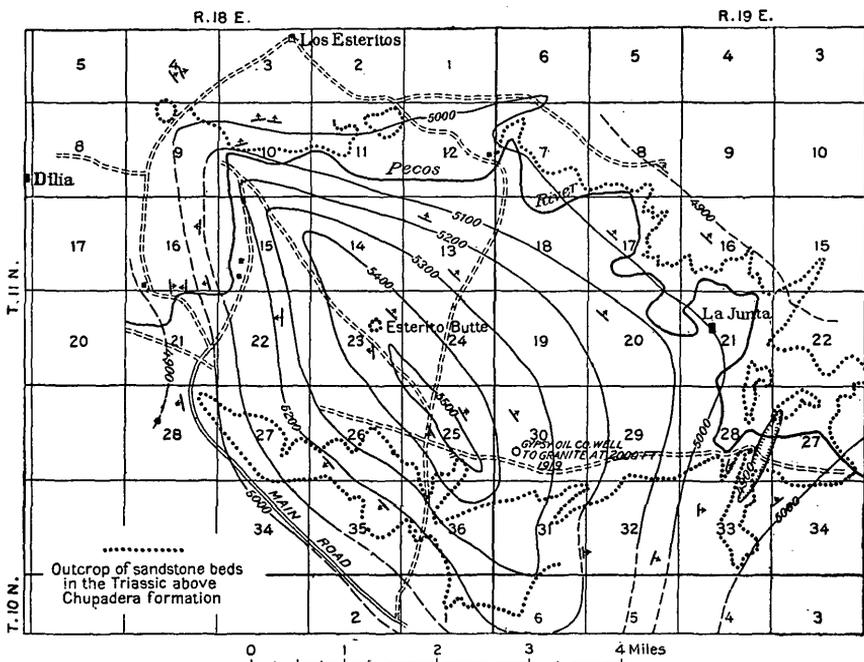
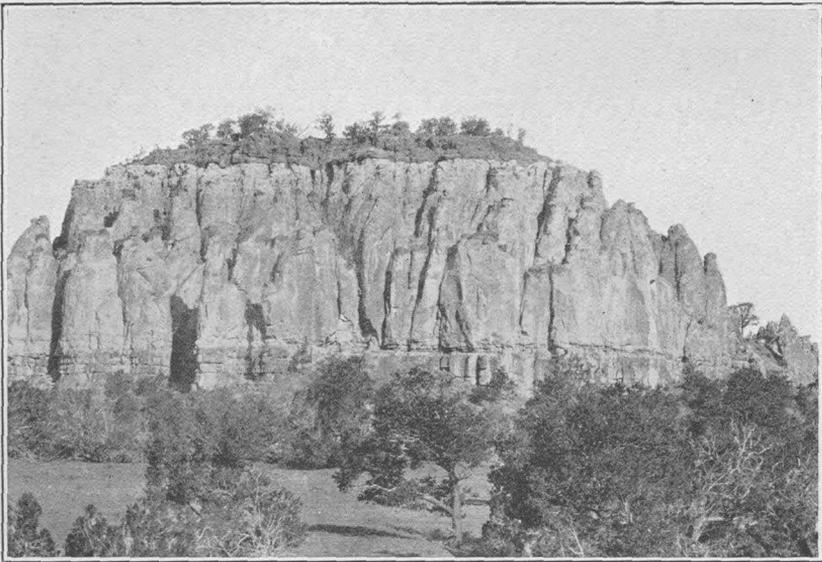
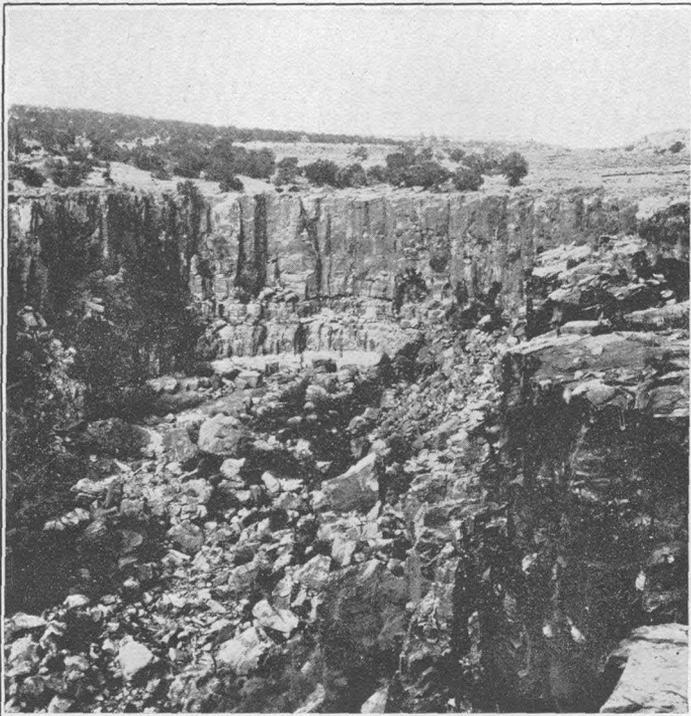


FIGURE 19.—Map of Esterito dome, Guadalupe County, N. Mex.

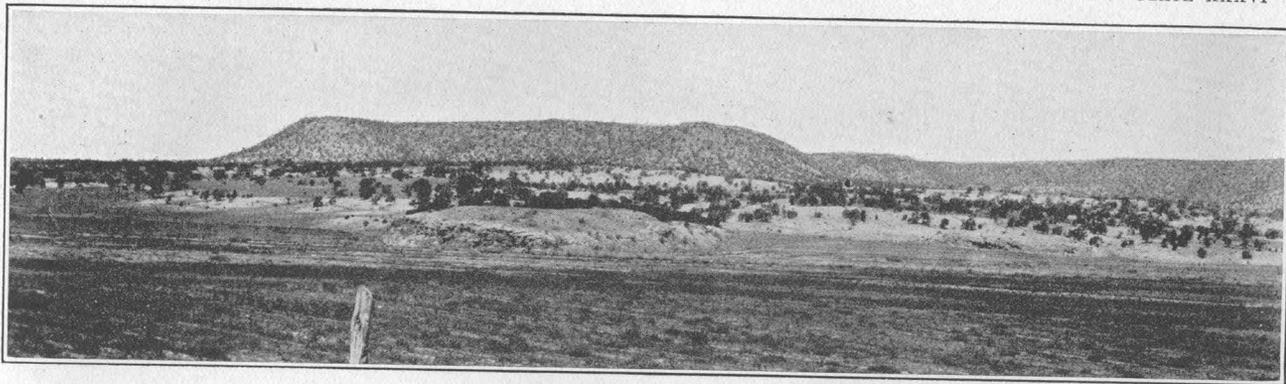
the resources of this dome. It was finally discontinued in granite at a depth of 2,013 feet. The strata penetrated, according to the log on pages 198-199, kindly furnished by Mr. G. C. Matson, are sandstone and limestone from the surface to probably about 1,045 feet, the Abo sandstone from 1,045 to 2,000 feet, and granite from 2,000 to 2,013 feet. The Magdalena group appears to be absent, although possibly it is represented by some of the red rocks with two thin beds of limestone between 1,575 and 2,000 feet. The character of the Chupadera formation in this region is indicated by strata below 575 or 580 feet, in the record of the 1,003-foot hole 15 miles east. (See p. 198.) Two domes of moderate prominence are indicated by outcrops of limestone of the Chupadera formation in Canyon Blanco, 10 miles southwest of Anton Chico.



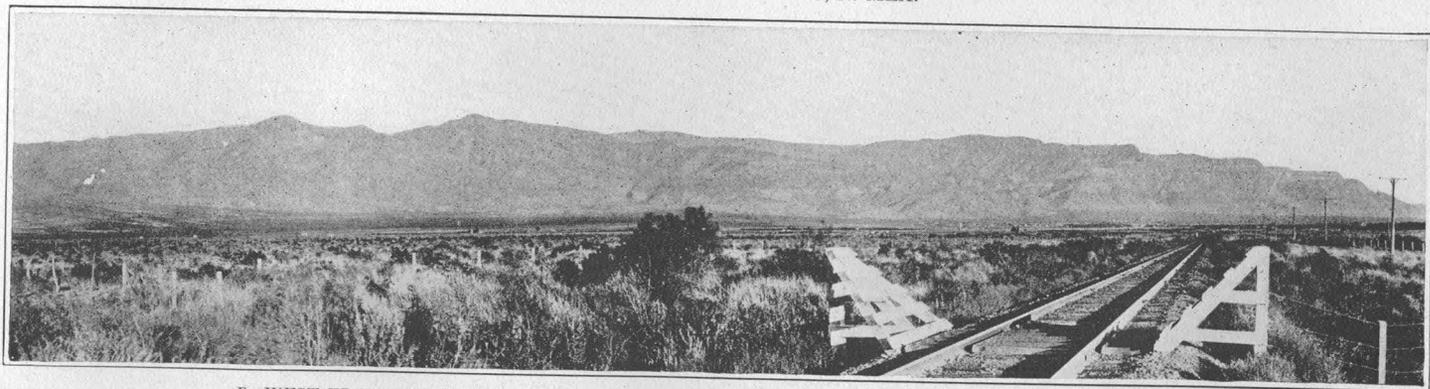
A. NAVAJO AND DAKOTA SANDSTONES AT ATARQUE, N. MEX.
Unconformity shows just above the tree tops.



B. DAKOTA SANDSTONE AT BLUEWATER FALLS, N. MEX., LOOKING WEST.



A. DOME NEAR SAN IGNACIO, N. MEX.



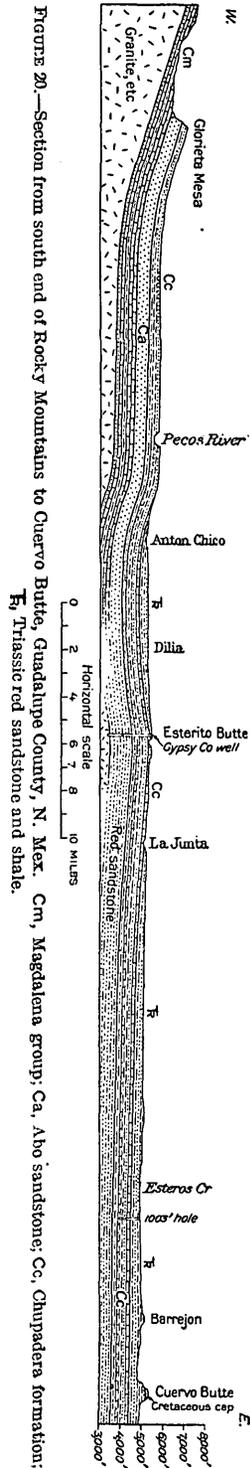
B. WEST FRONT OF SACRAMENTO MOUNTAINS, N. MEX., FROM A POINT NEAR ALAMOGORDO.

A small but well-defined dome is exhibited near the center of T. 8 N., R. 19 E., in Pintada Canyon a mile east of San Ignacio post office. It brings to the surface limestone and gypsum at the top of the Chupadera formation. The relations are shown in figure 18 and Plate XXXVI, A. Another dome appears in this canyon 3 miles above Pintada post office, but its crest is not sufficiently elevated to expose the top of the Chupadera formation, which, however, is not far below the bottom of the canyon.

There is a slight doming of the strata a short distance east of Santa Rosa and at several other places in the extensive region of red beds in the southeastern part of San Miguel County and the northeast corner of Guadalupe County. No details of the structure have been determined. A shallow synclinal basin east of Montoya extends across the western part of Quay County and the southeast corner of San Miguel County, as shown in figure 18. On the east side of this basin east of Tucumcari the strata rise on a low arch that extends some distance north up Ute Creek valley and some distance south, probably as far as the rise to the Staked Plains. In this arch the sandstones of the deeply buried Chupadera formation, probably 800 to 1,000 feet or more deep, should be tested, and possibly the underlying Abo sandstone and Magalena group. Minor domes were observed east and south of Tucumcari.

DEEP BORINGS.

Very few deep holes have been bored to test the strata in east-central New Mexico. Several years ago a hole was bored for oil on the Perea grant, on Pecos River 7 or 8 miles above Santa Rosa, but no facts as to depth or record were obtainable. In 1916 a 1,003-foot hole was bored on the Preston Beck grant, 12 miles north-northeast of Santa Rosa. It penetrated the Chupadera formation for some distance but was not in an area of favorable



structure and was not deep enough to test all the strata. The following record is made up from drillers' logs and my own tests of samples of the borings:

Record of boring on Beck grant, 12 miles north-northeast of Santa Rosa, N. Mex.

| | Feet. |
|--|-----------|
| Sandstone, gray..... | 0-140 |
| Sandstone and blue shale..... | 140-195 |
| Sandstone; some water..... | 195-205 |
| Shale, blue..... | 205-215 |
| Sandstone, gray; much water at top..... | 215-255 |
| Sandstone, with limestone in lower part..... | 255-345 |
| Shale, red, sandy..... | 345-380 |
| Shale, blue, part limy..... | 380-405 |
| Shale, red, brown, and gray..... | 405-425 |
| Shale, blue, and limestone..... | 425-450 |
| Shale, red; some gray..... | 450-490 |
| Shale, blue..... | 490-510 |
| Shale, red..... | 510-525 |
| Shale, blue..... | 525-535 |
| Shale, brown to red..... | 535-550 |
| Sandstone, gray; water..... | 550-560 |
| Shale, red, on gypsum..... | 560-580 |
| Limestone, dark shale, and gypsum..... | 580-680 |
| Gypsum, anhydrite, limestone, and black shale..... | 680-800 |
| Sandstone, gray..... | 800-915 |
| Limestone and shale..... | 915-935 |
| Sandstone..... | 935-955 |
| Gypsum and limestone..... | 955-975 |
| Sandstone; some brackish water..... | 975-1,003 |

The hole bored in 1918-19 by the Gypsy Oil Co. in the Esterito dome, in the Anton Chico grant, northwest of Santa Rosa, had the following record, supplied by Mr. G. C. Matson:

Record of hole bored by Gypsy Oil Co. in the SW. $\frac{1}{4}$ sec. 30, T. 11 N., R. 19 E., Guadalupe County, N. Mex.

| | Feet. |
|---|-------------|
| No record..... | 0-187 |
| Sandstone..... | 187-380 |
| Sandstone, dark..... | 380-425 |
| Sandstone, gray..... | 425-500 |
| Sandstone, black..... | 500-520 |
| Shale and sandstone, red..... | 520-1,026 |
| Limestone..... | 1,026-1,045 |
| Red rock..... | 1,045-1,065 |
| Sandstone; lower part white..... | 1,065-1,108 |
| Red rock..... | 1,108-1,155 |
| Sandstone..... | 1,155-1,175 |
| Shale, red..... | 1,175-1,195 |
| Shale, blue..... | 1,195-1,200 |
| Red rock..... | 1,200-1,265 |
| Sandstone; water..... | 1,265-1,287 |
| Limestone, red..... | 1,287-1,299 |
| Sandstone, red and gray, alternating..... | 1,299-1,575 |

| | Feet. |
|------------------------------|---------------|
| Sandstone; water..... | 1, 575-1, 588 |
| Limestone..... | 1, 588-1, 600 |
| Shale, red..... | 1, 600-1, 660 |
| Limestone..... | 1, 660-1, 675 |
| Red shale and sandstone..... | 1, 675-1, 800 |
| Red rock..... | 1, 800-1, 870 |
| Sandstone..... | 1, 870-1, 990 |
| No record..... | 1, 990-2, 000 |
| Granite..... | 2, 000-2, 013 |

The heavy sandstone of the Chupadera formation extends to a depth of 520 feet, and doubtless some of the underlying red beds are basal members of the formation, including, perhaps, the limestone at 1,026 to 1,045 feet. The Abo sandstone may extend to the granite, or some of the lower beds from 1,588 to 2,000 feet may represent the Magdalena group, but they include only 27 feet of limestone.

A 857-foot well for water at Pastura passed through 180 feet of alternating beds of limestone and compact gypsum, 15 feet of sandstone, 25 feet of hard dark limestone, 50 feet of sandstone, 60 feet of gypsum, and 280 feet of limestone and gypsum to sandstones of light color at 520 feet, which yielded considerable hard water.

A 3,200-foot hole 5 miles south of Buchanan penetrated alternating beds of red shale and limestone with much gypsum between 200 and 600 feet, also 200 feet of salt between 2,105 and 2,460 feet.

In 1919 several borings were being made in the eastern part of the area to test the strata for oil. One known as the McGee well, in the southeast corner of sec. 27, T. 10 N., R. 31 E., about 9 miles southeast of Tucumcari, had the following record:

Log of McGee boring, in sec. 27, T. 10 N., R. 31 E., Quay County, N. Mex.

| | Feet. |
|--|---------------|
| Sandstone, gray..... | 0-30 |
| Shale, red..... | 30-470 |
| Water sand, salty..... | 470-600 |
| Shale, red, with 10 feet of sandstone at 666 feet..... | 600-760 |
| Water sand..... | 760-783 |
| Shale, blue..... | 783-796 |
| Water sand..... | 796-800 |
| Shale, red..... | 800-905 |
| Shale, blue..... | 905-940 |
| Water sand..... | 940-970 |
| Shale, red..... | 970-1, 100 |
| Rock salt..... | 1, 100-1, 135 |
| Shale, red..... | 1, 135-1, 400 |
| Sandrock..... | 1, 400-1, 430 |
| Rock salt..... | 1, 430-1, 455 |
| Shale, red..... | 1, 455-1, 625 |
| Limestone, gray..... | 1, 625-2, 000 |
| Shale, brown..... | 2, 000-2, 200 |

| | Feet. |
|---|---------------|
| Limestone, dark; salt at 2,372-2,377 feet | 2, 200-2, 550 |
| Shale, brown | 2, 550-3, 200 |
| Limestone, black | 3, 200-3, 220 |
| Salt | 3, 220-3, 225 |
| Shale, brown | 3, 225-3, 325 |
| Limestone and sandstone, red | 3, 325-3, 340 |
| Shale, brown | 3, 340-3, 505 |
| Limestone, dark | 3, 505-3, 520 |
| Sandy shale, red | 3, 520-3, 550 |
| Limestone, blue | 3, 550-3, 575 |
| Shale, blue | 3, 575-3, 595 |
| Shale and lime, red | 3, 595-3, 685 |
| Sand, brown | 3, 685-3, 730 |
| Partly limy | 3, 730-3, 820 |
| Shale, blue | 3, 820-3, 825 |
| "Red lime with granitic sand" | 3, 825-3, 854 |
| Limestone, black | 3, 854-3, 859 |
| Shale, blue | 3, 859-3, 869 |
| Limestone, gray to brown | 3, 869-3, 953 |
| Shale | 3, 953-3, 958 |
| Limestone, brown | 3, 958-4, 014 |

A hole in sec. 7, T. 11 N., R. 36 E., was in progress in 1920. Blue shale was the prevailing material to 1,500 feet and limestone from 1,500 feet to 2,300 feet; red shale was entered at about 2,500 feet. A hole in sec. 25, T. 13 N., R. 32 E., on Canadian River 15 miles northeast of Tucumcari, had reached a depth of 1,210 feet. Sandstones and red shales predominate to a depth of 905 feet, below which are gray limestones with a few beds of brown and gray shale.

ROCKY MOUNTAINS.

The great uplift of the Rocky Mountains extends far southward into New Mexico as a series of high ridges consisting largely of granite, schist, and other crystalline rocks of pre-Cambrian age, overlain by limestones and sandstones of Carboniferous age. The range is relatively narrow, having a width of about 25 miles in Taos County and 35 miles east of Santa Fe. The principal structural feature is an anticline or series of anticlines. Two typical sections are given in figure 21.

Many of the details of the structure of the Rocky Mountains in New Mexico have not been determined, especially the relations of the faults and minor flexures. The uplift pitches steeply toward the south, and the crystalline rocks and limestone pass underground in the vicinity of latitude $35^{\circ} 30'$, or near the line of the Santa Fe Railway. The prolongations of the anticlines, however, are traceable for some distance farther south in the Glorieta and other mesas in the southwestern part of San Miguel County and the southeastern part of Santa Fe County, described on page 202. The principal sedimentary rocks in the Rocky Mountain uplift are those of the Magda-

lena group, which consists of limestones and sandstones, the latter predominating in the upper and later portions of the formation. These rocks arch over most of the higher parts of the range, but in some areas they have been removed by erosion and the underlying granites, schists, etc., are revealed. These limestones and sandstones, lying high on the mountain slopes, with so little cover, are not likely to contain oil or gas.

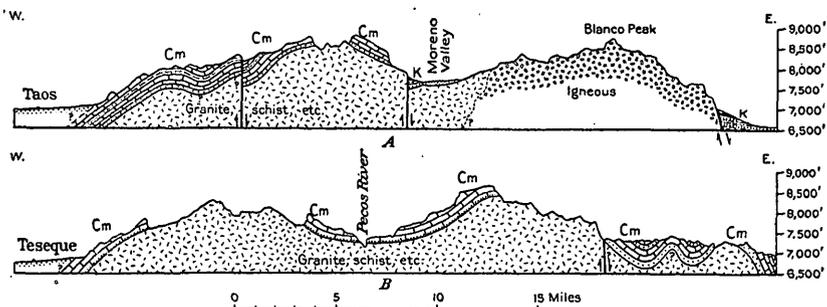


FIGURE 21.—Generalized sections across the Rocky Mountains in New Mexico. *A*, From Taos eastward; *B*, eastward from a point 6 miles north of Santa Fe. Cm, Magdalena group; K, Cretaceous sandstone and shale.

EAST-CENTRAL PLATEAU REGION.

GENERAL RELATIONS.

The east-central plateau region comprises the southeastern part of Santa Clara County, the western part of San Miguel County, and the eastern part of Torrance County. From the south end of the Rocky Mountains there extends southward a broad plateau which in the northern part of Lincoln County merges into the Sacramento Cuesta and in the southern part of Torrance County merges into the Chupadera Mesa. Glorieta Mesa is at the north end of the plateau, and it slopes eastward into the valley of Pecos River. The surface is sandstone to the north and limestone to the south, but from Pedernal Mountain to Pinos Wells the pre-Cambrian crystalline rocks appear, in places rising considerably above the general level.

STRATIGRAPHY.

The sedimentary strata underlying the east-central plateau region are shown in the following table:

Formations in the east-central plateau region of New Mexico.

| Formation. | Characteristics. | Thickness (feet). |
|-----------------------|--|-------------------|
| Chupadera formation. | Massive gray sandstone to north; alternating limestone, gray sandstone, gypsum, and soft red sandstone to south. | 1,000-1,100 |
| Abo sandstone. | Brown-red sandstone and red sandy shale; some gray sandstone. | 700-800 |
| Magdalena group. | Largely limestone, with alternations of limestone, sandstone, and shale in lower part. | 1,100-1,200 |
| Granite, schist, etc. | With thick mass of gray quartzite in Pedernal region. | |

The strata most favorable for oil or gas, if these materials are present, are the sandstones included in the Magdalena group, which lie at a depth of about 2,000 feet in most parts of the plateau area. Possibly some

of the coarser, more porous sandstones of the Abo may also be favorable, but the sandstone of the Chupadera formation apparently has little cover, some of the canyons cutting into or through it. The Magdalena group and Abo sandstone are absent in an area of considerable extent adjoining Pedernal Mountain and the associated quartzite ridges, which probably continue underground as far north as T. 10 N.

LOCAL STRUCTURE.

The main structural feature of this district is an anticline or a southward prolongation of part of the Rocky Mountain uplift, with a low dip to the east and steeper dips on the west, notably in the region east of Lamy. The sections in figure 22 show the chief structural features.

The strata dip down under Estancia Valley and the Galisteo Basin, where the Chupadera is overlain by later formations. To the east, in the southwestern part of San Miguel County, the larger valleys cut through to the underlying red Abo sandstone. Toward the south the pre-Cambrian quartzite of the

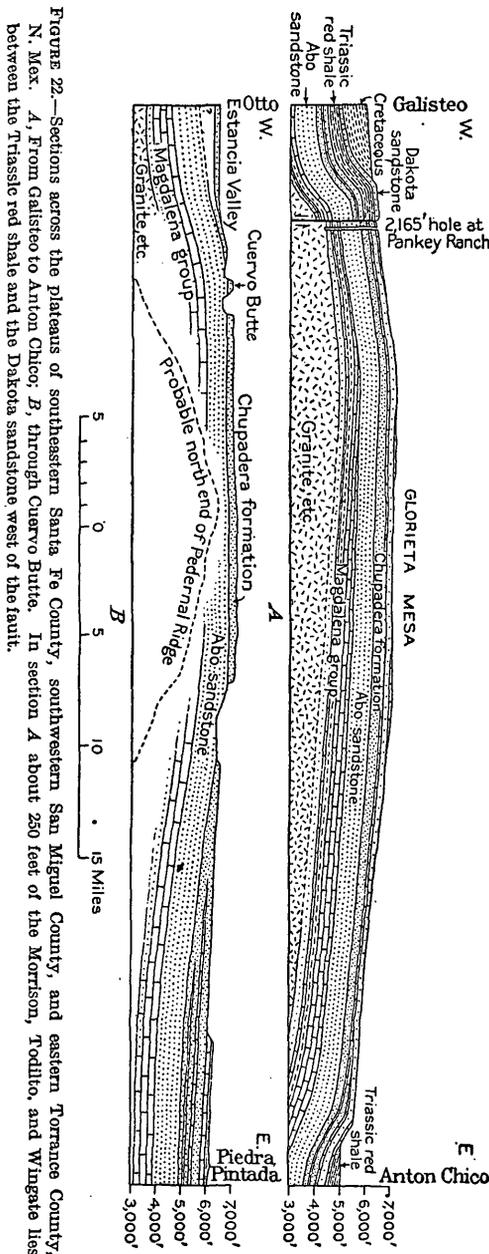


FIGURE 22.—Sections across the plateaus of southeastern Santa Fe County, southwestern San Miguel County, and eastern Torrance County, N. Mex. A, From Galisteo to Anton Chico; B, through Cuervo Butte. In section A about 250 feet of the Morrison, Todillo, and Wingate lies between the Trassic red shale and the Dakota sandstone west of the fault.

Pedernal region rises as an old ridge in the midst of the later Carboniferous sediments. How far north this quartzite extends is not known, but it may constitute the center of the uplift for some distance north of Pedernal Mountain, cutting out the lower formations.

DEEP BORINGS.

The most notable deep boring in this region is one sunk in 1918 for oil and gas near the Pankey ranch, on the Eaton grant, south of Lamy. The following record of the hole was kindly supplied by the Toltec Co., which made the boring:

Record of hole on Eaton ranch, 7 miles south of Lamy, N. Mex., approximately in sec. 2, T. 13 N., R. 10 E.

| | Feet. |
|--|-------------|
| Sandstone, buff, coarse..... | 0-40 |
| Shale, blue, gritty..... | 40-100 |
| Sandstone..... | 100-150 |
| Shale..... | 150-165 |
| Sandstone, chocolate-colored..... | 165-185 |
| Shale, chocolate-colored..... | 185-215 |
| Limestone, dolomitic, fine grained..... | 215-250 |
| Shale, sandy, chocolate-colored to red..... | 250-300 |
| Sandstone, fine, white..... | 300-360 |
| Gypsum (?), white, sandy..... | 360-400 |
| Limestone, gray, and sandstone..... | 400-580 |
| Sandstone, fine, gray..... | 580-600 |
| Gypsum, limestone, and shale..... | 600-630 |
| Sandstone, white..... | 630-640 |
| Shale, sandy, chocolate-brown..... | 640-775 |
| Sandstone, white..... | 775-780 |
| Shale, red..... | 780-820 |
| Shale, chocolate-colored..... | 820-880 |
| Shale, sandy, limy..... | 880-890 |
| Sandstone, fine, white..... | 890-940 |
| Shale, blue..... | 940-1,003 |
| Shale, chocolate-colored, sandy..... | 1,003-1,035 |
| Sandstone, red..... | 1,035-1,070 |
| Shale, chocolate-colored; some sand..... | 1,070-1,100 |
| Sandstone, fine, light red..... | 1,100-1,150 |
| Shale, greenish..... | 1,150-1,200 |
| Shale, with some sand, chocolate-colored at top..... | 1,200-1,300 |
| Shale, sandy and limy..... | 1,300-1,400 |
| Limestone, gritty (?). | 1,400-1,455 |
| Shale, limy to sandy, chocolate-colored..... | 1,455-1,590 |
| Shale, more sandy..... | 1,590-1,640 |
| Sandstone, red, and chocolate-colored shale..... | 1,640-1,715 |
| Conglomerate..... | 1,715-1,720 |
| Shale, dark; some sandy..... | 1,720-1,865 |
| Limestone, blue..... | 1,865-1,920 |
| Limestone, dark gray..... | 1,920-1,980 |
| Sandstone, dark red..... | 1,980-1,994 |
| Schist and quartzite (probably pre-Cambrian)..... | 1,994-2,165 |

Samples of the materials from various depths were furnished and tested in the laboratory of the United States Geological Survey. The sample at 1,895 feet was limestone, those at 1,910, 1,930, and 1,950 feet calcareous shale, at 1,994 feet quartz, at 2,012 feet schist,

at 2,080 feet quartzitic schist, at 2,090 feet quartz, and at 2,150 feet schist.

The record does not give the characteristics of all the beds penetrated, so that the position of the Chupadera formation is not apparent, but the base of the Abo appears to have been reached at 1,400 feet, below which to 1,950 feet the boring was in the Magdalena group. A conglomerate with granite fragments from 1,720 to 1,725 feet was a notable feature. The material from 1,994 feet to the bottom appears to be quartzite and schist of pre-Cambrian age, the bedrock basement. As shown in section *A*, figure 22, the hole is in a monocline just east of a large fault, and the structural conditions are not favorable for oil or gas.

The State well in sec. 8, T. 8 N., R. 13 E., about 6 miles north of Pedernal Mountain, had the following record:

Record of well in sec. 8, T. 8 N., R. 13 E., Torrance County, N. Mex.

| | Feet. |
|--|---------|
| Clay, yellow..... | 0-14 |
| Limestone..... | 14-29 |
| Sandstone, yellow..... | 29-90 |
| Sandstone, red, with shale beds..... | 90-160 |
| Limestone and gypsum..... | 160-170 |
| Sandstone, yellow..... | 170-180 |
| Sandstone, red, with thin beds of shale..... | 180-590 |
| Shale, hard, blue..... | 590-598 |
| Limestone..... | 598-608 |
| Shale, hard, blue..... | 608-645 |
| Sandstone, hard, white..... | 645-655 |
| Limestone, blue..... | 655-670 |

A 528-foot boring in sec. 8, T. 8 N., R. 14 E., about 2 miles southwest of Palma post office, in Torrance County, had the following record:

Record of State well No. 2, in sec. 8, T. 8 N., R. 14 E., Torrance County, N. Mex.

| | Feet. |
|------------------------------------|---------|
| Limestone (?) and yellow clay..... | 0-30 |
| Limestone and gypsum (?)..... | 30-90 |
| Sandstone, yellow..... | 90-470 |
| Sandstone, red..... | 470-480 |
| Sandstone, cream-colored..... | 480-524 |
| Shale, yellow to reddish..... | 524-528 |

This well evidently was in the Chupadera formation throughout.

A 615-foot boring for water in sec. 2, T. 2 N., R. 16 E., had the following record:

Record of boring in sec. 2, T. 2 N., R. 16 E.

| | Feet. |
|---|---------|
| Soil and clay..... | 0-60 |
| Limestone..... | 60-140 |
| Limestone and gypsum..... | 140-210 |
| Sandstone..... | 210-290 |
| Limestone..... | 290-300 |
| Sandstone..... | 300-360 |
| Gypsum..... | 360-380 |
| Sandstone, soft from 410 to 420 feet; some water at 575 feet, 20 gallons at 612 feet; hard water..... | 380-615 |

A deep hole sunk for water by the Atchison, Topeka & Santa Fe Railway Co. at Chapelle had the following record:

Record of well of Atchison, Topeka & Santa Fe Railway Co. at Chapelle.

| | Feet. |
|--|---------|
| Loam..... | 0-52 |
| Sandstone, brown..... | 52-56 |
| Sandstone, gray..... | 56-72 |
| Sandstone, white..... | 72-82 |
| Sandstone, yellow..... | 82-122 |
| Sandstone, alternating white and yellow..... | 122-340 |
| Limestone..... | 340-345 |
| Sandstone, white..... | 345-350 |
| Sandstone, red..... | 350-355 |
| Limestone..... | 355-385 |
| Not given..... | 385-460 |
| Conglomerate, sandy..... | 460-465 |
| Shale and sandstone, red..... | 465-605 |
| Sandstone, red..... | 605-897 |
| Sandstone, red, with some white..... | 897-960 |

The sandstones of the Chupadera formation extended to a depth of 350 feet or possibly to 465 feet, where characteristic red strata of the Abo sandstone were encountered. The hole was discontinued in this formation, probably about 300 feet above the top of the Magdalena beds.

A 350-foot well at Lucy passed through 125 feet of gravel to a thin bed of hard white sandstone. Below this were alternating red shale and gray limestone of the lower part of the Chupadera formation. At Pedernal Siding the white marl (80 feet) and conglomerate (40 feet) of the valley fill were found to be underlain by 70 feet of red shale with limestone beds (Chupadera formation), lying on granite, which was penetrated from 190 to 270 feet. At Negra a 500-foot boring was in mica schist and quartzite below 150 feet. The overlying beds were red shale and red sandstone, including a 10-foot bed of limestone at 110 feet.

ESTANCIA VALLEY.

The Estancia Valley is a wide, flat-bottomed basin occupying the central part of Tarrant County and most of the southern part of Santa Fe County. Its length from north to south is about 50 miles, and its average width about 25 miles. Many data relating to the geology of this area are given in a report by Meinzer.²⁶ The greater part of the surface is covered by sand and gravel several hundred feet thick, which hide the structural relations. In general the strata lie in a monocline that dips at low angles to the east, but along the east side some of the strata rise again with westerly dip on the flank of the anticline of the southern prolongation of the Rocky Mountain. (See fig. 22, p. 202.) To the south there appear in the axis of this ridge extensive exposures of pre-Cambrian quartzite constituting Pedernal Mountain and the Hills of Pedernal, and farther south, in the vicinity of Lucia and Rattlesnake Hill, schists are exposed. On the west side of Estancia Valley are long slopes of eastward-dipping limestones of the Magdalena group, which in the vicinity of Manzano and Punta pass under red sandstones of the Abo formation. (See fig. 26, p. 219.) To the south is a high wall of the Jumanes Mesa, at the north end of the Chupadera Mesa, consisting of red beds overlain by limestone of the Chupadera formation. In the slopes of the Galisteo Basin just north of Estancia Valley are exposures of Cretaceous rocks, mostly the Mancos shale, which doubtless extend for some distance southward, possibly as far as Stanley or Otto. Cerrito del Lobo is an outlying mass of pre-Cambrian quartzite, and it is stated that this rock was found in the SE. $\frac{1}{4}$ sec. 17, T. 6 N., R. 12 E., at a depth of 40 feet and in the SE. $\frac{1}{4}$ sec. 32, T. 5 N., R. 11 E., at a depth of 145 feet. A well 232 feet deep in the NE. $\frac{1}{4}$ sec. 14, T. 7 N., R. 11 E., did not find quartzite. It is evident from these facts that under the center of the southern part of Estancia Valley there is an overlap of the later Carboniferous rocks on the slope of an old ridge of quartzite, which reaches the present surface in the Hills of Pedernal.

Many shallow wells have been sunk for water in Estancia Valley, but no suitable tests have been made for petroleum, and although the prospects, structural or stratigraphic, appear not to be promising, still it is possible that oil might be found in the Magdalena group in the west half of the valley. Owing, however, to the cover of superficial materials the structural relations are hidden in the greater part of this region. In the area to the west where the limestone constitutes the surface there are several domes and anticlines, notably in the ridges east of Chilili, but the structure of these features

²⁶ Meinzer, O. E., Geology and water resources of Estancia Valley, N. Mex.: U. S. Geol. Survey Water-Supply Paper 275, 1911.

has not been unraveled in detail. The Magdalena group appears to be about 1,200 feet thick, and though it consists mainly of limestone, it includes several beds of sandstone, notably in its lower portion.

SACRAMENTO CUESTA.

GENERAL RELATIONS.

The Sacramento Mountains form the highly elevated portion of the western margin of the great limestone cuesta that extends from the east side of the Tularosa Basin to the Pecos Valley. (See Pl. XXXVI, *B*, p. 197.) This cuesta attains an altitude of more than 9,000 feet south of Cloudcroft and slopes down on the east to an altitude of about 3,200 feet in the Pecos Valley in Eddy County. To the south the high cuesta continues into the Guadalupe Mountains, which extend to the southern margin of New Mexico and to El Capitan Peak, in Texas, where the altitude is 8,690 feet. The principal structural features of this region are shown in the cross sections in figure 23. In the northwestern portion of the region there is a deep basin of Cretaceous and overlying igneous rocks, and to the north, in Capitan Mountain, the strata are cut by a large mass of later Tertiary intrusive rock. In the greater part of the region there is a general uniform dip to the east, with a few local variations and some faults. The details of structure in this region have not yet been investigated, and it is probable that when detailed surveys are made domes, anticlines, and terraces will be found on the monocline.

STRATIGRAPHY.

The rocks underlying this cuesta consist of a thick mass of the Chupadera formation, the red Abo sandstone, and 2,500 feet or more of limestones, shales, and sandstones of the Magdalena group and older formations. It appears probable that this succession includes some beds that may be favorable as sources or reservoirs of oil or gas, especially toward the east. Moreover, it is in the Chupadera formation that the oil at Dayton occurs; and although the pool in that place appears to be of small area it is not unlikely that the conditions of occurrence may be duplicated, possibly on a much larger scale, in other portions of the region. To the west the higher sandstones of the Chupadera formation are deeply trenched by the stream valleys, but to the east they pass under cover and storage conditions may be more favorable. Probably in the underlying red beds of the lower half of the Chupadera formation and in the 500 to 1,000 feet of sandstones that constitute the Abo formation the prospects for oil are very poor. On account of the more favorable composition of the beds the prospects may be better in the sandstone of the underlying Magdalena group, which are from 2,000 to 3,000 feet below the surface in this region.

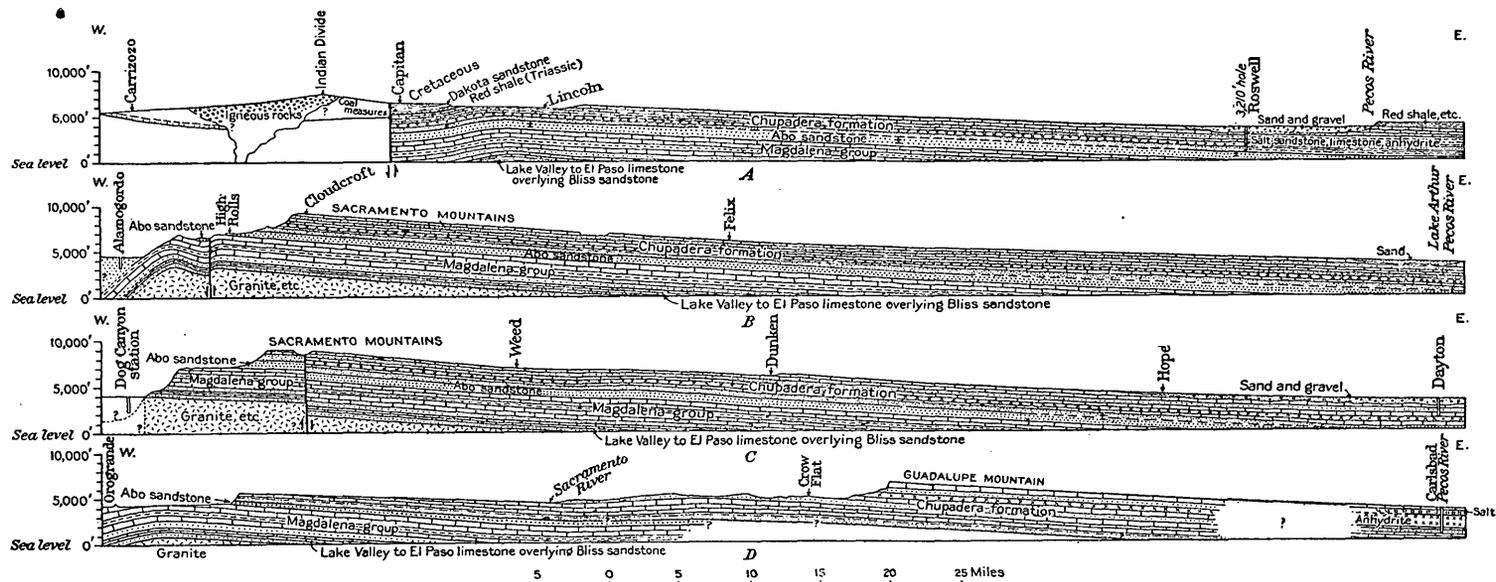


FIGURE 23.—Sections across the Sacramento Cuesta and Guadalupe Mountains in Lincoln, Chaves, Sandoval, and Eddy counties, N. Mex. *A*, From Carrizozo through Roswell; *B*, Alamogordo to Lake Arthur; *C*, Dog Canyon (Shamrock place) to Dayton; *D*, Orogrande to Carlsbad.

LOCAL STRUCTURE.

The Sacramento Mountains are due mainly to an anticlinal uplift which in the higher portion of the range for a few miles southeast of Alamogordo is probably broken by a fault. North of Alamogordo, as shown in section *B*, figure 23, the arch is complete, at least in the Magdalena group, and southeast of Alamogordo the uplift is well exposed in Alamo Creek. The arch rises so high in Agua Chiquita Canyon that the pre-Cambrian granites appear for a short distance in the west foot of the mountain. A fault passes into the mountain front 4 miles southeast of Alamogordo. At La Luz the westerly dips are pronounced. Anticlinal structure appears again to the south in and south of T. 20 N., as shown in section *D*, figure 23, and the fold is well marked east and southeast of Orogrande, where it finally continues into the Hueco Mountains in Texas. (See also section *F* in fig. 28.) Just west of High Rolls there is a second anticline, whose western limb is steeply upturned and somewhat faulted. The

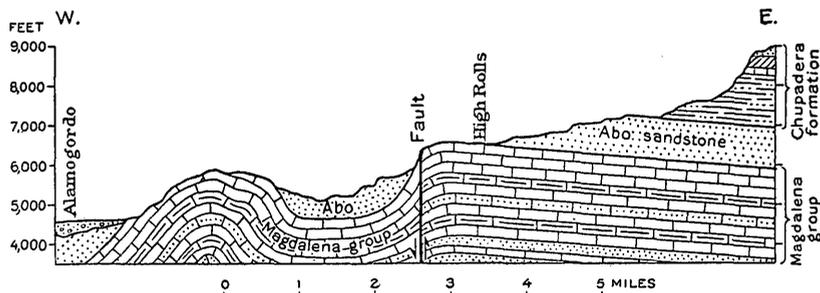


FIGURE 24.—Sketch section of anticlines and fault between Alamogordo and High Rolls, N. Mex.

Magdalena group appears in both anticlines at this place, with an intervening basin of the Abo sandstone, as shown in figure 24.

In the broad cuestas on the east slope of the Sacramento Mountains there are local deviations from the uniform eastward dip, notably below Elk, where a small anticline appears. Domes are reported near Tinnie and Picacho. In the southern extension of the range there are many undulations of the strata, notably between Sacramento River and Crow Flat, where the limestones of the Chupadera formation are somewhat flexed, as indicated in section *D*, figure 23.

In the northwestern extension of the Sacramento Cuesta in Lincoln County the strata bend down into a basin which is occupied by an extensive area of Cretaceous shales and sandstones and Tertiary igneous rocks of the Sierra Blanca. East of this basin is an anticline of considerable prominence, which, as shown in section *A*, figure 23, passes a short distance west of Lincoln. Its axis is in the outcrop of the Chupadera formation, which is underlain by the Abo sandstone and Magdalena group in regular order. This uplift passes northward through the Jicarilla Mountains and dies out in the plateaus northeast

of Ancho. A minor dome on its east slope has its crest near the center of T. 7 S., R. 16 E., not far east of the Block ranch (Richardson post office). In places along the slopes near Lincoln the lower shaly and gypsiferous beds of the Chupadera formation are considerably crumpled, presenting numerous arches and basins. This deformation is due mainly to the great intrusive mass of Capitan Mountain, not far north. The more massive upper beds are not much affected.

BORING.

A 2,199-foot hole in sec. 21, T. 11 S.; R. 18 E., near Picacho, penetrated shale with thin beds of limestone and gypsum at 113 to 445 feet, red clay and gypsum at 445 to 530 feet, limestone (mostly) at 530 to 770 feet, sandstone at 770 to 921 feet, red clay at 921 to 968 feet, limestone, shale, and sandstone at 968 to 1,670 feet, including 35 feet of rock salt at 1,109 feet, and granite at 1,670 to 2,199 feet.

PECOS VALLEY IN CHAVES AND EDDY COUNTIES.

GENERAL RELATIONS.

As stated above, the cuesta of the Sacramento Mountains slopes down eastward to the Pecos Valley, east of which the limestones of the Chupadera formation are overlain by red shales of probably Lower Triassic age. The large supplies of underground water obtained at Roswell and farther south originate in the sandstones included in the Chupadera formation. The cross sections in figure 23 show the structure of this region in the vicinity of Roswell, Lake Arthur, Dayton, and Carlsbad and indicate the general structure of a large part of the valley. The predominating feature is a monocline dipping eastward at a very low angle, which east of Pecos River carries the Chupadera formation to a moderate depth.

STRATIGRAPHY.

The surface rocks in the Pecos Valley in Chaves and Eddy counties are limestones, red shales, and gypsum beds at the top of and overlying the Chupadera formation. North of Lakewood there is a broad cover of sand and gravel, especially on the west side of the valley. Several deep borings show the character of the rocks underground to a considerable depth. The records of some of these holes are given on pages 212-215.

It will be seen from these records that the region is underlain by a thick succession of limestone, sandstone, anhydrite, and gypsum, including thick deposits of salt.^{26a} It is probable that none of these borings reached the base of the Chupadera formation, which therefore has a thickness of more than 3,000 feet under the Pecos Valley.

^{26a} For further information regarding the salt deposits and associated strata see Darton, N. H., Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, pp. 205-223, 1921.

Next below the Chupadera are the red sandstones of the Abo formation, probably at least 700 feet thick, and then the limestones and sandstones of the Magdalena group, 2,500 feet thick, which may either extend to the pre-Cambrian basement or be separated from the crystalline rocks by older limestones and shales.

East of Pecos River there is a long irregular upgrate to the foot of the Llano Estacado. This slope consists of red beds overlying the Chupadera formation and in general having the same low dip toward the east. The rocks are mainly red shales and sandstones, with beds of limestone and gypsum not unlike those constituting part of the Chupadera formation. The total thickness of this series of deposits from the east bank of the river to the foot of the rise to the Llano Estacado is between 600 and 700 feet. A boring 25 miles east of Roswell penetrated the lower half of the series and then continued deeply into the Chupadera formation. The record given on pages 214-215 shows the beds penetrated.

LOCAL STRUCTURE.

The Pecos Valley in Chaves and Eddy counties is in general an eastward-dipping monocline, in which the dips at most places are very low. No special scrutiny was given to the details of structure, and probably there are minor domes and anticlines which might possibly present favorable conditions for the accumulation of oil or gas. A short distance southwest of Roswell there appears to be a feature of this sort, and others occur west and northwest of Carlsbad. In much of the area along the river and extending far up the slopes to the west there is a mantle of sand and gravel which hides the rocks, so that the structure can not be determined by observations at the surface.

OIL.

The only occurrence of oil in notable amount in the Pecos Valley in New Mexico is in a few wells near Dayton.²⁷ These wells are in secs. 25, 15, and 26, T. 18 S., R. 26 E. The largest yield of petroleum reported came from the Brown well, sunk in 1909 to a depth of 950 feet. The amount which this well was capable of producing was reported to be about 25 barrels a day between 911 and 926 feet. Small quantities of gas and oil were obtained from the Belt well, in the NW. $\frac{1}{4}$ sec. 25, about 1,000 feet deep, and considerable gas was struck in the Platt well, in the SW. $\frac{1}{4}$ sec. 26, at a depth of 869 feet. These wells were all in a sand-covered plain, and no information could be obtained as to the structural conditions. A number of test borings sunk in the same vicinity failed to obtain oil. Whether the failure was due to unfavorable structure or to the small extent of the oil-bearing sands could not be ascertained. The

²⁷ Richardson, G. B., Petroleum near Dayton, N. Mex.: U. S. Geol. Survey Bull. 541, pp. 22-27, 1914.

beds are in the Chupadera formation, and they underlie a wide area of the Pecos Valley at about the same depth as in the wells that yield oil. It is not unlikely that these beds will be found to contain oil at other localities, especially if favorable structure exists.

In testing for oil in Pecos Valley it is desirable not only to penetrate all the beds of the Chupadera formation but if no oil is found to sink through the Abo sandstone into sandstones of the Magdalena group. Unfortunately, however, the Magdalena beds lie at a depth approaching 5,000 feet, which will make the cost of test wells rather too high to undertake unless favorable structure can be found.

DEEP BORINGS.

The deep boring 13 miles northeast of Roswell was undoubtedly in the Chupadera formation throughout. Probably, however, the top of the Abo sandstone was not far below its bottom. The following record was kindly furnished by the Toltec Co.

Record of boring in sec. 31, T. 8 S., R. 24 E., 13 miles north-northeast of Roswell, N. Mex.

| | Feet. |
|--|---------------|
| Dolomite..... | 0-90 |
| Sandstone on dolomite..... | 90-110 |
| Gypsum and dolomite..... | 110-140 |
| Limestone..... | 140-165 |
| Dolomite..... | 165-250 |
| Limestone and dolomite..... | 250-390 |
| Sandstone..... | 390-396 |
| Limestone; some sandstone at 518-600 feet..... | 396-620 |
| Limestone and dolomite..... | 620-710 |
| Sandstone..... | 710-770 |
| Dolomite..... | 770-860 |
| Shale, dark..... | 860-864 |
| Sandstone, red and pink..... | 864-1, 033 |
| Salt on dark shale..... | 1, 033-1, 052 |
| Gypsum..... | 1, 052-1, 067 |
| Dolomite..... | 1, 067-1, 076 |
| Anhydrite..... | 1, 076-1, 123 |
| Dolomite on thin gypsum..... | 1, 123-1, 168 |
| Salt..... | 1, 168-1, 200 |
| Gypsum..... | 1, 200-1, 230 |
| Dolomite..... | 1, 230-1, 280 |
| Shale, dark..... | 1, 280-1, 295 |
| Dolomite..... | 1, 295-1, 318 |
| Shale, red..... | 1, 318-1, 349 |
| Dolomite..... | 1, 349-1, 366 |
| Sandstone..... | 1, 366-1, 380 |
| Anhydrite..... | 1, 380-1, 386 |
| Salt..... | 1, 386-1, 449 |
| Sandstone, red, with 15 feet of gypsum..... | 1, 449-1, 504 |
| Salt..... | 1, 504-1, 565 |
| Dolomite on shale..... | 1, 565-1, 582 |

| | Feet. |
|---|---------------|
| Sandstone, red..... | 1, 582-1, 620 |
| Salt..... | 1, 620-1, 645 |
| Dolomite, gray to brown..... | 1, 645-1, 730 |
| Sandstone, red..... | 1, 730-1, 771 |
| Salt..... | 1, 771-1, 800 |
| Anhydrite..... | 1, 800-1, 858 |
| Dolomite..... | 1, 858-1, 906 |
| Salt..... | 1, 906-2, 010 |
| Shale, gray..... | 2, 010-2, 025 |
| Salt..... | 2, 025-2, 050 |
| Dolomite, with two beds of gypsum..... | 2, 050-2, 154 |
| Salt..... | 2, 154-2, 205 |
| Dolomite on sandstone..... | 2, 205-2, 268 |
| Salt..... | 2, 268-2, 310 |
| Dolomite..... | 2, 310-2, 317 |
| Anhydrite..... | 2, 317-2, 335 |
| Dolomite..... | 2, 335-2, 375 |
| Gypsum..... | 2, 375-2, 435 |
| Salt..... | 2, 435-2, 455 |
| Sandstone, red, on pink shale..... | 2, 455-2, 507 |
| Dolomite on red sandy clay..... | 2, 507-2, 530 |
| Shale, dark, and dolomite..... | 2, 530-2, 548 |
| Sandstone, red..... | 2, 548-2, 625 |
| Gypsum..... | 2, 625-2, 685 |
| Salt..... | 2, 685-2, 710 |
| Anhydrite, 9 feet, on dolomite..... | 2, 710-2, 730 |
| Sandstone..... | 2, 730-2, 740 |
| Salt..... | 2, 740-2, 750 |
| Anhydrite..... | 2, 750-2, 770 |
| Sandstone, red..... | 2, 770-2, 800 |
| Anhydrite..... | 2, 800-2, 805 |
| Dolomite..... | 2, 805-2, 830 |
| Salt..... | 2, 830-2, 860 |
| Gypsum..... | 2, 860-2, 950 |
| Dolomite..... | 2, 950-2, 971 |
| Gypsum and sandy clay..... | 2, 971-3, 025 |
| Sandstone, red, dolomitic below 3,063 feet..... | 3, 025-3, 120 |

The following record of a deep boring for oil near Carlsbad shows a great thickness of salt and anhydrite in the Chupadera formation:

Record of boring in the NE. $\frac{1}{4}$ sec. 4, T. 22 S., R. 28 E., near Carlsbad, N. Mex.

| | Feet. |
|------------------------------|---------------|
| Gypsum..... | 0-14 |
| Sand, red..... | 14-120 |
| Limestone, soft..... | 120-175 |
| Clay, light, sandy..... | 175-300 |
| Anhydrite..... | 300-485 |
| Salt..... | 485-618 |
| Anhydrite..... | 618-650 |
| Salt..... | 650-1, 118 |
| Anhydrite..... | 1, 118-2, 380 |
| Limestone and anhydrite..... | 2, 380-2, 490 |
| Sandstone, hard..... | 2, 490-2, 500 |

| | Feet. |
|-----------------------------|---------------|
| Limestone..... | 2, 500-2, 555 |
| Sandstone..... | 2, 555-2, 630 |
| Limestone..... | 2, 630-2, 700 |
| Sandstone, mostly fine..... | 2, 700-2, 810 |
| Limestone..... | 2, 810-2, 820 |

Record of boring of Dayton Petroleum Co., in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 23, T. 18 S., R. 26 E.

| | Feet. |
|---|------------|
| [April, 1913.] | |
| Sand and gravel..... | 0-25 |
| Gypsum..... | 25-65 |
| Shale, blue to gray..... | 65-350 |
| Sand..... | 350-355 |
| Shale, gray..... | 355-434 |
| Sandstone, hard..... | 434-436 |
| Shale, blue, on gravel and sand..... | 436-468 |
| Gypsum..... | 468-482 |
| "Concrete"..... | 482-488 |
| Shale, gray and blue..... | 488-630 |
| Red sand on red sandy shale..... | 630-685 |
| Clay and red sand..... | 685-699 |
| Hard rock..... | 699-715 |
| Red sand and shale..... | 715-750 |
| Limestone, some soft, and red shale..... | 750-879 |
| Gypsum..... | 879-894 |
| Limestone and red shale; "oil at 930-935 feet"..... | 894-957 |
| Limestone, with 5 feet of white sand..... | 957-1, 126 |

Record of boring on Arroyo ranch of Southspring Ranch & Cattle Co., in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 5, T. 11 S., R. 28 E., Chaves County, about 25 miles east of Roswell.

| | Feet. |
|--|---------------|
| Clay, sand, and gravel..... | 0-75 |
| Sandstone, red..... | 75-150 |
| Sandstone, red, and shale..... | 150-300 |
| Red rock and "lime shells"; gas at 435 and 460 feet..... | 300-600 |
| Shale, pink, and "lime shells"..... | 600-640 |
| Shale, red..... | 640-700 |
| Limestone, hard..... | 700-710 |
| Red rock and "lime shells"..... | 710-750 |
| Pink rock..... | 750-800 |
| Sandstone, red, limestone, and 2 feet of salt..... | 800-850 |
| Pink rock..... | 850-900 |
| Limestone, white..... | 900-915 |
| Pink and red rocks..... | 915-990 |
| Sandstone, red..... | 990-1, 010 |
| Red rocks and white limestone..... | 1, 010-1, 125 |
| "Lime shell" and red sandrock..... | 1, 125-1, 140 |
| Sandstone, red, and shale..... | 1, 140-1, 350 |
| Sandstone, red, with "lime shells"..... | 1, 350-1, 400 |
| Shale, red..... | 1, 400-1, 450 |
| Sand, red and gray..... | 1, 450-1, 485 |
| Sand, red, and white limestone..... | 1, 485-1, 540 |
| Limestone and pink rock..... | 1, 540-1, 625 |
| Limestone, light and dark..... | 1, 625-2, 098 |
| Sand, brown, "showing of oil"..... | 2, 098-2, 118 |
| Limestone, sandy, brown..... | 2, 118-2, 150 |

| | Feet. |
|---|---------------|
| Limestone, light and dark..... | 2, 150-2, 756 |
| Pebbly sand, white, with 4 feet of red sandstone..... | 2, 756-2, 800 |
| Limestone, light and dark..... | 2, 800-2, 850 |
| Clay and blue shale..... | 2, 850-2, 943 |

Record of Tannehill well, 7 miles northeast of Roswell, N. Mex.

| | Feet. |
|--------------------------|---------------|
| Gypsum and clay..... | 0-60 |
| White sand..... | 60-140 |
| Clay and gypsum..... | 140-280 |
| Red sand..... | 280-330 |
| Clay..... | 330-340 |
| Water rock..... | 340-390 |
| Limerock..... | 390-410 |
| Red cave..... | 410-415 |
| Water rock..... | 415-510 |
| Loose clay rock..... | 510-565 |
| Black lime..... | 565-620 |
| Water rock..... | 620-650 |
| Black lime..... | 650-740 |
| White lime..... | 740-775 |
| Sandstone..... | 775-810 |
| White lime..... | 810-850 |
| Black lime..... | 850-900 |
| Gray and white lime..... | 900-1, 050 |
| Sandstone..... | 1, 050-1, 175 |
| Limestone..... | 1, 175-1, 205 |
| Shells and mud..... | 1, 205-1, 360 |
| Limerock and salt..... | 1, 360-1, 385 |
| Red rock..... | 1, 385-1, 405 |
| Limestone..... | 1, 405-1, 510 |
| Blue shale..... | 1, 510-1, 520 |
| Limestone..... | 1, 520-1, 600 |
| Mud and lime shells..... | 1, 600-1, 670 |
| Limestone..... | 1, 670-1, 805 |
| Red mud..... | 1, 805-1, 850 |
| Limestone..... | 1, 850-1, 925 |
| Salt..... | 1, 925-1, 940 |
| Blue lime..... | 1, 940-1, 970 |
| Black lime..... | 1, 970-2, 005 |
| Blue shale..... | 2, 005-2, 008 |
| Limestone..... | 2, 008-2, 030 |
| Blue shale..... | 2, 030-2, 037 |
| Black lime..... | 2, 037-2, 060 |
| Shale..... | 2, 060-2, 080 |

Late in 1920 borings were in progress at the following places in Pecos Valley in Chaves and Eddy counties:

- SE. $\frac{1}{4}$ sec. 15, T. 12 S., R. 25 E., 10 miles southeast of Roswell.
- SW. $\frac{1}{4}$ sec. 15, T. 15 S., R. 26 E., 2 $\frac{1}{2}$ miles northeast of Lake Arthur.
- Sec. 15, T. 24 S., R. 27 E., 6 miles east of Carlsbad.
- NE. $\frac{1}{4}$ sec. 18, T. 22 S., R. 27 E., 1 $\frac{1}{2}$ miles south of Carlsbad.
- Sec. 10, T. 20 S., R. 25 E., 15 miles northwest of Carlsbad.
- Sec. 27, T. 19 S., R. 23 E., 30 miles northwest of Carlsbad.
- Sec. 16, T. 19 S., R. 26 E., 1 $\frac{1}{2}$ miles north of Lakewood.
- SE. $\frac{1}{4}$ sec. 28, T. 18 S., R. 26 E., in Dayton.

The hole $1\frac{1}{2}$ miles south of Carlsbad penetrated red beds to 300 feet; anhydrite, 302 to 406 feet; rock salt, 460 to 744 feet; limestone, black in lower part, 744 to 1,748 feet; and sandstones and shales, 1,748 to 2,071 feet. The hole near Orchard Park, 10 miles south of Roswell, penetrated beds predominantly red to 534 feet, limestones and red clays to water sand at 810 feet and limestones, from 810 to 2,295 feet. A 2,966-foot boring northeast of Lake Arthur penetrated red shales with gypsum to 534 feet, below which limestone was the principal material. A large artesian flow was found at 1,205 feet.

STAKED PLAINS REGION.

In the Staked Plains region, the high plateau east of Pecos Valley, the beds lie in a general monocline with eastward dips at very low angles. Doubtless, however, there are many local irregularities in the amount and direction of dip, and there may be low domes and arches and shallow basins. The region is covered by a mantle of Tertiary sand and gravel 100 feet or more thick which conceals the underlying red beds. These rocks, however, are exposed all around the edges of the plateau and have been penetrated by borings. They are mostly red shale with thin layers of limestone and deposits of gypsum. They are underlain at moderate depths by a thick succession of older red beds and limestones containing widespread deposits of salt, anhydrite, and gypsum. To the north and possibly locally in other areas thin masses of earlier Cretaceous sandstone lie between the red beds and the overlying mantle of Tertiary deposits. The succession and structure in the red beds have not been ascertained. In 1920 wells prospecting for oil were in progress at Kenna, at a point 4 miles southeast of Garrison, and 10 miles southeast of Portales. In the last a depth of 900 feet was attained, all in red beds.

CERRILLOS BASIN.

The Cerrillos coal basin is a syncline that contains coal measures of Mesaverde age, overlain by the Galisteo sandstone, of supposed early Tertiary age. The axis of the basin extends east and southeast across the west-central part of Santa Fe County. Cerrillos is on its north slope, and the coal-mining town of Madrid is near its center. Most of the structural features have been presented by Johnson²⁷ and Lee.²⁸ To the south, north, and east the strata are cut by thick masses of early Tertiary igneous rock and penetrated by numerous dikes. To the west the basin is cut off by a fault, the country to the

²⁷ Johnson, D. W., *Geology of the Cerrillos Hills, N. Mex.*; School of Mines Quart., vol. 24, pp. 173-246, 303-350, 456-500; vol. 25, pp. 69-98, 1903.

²⁸ Lee, W. T., *Stratigraphy of the coal fields of northern New Mexico*; Geol. Soc. America Bull., vol. 23, pp. 571-686, 1912; *The Cerrillos coal field, Santa Fe County, N. Mex.*; U. S. Geol. Survey Bull. 531, pp. 285-312, 1913.

northwest is covered by a recent lava sheet, to the northeast there is a heavy covering of the Santa Fe formation, and to the south and southwest lies the laccolithic igneous mass of Ortiz Mountain. The rocks below the Mesaverde formation rise in regular succession to the northwest, the lowest formation exposed being the top of the red beds. (See Pl. XXXIX, A, p. 220.) To the east there is a similar rise to the long monoclinical slope east of Galisteo. No subordinate domes or anticlines were observed. Several deep holes have been bored in the basin in a search for coal, and no gas or oil was reported in them.

UPPER RIO GRANDE VALLEY.

The valley of the Rio Grande in Taos, Rio Arriba, and Santa Fe counties is occupied by thick deposits of the sands, loams, and gravels of the Santa Fe formation (Miocene and Pliocene), overlain in part by lavas that have flowed down the valley in relatively recent geologic time. The underlying rocks are probably very largely pre-Cambrian granites and schists similar to those which constitute the adjoining Rocky Mountains on the east and appear in the scattered outcrops in the high ridges on the east side of Rio Arriba County. These rocks do not offer any prospects whatever for oil or gas. It is probable that some portions of the bottom of the basin are underlain by limestones and sandstones of the Magdalena group, which appear so extensively in the Rocky Mountains to the east. From Santa Fe to Truchas these rocks dip under the valley, but how far they extend in that direction can not be determined without test borings. Pre-Cambrian schists appear in the bottom of the valley at Glenwoody, and along the west side of the valley granite or schist extends down to the great lava flow at Tres Piedras, Petaca, and Ojo Caliente.

SANDIA AND MANZANO MOUNTAINS AND SIERRA DE LOS PINOS.

GENERAL RELATIONS.

The Sandia Mountains, which lie on the east side of the Rio Grande east of Albuquerque, mark an uplift of considerable magnitude which is continued southward in the Manzano Mountains and the Sierra de los Pinos, extending into the central eastern portion of Socorro County. This series of ranges presents a continuous exposure of granite, schist, quartzite, and other pre-Cambrian crystalline rocks along its steep west face, as shown in Plate XXXVII, and long slopes of limestones of the Magdalena group on its east side, which extends to Estancia Valley. Along part of its west face there is considerable faulting, with the downthrow on the west side, but the relations in this direction are obscured by the heavy cover of sand and talus that slopes to the Rio Grande valley. Sections 1 to 3 in figure 26 show the principal structural relations of this series of ranges.

The monocline on the east side presents a gradual, nearly regular easterly dip for many miles, but locally there are minor flexures, anticlines, and domes, which may possibly present conditions favorable for oil or gas. One of the most notable of these is the faulted anticline north of Tijeras, some features of which are shown in figure 25. At the north end of the range, a few miles northeast of Algodones, the general anticline of the Sandia Mountains pitches gradually beneath the surface, and this may prove to be a favorable structural condition for oil or gas if these materials are present. The

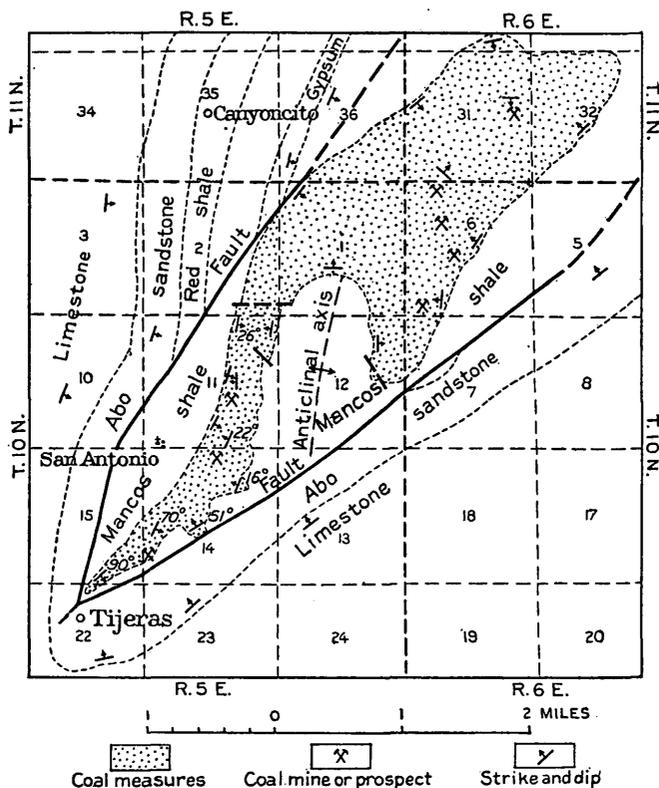
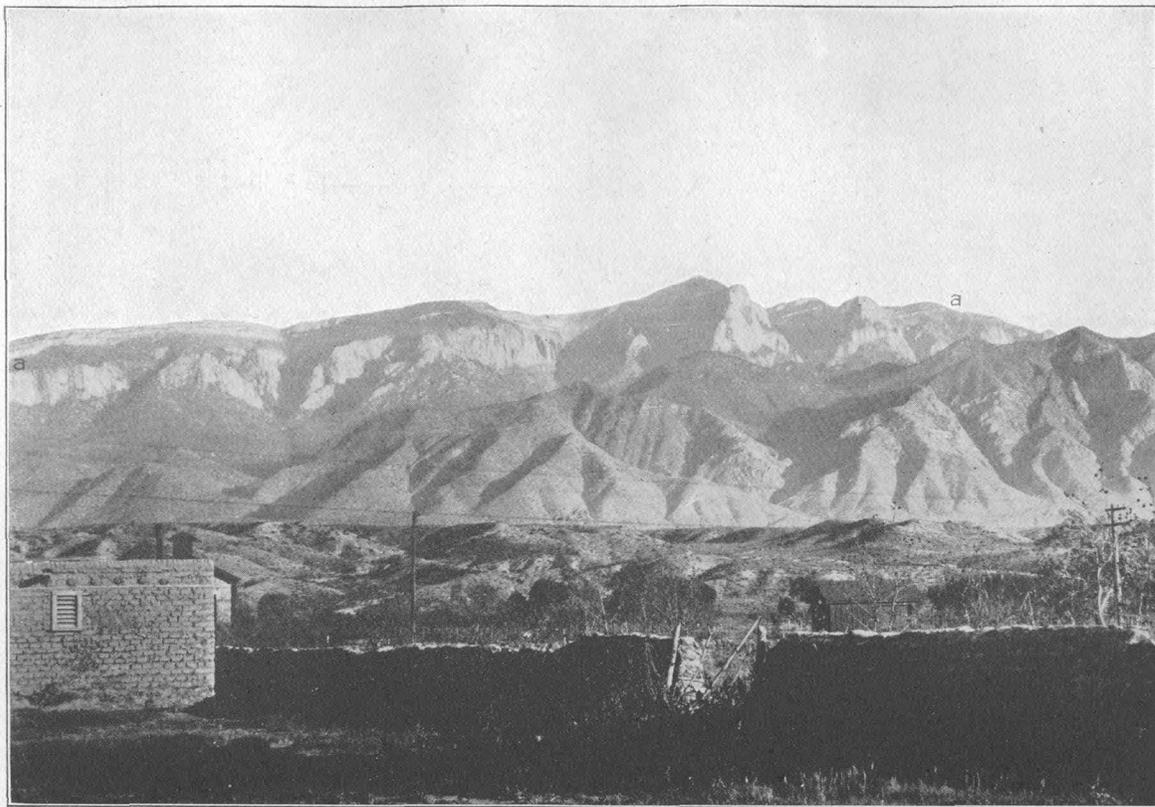


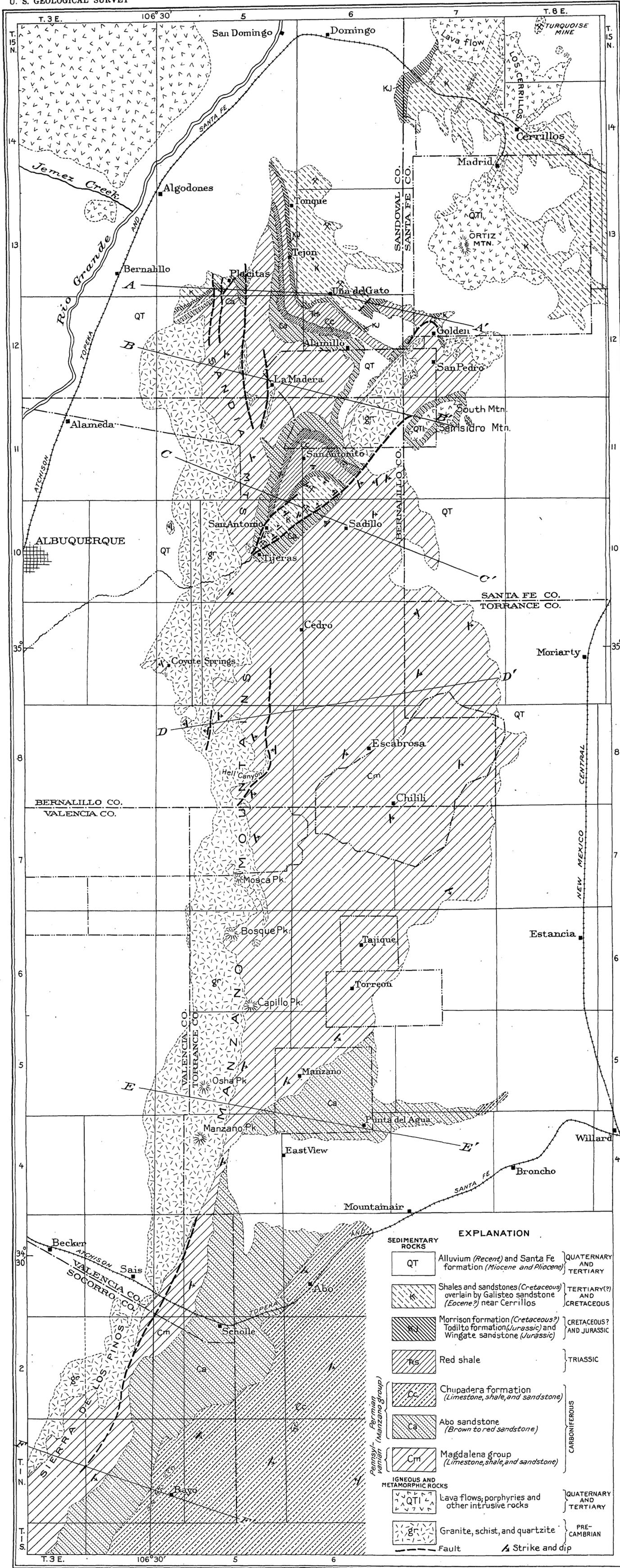
FIGURE 25.—Map showing relation of anticline in Tijeras coal field, on east slope of Sandia Mountains, east of Albuquerque, Bernalillo County, N. Mex.

Magdalena group, which lies directly on the granite and other crystalline rocks, is about 1,500 feet thick and comprises extensive deposits of sandstone in its lower portion and massive limestone in its medial and upper portions. Although there is no direct evidence that there is oil in this formation, it may be desirable to drill test holes in the domes near Chilili, as well as in the northward-pitching anticline at the north end of the uplift. In this anticline the Permian, Triassic, Jurassic, and Cretaceous rocks pass over the axis, and possibly they include some strata favorable for the occurrence of oil or gas. The anticline north of Tijeras may also merit testing, for it includes a thick mass of Cretaceous strata. (See fig. 25.)



WEST FRONT OF SANDIA MOUNTAINS AT BERNALILLO, N. MEX.

a, Sandia formation on granite, etc.



GEOLOGIC MAP OF SANDIA AND MANZANO MOUNTAINS AND SIERRA DE LOS PINOS, NEW MEXICO

5 0 5 10 Miles

| EXPLANATION | |
|--------------------------------------|---|
| SEDIMENTARY ROCKS | |
| QT | Alluvium (Recent) and Santa Fe formation (Miocene and Pliocene) } QUATERNARY AND TERTIARY |
| K | Shales and sandstones (Cretaceous) overlain by Galisteo sandstone (Eocene?) near Cerrillos } TERTIARY(?) AND CRETACEOUS |
| KJ | Morrison formation (Cretaceous?) Todilto formation (Jurassic) and Wingate sandstone (Jurassic) } CRETACEOUS? AND JURASSIC |
| Rs | Red shale } TRIASSIC |
| Cc | Chupadera formation (Limestone, shale, and sandstone) } CARBONIFEROUS |
| Ca | Abo sandstone (Brown to red sandstone) |
| Cm | Magdalena group (Limestone, shale, and sandstone) |
| IGNEOUS AND METAMORPHIC ROCKS | |
| QTI | Lava flows, porphyries and other intrusive rocks } QUATERNARY AND TERTIARY |
| g | Granite, schist, and quartzite } PRE-CAMBRIAN |
| — | Fault |
| ▲ | Strike and dip |

DEEP BORINGS.

Test wells sunk several years ago on Tonque Creek 10 miles east of Algodones were unsuccessful, but they were situated on the eastward-dipping monocline east of the main Sandia axis. A boring in prog-

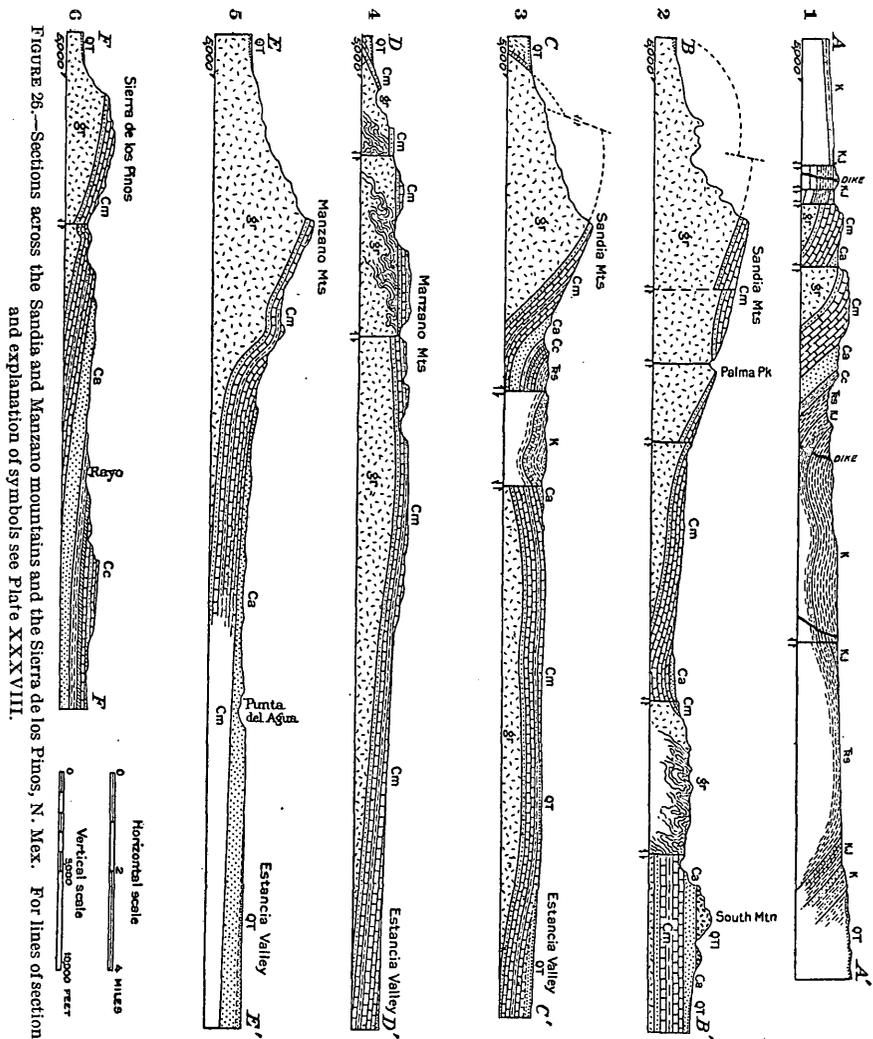


Figure 26.—Sections across the Sandia and Manzano mountains and the Sierra de los Pinos, N. Mex. For lines of sections and explanation of symbols see Plate XXXVIII.

ress early in 1919 about 2 miles west of Eastview is also on the eastward-dipping monocline and will have to penetrate 900 feet or more of the Abo red sandstone before reaching the Magdalena group. The structural conditions in the vicinity of this well are shown in section 5, figure 26. A hole 1,100 feet deep bored at Abo siding by the Atchison, Topeka & Santa Fe Railway Co. obtained considerable

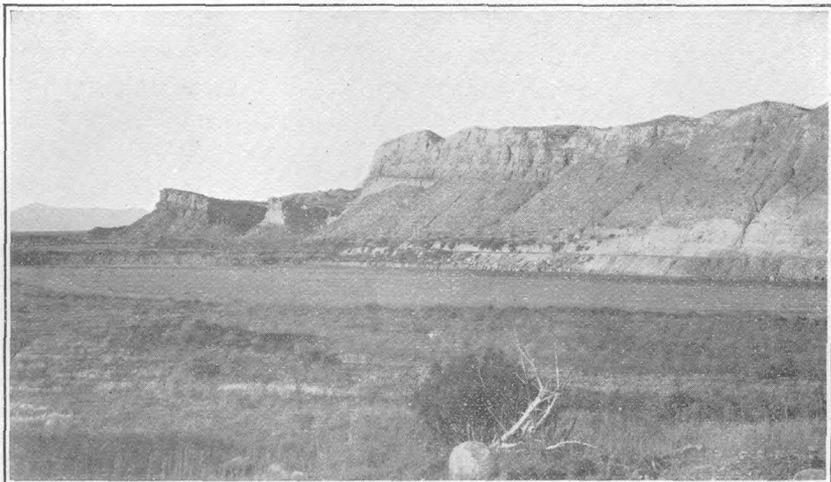
saline water.³⁰ The material penetrated was sandstone and shale, nearly all red and representing almost the full thickness of the Abo sandstone, here dipping at a low angle to the east. This hole shows practically the same conditions as those at Eastview, except that at the latter place there is a thick cover of gravel and sand.

If oil pools are developed in the Pecos Valley, it is likely that well-located test holes will be drilled in the region just described.

RIO GRANDE VALLEY IN CENTRAL NEW MEXICO.

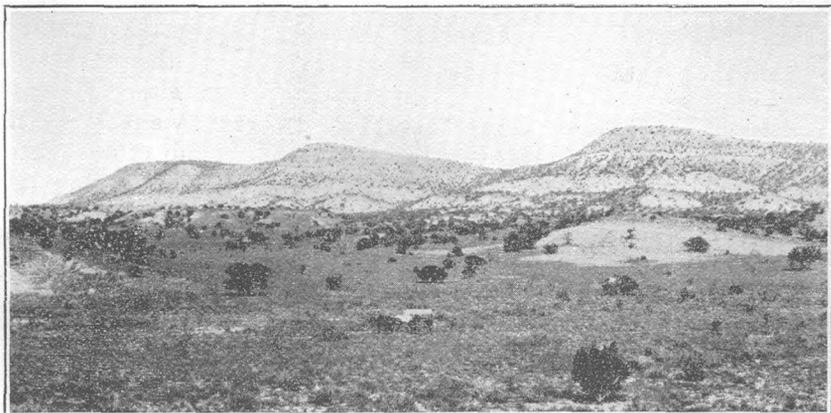
South of the Valle Grande Mountains and White Rock Canyon the valley of the Rio Grande widens greatly, and from Bernalillo County nearly to Socorro, a distance of 60 miles, it is 30 miles wide. This broad valley is floored by a thick body of loam, sand, and gravel of the Santa Fe formation, largely covered by talus from the adjoining slopes and alluvium in the valley bottom. The underground structure has not been determined, for the few borings that have been made are not sufficiently deep to reach the hard-rock strata and the relations exposed in the adjoining ridges do not indicate the structure. As shown in figure 26, the entire west front of the Sandia and Manzano mountains and the Sierra de los Pinos consists of granite, schist, and other pre-Cambrian rocks, with a few small showings of westward-dipping limestones of the Magdalena group at the foot of the range. Near La Joya and on the east slope of the Sierra Ladrones granite appears, which may indicate that this rock underlies a considerable portion of the valley. Along the west side of the valley are areas of the Magdalena group and some of the immediately overlying sandstones and limestones, but they are cut off by a fault, so that the relations to the east are not indicated. Along the valley of Rio Puerco in most of Bernalillo County the Mancos and overlying higher Montana rocks are exposed, but they also are cut off to the east by a fault. It seems probable that although the west side of the Sandia-Manzano-Pinos uplift is marked by a fault of considerable amount, the dropped westward-dipping limb of the anticline lies west of this fault, and that there is a continuous series of westward-dipping sedimentary formations extending along the east side of the valley in Valencia, Bernalillo, and Sandoval counties. The valley is therefore probably a basin underlain by a regular succession of sedimentary strata from the Magdalena group to beds high in the Cretaceous, some of which come to the surface in the Puerco Valley west of Albuquerque. It is of course possible that a syncline of this character might be interrupted by domes or anticlines or other structural features favorable for the accumulation of oil or gas. Owing, however, to the heavy covering of the young formations in the valley it is not possible to advance any definite opinion in this

³⁰ The railroad chemist reported that water from a depth of 1,045 feet contained 1,710 grains per gallon of saline materials, comprising about $\frac{1}{3}$ sodium chloride, $\frac{1}{4}$ sodium sulphate, $\frac{1}{8}$ sodium carbonate, and $\frac{1}{8}$ calcium carbonate expressed in these probable combinations.



A. DAKOTA SANDSTONE ON WEST SLOPE OF CERRILLOS BASIN, N. MEX.

Two miles east of Rosario station, Atchison, Topeka & Santa Fe Railway. Thick bed of gypsum of Todilto formation in lower slope.



B. WEST FRONT OF CHUPADERA MESA, N. MEX., LOOKING NORTH.

Limestone and gypsum of Chupadera formation.

regard. In places the sandstones of the Santa Fe formation dip in various directions, but this structure should not be expected to continue downward into the Cretaceous and underlying rocks, to which the Santa Fe formation is entirely unconformable.

The only deep borings reported in this area are two 500-foot holes for water at Becker and Bodega. The hole at Becker penetrated red clay with "gravel" intercalated to 375 feet and solid red clay below. The hole at Bodega, which is 10 miles southeast of Belen, was in sand to 290 feet, light clay from 290 to 340 feet, and red clay from 340 to 500 feet. The formations represented by these materials are not identified. They may all be either Pleistocene or late Tertiary.

CHUPADERA MESA.

GENERAL RELATIONS.

Chupadera Mesa is a high plateau covered with limestone that occupies the eastern part of Socorro County and extends northward into Mesa Jumanes, in the southern part of Torrance County. Its higher portions in the high escarpment 6 miles south of Mountainair reach an altitude considerably above 7,500 feet. In greater part the strata in the mesa have a general monoclinical structure, with a slight nearly uniform dip to the east and southeast. The mesa presents on the north and west high cliffs of sandstone and limestone, as shown in Plate XXXIX, B.

STRATIGRAPHY.

The entire surface of Chupadera Mesa has a thick capping of limestone, but some of the canyons expose underlying sandstones and lower limestone members. All these beds are part of the Chupadera formation, which in this area has a thickness of about 1,400 feet. It is underlain by the red sandstone of the Abo formation, nearly 1,000 feet thick, which in turn lies on 1,200 to 1,500 feet of limestones with included beds of shale and sandstone belonging to the Magdalena group. The lower beds of the Magdalena group, which lie on granite and schists, are largely sandstone.

LOCAL STRUCTURE.

The principal structural features and relations of Chupadera Mesa are indicated in the sections in figure 27. The higher part of the mesa consists of a monocline dipping gently to the southeast on the east slope of the Oscura anticline. Careful inspection of the area, however, may reveal some irregularities in this structure. On the west side of the mesa there is a prominent anticline which marks the northern continuation of the uplift of the Sierra Oscura. (See fig. 27.) This arch pitches down to the north and passes into the mesa in T. 1 N., where it appears to merge into the general monocline. In Tps. 1, 2, 3, and 4 S., however, this anticline presents favorable

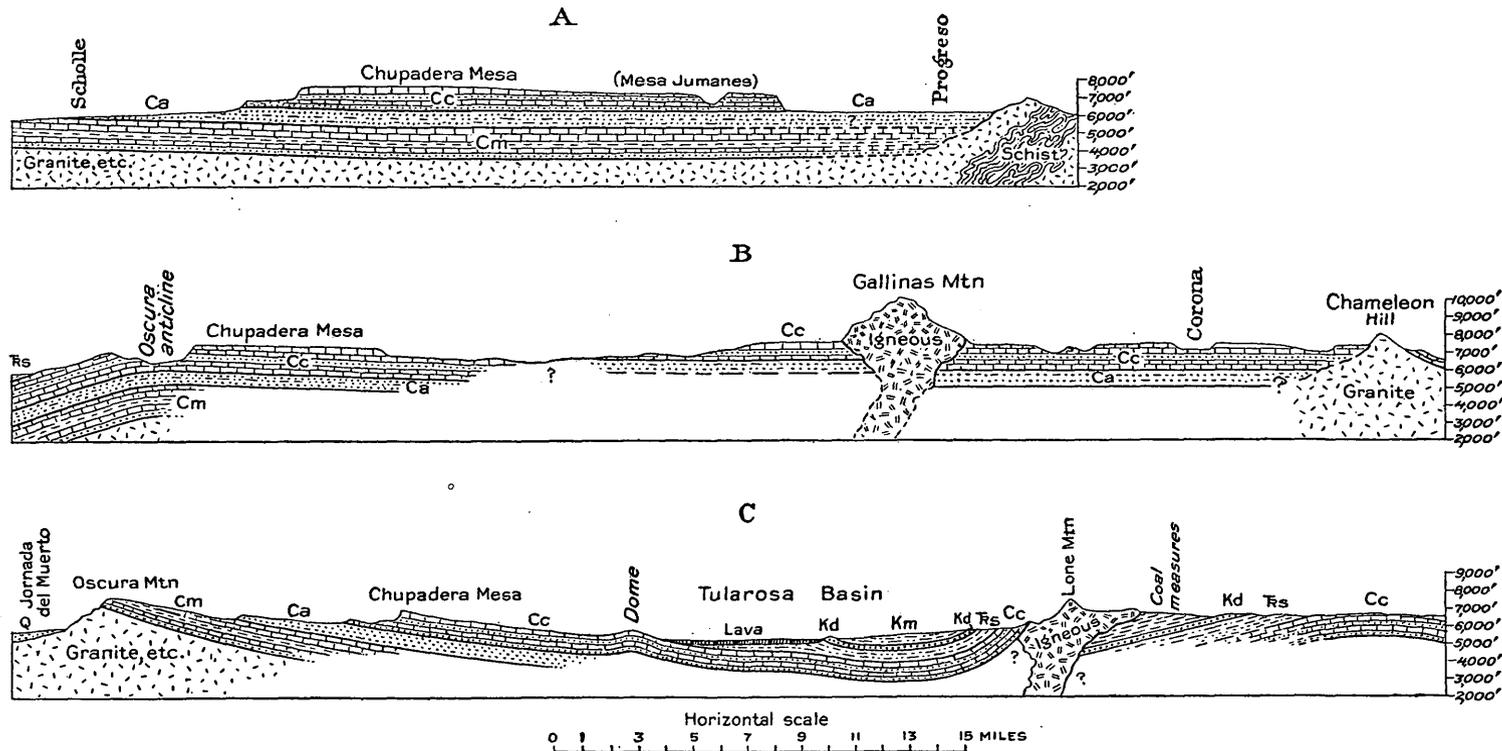


FIGURE 27.—Sections across Chupadera Mesa, in the southern part of Torrance County and the eastern part of Socorro County, N. Mex., showing relations to some adjoining ridges. A, From Scholle to Progreso; B, from a point north of the north end of Oscura Mountain to Chameleon Hill, northeast of Corona; C, from Oscura Mountain through Lone Mountain near Whiteoaks. Q, Quaternary; Km, Mancos (?) shale; Kd, Dakota (?) sandstone; Rs, Dockum group; Cc, Chupadera formation; a, Abo sandstone; Cm, Magdalena group.

structural conditions, and oil or gas, if they are present in this region, may possibly be found in the Magdalena group at depths of 1,000 to 2,000 feet. A small dome on the east slope of the mesa, with its crest in T. 6 S., R. 9 E., shown in section C, figure 27, may also be of importance.

TULAROSA BASIN.

GENERAL RELATIONS.

Most of the surface of Tularosa Basin from Carrizozo southward is covered by sand, lava, and wash, but data obtained at intervals along its edges indicate that the general structure is synclinal. There is some faulting along the edges and possibly also in its central part, toward the south. The idea sometimes advanced that it is simply a down-faulted block is erroneous. In Plate XL and figure 28 are shown the principal structural features. Near Carrizozo there is a thick eastward-dipping succession from Chupadera limestones on the west to Cretaceous rocks as high as coal measures of Mesaverde age on the east. Near Alamogordo a great thickness of eastward-dipping limestones and sandstones constitute the high Sacramento Mountains. On the west side of the basin is the east face of the San Andres Mountains, with westward-dipping Paleozoic limestones surmounting steep slopes of granites and schists, and to the northwest are the eastward-dipping cuesta of the Sierra Oscura and Chupadera Mesa. An anticlinal arch crosses the basin diagonally southwest of Carrizozo and west of Oscuro, passes under the eastern part of Alamogordo, rises in the west face of the Sacramento Mountains, and continues southward into the Hueco Mountains. The structure west of this anticline to the foot of the San Andres Mountains is concealed by the valley fill.

STRATIGRAPHY.

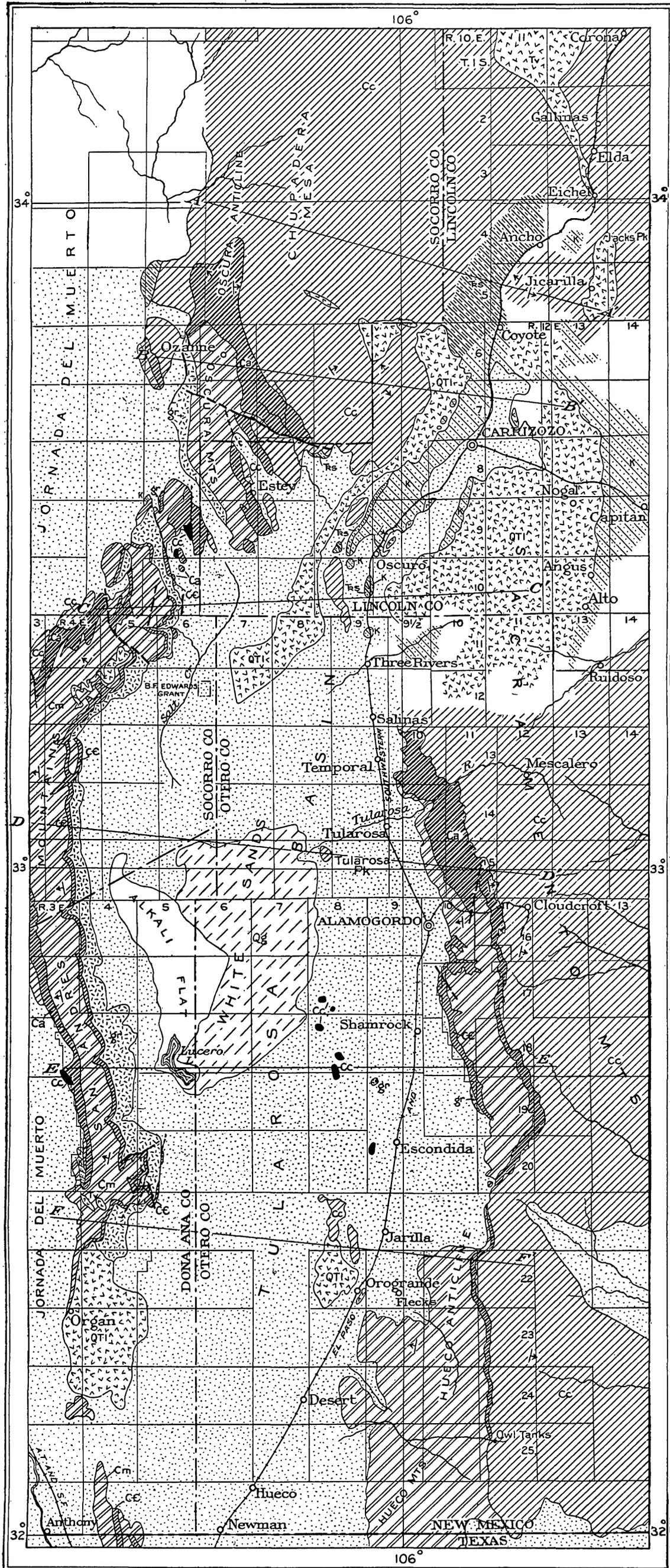
The rocks in the Tularosa Basin region comprise strata ranging from Cambrian to late Cretaceous in age, on a basement of pre-Cambrian granite and schists. A considerable thickness of gravel and sand occupies the center of the basin, and volcanic rocks are abundant, including an older porphyry and a thick succession of late Tertiary fragmental and effusive sheets, dikes, and stocks of various kinds. A long, narrow recent lava flow, "the Malpais," is conspicuous in the center of the basin. The following table shows the principal features of the strata, mainly as exhibited in the adjoining Sacramento and San Andres mountains. The rocks from Cambrian to Carboniferous age have been described in considerable detail in a previous report.³¹

³¹ Darton, N. H., A comparison of Paleozoic sections in southern New Mexico: U. S. Geol. Survey Prof. Paper 108, pp. 31-55, 1917.

Sedimentary formations in Tularosa Basin and adjoining ridges.

| Age. | Group and formation. | Character. | Thickness (feet). | |
|-------------------|--------------------------|--|--|-----------|
| Upper Cretaceous. | Mesaverde (?) formation. | Sandstone and shale, coal bearing. | 630 | |
| | Mancos (?) shale. | Shale; some sandstone; limestone in lower part. | 900 | |
| | Dakota (?) sandstone. | Sandstone, massive, hard, gray to buff. | 150 | |
| Triassic. | | Red sandy shales with layers of brown sandstone and limy concretions. | 340 | |
| Permian. | Manzano group. | Chupadera formation. | Upper part limestones and gray sandstones; lower part gypsum, soft red sandstones, then limestones and gypsum. | 1200-1600 |
| | | Abo sandstone. | Brown-red sandstones and red sandy shales; thin toward the south. | 500-900 |
| Pennsylvanian. | Magdalena group. | Limestones with beds of shale and sandstone; several sandstone beds in lower part. | 2200-2500 | |
| Mississippian. | Lake Valley limestone. | Coarsely crystalline limestone and limy shale. | 0-150 | |
| Devonian. | Percha shale. | Gray shale. | 0-125 | |
| Silurian. | Fusselman limestone. | Limestone, massive, dark above; weathers white below. | 0-200 | |
| Ordovician. | Montoya limestone. | Massive limestone, cherty above, dark below, sandy at base. | 0-200 | |
| | El Paso limestone. | Limestone; weathers light gray, slabby in part. | 0-350 | |
| Cambrian. | Bliss sandstone. | Sandstone, massive, gray. | 0-125 | |
| Pre-Cambrian. | | Granites, schists, and quartzites. | | |

The Bliss sandstone is coarse and porous. The overlying limestones present considerable variety in character. Some of them are compact, some are mixed with considerable clay and sand, and some are cherty. The Fusselman limestone, which is especially massive and compact, thins out not far north of latitude 36°. The base of the Montoya is a sandstone at most places, and locally this member is 10 to 20 feet thick. The Percha shales are dark and carbonaceous and should be tested. The basal portion of the Magdalena group includes much coarse gray sandstone, and layers of sandstone occur at intervals higher up in the formation. These sandstones would afford suitable reservoirs for oil. It is not known, however, whether



EXPLANATION

SEDIMENTARY ROCKS

- Alluvium
- Gypsum of the "White Sands"
- Sandstones and shale
- Red shale
- Chupadera formation
(Limestone, sandstone, and gypsum)
- Abo sandstone
(Brown to red sandstone)
- Magdalena group
(Limestone, shale, and sandstone)
- Lake Valley limestone (Mississippian), Percha shale (Devonian), Fusselman limestone (Silurian), Montoya and El Paso limestones (Ordovician), and Bliss sandstone (Cambrian)

IGNEOUS AND METAMORPHIC ROCKS

- Lava flows, tuffs, and intrusive masses
- Granite, schist, and quartzite

STRUCTURAL FEATURES

- Strike and dip
- Fault

PERMIAN (Manzano group)

- Chupadera formation
- Abo sandstone
- Magdalena group

PENNSYLVANIAN

- Magdalena group

CARBONIFEROUS

- Abo sandstone
- Magdalena group

CARBONIFEROUS, DEVONIAN, SILURIAN, ORDOVICIAN, AND CAMBRIAN

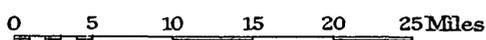
- Lake Valley limestone

QUATERNARY

- Alluvium
- Gypsum of the "White Sands"

TRIASSIC CRETACEOUS

- Sandstones and shale
- Red shale



GEOLOGIC MAP OF TULAROSA BASIN, N. MEX.

A-A', etc., lines of sections in figure 28.

the carbonization of the organic débris in these formations has proceeded so far as to preclude the occurrence of oil in commercial amounts, though gas may be present.

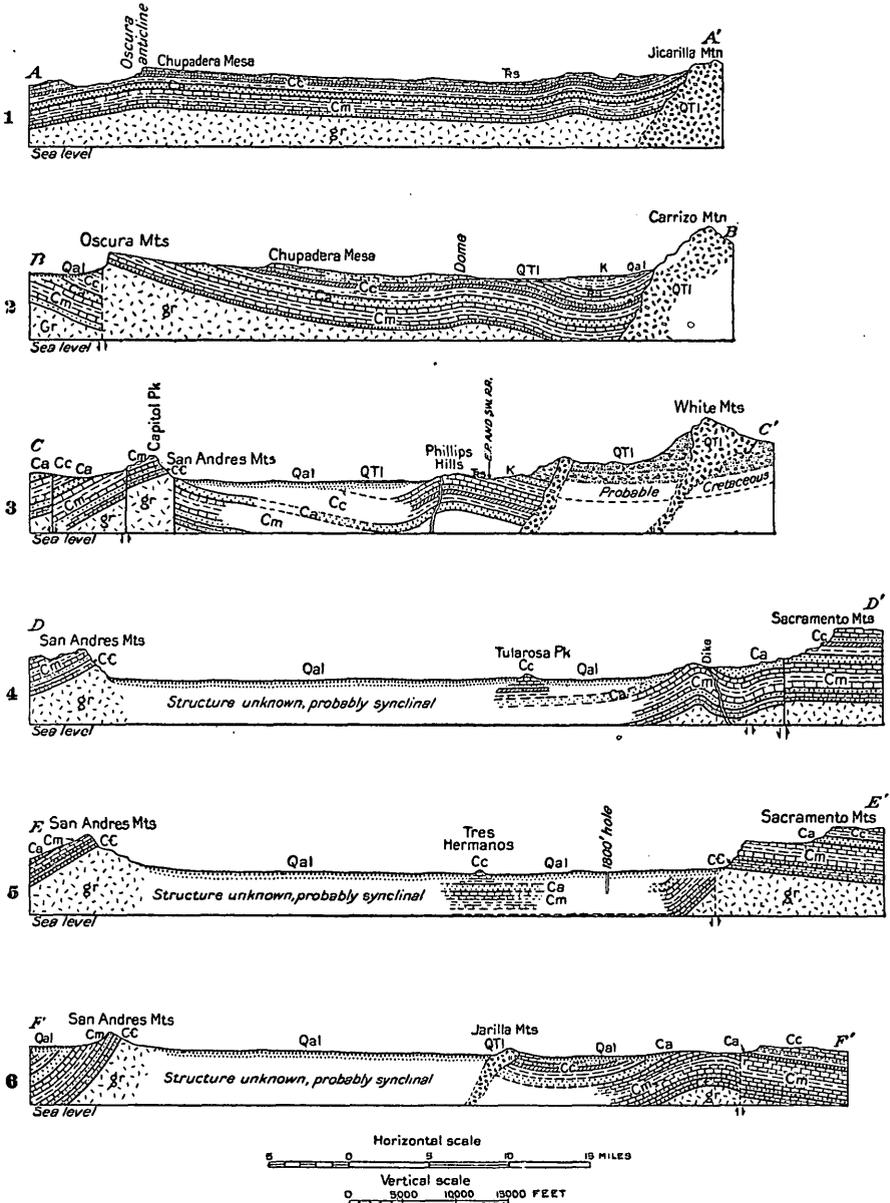


FIGURE 28.—Sections across Tularosa Basin, N. Mex. For lines of sections and explanation of symbols see Plate XL.

The red sandstones of the Abo formation appear not to be favorable sources of oil, but owing to their porosity they might serve as reservoirs. In the Chupadera formation there are alternations of

massive, compact gray limestone, thick gypsum beds, red sandstone, and porous gray sandstone. The gray sandstones may prove to be oil bearing in some portions of the area. They are known to underlie the upper part of the basin and are believed to extend far southward under it, as shown in the cross sections in figure 28.

LOCAL STRUCTURE.

The anticline of the Sacramento Mountain front is first manifested in an anticline or dome west of "the Malpais" (recent lava flow), 15 miles northwest of Carrizozo. Its axis crosses the basin west of Oscuro, where it is marked by a dome of limestone of the Chupadera formation in T. 8 E., R. 9 S., and appears in the Phillips Hills, which present a complete arch of the Chupadera formation along their western slope. Limestone at the top of the Magdalena group rises on this axis a short distance southeast of Tularosa, and the uplift is well exposed from La Luz to High Rolls, where there are two arches and an intervening basin containing the Abo sandstone. (See fig. 24, p. 209.) The anticline is well defined east of Alamogordo and in Alamo Canyon. South of the latter place the beds on the axis rise rapidly, and near the center of T. 19 S., R. 11 E., the basement of granite is brought up at the foot of the west front of the mountain. Doubtless in this region for some distance the west limb of the uplift is faulted, with the dropped block on the west side. A diagonal fault passing into the Sacramento Mountain front is well exposed 5 miles south-southeast of Alamogordo. South of Escondida the anticline pitches down again to the south, and its wide, low arch is well exhibited southeast of Turquoise, as shown in section 6, figure 28.

Limestone of the Chupadera formation (the same as that on top of the mountain at Cloudercroft) is exposed in scattered outcrops along the desert, forming Cerrito Tularosa, Tres Hermanos, and some of the ridges of the Jarilla Range west of Turquoise. In the Jarilla Range and in the eastern part (One Butte) of Tres Hermanos this formation is cut by igneous rocks. In these outlying exposures the beds lie nearly horizontal or dip to the west at a very low angle.

West of these small outcrops there are no rock exposures until the east slope of the San Andres Mountains is reached, a distance of 22 to 25 miles. This range is an anticline, and outcrops along the east foot of the northern part of the range indicate the eastward-dipping monocline on its east slope. In the higher eastern ridges of this range, especially at its north and south ends, the anticline is considerably faulted, both longitudinally and transversely. (See section 3, fig. 28.) In T. 20 S., R. 5 E., there are several small exposures of eastward-dipping rocks at the foot of the mountains, and where the east front of the range bears toward the east again

for a few miles in Tps. 9, 10, and 11 S., similar features are exposed, indicating very clearly that the east front of the mountain is part of an anticline. This being the case, the east limb of the uplift doubtless forms the west limb of a syncline, in which Chupadera limestone is exposed in the Jarilla Hills, Tres Hermanos, Cerrito Tularosa, and Phillips Hills. It is quite likely that this syncline holds Triassic "Red Beds" and a thick body of Cretaceous shales and even the coal measures and overlying early Tertiary deposits. Originally the wide Tularosa Basin was much deeper, its bottom being excavated in the softer rocks, which have later been covered by sand and gravel from the adjoining mountains. Minor structural features in or adjoining the Tularosa Basin are found in the region north of Oscuro and Carrizozo. The beds of Chupadera limestone are arched in an elongated dome in the Phillips Hills and in an oval dome in the western part of Tps. 6 and 7, R. 9 E. Both these domes are on the anticline above referred to. A small dome of similar character exists in the northeastern part of T. 9 S., R. 8 E., and another has its apex in the center of T. 5 S., R. 12 E., about 5 miles southwest of Ancho. In these uplifts the gray sandstones of the Chupadera formation are at no great depth and may yield oil, but in the 800 to 1,000 feet of red sandstones of the Abo formation next below the prospects are less promising. In the still lower Magdalena group there are several beds of sandstone, especially near its base. The thickness of this group is somewhat more than 2,000 feet. In the northern part of the area it lies on the pre-Cambrian granite and schist, but to the south Mississippian to Ordovician limestones intervene. These limestones are 600 feet thick in the west face of the Sacramento Mountains southeast of Alamogordo.

DEEP BORINGS.

Several deep borings have been made in the Tularosa Basin. During 1918 a hole was being bored for oil 10 or 15 miles southwest of Alamogordo, but nothing has been learned as to its record. Two holes half a mile north of Dog Canyon station, in the NE. $\frac{1}{4}$ sec. 14, T. 18 S., R. 9 E., were 1,235 and 1,800 feet deep. The record furnished by the El Paso & Southwestern Railroad Co. showed "red clayey material" with deposits of sand and gravel 20 to 25 feet thick every 300 or 400 feet. From the record it is impossible to recognize the formations penetrated; the material may be all valley fill, but it is not unlikely that the lower part of the Chupadera formation and possibly also the Abo sandstone were penetrated. A 1,004-foot hole bored by the railroad company about $1\frac{1}{2}$ miles west of Alamogordo, in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 26, T. 16 S., R. 9 E., was reported to have penetrated 10 feet of limestone at a depth of 130 feet, lying on 85 feet of yellow clay and clay stone, 250 feet of red clay, alter-

nating yellow, red, blue, and yellow clay at 450 to 500 feet, and "clayey material" from 500 feet to the bottom. This record doubtless represents the same conditions as in the Dog Canyon hole. A 960-foot hole at Orogrande passes through "granite" (porphyry) and similar igneous rocks to a depth of 590 feet, where the Carboniferous limestone (probably Chupadera) was entered. Near the south margin of sec. 3, T. 22 S., R. 8 E., a shaft 250 feet deep with a 160-foot drill hole in its bottom revealed 235 feet of limestone underlain by "granite" (porphyry). An 800-foot hole bored by the railroad

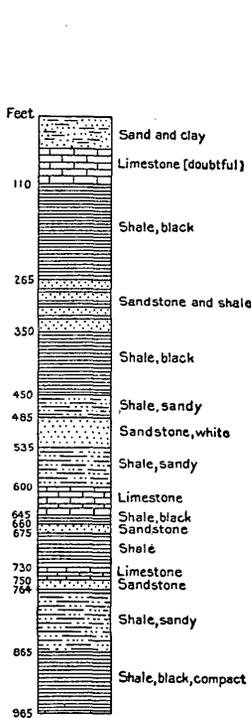


FIGURE 29.—Log of deep boring at Oscuro, N. Mex.

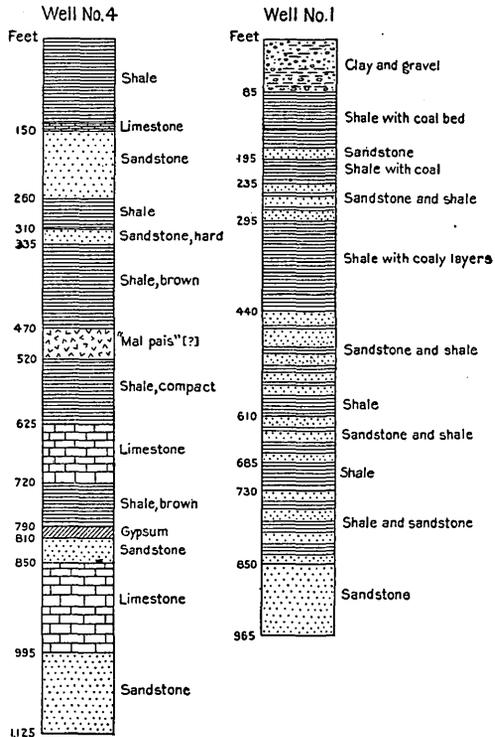


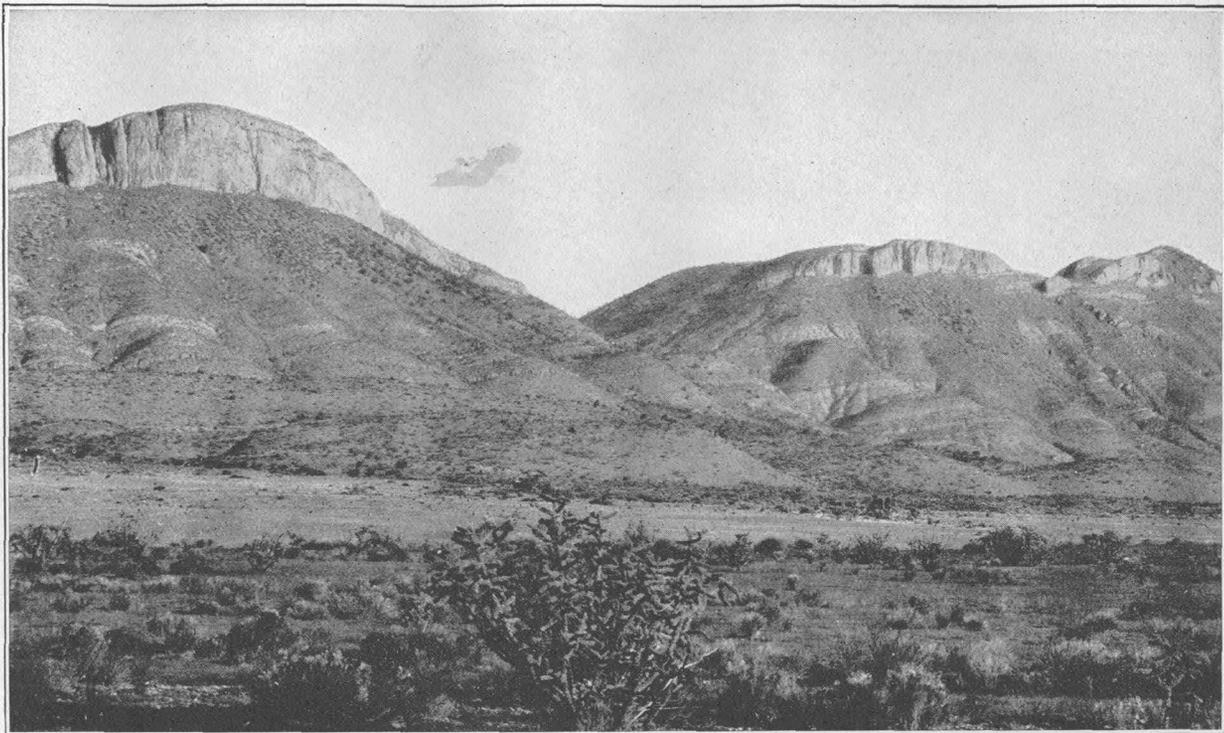
FIGURE 30.—Logs of two railroad wells at Carrizozo, N. Mex.

company at Temporal is reported to have penetrated 185 feet of wash, 20 feet of pink clay, and 595 feet of alternating gravel, sand, clay, and conglomerate.

A hole drilled for oil in sec. 34, T. 13 S., R. 7 E., about 12 miles northwest of Tularosa, is said to have reached a depth of 1,600 feet.

Two wells sunk by the railroad company at Oscuro are 965 and 489 feet deep. The log of the deeper one is given in figure 29. The strata are apparently all Cretaceous and lie below the coal measures that crop out a short distance northeast of Oscuro.

The El Paso & Southwestern Railroad Co. sunk several wells at Carrizozo, and one of them reached a depth of 1,125 feet and obtained



PILOT KNOB, ON WEST SLOPE OF SAN ANDRES MOUNTAINS, N. MEX., LOOKING WEST.

Massive limestone of Chupadera formation.

excellent water. The logs of the two deeper ones are given in figure 30. The strata penetrated appear to be Cretaceous and possibly include also the underlying Triassic red shale and Chupadera formation.

An 850-foot well bored by the railroad company 2 miles east of Ancho penetrated alternating red and blue clay to 340 feet, red shale from 340 to 415 feet, sandstone from 415 to 425 feet, red clay from 435 to 715 feet, including a 50-foot bed of gypsum, red sandstone from 715 to 795 feet, and red clay and shale from 795 to 855 feet, presumably all beds above the Chupadera formation or possibly including the upper member of that formation.

SAN ANDRES MOUNTAINS.

The San Andres Mountains form a long, narrow ridge that extends through the northern part of Dona Ana County and the southeastern part of Socorro County and separates the Tularosa Basin on the east from the Jornada del Muerto on the west. As shown in cross sections 3, 4, 5, and 6, figure 28, and sections 3, 4, and 5, figure 31, the ridge consists mainly of a monocline of limestones and red beds dipping to the west and passing under the Jornada del Muerto. The uplift in general, however, is an anticline, and eastward-dipping strata are exposed at its foot toward the north and south ends of the ridge. For many miles along the steep eastern face of the mountains there are exposures of pre-Cambrian granites and schists capped by the westward-dipping Ordovician to Pennsylvanian limestones. The Pennsylvanian limestone constitutes most of the summit and higher western slopes of the range and finally passes beneath the red sandstones of the Abo, and these in turn under the sandstones and limestones of the Chupadera formation (see Pl. XLI), which slope down to the desert at the western foot of the range. As the structural conditions in a mountain range of this sort are entirely unfavorable for oil or gas, no further consideration will here be given to the details.

JORNADA DEL MUERTO.

GENERAL RELATIONS.

The name Jornada del Muerto (Spanish, journey of the dead) is applied to the long, wide desert valley extending through the eastern part of Socorro County and southward across the eastern part of Sierra County into Dona Ana County, a distance of 125 miles. To the east rise the high San Andres Mountains and Sierra Oscura and Chupadera Mesa, and along the western margin of the valley flows the Rio Grande. Its remarkably smooth and nearly level floor consists mostly of sand or loam which in an area southeast of San Marcial is covered by a large sheet of recent lava. In most places

the deposit of sand, loam, and gravel is so thick that the rocks are not exposed, but the general structure is plainly indicated by the relations of the formations in the adjoining ridges, and some additional data are afforded by records of a few widely scattered

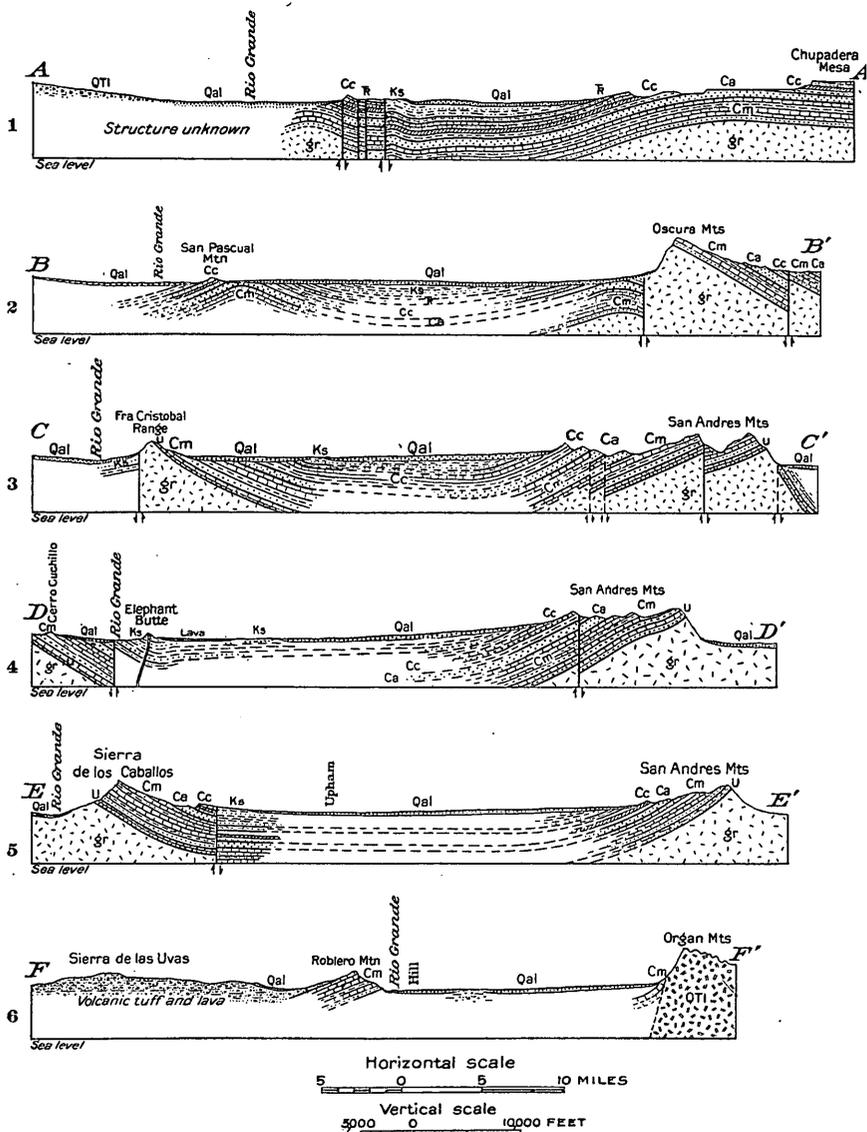
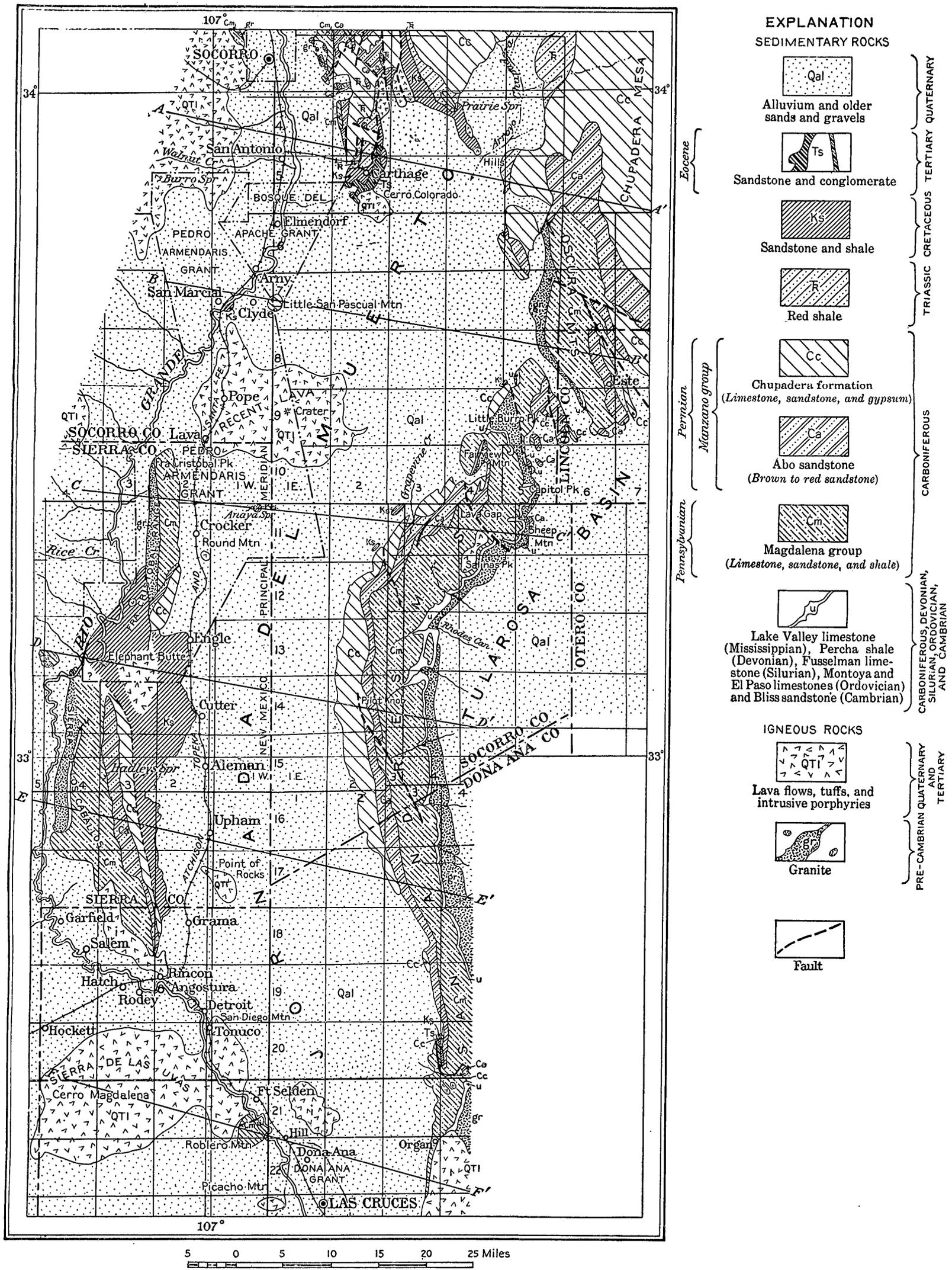


FIGURE 31.—Sections across the Jornada and del Muerto, N. Mex. For lines of sections and explanation of symbols see Plate XLII.

wells. The principal data and their interpretation are shown in Plate XLII and figure 31. The chief feature is a long, moderately narrow syncline, which is not very deep, for the dips appear to be gentle at most places.



GEOLOGIC MAP OF JORNADA DEL MUERTO, N. MEX.

A-A', etc., lines of sections in figure 31.

LOCAL STRUCTURE.

Local anticlines or domes may occur in this valley, but except for those on the margin no evidence can be obtained as to their existence until numerous borings are made. It appears unlikely that many such features are present. The anticline at Carthage and Prairie Springs and the prominent plunging anticline at the north end of the Oscura uplift, in Tps. 2, 3, 4, and 5 S., R. 6 E., are outside of the main basin. In the valley of Arroyo Chupadera, at the north end of the Jornada syncline, the shallow basin of limestone of the Chupadera formation contains a thin remnant of Triassic red shales, mostly hidden by loose sand. The basin deepens gradually toward the south, and in T. 4 S. Cretaceous shales and sandstones appear in regular order. These rocks are extensively exposed about Carthage, where the higher sandstones carry a coal bed that is extensively mined. The structural relations from Prairie Spring to Carthage are described on page 238. Early Tertiary conglomerate crops out south and east of Carthage, and this formation may extend widely under the basin to the south. The Cerro Colorado in this vicinity is a mass or group of masses of igneous rocks of the Tertiary volcanic series. Probably these rocks are not of wide extent underground. The eastward-dipping limestone of the Magdalena group in the ridge in T. 6 S., Rs. 4 and 5 E., appears to be cut off by a fault on its west side, for Cretaceous sandstone crops out a short distance southwest of its foot, and wells 250 and 300 feet deep in this vicinity are in sandstone that is reported to be coal bearing and to show traces of oil. The higher part of the west face of the Sierra Oscura, in which granite and other old crystalline rocks rise 1,500 feet or more above the Jornada, is doubtless due to a fault, but it is probable that westward-dipping rocks occur not far west of the foot of these mountains. This structure is indicated by outcrops of Cretaceous sandstone (Mesaverde?) in the southeast corner of T. 8 S., R. 4 E., and by outcrops of westward-dipping Dakota (?) sandstone in the northern part of T. 11 S., R. 3 E., and the southeastern part of T. 11 S., R. 2 E. In a well in sec. 36, T. 10 S., R. 2 E., an 18-inch bed of coal was reported at a depth of 320 feet, indicating the presence of the higher sandstones of the Cretaceous (Mesaverde?), and a similar occurrence is reported in wells in the center of T. 11 S., R. 2 E., where the sandstone lies under 60 to 70 feet of wash. A well in the east-central part of T. 10 S., R. 1 E., penetrated sandstone reported to carry coal streaks and "oil indications." In Tps. 9 and 10 S. limestone of the Chupadera formation dips gently to the west on the west slope of the San Andres Mountains and rises again on an east dip on the east slopes of the Fra Cristobal and Caballos mountains, thus forming a synclinal basin, as shown in sections 3 and 5, figure 31. A fault along the west side of the basin is traceable along the east side of the

Caballos Mountains. The basin flattens and spreads to the west near Engle and Elephant Butte, as shown in section 4, figure 31.

Wells in the Engle and Carthage regions penetrated sandstone, presumably in the Cretaceous coal measures (Mesaverde?). The 300-foot well 3 miles northeast of Engle is reported to have passed through about 100 feet of wash into hard dark-gray sandstone with a 3-foot bed of coal at 300 feet. In the Hickox well, sunk 6 miles southwest of Engle early in 1915, the Cretaceous sandstone began near the surface and a thin bed of coal with "oil indications" was reported at about 120 feet. A 1,200-foot boring was made by the Atchison, Topeka & Santa Fe Railway Co. a short distance northwest of Engle, and a 600-foot hole was sunk by the Victorio Cattle Co. 4 miles east of Engle, but no records have been obtained. A well in sec. 15, T. 14 S., R. 3 W., 5 miles west of the Hickox well, penetrated 250 feet of sandstone and found a 4-foot bed of coal. The 365-foot well at Engle is all in hard dark-gray sandstone except a few feet of wash. Similar sandstones have been penetrated in several wells in the Jornada south of Cutter, and there is every reason to believe that Cretaceous sandstone and shales occupy the basin as far south as Las Cruces. In the Point of Rocks area, San Diego Mountain, and the Dona Ana Hills the Tertiary agglomerate and lavas overlie these Cretaceous rocks, which are doubtless interrupted by dikes and other intrusive bodies of the igneous rocks.

LOWER RIO GRANDE VALLEY.

The Jornada del Muerto extends to the lower Rio Grande valley between Rincon and Las Cruces. From Las Cruces southward the valley of the Rio Grande consists of a long down slope from the mountains on the east, a trench occupied by the river, and a higher plain or mesa which extends far to the west across Dona Ana and Luna counties. This plain, the valley trench, and the slope on the east are all underlain by a thick deposit of sand and gravel which completely hides the underlying rocks over wide areas, so that their character and structure can not be determined. Ridges and knobs consisting of igneous rocks or limestone rise above the plain in places, and portions of the plain south of Afton and Aden are covered by lava flows.

A few deep holes that have been bored along the Southern Pacific and El Paso & Southwestern railroads in southern Dona Ana County throw light on the character of the underlying rocks. One at Strauss is 1,330 feet deep. Down to 120 feet the material is sand and clay on a bed of "cemented sand"; from 120 to 360 feet are yellow clay, sand, and red clay of unknown age; the material below is not reported. Three holes at Noria are 565, 600, and 1,000 feet deep. The deepest one went through 160 feet of sand, clay, and gravel; the material from

160 to 220 feet was not reported; from 220 to 1,000 feet were sand, shale, and shells alternating. The 565-foot hole was reported to have penetrated 375 feet of sand, clay, and gravel, 100 feet of shale with red clay at the top and bottom, and 90 feet of alternating shale, "pack sand," and red clay.

A hole 515 feet deep at Mount Riley siding was reported to have penetrated clay to 80 feet, alternating clay and sand from 80 to 240 feet, silt from 240 to 275 feet, and clay, gravel, and rock from 275 to 515 feet. Another one 715 feet deep was reported as follows: 0-170 feet, clay and sand with streaks of white rock; 170-280 feet, clay; 280-300 feet, clay and sand; 300-325 feet, water sand; 325-715 feet, clay, sand, gravel, and boulders, in part cemented.

A 950-foot well sunk by the Southern Pacific Co. at Lenark had the following record:

Record of deep well at Lenark, N. Mex.

| | Feet. |
|--------------------------|---------|
| Red soil..... | 0-13 |
| Chalky clay..... | 13-15 |
| Sandrock, hard..... | 15-78 |
| Cemented stones..... | 78-125 |
| Red clay..... | 125-186 |
| White sand..... | 186-204 |
| Sandy clay..... | 204-214 |
| Sand..... | 214-226 |
| Red clay..... | 226-252 |
| Sand..... | 252-290 |
| Cemented sand, hard..... | 290-294 |
| Red clay, hard..... | 294-336 |
| Yellow clay..... | 336-382 |
| Sand..... | 382-396 |
| Red clay, hard..... | 396-428 |
| Quicksand..... | 428-446 |
| Cemented sand..... | 446-452 |
| Clay..... | 452-456 |
| Sand..... | 456-562 |
| Red clay..... | 562-590 |
| Yellow clay..... | 590-640 |
| Sandstone, soft..... | 640-666 |
| Sandstone, hard..... | 666-668 |
| Yellow clay..... | 668-700 |
| Sand..... | 700-710 |
| Sandy clay..... | 710-730 |
| Clay..... | 730-750 |
| Sand..... | 750-775 |
| Clay, hard..... | 775-781 |
| Yellow clay..... | 781-800 |
| Sand..... | 800-810 |
| Sandy clay..... | 810-840 |
| Sand..... | 840-870 |
| Sandy clay..... | 870-892 |
| Clay..... | 892-900 |
| Sandy clay..... | 900-950 |

A 1,077-foot hole at Kenzin siding, Dona Ana County, had the following record:

Record of deep well at Kenzin, Dona Ana County, N. Mex.

| | Feet. |
|--|-----------|
| Soil and sand..... | 0-50 |
| Clay and sand..... | 50-140 |
| Cement, clay, and sand alternating..... | 140-324 |
| Solid rock..... | 324-326 |
| Sand, cement, and clay, with gravel..... | 326-395 |
| Clay..... | 395-515 |
| Clay and rocks; water..... | 515-550 |
| Solid rock..... | 550-802 |
| Conglomerate..... | 802-807 |
| Solid rock..... | 807-827 |
| Solid rock, lava (?), and conglomerate..... | 827-844 |
| Solid rock and conglomerate alternating..... | 844-1,027 |

A 445-foot well at Malpais siding passed through 108 feet of clay, 262 feet of lava, and 75 feet of sand and clay.

It is difficult to interpret the records of these borings. They indicate that a diversity of rocks underlie the wide plains of southern Dona Ana County. To the south the sandstones and limestones of Comanche age may be extensively distributed, for they appear at El Paso and near Montoya and apparently were penetrated by the holes at Noria, Strauss, and Lenark.

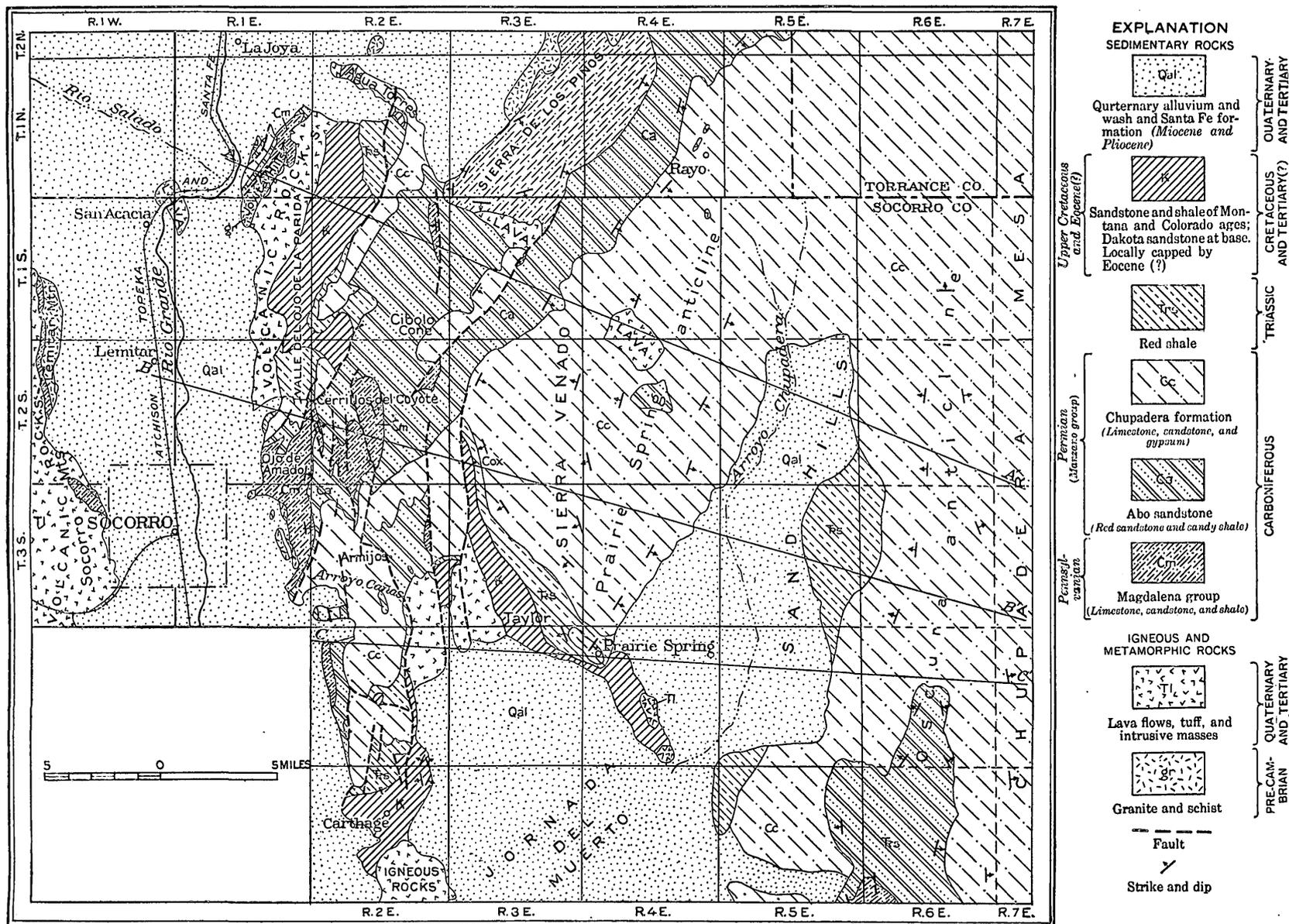
EASTERN SOCORRO COUNTY.

GENERAL RELATIONS.

The ridges lying between Socorro and the north end of the Jornada del Muerto consist of limestones, sandstones, and red shales presenting somewhat complex structural relations. The dominant features are the southward prolongation of the anticline of the Sierra de los Pinos, complicated by faults and minor flexures, the northern extension of the Jornada del Muerto, and the eastern face of Chupadera Mesa. Plate XLIII and the cross sections of figure 32 show the principal structural features. It will be seen from these sections that nearly all the anticlines to the west are cut off by faults, which might have an unfavorable effect on the migration of oil if that substance is present. On the other hand, these faults might afford the oil an outlet from one horizon to another.

LOCAL STRUCTURE.

Cerrillos del Coyote to Carthage.—The series of high limestone ridges that begin about 5 miles east of Socorro occupy a narrow belt about 18 miles long extending from Cerrillos del Coyote nearly to Carthage. They are in greater part in Rs. 1 and 2 E. The structure is in the main anticlinal, being a continuation of the uplift of the Sandia and Manzano mountains and the Sierra de los Pinos. There



GEOLOGIC MAP OF PART OF SOCORRO COUNTY, N. MEX.

A-A', etc., Lines of sections in figure 32.

are many faults and minor flexures, most of them longitudinal to the main line of uplift—that is, with trend nearly north. Some of the faults, however, are transverse to this course, and the flexures have

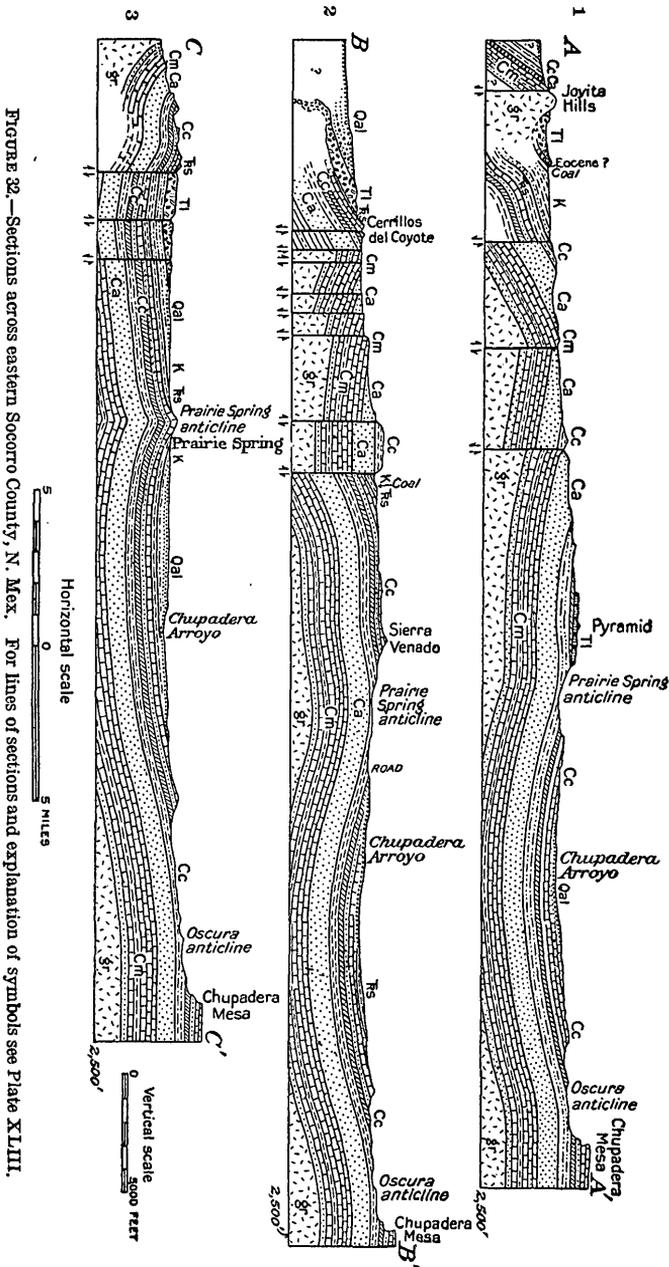


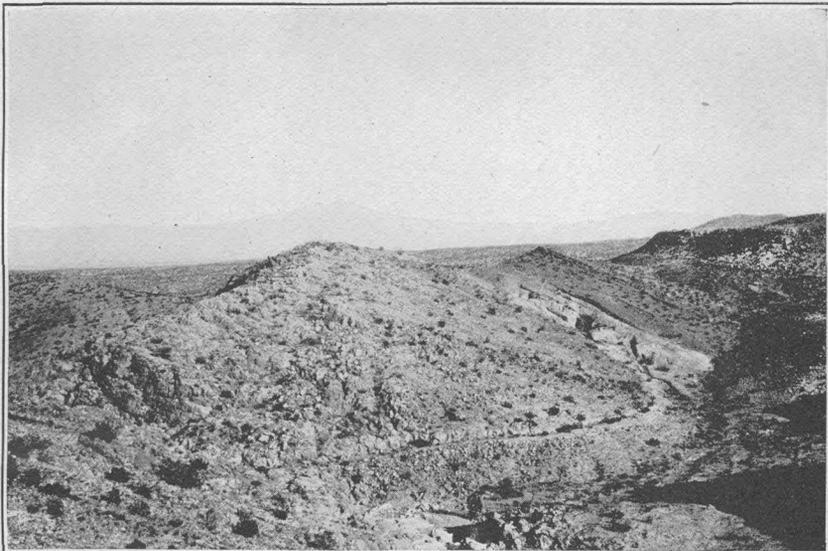
FIGURE 32.—Sections across eastern Socorro County, N. Mex. For lines of sections and explanation of symbols see Plate XLIII.

much pitch. Some general features are shown in the sections in figure 32. The formations presented are the Magdalena, Abo, Chupadera, Triassic, and Upper Cretaceous, with more or less overlap of Tertiary

and Quaternary deposits and Tertiary igneous rocks. The underlying pre-Cambrian granite is exposed in the axis of two small uplifts about 6 miles east of Socorro.

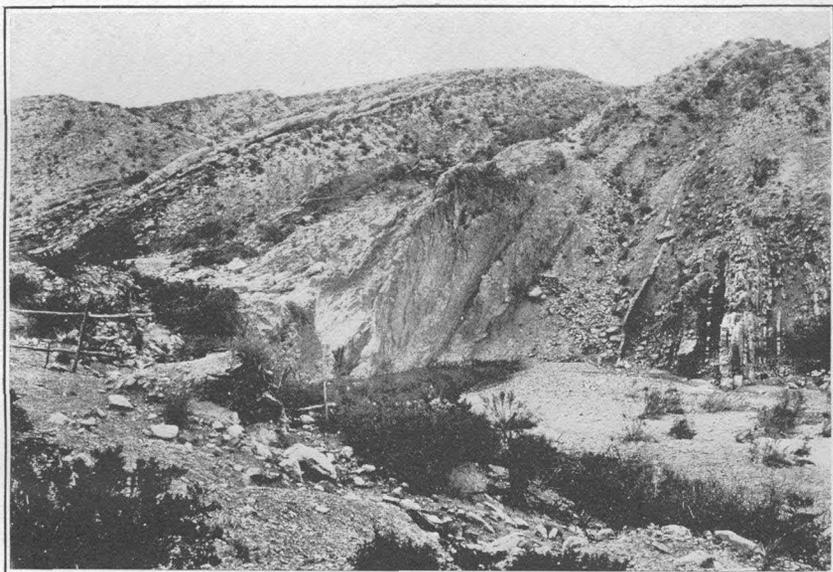
The Cerrillos del Coyote consist of a small group of buttes (see Pl. XXXI, *B*, p. 188) of limestone lying on massive gray sandstone, with soft red sandstone, gypsum, and thin limestone on the lower slope, all belonging to the Chupadera formation. The beds dip west and are traversed by faults, as shown in section 2, figure 32. To the south the underlying Abo beds appear; to the north the limestone passes under red shale of Triassic age, and in places some Tertiary agglomerate abuts against it. On the east side the fold brings up limestone of the Magdalena group, which constitutes an extensive series of ridges to the south, where its outcrop continues to the Arroyo de las Canas, in the southeastern part of T. 3 S., R. 1 E. The Magdalena outcrop is wide in the southeastern part of T. 2 S., R. 1 E., where, as shown in section 2, figure 32, it presents an anticline (see Pl. XLIV, *B*), a syncline, and a broad anticline. On the east side of the anticline lies a basin of the Abo sandstone along the west side of R. 2 E., east of which is limestone of the Magdalena group, brought up again by a fault of considerable throw. South of Arroyo de los Pinos the anticline in the Magdalena beds rises gradually, and in the northeastern part of T. 3 S., R. 1 E., the underlying granite appears. Another parallel exposure of granite occurs in another anticline lying a short distance to the west. The axis of this anticline passes just east of Ojo del Amado (see Pl. XLIV, *B*), and the uplifted rocks are mostly buried under Tertiary and later deposits. The granite appears in several other arroyos in this vicinity. The relations along the eastern axis are well exposed near the old fire-clay pits 6 miles east of Socorro. Here, as shown in Plate XLIV, *A*, there is a fault which repeats the outcrop of the granite and the overlying quartzite and fire clay. Eastward up the arroyo a regular monocline exposes a complete section of beds of the Magdalena group and above them all the overlying Abo beds and the lower members of the Chupadera formation.

The ridges in the eastern part of T. 3 S., R. 1 E., consist of an eastward-dipping succession of limestone on gray massive sandstone, representing the upper members of the Chupadera formation, repeated somewhat by faulting, as shown in section 3, figure 32. East of these ridges the upper limestone passes beneath red shale (Triassic) and there is a fault which in the vicinity of the Armijo ranch, in the center of T. 3 S., R. 2 E., lifts the lower part of the Abo sandstone to the level of the upper limestone of the Chupadera formation. To the east are lower beds of the Chupadera formation—soft red sandstone, limestones, and gypsum beds. In sec. 25, T. 3 S., R. 2 E., these beds

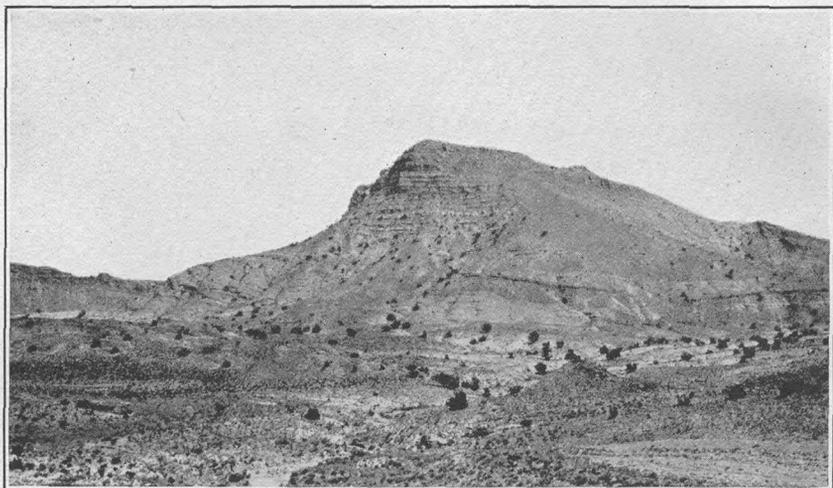


A. BASE OF MAGDALENA GROUP 8 MILES SOUTHEAST OF SOCORRO, N. MEX.,
LOOKING NORTH.

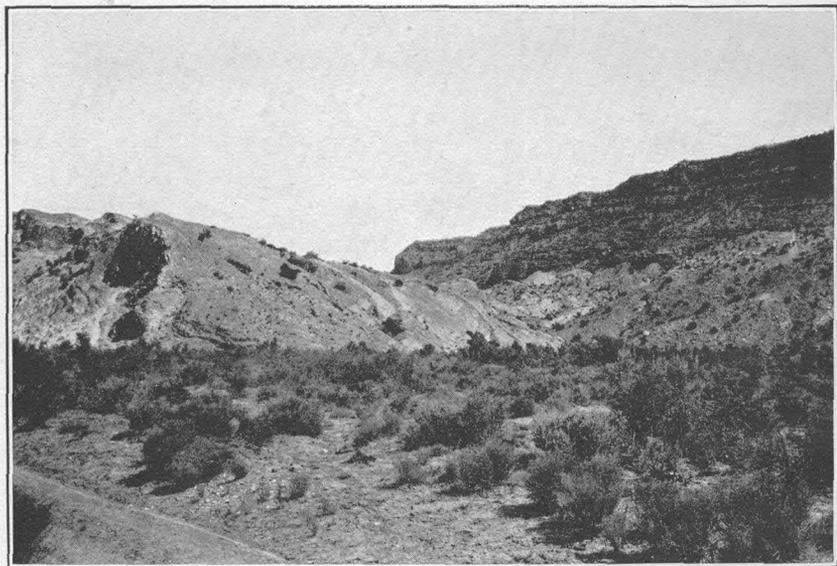
Beds lie on granite in foreground. Fire-clay mine and fault to right.



B. UPTURNED MAGDALENA BEDS AT OJO DE AMADO, 7 MILES EAST-NORTHEAST
OF SOCORRO, N. MEX.



A. MESA DEL YESO, 15 MILES NORTHEAST OF SOCORRO, N. MEX., LOOKING NORTH.
Limestone and gypsum of Chupadera formation.



B. SIERRITA MESA, NACIMIENTO UPLIFT, N. MEX., LOOKING NORTHEAST.
Todilto limestone and gypsum to left.

are upturned sharply and cut off by a fault along which appear the Abo sandstone, standing nearly vertical, and in due order to the west the Magdalena beds. West of the Magdalena is a small showing of overlapping Tertiary agglomerate.

In secs. 31 and 32, T. 3 S., R. 3 E., two anticlines bring up the Abo sandstone in the midst of an outcrop of lower beds of the Chupadera formation, and some of the higher sandstones and limestones of the Chupadera are dropped by a fault in the western part of sec. 31. At the south end of this area there is a continuous zone of high ridges of the upper limestone and sandstone of the Chupadera formation extending nearly to Carthage and having the structure shown in section 3, figure 32. There is considerable faulting but in general a regular succession from the Magdalena on the west to Triassic red shale and the Dakota (?) sandstone on the east. A strong cross fault in the center of T. 4 S., R. 2 E., gives some complexity to the structure. South of this fault there is a general downward pitch to the south, the Triassic outcrop widens, and finally the Cretaceous rocks extend across the anticline in the coal basin of Carthage. Overlying the Cretaceous beds is a conglomerate of early Tertiary age, which also appears at intervals to the north, in Tps. 2 and 3 S., R. 3 E. On the east side of this part of the Tertiary area, in the western part of sec. 1, T. 5 S., R. 2 E., there is a well-defined anticline or elongated dome of Cretaceous coal measures. On its west side is the main fault, which extends far north from the eastern part of Carthage.

Cibola Cone syncline and fault.—The southern prolongation of the anticline of the Sierra de los Pinos, pitching downward, bears on its eastern slope in T. 1 S., R. 3 E., and farther south a thick wedge-shaped mass of the Chupadera formation. On its east side the wedge is cut off by a fault with upthrow on the east that brings into view the top limestone of the Magdalena group. The resulting topographic features are strongly marked, as the hard limestone and sandstone of the Chupadera formation give rise to a prominent ridge culminating in the very conspicuous butte long known as Cibola Cone, and east of the fault the uplifted Abo sandstone presents to the west a high red escarpment. Some of these features are shown in section 1, figure 32. The Chupadera and Abo formations in the area do not present any unusual features.

Valle del Ojo de la Parida.—Structurally the Valle del Ojo de la Parida is a syncline with a regular succession of Cretaceous to Pennsylvanian rocks rising in its east side and an overlap of Tertiary igneous rocks on its west side. Possibly the igneous rocks are cut off by a fault at the Joyita Hills and farther south, along the prolongation of the east side of the Joyita uplift. A heavy covering by Santa Fe and later deposits in and south of T. 1 S. hides the structural relations.

Part of the valley is floored with sand and gravel, but ridges and slopes show Triassic and Cretaceous rocks along its center, and the outcrop of the Cretaceous widens greatly in the southern part of T. 1 N., R. 2 E. The structure of the principal features of the valley and adjoining ridges is shown in section 1 in figure 32. The Mesa del Yeso, a prominent butte of the Chupadera formation, rising in the center of the area, is shown in Plate XLV, A.

Taylor coal basin.—The Cretaceous rocks occupy a trough of considerable extent along the valley of Taylor Creek and the adjoining slopes. As shown in section 2, figure 32, they lie in a regular succession on red shales of Triassic age and dip at low angles to the west. To the south they are overlain by a thick mass of Tertiary igneous rocks, in places at least with an intervening conglomerate (Eocene?), which is well exposed northwest of the Cox ranch and west of the old coal pit 4 miles north of Taylor's ranch. This basin is cut off by a fault on its west side. In the higher beds near this fault there is a thin coal bed which has been prospected at several places. Probably this basin underlies a wide area of the Jornada del Muerto south of Taylor's ranch, but owing to the cover of sand and gravel and the absence of borings nothing is known of its character or relations in that area.

Prairie Spring anticline.—Rising from the Jornada del Muerto near Prairie Spring is an anticline which is expressed in the wide area of ridges of limestone and other rocks of the Chupadera formation extending to the mesas east of Rayo and beyond. In the center of this area, or near the middle of T. 2 S., R. 4 E., the red Abo sandstone is exposed for about a square mile along the axis of the anticline. The line of ridges east of the old auto road in that vicinity consists of limestone of the Chupadera formation dipping eastward into the basin of Arroyo Chupadero. The Sierra del Venado consists of the same limestones dipping west on the west side of the axis. Between these limestone ridges is a wide area of lower beds of the Chupadera formation.

Just west of Prairie Spring is a small local anticline or elongated dome on the west slope of the main anticline. It is shown by limestone of the Chupadera formation dipping on all sides below red shale of Triassic age. The spring is on the southwest end of this minor uplift.

A few other local irregularities were noted, but the details of structure were not ascertained. One remarkable local twist of the strata is exposed under the edge of the lava cap from Pyramid Crater, an old cone in the southwestern part of T. 2 S., R. 4 E. The beds are red sandstone and gypsum in the lower part of the Chupadera formation and evidently were contorted before the extrusion of the lava, which lies on a smooth plain.

Basin of Arroyo Chupadero.—The valley of Arroyo Chupadero is in a broad syncline (see section 2, fig. 32), which is a northern extension of the basin of the Jornada del Muerto. It rises to the north and is lost in the tablelands of southern Torrance County. The sides are broad outcrops of the Chupadera formation, and in the center, in Tps. 2 and 3 S., are red shales of Triassic age, largely covered by dune sand. In the center of T. 4 S., R. 4 E., the overlying Cretaceous strata appear, cut by some igneous intrusive rocks. Farther south are the wide sandy flats of the Jornada del Muerto.

Oscura anticline.—The prominent anticline which has produced Oscura Mountain extends far north of the northern termination of the mountains, probably to the Torrance-Socorro County line. The limestones of the Magdalena group pitch down rapidly in the northern part of T. 5 S., R. 6 E., and there is considerable faulting for some distance in the southwest corner of the township. Northward for 8 or 9 miles there is a broad anticline of the Abo sandstone flanked on both sides by the Chupadera formation. On the west side of the axis this formation constitutes ridges of moderate prominence, and on the east it constitutes the western slope of Chupadera Mesa. The dips are low, especially those on the east side. Near the center of T. 4 S., R. 6 E., the Abo sandstone pitches down to the north, and for 15 miles or more the uplift is expressed in Chupadera beds. The west limb of the anticline, where the dips are mostly from 5° to 10° , is marked by a north-south ridge of the limestones of the Chupadera formation. The dips on the east side are very low, and, as shown in section 2, figure 32, the limestones cap Chupadera Mesa. In general the anticline is fairly regular, but there are a few local irregularities. One of the most notable of these is a subordinate syncline and anticline with steep dips in and near the western part of T. 4 S. and the northwestern part of T. 3 S., R. 7 E.

Joyita Hills.—The Joyita Hills, which lie mostly in T. 1 N., R. 1 E., present a prominent anticline with pre-Cambrian granite exposed for a distance of about 3 miles along the center of its north-south course. Some of the features are shown in section 1, figure 32.

At the north end of the area the limestone of the Magdalena group is exposed, pitching down into the Abo sandstone, but at the south the relations are hidden by sand and gravel. On the east there is a broad belt of the Tertiary igneous rocks, which overlap on the granite unless, perhaps, there is a separating fault. The cross section in figure 33 shows some of the local details of structure.

The central ridge of granite is the highest topographic feature, and next west of it are slopes of limestone of the Magdalena group. A fault separates this limestone from granite. The red sandstone of the Abo formation, about 800 feet thick, forms a line of ridges or

knobs, just west of which are soft beds of the lower member of the Chupadera formation. These lower beds comprise 400 feet of reddish shales and soft red sandstones with some included limestone beds but no gypsum. Next above are soft red sandstones that grade up into massive gray sandstone, mostly hard, with one or two thin beds of limestone. This sandstone is overlain by limestone, the usual top member of the Chupadera formation. These upper sandstones and limestones, about 700 feet thick in all, constitute a line of ridges and knobs of considerable prominence extending all along the west side of the uplift. The Abo sandstone, shown at the left end of the section in figure 33, is in an uplifted block, which crops out only for a short distance and west of which are agglomerate, a bed of limestone conglomerate, and igneous rocks, all of Tertiary age.

On its east side the granite ridge is flanked by limestone of the Magdalena group, dipping steeply to the east. To the south these rocks show only in places, as the Tertiary igneous succession extends to the foot of the ridge, but to the north the limestone area widens

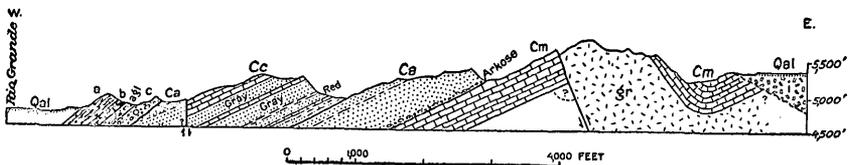


FIGURE 33.—Sketch section across the Joyita Hills, in T. 1 N., R. 1 E., Socorro County, N. Mex. Qal, Alluvium; a, andesite; b, basalt; agl, agglomerate; c, conglomerate; Cc, Chupadera formation; Ca, Abo sandstone; Cm, Magdalena group; gr, granite; l, lava, etc.

and reveals a pitching anticline. As the anticline pitches down to the north the limestone area widens, and it passes across the end of the uplift, as shown in Plate XLIII (p. 234). In this locality a deep canyon cut by a small arroyo reveals the limestone of the Magdalena group overthrust locally upon the red Abo sandstone, apparently by an extension of the fault shown to the right of the center of the section in figure 33. The limestone dips to the north and northwest, and the Abo sandstone to the west. The limestone extends north to Arroyo Cibola, where it pitches below the Abo sandstone, and this in turn is covered by sand, gravel, and the Tertiary igneous succession. There is no evidence of its extension in Agua Torres, and the isolated knob of granite 6 miles east of La Joya is due to a separate uplift.

Socorro and Lemitar mountains.—The Socorro and Lemitar mountains are parts of a westward-dipping succession of Tertiary igneous rocks on a platform of limestone of the Magdalena group underlain by pre-Cambrian rocks. The pre-Cambrian is exposed in a very small area low in the east slope of the Socorro Mountains, but granite is a prominent feature for 6 miles along the east slope of the Lemitar Mountains.

East of these mountains are the long sand and gravel covered slopes extending to the Rio Grande and in part underlain by tilted sandstones, etc., of the Santa Fe formation, which are well exposed near the north end of the Lemitar Mountains. To the west, as well as on the north and south ends of the range, lies a thick body of the Tertiary igneous rocks, which extend to the wide valley separating these ranges from the Magdalena Mountains. At the south end of the Socorro Mountains is a deposit of fuller's earth overlain by a sheet of basalt.

On account of the eastward-dipping limestone on the east side of these ridges, it is believed that they are of anticlinal structure throughout and that probably under the plain east of them there is a regular succession of Abo, Chupadera, Triassic, and Cretaceous rocks in a syncline. Ladrones Peak is on a northern continuation of the anticlinal axis. There is no evidence that the mountains are fault blocks, and the only fault noted is in the middle of the Lemitar Mountains, where the displacement is 500 feet or more, with the drop on the east side.

NACIMIENTO UPLIFT.

GENERAL RELATIONS.

In the north-central part of Sandoval County there is a prominent arch which gives rise to the Nacimiento Range and San Pedro Mountain. The beds are uplifted so high that in the central portions of the ridges the pre-Cambrian granites and schists appear. On the west side of this uplift the strata are upturned very steeply, constituting the east or southeast margin of the wide San Juan Basin. (See Pl. XLV, *B*, p. 237.) On the east side the dips are gentler, and limestones of the Magdalena group and overlying red shales and sandstones are spread out considerably and pass under the great pile of volcanic materials of the Valle Grande eruptions. The principal structural features are shown in figure 34.

STRATIGRAPHY.

The rocks exposed in these mountains are granites and schists; limestones and sandstones of the Magdalena group; and red shales and gray sandstones of the Permian and Triassic, which extend across the range in a depression of the anticline east of Senorito. Overlying strata as high as coal measures of the Mesaverde formation and early Tertiary deposits extend along the west slope of the mountains. The limestones on the east slope of the Sierra Nacimiento are extensively exposed in the deep canyons of the Rio de la Vaca and Jemez Creek, and on the intervening high mesas there is an extensive thick capping of tuffs and lavas of the Valle Grande volcanic area.

LOCAL STRUCTURE.

A short distance north of Jemez Springs a local anticline brings up the entire thickness of the Magdalena group, and the underlying granites are exposed in a small area in the bottom of the canyon. As the conditions in this area appear to be unfavorable for oil or gas, the minor details of flexure and faulting need not be presented here. At the south end of the mountains, however, south of Rio Salado, the strata pitch down, and although a profound fault cuts the east side of the uplift the arch is continued far southward in the Cretaceous

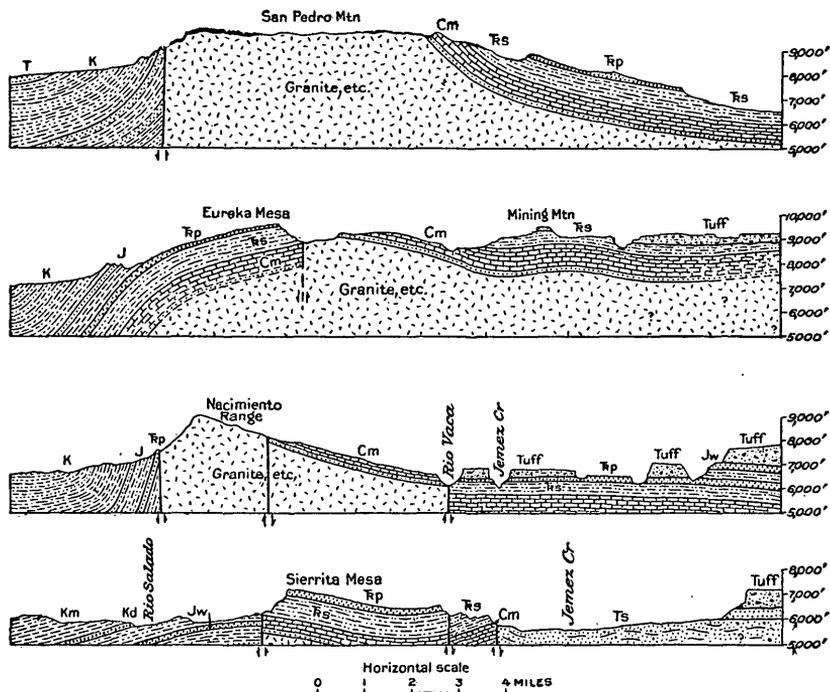


FIGURE 34.—Sections across San Pedro Mountain and the Nacimiento Range, in Sandoval and Rio Arriba counties, N. Mex. T, Tertiary; Ts, Santa Fe formation; K, Cretaceous; J, Jurassic; Jw, Wingate sandstone; Rp, Poleo sandstone; Rs, red shale; Cm, Magdalena group.

strata. This anticline is well exhibited through R. 1 W., from T. 15 N. to T. 13 N., and appears to extend still farther southwest, but the geology of the district has not been explored.

CHAMA BASIN.

GENERAL RELATIONS.

In the region above Abiquiu Rio Chama flows in canyons and broad valleys cut in a wide plateau on the northeast flank of a northern extension of the Nacimiento uplift. Above El Vado for many miles there is a broad valley in the Cretaceous shales, but below that place the Dakota sandstone is deeply trenched and

finally the underlying "Red Beds" are widely bared. In the greater part of the area the strata dip at very low angles; to the west they descend steeply into the San Juan Basin, and to the east they are cut off by faults and a steep uplift which brings up the pre-Cambrian

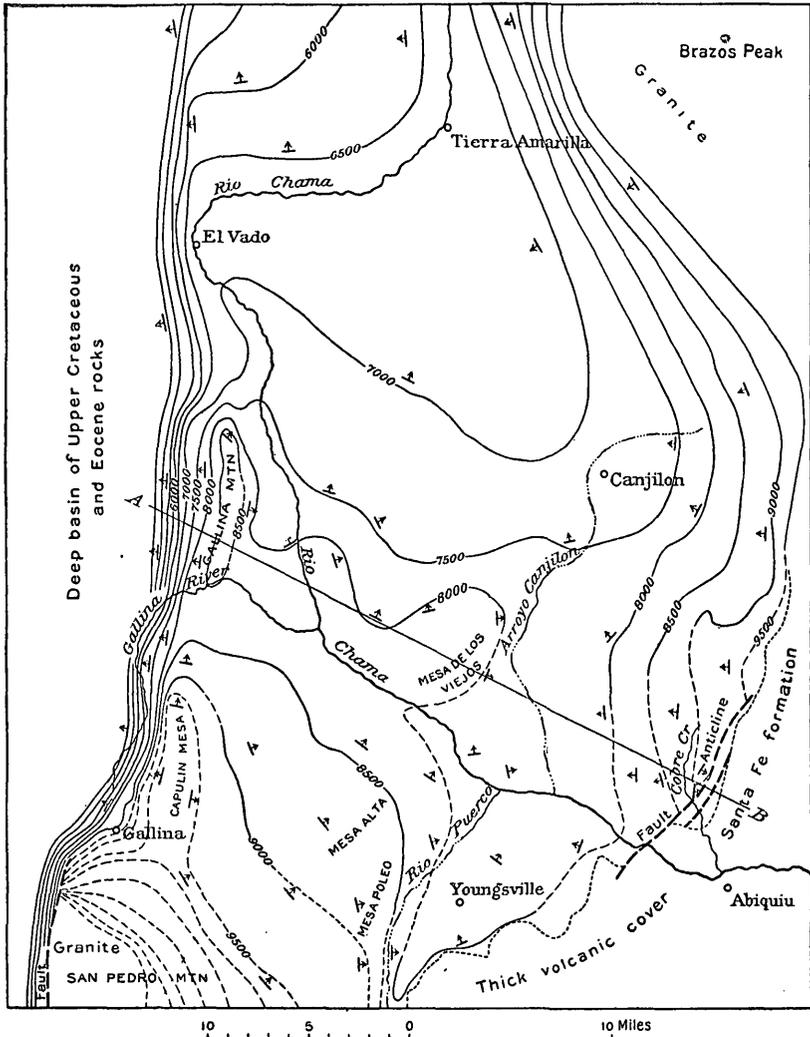


FIGURE 35.—Map showing structure in part of Rio Arriba County, N. Mex. Represented by contour lines at the top of the Dakota sandstone. Broken lines indicate areas from which the Dakota sandstone has been eroded. A-B, Line of section shown in figure 36.

crystalline rocks in the Brazos Peak district. Some of the broader structural features are shown by contours in figure 35, and the cross section, figure 36, shows the relations in the plateaus southwest of Canjilon, from T. 26 N., R. 1 W., to a point not far north of Abiquiu.

STRATIGRAPHY.

The principal formations in the Rio Chama basin are given in the following table:

Formations in southeastern part of Rio Arriba County, N. Mex.

| Age. | Group and formation. | Characteristics. | Thickness (feet). |
|-------------------|-----------------------|---|-------------------|
| Upper Cretaceous. | Mesaverde formation. | Sandstone and shale, with coal beds. | 800 |
| | Mancos shale. | Shale and sandstone. | 500-1,000 |
| | Dakota sandstone. | Sandstone, massive, hard, gray to buff. | 150-250 |
| Cretaceous (?). | Morrison formation. | Shale, massive, greenish gray, buff, maroon; some sandstone. | 100-180 |
| | Navajo (?) sandstone. | Sandstone, chocolate-brown. | 150 |
| Jurassic. | Todilto formation. | {Gypsum member 60 Limestone in thin layers, locally very sandy. . . 4-12 | |
| | Wingate sandstone. | Sandstone, very massive, fine grained; red below, white and buff at top. | 200 |
| | Chinle (?) formation. | Red shale. | 250 |
| Triassic. | Poleo sandstone. | Sandstone; maker of prominent ridges, plateaus, and cliffs. | 50-150 |
| | Permian (?). | Red shale and red and brown sandstone. | 250-550 |
| Pennsylvanian. | Magdalena group. | Limestone mainly; sandstone at base and top. | 60-450 |
| Pre-Cambrian. | | Granite. | |

Of the sandstones in the region east of the Mesaverde ridge those which possibly contain oil if oil is present in this area are the Dakota, which lies at moderate depth in the Chama Valley above El Vado; the Navajo, 100 to 180 feet below the Dakota; the Wingate; the Poleo; and some sandstones in the Magdalena group. The Navajo (?) sandstone is in the midst of a series poor in carbonaceous sediments. The Poleo and Magdalena sandstones are at considerable depth below the valley in the El Vado-Amarillo region, but they crop out toward the south, the Magdalena rocks being exposed on the slopes of the San Pedro Mountains.

LOCAL STRUCTURE.

As shown in figure 35, part of the area is a flat-bottomed synclinal basin, and although doubtless there are local domes and anticlines in this basin surveys have not been sufficiently detailed to locate them. Gallina Mountain and Capulin Mesa are anticlines or elongated domes of considerable prominence, but they are to be regarded as northern extensions of the Nacimiento uplift. They will in due course probably receive the attention of the wildcat driller. Care, however, should first be taken to ascertain whether the carbonization of the carbonaceous debris has advanced so far as to preclude the survival of oil in the formations in which the oil is sought.

out in a broad area to the west and south and in a narrow zone along the east margin of the basin. To the west is the Defiance anticline; to the east is the western limb of the Nacimiento uplift, steeply upturned for most of its course; and to the south is the broad anticline of the Zuni Mountain uplift. (See fig. 39, p. 255.) In the wide basin area the strata present very low dips, mostly 1° to 2° or even less, an inclination which is hardly perceptible to the eye. There is gradual deepening of the basin to the north. The general stratigraphic succession and relations are shown in figure 37, taken from Bauer's report³² on part of the basin. There is a finely developed dome with its apex in the north-central part of T. 15 N., R. 6 W.

OIL.

Petroleum is present in this general region, locally at least, as a small amount was found several years ago in relatively shallow wells at Seven Lakes, and oil seeps are reported near Baker's trading post

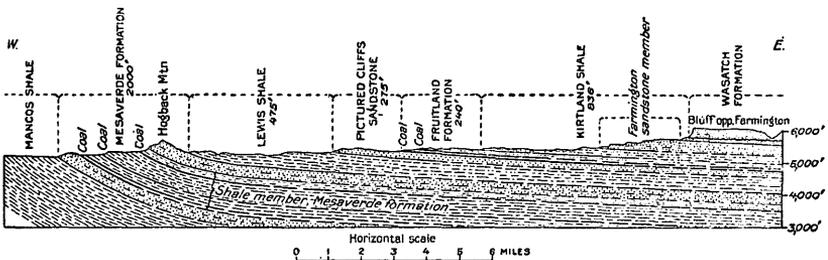


FIGURE 37.—Section along San Juan River from the Great Hogback to the bluff opposite Farmington, San Juan County, N. Mex. By C. M. Bauer.

and in Chaco Plateau. The first of these wells was one sunk for water in 1912 in sec. 18, T. 18 N., R. 10 W., in which considerable gas and oil were reported. Six other wells bored later found gas and some of them small amounts of oil at depths of 350 to 600 feet in Mesaverde beds. Whether or not this oil comes from a deep source and might be found in larger amounts at suitable depths where the strata are arched or domed can not be known until test borings are made.

It is generally believed that the structure in this region is not favorable for extensive reservoirs, but it is probable that detailed mapping of the structure will reveal somewhere in the region faint anticlines or domes in the Mancos and Mesaverde beds which may deserve testing.

A moderate amount of oil occurs in the sandstone of the Goodridge formation (probably equivalent to the Chupadera) in the canyon of San Juan River at Goodridge, Utah, 50 miles west of the northwest

³² Bauer, C. M., Stratigraphy of a part of the Chaco River valley: U. S. Geol. Survey Prof. Paper 98, fig. 27, p. 275, 1916.

corner of New Mexico. There are several productive wells, and the oil is of excellent quality. This formation lies far below the surface in the San Juan Basin, being probably almost 3,000 feet below at Ship Rock post office, 4,500 feet at Farmington, and 4,000 feet at Seven Lakes, but it comes to the surface in the Zuni Mountains.

It is claimed also that oil was found in some of the deep borings near Farmington, Fruitland, and Flora Vista.

LOCAL STRUCTURE.

Although the rocks in the greater part of the San Juan Basin appear to dip regularly into a wide basin, there are doubtless many local irregularities and reversals of dip due to domes, anticlines, and terraces. Only a small portion of the great area has been surveyed with care, and in the central part there is a widespread covering of early Eocene deposits, which conceal the structure of the underlying Cretaceous rocks. Figure 38 shows some structural features in the southeastern part of the basin.

One of the most notable structural irregularities in this area is the dome in Tps. 15 and 16 N., Rs. 6 and 7 W. The vertical uplift is more than 250 feet, and the dome brings to the surface the lower sandstone of the Mesaverde. The strata on the slopes have dips of 1° to 9° . Several faint domes occur farther west along the Mesaverde outcrop zone, and J. B. Reeside has noted one in the Navajo Indian Reservation about 12 miles west of Hunter's store.

According to Schrader³³ the coal-bearing rocks in the upper part of the beds of Montana age are uplifted in a low dome on Hosta Butte.

The hogback ridge that forms a prominent topographic feature extending from southwest to northeast across the western part of San Juan County is due to steeply uplifted sandstones of the Mesaverde group. San Juan River cuts through it in a gap. In this ridge the strata dip steeply southeastward along a zone 45 miles long. According to plats made by L. S. Gillett, of the General Land Office, there is behind this hogback, in the southern part of the Southern Ute Reservation, an anticline of considerable prominence in which the Mancos shale is bared for 15 miles or more. Apparently this anticline flattens out in the area east of Ship Rock post office, for it has not been noted near San Juan River. The dips are 8° to 10° on the southeast side of the flexure and very low on the northwest side, where there are southward-facing cliffs of sandstone of the lower part of the Mesaverde group.

³³ Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, p. 253, 1906.

DEEP BORINGS.

Several deep holes have been bored for oil in the San Juan Basin. The deepest one was sunk in 1913 by the Farmington Oil & Gas Co. on the Blake farm, near Farmington, in sec. 15(?), T. 29 N., R. 13 W. The record was as follows:

Record of deep well in sec. 15 (?), T. 29 N., R. 13 W., near Farmington, N. Mex.

| | Feet. |
|---|-------|
| Soil and cobblestones..... | 20 |
| Sand..... | 21 |
| Sandy shale..... | 31 |
| Shale, light..... | 215 |
| Sand; gas..... | 240 |
| Shale, light..... | 280 |
| Sand, gray..... | 285 |
| Shale..... | 320 |
| Sand..... | 325 |
| Shale; gas..... | 387 |
| Sand; gas..... | 394 |
| Shale..... | 425 |
| Sand..... | 432 |
| Shale, light..... | 582 |
| Shale, brown; gas at 730 and 790 feet..... | 797 |
| Shale, dark..... | 1,075 |
| Sand; gas..... | 1,160 |
| Shale, light..... | 1,185 |
| Sand..... | 1,220 |
| Shale, brown..... | 1,370 |
| Sand, gray..... | 1,375 |
| Shale, brown..... | 1,710 |
| Sand, dark..... | 1,780 |
| Shale, sandy, light..... | 1,830 |
| Shale, sandy, dark..... | 1,940 |
| Sand, dark..... | 1,965 |
| Shale, sandy, dark..... | 2,045 |
| Sand, white, fine..... | 2,050 |
| Shale, sandy; dark shells..... | 2,205 |
| Sand, hard..... | 2,210 |
| Shale, sandy; dark shells; salt water at 2,300 feet..... | 2,310 |
| Sand, dark..... | 2,430 |
| Sand, white..... | 2,435 |
| Sand, dark gray..... | 2,495 |
| Sand, white..... | 2,580 |
| Sand, gray; coal at 2,620 and 2,640 feet..... | 2,610 |
| Shale, sandy..... | 2,640 |
| Sand, white, hard..... | 2,655 |
| Coal..... | 2,658 |
| Sand and shale; strong flow of water over top of casing..... | 2,678 |
| Sand, red-brown; some oil (pit asphaltum or maltha)..... | 2,685 |
| Sand, gray, with specks of coal; water from well dark brown, cooler and less salty..... | 2,695 |
| Sand, gray-white..... | 2,725 |
| Coal and shale..... | 2,730 |
| Shale, tough; water milky. | |

It is suggested by Mr. Reeside, who kindly furnished the record, that the hole penetrated the Kirtland shale at 16 to 797 feet, the Fruitland formation at 797 to 1,075 feet, the Pictured Cliffs sandstone at 1,075 to 1,370 feet, the Lewis shale at 1,370 to 1,940 feet, the Cliff House sandstone (top formation of Mesaverde group) at 1,940 to 2,610 feet, and the Menefee (or middle formation of the Mesaverde group) at 2,610 to 2,730 feet, where the drill stuck.

A well in progress in sec. 2, T. 30 N., R. 12 W., was reported to have reached a depth of 2,900 feet in December, 1920. Some gas was reported in sands at 2,100 to 2,250 feet and at other horizons, and coal, one bed of which was 14 feet thick, between 1,700 and 2,085 feet.

A hole sunk in sec. 16, T. 30 N., R. 15 W., by the San Juan Basin Oil & Gas Co. to a depth of 2,080 feet had the following record:

Record of deep well in sec. 16, T. 30 N., R. 15 W., about 5 miles north of Fruitland, N. Mex.

| | Feet. |
|---|--------|
| Record lost; thin coal at 84 feet..... | 0-400 |
| Blue mud..... | 450 |
| Shale, sandy..... | 470 |
| Shale, blue..... | 524 |
| Sand; showing of oil..... | 525 |
| Shale, blue..... | 670 |
| Lime shell..... | 672 |
| Shale, blue..... | 680 |
| Lime, shell..... | 681 |
| Shale, blue..... | 706 |
| Limestone..... | 710 |
| Lime shells and blue shales..... | 810 |
| Shale, brown..... | 840 |
| Shale and lime shells..... | 965 |
| Sand; salt water..... | 973 |
| Shale, sandy, brown..... | 988 |
| Lime shells and blue shales..... | 1, 038 |
| Softer shales and lime shells..... | 1, 158 |
| Shale, blue..... | 1, 208 |
| Shale, blue, with lime streaks..... | 1, 403 |
| Light shale and lime shells..... | 1, 530 |
| Shale, brown..... | 1, 580 |
| Hard lime..... | 1, 586 |
| Sand; salt water..... | 1, 598 |
| Shale, blue, with lime streaks..... | 1, 615 |
| Hard lime..... | 1, 625 |
| Sand; good showing of oil..... | 1, 640 |
| Sand; salt water..... | 1, 665 |
| Shale, sandy..... | 1, 690 |
| Sand; salt water..... | 1, 720 |
| Shale, gray, with strata of lime..... | 1, 900 |
| Shale with lime streaks..... | 1, 980 |
| Lime with burnt formation..... | 2, 010 |
| Shale, black, with lime streaks..... | 2, 070 |
| Hard sandrock with artesian salt water, which ran over casing in small stream..... | 2, 080 |

According to Mr. Reeside, who kindly furnished the log, the hole began in the Fruitland formation, penetrated the Pictured Cliffs sandstone and Lewis shale from 84 to 965 feet and the Cliff House sandstone from 965 to 1,580 feet, and ended in the Menefee formation.

Another hole 1,719 feet deep, sunk by the same company in the adjoining sec. 21, is reported to have struck considerable oil, but owing to breaking of tools the well was abandoned. It is said that the well passed through a thin bed of coal with salt water at 83 feet and found fresh water at 113 feet and at 740 feet. Shale, presumably the Lewis shale, began at 200 feet, and the first indications of oil were at 1,715 feet. These two holes near the center of T. 30 N., R. 15 W., appear to have been in some small anticlinal crumples on the slope of the main hogback monocline, and unfortunately they did not test all the Mesaverde strata.

A hole in sec. 16, T. 30 N., R. 12 W., 3 miles northwest of Flora Vista, reached a depth of 1,512 feet in July, 1920, and reported a small amount of oil. It penetrated the Wasatch formation and the Kirtland shale and Fruitland formation. The Mesaverde, according to Bauer's section, is about 400 feet below. The beds dip to the east at a low angle, averaging about 1°.

Another test hole 2 miles to the west, in sec. 18, about 200 feet higher, was 890 feet deep and is reported to have found a small amount of oil.

A well 1,111 feet deep at the Pueblo Bonito School, in sec. 30, T. 17 N., R. 12 W., penetrated alternating sandstone and shale with four thin beds of coal near 700 feet.³⁴ Another well, 1,205 feet deep,³⁴ 5 miles to the northwest, in sec. 10, T. 17 N., R. 13 W., penetrated shale and sandstone. Both of these holes were in the Mesaverde and Mancos formations. A third hole in the same general vicinity, in sec. 12, T. 18 N., R. 12 W., is 1,030 feet deep and yields a flow of water.

Several wells have been bored for oil recently in the Seven Lakes district. One in sec. 31, T. 18 N., R. 9 W., reached a depth of 800 feet without success. Below 65 feet continuous sandstone was reported. A 390-foot hole in sec. 16, T. 17 N., R. 11 W., penetrated sand and shale with thin layers of lignite.

A well in the center of sec. 18, T. 18 N., R. 13 W., 35 miles northeast of Gallup, had the following log, according to Mr. Gus Mulholland, of Gallup:

Log of boring 10 miles northwest of Crown Point, McKinley County, N. Mex.

| | Feet. |
|-----------------------|---------|
| Sand and mud..... | 0-80 |
| Sandstone, white..... | 80-240 |
| Lime shell..... | 240-245 |
| Shale..... | 245-475 |

³⁴ For records see Gregory, H. E., *The Navajo country*: U. S. Geol. Survey Water-Supply Paper 380, p. 181, 1916.

| | Feet. |
|--|---------------|
| Sandstone, gray; water alkaline | 475-525 |
| Lime shell..... | 525-535 |
| Sandstone, hard, gray..... | 535-585 |
| Shale..... | 585-635 |
| Sandstone..... | 635-655 |
| Coal and shale..... | 655-665 |
| Sandstone, white..... | 665-700 |
| Shale, blue..... | 700-725 |
| Sandstone..... | 725-785 |
| Lime shell..... | 785-805 |
| Sandstone..... | 805-845 |
| Shale..... | 845-1, 000 |
| Sandstone; good water..... | 1, 000-1, 030 |
| Shale, sandy..... | 1, 030-1, 050 |
| Sandstone, gray..... | 1, 050-1, 090 |
| Shale..... | 1, 090-1, 120 |
| Sandstone, with good flow of water | 1, 120-1, 200 |
| Lime shell..... | 1, 200-1, 210 |
| Sandstone, hard, gray..... | 1, 210-1, 320 |
| Sandstone; flow of good water at top | 1, 320-1, 400 |
| Shale, hard, brown..... | 1, 400-1, 520 |
| Shale and fire clay; small flow of oil, some gas | 1, 520-1, 540 |

This well penetrated the Mesaverde strata and entered the shales of the Mancos group.

Record of artesian well 9 miles southeast of Tohachi, N. Mex.

| | Feet. |
|--|---------|
| Sand and clay..... | 0-80 |
| Fine sand..... | 80-102 |
| Shale..... | 102-104 |
| Tough blue clay..... | 104-112 |
| Shale and shallow layers of rock..... | 112-174 |
| Light-gray sandstone, hard..... | 174-186 |
| Shale and slate..... | 186-192 |
| Light-gray sandstone, hard..... | 192-225 |
| Shale..... | 225-234 |
| Sandstone..... | 234-236 |
| Shale..... | 236-242 |
| Slate, hard..... | 242-250 |
| Sandstone..... | 250-262 |
| Shale..... | 262-285 |
| Sandstone, extraordinarily hard..... | 285-288 |
| Sandrock, loose..... | 288-298 |
| Coal; water rose within 28 feet of surface..... | 298-299 |
| Shale, tough and sticky..... | 299-332 |
| Shale..... | 232-340 |
| Sandstone..... | 340-342 |
| Slate, very hard..... | 342-356 |
| Sandstone..... | 356-357 |
| Shale..... | 357-398 |
| Sandstone; water rose within 20 feet of surface..... | 398-402 |
| Shale..... | 402-422 |
| Shale, sandstone, and coal..... | 422-426 |

| | Feet. |
|--|---------------|
| Gallup fire clay..... | 426-446 |
| Rock, very hard, dark, carrying mineral..... | 446-454 |
| Light-gray sandstone..... | 454-620 |
| Fire clay..... | 620-622 |
| Light-gray sandstone..... | 622-684 |
| Dark-brown sandstone..... | 684-702 |
| Fire clay..... | 702-722 |
| Light-gray sandstone..... | 722-742 |
| Fire clay..... | 742-753 |
| Light-gray sandstone..... | 753-774 |
| Fire clay..... | 774-800 |
| Sandstone; thin layer of coal..... | 800-816 |
| Fire clay..... | 816-906 |
| Light-gray sandstone; water over casing, 90 gallons an hour..... | 906-943 |
| Coal..... | 943-946 |
| Light-gray sandstone..... | 946-949 |
| Fire clay..... | 949-955 |
| Dark close-grained rock, hard..... | 955-964 |
| Fire clay..... | 964-988 |
| Shale..... | 988-1, 001 |
| Close-grained sandrock, hard..... | 1, 001-1, 018 |
| Fire clay, very tough and sticky..... | 1, 018-1, 035 |
| Close-grained sandrock, very hard..... | 1, 035-1, 050 |
| Light-yellow sandrock; water flows 300 gallons an hour..... | 1, 050-1, 058 |
| Light-gray sandrock..... | 1, 058-1, 082 |
| Light-yellow sandrock; well flows 2,500 gallons an hour.... | 1, 082-1, 094 |
| Light-gray sandrock; well flows 6,000 gallons an hour..... | 1, 094-1, 108 |
| Shale..... | 1, 108-1, 150 |

ZUNI MOUNTAINS.

GENERAL RELATIONS.

The Zuni Mountains, in McKinley and Valencia counties, are due to hard rocks uplifted by an extensive anticline or elongated dome. This uplift has steep dips on its west side, where the strata pass under the Zuni-Gallup coal basin (see Pl. XLVII, *A*), and very gentle dips on the north and northwest sides into the San Juan Basin (see Pls. XLVI, *A*; XLVII, *B*). Toward the southeast the flexure flattens into a broad monocline extending under the Cebolleta Mesa. The sections in figure 40 show the principal structural features of the Zuni Mountain uplift, and some general relations are shown in figure 39. As is shown in the cross sections, the uplift is relatively regular, but the rate of dip varies from place to place, and there is considerable faulting in part of the area. The pre-Cambrian granite is exposed by erosion in three areas in the center of the uplift. Well-marked subordinate structural features such as local or minor domes and anticlines are rare, although all of the area has not been closely scrutinized for those features. West of Grant there are a number of minor domes near the foot of the limestone slopes, and it is possible that in the wide shale valley extending from Bluewater to the area northwest of Wingate there may be some local uplifts.

STRATIGRAPHY.

The strata exposed in the Zuni Mountain uplift comprise formations from the base of the Abo sandstone (Permian) to the coal measures of the Upper Cretaceous.

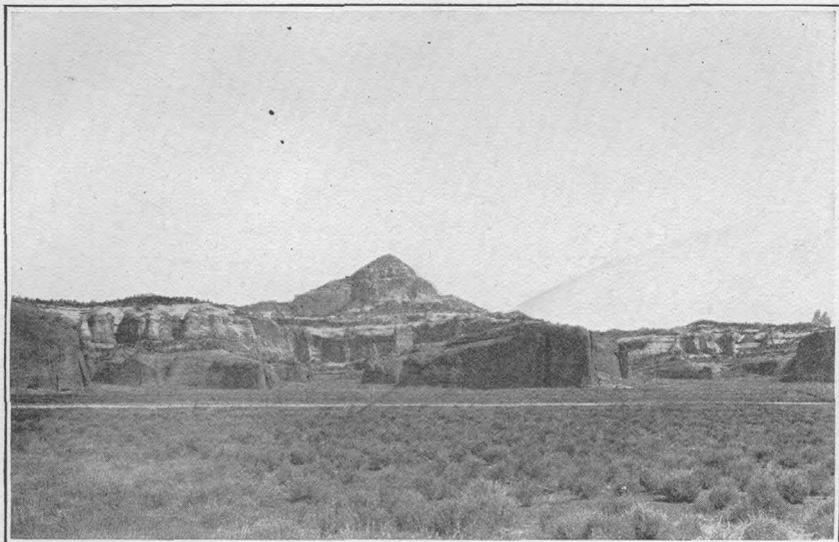
Formations in the Zuni Mountain uplift.

| Age. | Group and formation. | Characteristics. | Approximate average thickness (feet). | |
|-------------------|-------------------------|---|---|---------|
| Upper Cretaceous. | Mesaverde formation. | Sandstone with coal beds. | 1,000 | |
| | Mancos shale. | Shales and sandstones; coal in upper part. | 750 | |
| | Dakota sandstone. | Sandstones, massive, gray, hard. | 120-250 | |
| Cretaceous (?). | McElmo formation. | Sandstone and sandy shale, gray-greenish to maroon. | 150 | |
| Jurassic. | Navajo sandstone. | Sandstone, massive, gray to pink. | 300-650 | |
| | Todilto limestone. | Limestone, mostly very thin bedded. | 0- 20 | |
| | Wingate sandstone. | Sandstone, fine-grained, massive, pink, hard, making high cliffs on north side, soft on south side of uplift. | 300-400 | |
| Triassic. | Chinle formation. | Shale, red to gray, limestone concretions. | 850 | |
| | Shinarump conglomerate. | Sandstone, gray to buff, locally conglomeratic. | 20- 60 | |
| | Moenkopi formation. | Shale, mostly sandy and red. | 500-850 | |
| Permian. | Manzano group. | Chupadera formation. | Limestone and hard gray sandstone above, soft red sandstone below. | 500 |
| | | Abo sandstone. | Brown-red slabby sandstone and sandy shale, with locally basal limestone and sandstone. | 600-700 |
| Pre-Cambrian. | | Granite, etc. | | |

The sandstones in the Chupadera formation and the Shinarump conglomerate can be reached by borings of moderate depth in the valleys adjoining the uplift. These sandstones, however, lie very deep in the basin west of the uplift and under the valley of Mancos shale to the north.

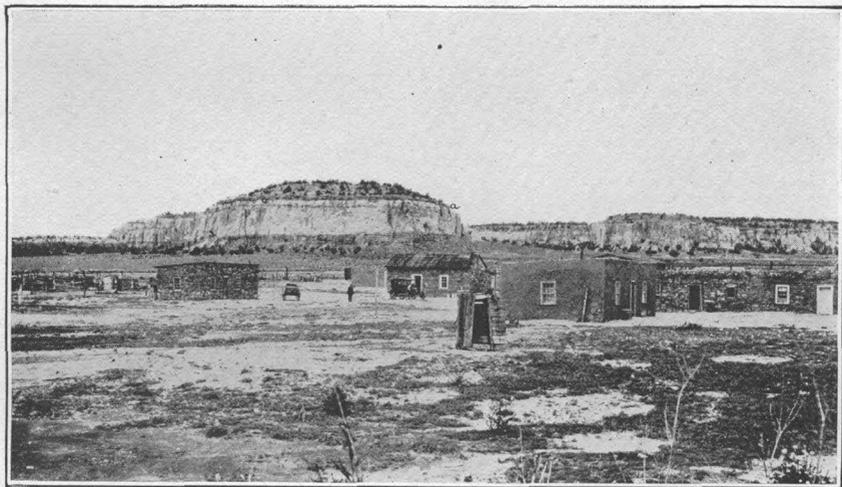
DEEP BORINGS.

Holes of considerable depth have been bored for water at several points along the Atchison, Topeka & Santa Fe Railway between Bluewater and Gallup. At Gallup, which is in the basin west of the uplift, the borings obtain artesian water from the Dakota and over-



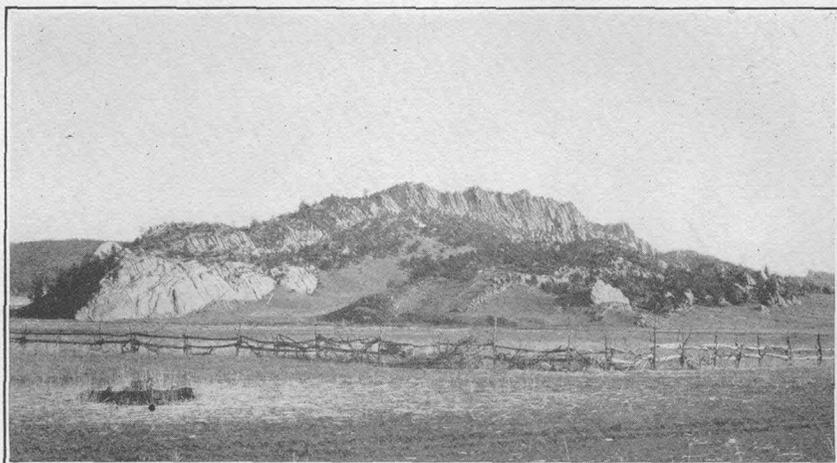
A. PYRAMID ROCK, 10 MILES EAST OF GALLUP, N. MEX.

Red cliffs of Wingate sandstone in foreground; Navajo sandstone and higher beds on ridge and pyramid.

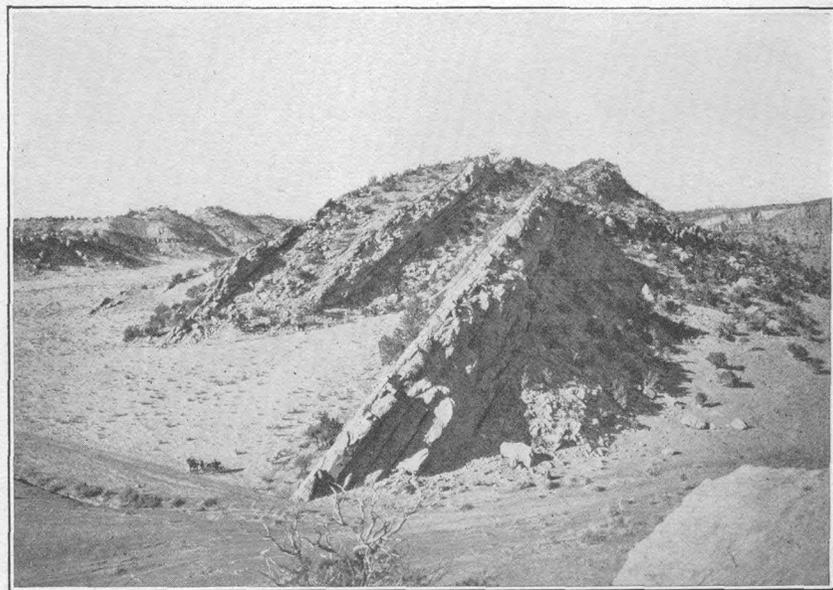


B. UPLIFT AT ATARQUE, SOUTHWESTERN VALENCIA COUNTY, N. MEX.,
LOOKING NORTHEAST.

Dakota sandstone lying unconformably on Navajo sandstone.



A. WEST SLOPE OF ZUNI UPLIFT AT NUTRIA, N. MEX., LOOKING SOUTHEAST.
Navajo and Wingate sandstones.



B. NORTHWEST SLOPE OF ZUNI UPLIFT EAST OF GALLUP, N. MEX., LOOKING
NORTH.
Dakota and overlying sandstones.

lying sandstones. None of these holes except possibly the wells at Gallup and Bluewater have been sunk in places where the structure would be favorable for oil accumulation, and, moreover, none of them

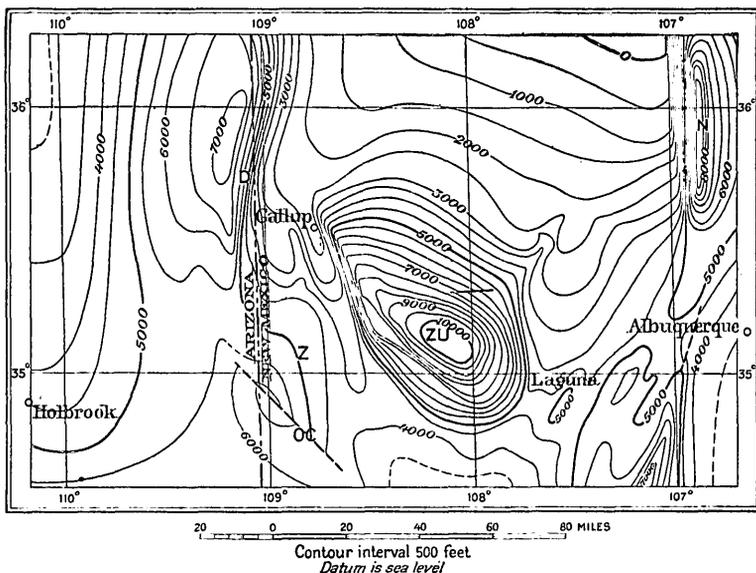


FIGURE 39.—Map showing structure of part of northwestern New Mexico. ZU, Zuni uplift; N, Nacimiento uplift; D, Defiance uplift; OC, Ojo Caliente uplift and fault; Z, Zuni. Contours represent top of Chupadera formation, which, however, is absent on the higher uplifts.

are sufficiently deep to reach the sandstones of the Chupadera formation. No traces of oil or gas were reported. The well at Bluewater had the following record:

Record of boring at Bluewater station, N. Mex.

| | Feet. |
|---|---------|
| Lava, two beds (?), with thin bed of tuff and red clay between..... | 0-90 |
| Clay, red..... | 90-159 |
| Clay, blue..... | 159-260 |
| Sandstone, gray, soft..... | 260-263 |
| Clay, blue..... | 263-270 |
| Sandstone, gray, hard above, red below..... | 270-291 |
| Limestone, hard, with hard dark sandstone at 439-447 feet..... | 291-455 |
| Sandstone, white; water in small amount..... | 455-575 |
| Sandstone, red; bad water..... | 575-735 |

This hole passed through clays in the lower part of the Moenkopi formation to 291 feet, limestones and sandstones of the Chupadera formation to 575 feet, and lower red beds at the base of the Chupadera, possibly reaching the top beds of the Abo sandstone, to the bottom.

An artesian well at North Chaves, 707 feet deep, doubtless draws its supply of excellent water from the Shinarump conglomerate,

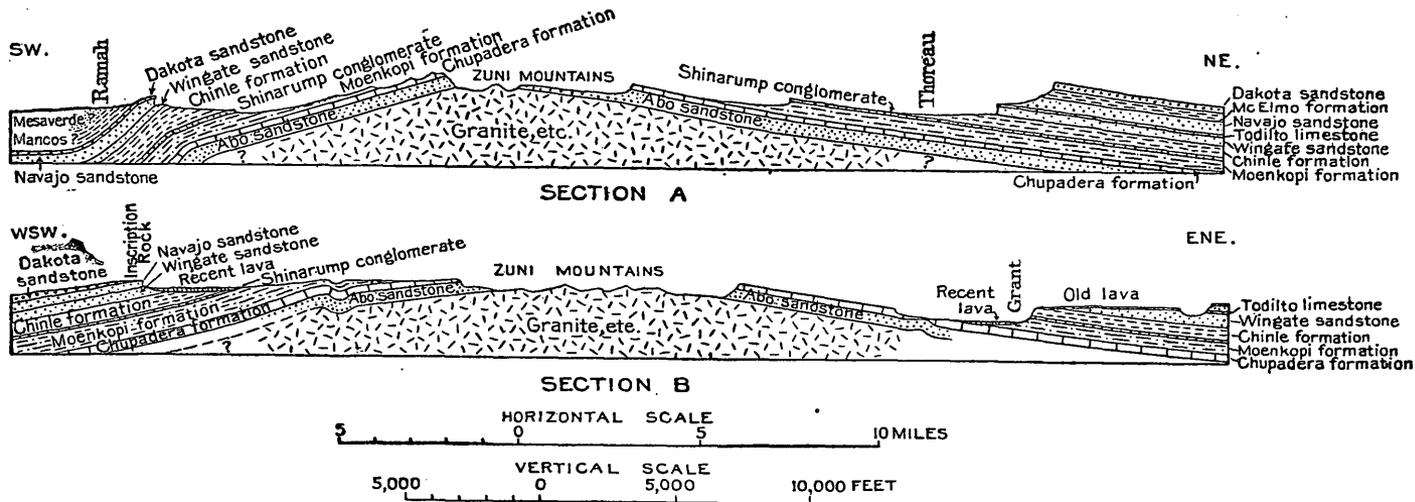


FIGURE 40.—Sections across the Zuni Mountain uplift in McKinley and Valencia counties, N. Mex.

which rises to the surface on the dip not far south of the railroad. The following record is given:

Record of well at North Chaves siding, McKinley County, N. Mex.

| | Feet. |
|-----------------------------|---------|
| Clay, sand, and gravel..... | 0-52 |
| Sandstone, gray..... | 52-195 |
| Clay, red..... | 195-530 |
| Clay, blue..... | 530-570 |
| Sandstone, gray..... | 570-595 |
| Sand, black..... | 595-600 |
| Sandstone, gray..... | 600-700 |

A 600-foot hole at Guam penetrated the following strata:

Record of boring at Guam, N. Mex.

| | Feet. |
|--|---------|
| Sand, clay, and gravel..... | 0-55 |
| Sandy clay, with petrified wood at base..... | 55-76 |
| Shale, blue, compact..... | 76-92 |
| Sandstone, soft, white..... | 92-103 |
| Shale, red..... | 103-108 |
| Sandstone, red, hard..... | 108-135 |
| Shale, red..... | 135-145 |
| Sandstone and conglomerate; small supply of water..... | 145-155 |
| Sandstone, gray..... | 155-210 |
| Shale, blue, compact..... | 210-410 |
| Shale, soft..... | 410-540 |
| Sandstone, red, hard..... | 540-560 |
| Shale, red, hard..... | 560-600 |

These strata are all in the Chinle formation, but the Shinarump conglomerate was not far below and no doubt would have yielded a satisfactory water supply.

GALLUP-ZUNI BASIN.

GENERAL RELATIONS.

West of the Zuni uplift there is a basin of considerable extent which holds a wide area of Cretaceous coal measures at Gallup and extends southward for 60 miles or more into Valencia County. The succession of rocks in this basin comprises strata from late Cretaceous probably to Pennsylvanian. As shown in the cross sections of figure 41 the principal structural features are the steep descent of the strata along the west side of the Zuni uplift; the wide, flat-bottomed basin to the west; and the gradual reappearance of the Cretaceous and Jurassic beds as the strata rise and the country drops toward the west. West of the axis of the basin the strata dip east at very low angles, in most places appearing to be practically horizontal. In this part of the area there are low domes and structural terraces, but only a few of the features of this character have been investigated.

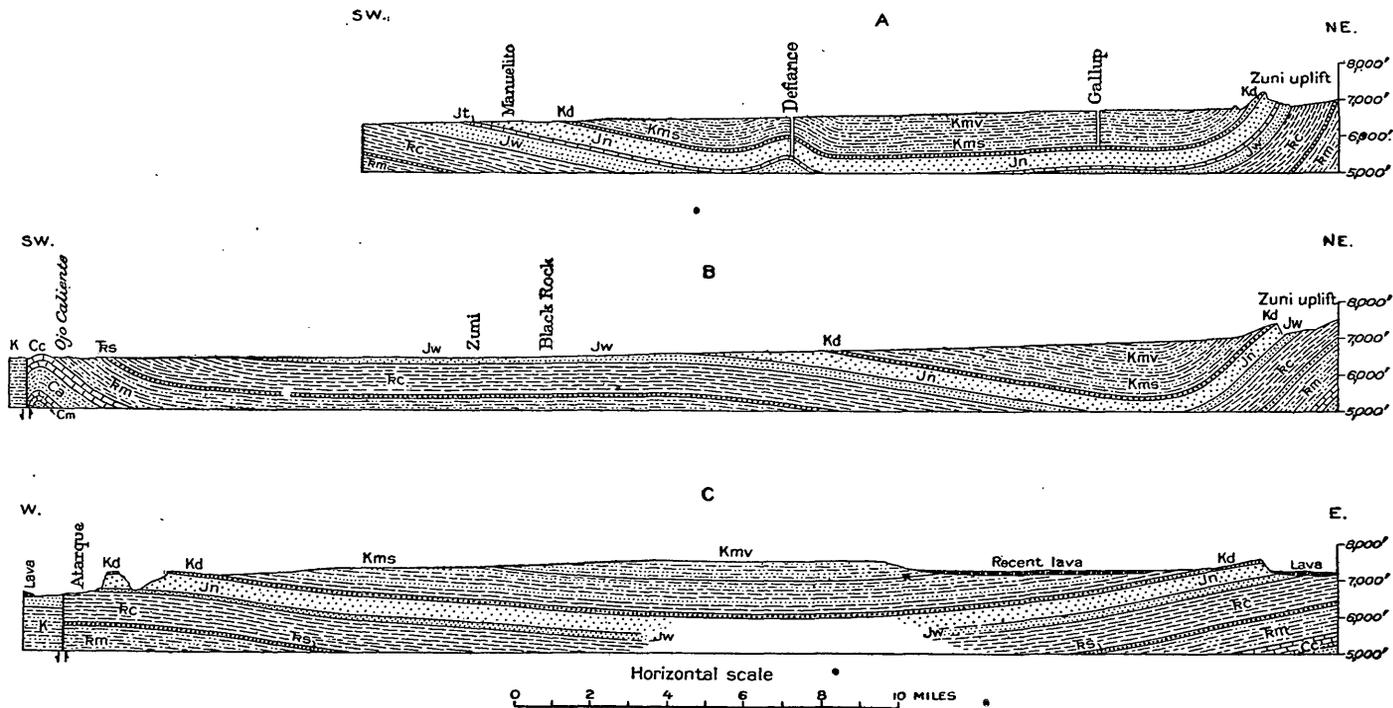


FIGURE 41.—Sections across the Gallup-Zuni Basin, N. Mex. A, Through Gallup; B, near Zuni; C, near Atarque. K, Cretaceous; Kmv, Mesaverde formation; Kms, Mancos shale; Kd, Dakota sandstone; Jn, Navajo sandstone; Jt, Todilto limestone; Jw, Wingate sandstone; Rc, Chinle formation; Fs, Shinarump conglomerate; Rm, Moenkopi formation; Ca, Abo sandstone; Cm, Magdalena group.

STRATIGRAPHY.

The formations underlying the Gallup-Zuni Basin are set forth in the following table:

Formations in Gallup-Zuni Basin.

| Age. | Group and formation. | Character. | Thickness (feet). |
|-------------------|-------------------------|--|-------------------|
| Upper Cretaceous. | Mesaverde formation. | Sandstones with coal beds. | 1,000± |
| | Mancos shale. | Upper half sandstones and shales; lower half mostly shale. | 900 |
| | Dakota sandstone. | Sandstone, massive, gray to buff. | 50-100 |
| Jurassic. | Navajo sandstone. | Sandstone, gray to pink, massive. | 450-600 |
| | Todilto limestone. | Limestone, thin bedded. | 15-25 |
| | Wingate sandstone. | Sandstone, pink, massive and hard to north. | 280-400 |
| Triassic. | Chinle formation. | Shale, red, gray, and purple. | 350-900 |
| | Shinarump conglomerate. | Sandstone, partly conglomeratic. | 50-80 |
| | Moenkopi formation. | Shale, gray to red, part sandy; thickens to southwest. | 500-900 |
| Permian. | Manzano group. | Chupadera formation. | 800± |
| | | Abo sandstone. | 800± |
| Pennsylvanian. | Magdalena group. | Limestone. (Probably present.) | (?) |
| Pre-Cambrian. | | Granite, etc. | |

These rocks present the same features that they have in other portions of western New Mexico. The Magdalena group is not exposed, but on account of the thickness of limestones of Pennsylvanian age farther west it is believed to be present. Sandstones texturally favorable for oil or gas, if these materials are present, are those in the Mesaverde, which is at or near the surface throughout, the Mancos, which is 600 feet or more deep in places, the Dakota sandstone, the Shinarump, and especially the massive gray sandstone in the Chupadera formation. The Dakota sandstone, however, is usually full of water.

LOCAL STRUCTURE.

A well-defined anticline or dome at Defiance switch, 8 miles west of Gallup, brings up the sandstone at the top of the Mancos shale in a small area. (See section A, fig. 41.) The extent of the flexure

was not determined. In 1918 a 1,155-foot hole was bored on this anticline by the Carter Oil Co., with the record given on page 261. There is a broad terrace or doming of the strata near Zuni pueblo. North of Zuni Buttes a prominent arch which extends to and beyond the valley of Whitewater Creek brings to the surface the Chinle formation in an area of moderate extent. In 1919 a test hole was bored near the crest of this anticline by the Carter Oil Co.; the strata penetrated are given on page 262.

A pronounced doming of the strata in the eastern part of Gallup is indicated by the altitude and relations of the coal measures. The vertical uplift is several hundred feet, but no precise measurements have been made. The dome pitches down to the north, and in the vicinity of the coal mines at Gibson it is also considerably faulted. The anticlinal structure appears to continue for some distance south of Gallup. The 1,112-foot artesian well at Gallup draws from the Dakota sandstone near the crest of this dome. This sandstone appears to have been reached at a depth of 940 feet.

In the vicinity of Ojo Caliente there is a well-marked anticlinal uplift, cut off on the west side by a fault, which brings the Mancos and Chupadera formations into contact, as shown in section B, figure 41. At the axis of this uplift a small area of the top limestone of the Chupadera formation is exposed. This uplift extends southeastward to Atarque, where it is exhibited in a low arch of the red Navajo sandstone. (See Pl. XLVI, B, p. 254.) Whether or not the fault extends as far southeast as this locality was not determined. The structural conditions at Atarque, Ojo Bonito, and Ojo Caliente appear to be favorable for the accumulation of oil or gas provided those materials are present in the strata. At all these points the strata that may prove to be oil bearing are sandstones in the Chupadera formation, which are at a very moderate depth, or sandstones or limestones of the Magdalena group, which may underlie the area. The Chupadera formation and the Magdalena group are separated by about 800 feet of the red sandstones of the Abo formation, which is not promising as a source of oil or gas.

DEEP BORINGS.

A few deep holes in the southern part of the basin have not revealed any evidence of oil or gas. A 1,112-foot well at Gallup furnishes a flow of excellent water from the Dakota sandstone. Its record is as follows:

Record of city artesian well at Gallup, N. Mex.

| | |
|-----------------------------|---------|
| Upper part of Mancos shale: | Feet. |
| Wash. | 0-75 |
| Sandstone..... | 75-95 |
| Shale..... | 95-128 |
| Sandstone..... | 128-136 |
| Shale..... | 136-141 |

| Lower part of Mancos shale: | Feet. |
|--|------------|
| Sandstone..... | 141-195 |
| Shale..... | 195-225 |
| Sandstone..... | 225-296 |
| Sandy shale..... | 296-309 |
| Shale..... | 309-798 |
| Sandstone and shale..... | 798-814 |
| Sandstone..... | 814-855 |
| Shale..... | 855-908 |
| Sandstone..... | 908-912 |
| Shale..... | 912-940 |
| Sandstone (Dakota), with 20 pounds pressure, 15-gallon flow. | 940-1, 112 |

A 1,155-foot hole sunk on the anticline at Defiance switch, in the SW. $\frac{1}{4}$ sec. 29, T. 15 N., R. 19 W., 8 miles west of Gallup, found an artesian flow of water and ended in the upper part of the Navajo sandstone. If boring had continued 1,500 feet deeper the drill would have tested the Shinarump conglomerate. The sandstone in the Chupadera formation lies about 800 feet still deeper. This well was drilled in 1918 by the Carter Oil Co. The following record made by the driller was kindly supplied by the Atchison, Topeka & Santa Fe Railway Co.:

Record of boring at Defiance siding, McKinley County, N. Mex.

| | Feet. |
|--|---------------|
| Soil..... | 0-6 |
| Quicksand..... | 6-200 |
| Shale..... | 200-203 |
| Sandstone, light..... | 203-235 |
| Sandstone, in part conglomeratic; water..... | 235-251 |
| Shale, blue..... | 251-252 |
| Sandstone, white; water..... | 252-290 |
| Shale, blue..... | 290-295 |
| Sandstone, light..... | 295-330 |
| Shale, light..... | 330-380 |
| Sand, light brown..... | 380-385 |
| Shale, blue..... | 385-403 |
| Sandstone, white; artesian flow..... | 403-535 |
| Shale, sandy..... | 535-555 |
| Sandstone..... | 555-567 |
| Sandstone, red..... | 567-570 |
| Sandstone, white..... | 570-600 |
| Sandy shale..... | 600-765 |
| Sandstone, white..... | 765-885 |
| Sandstone, gray; artesian flow at 1,030 feet, 25 gallons a minute..... | 885-1, 125 |
| Sandstone, pink, hard..... | 1, 125-1, 155 |

It is difficult to recognize strata in this record, because the sandy component of the material has been exaggerated. Shales of the Mancos formation extend to a depth of 765 feet, where the Dakota sandstone was entered. Doubtless the Dakota extends to 885 feet, where the drill entered the Navajo sandstone. It is unfortunate

that this hole was not continued through the Wingate sandstone and underlying red beds to test lower strata—the Shinarump, Chupadera, and Abo.

Several deep holes have been sunk in the coal measures near Gibson and Clarkville, north of Gallup. One of these at the Heaton mine, 1 mile northeast of Gibson, was 1,033 feet deep, and one at Gibson was 935 feet deep. Both were in Mesaverde and Mancos beds.

The test well sunk by the Carter Oil Co. in 1919 in the SW. $\frac{1}{4}$ sec. 17, T. 11 N., R. 19 W., about 30 miles southwest of Gallup, reached a depth of 1,980 feet. The boring began not far below the top of the Chinle formation and was discontinued in the Abo sandstone. The following strata were reported by Mr. Nesselrode, the superintendent; the identifications of the formations are my own:

Record of well in the SW. $\frac{1}{4}$ sec. 17, T. 11 N., R. 19 W., N. Mex.

| | |
|---|-------------|
| Chinle, Shinarump, and Moenkopi formations: | Feet. |
| Shale, all red..... | 0-1,006 |
| Sandstone, gray to white..... | 1,006-1,010 |
| Shale, red..... | 1,010-1,070 |
| Chupadera formation: | |
| Limestone..... | 1,070-1,100 |
| Sandstone, gray..... | 1,100-1,355 |
| Shale, red..... | 1,355-1,630 |
| Abo sandstone: | |
| Limestone, very hard, some grit..... | 1,630-1,650 |
| Shale, red..... | 1,650-1,980 |

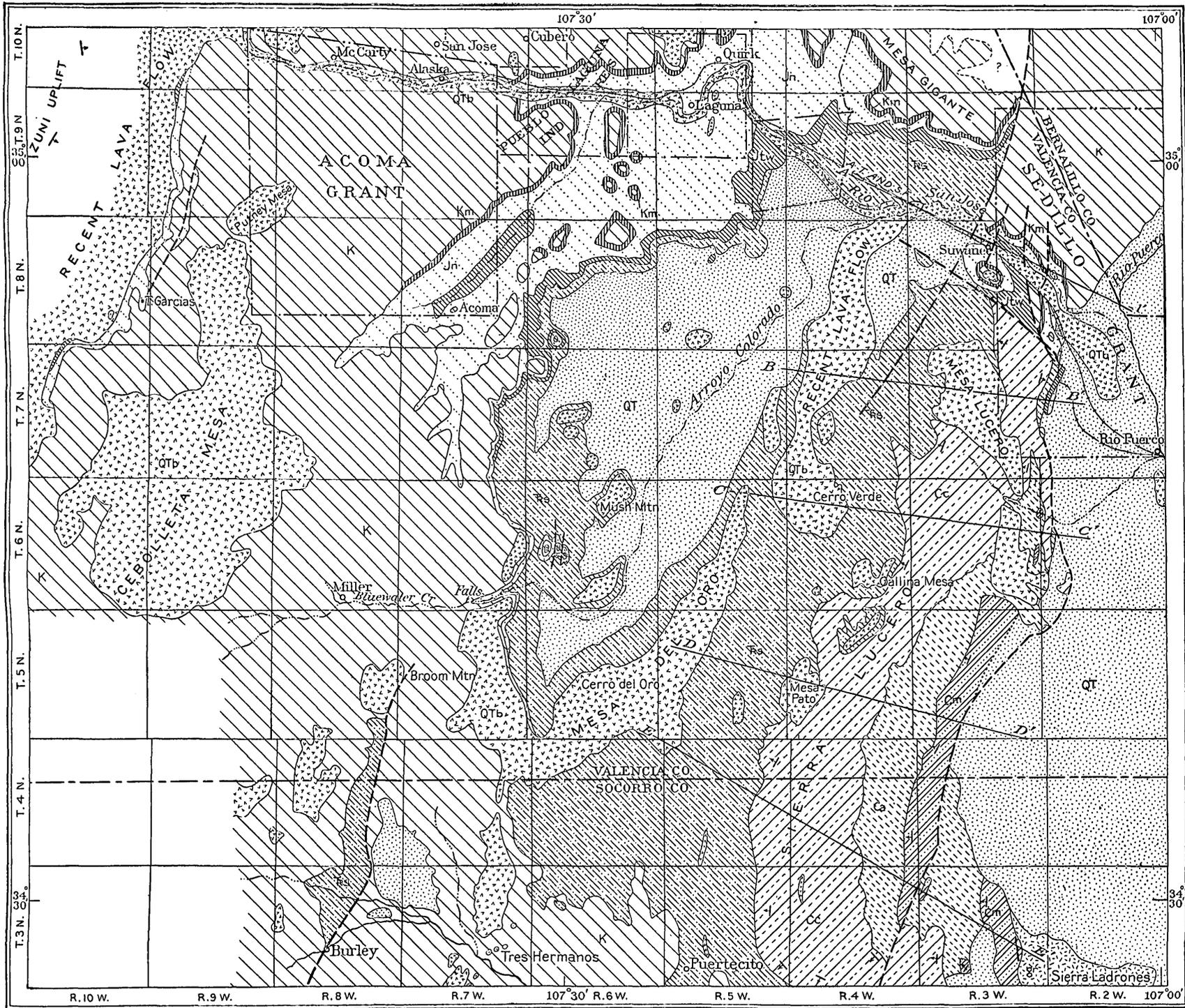
Boring was discontinued mainly because it was supposed that the hole had nearly reached the base of the sedimentary succession. The report that this hole reached granite is doubtless a mistake. It is likely that the Abo formation is at least 800 feet thick at this place, in view of the probable thickness from the Zuni Mountain uplift to the outcrops of corresponding strata in eastern Arizona, and that a considerable thickness of the underlying Magdalena is also present. The Magdalena is apparently absent in the Zuni Mountain uplift, but its equivalent is prominent not far west in Arizona.

EAST-CENTRAL VALENCIA COUNTY.

GENERAL RELATIONS.

The region extending from Cebolleta Mesa to the Sierra Lucero is in general a broad basin, whose west side rises to the faulted zone on the western margin of the Rio Grande basin. The principal structural features of the eastern part of this region are shown in the cross sections on Plate XLIX, and the distribution of formations is shown in Plate XLVIII.

Although in general this region is one of widespread monoclines, there are irregularities in dip which may indicate the presence of low domes, anticlines, and structural terraces that might possibly be favorable to the accumulation of oil or gas.



EXPLANATION

SEDIMENTARY ROCKS

QT
Sand, gravel, and loam

K
Sandstone and shale of Montana and Colorado ages; Dakota sandstone at base

Morrison shale
(Light-colored massive shale)

Jn
Navajo sandstone
(Massive sandstone, in greater part gray; red at base)

Jtw
Todilto formation
(Limestone with thick bed of gypsum at top to northeast on Wingate sandstone
(Mostly pink sandstone)

Rs
Red shale

Cc
Chupadera formation
(Limestone, sandstone, and gypsum)

Ca
Abo sandstone
(Red sandstone and sandy shale)

Cm
Magdalena group
(Mostly limestone)

IGNEOUS AND METAMORPHIC ROCKS

QTb
Lava flows
(Basalt)

g
Granite, gneiss, etc.

Fault

Strike and dip

Upper Cretaceous

CRETACEOUS(?)

JURASSIC

TRIASSIC

CARBONIFEROUS

Permian (Manzano group)

Permian (Magdalena group)

PRE-QUATERNARY AND CAMBRIAN

QUATERNARY AND TERTIARY

TERTIARY(?)

GEOLOGIC MAP OF PARTS OF VALENCIA AND SOCORRO COUNTIES, N. MEX.

A-A', etc., lines of sections in Plate XLIX.

STRATIGRAPHY.

The strata in this region extend from a horizon high in the Mesaverde to the base of the Magdalena group, which lies on pre-Cambrian granite in the Sierra Ladrones. The following table shows the principal features and thickness of the formations:

Sedimentary formations in the eastern half of Valencia County, N. Mex.

| Age. | Group and formation. | Character. | Thickness (feet). | |
|-------------------|------------------------|--|--|------|
| Miocene. | Santa Fe formation. | Silt, clay, sand, and gravel, locally consolidated. | 100+ | |
| Upper Cretaceous. | Mesaverde formation. | Sandstone, with some shale. | 800+ | |
| | Mancos shale. | Shale with several beds of hard gray to buff sandstone. | 1400+ | |
| | Dakota sandstone. | Sandstone, gray to buff, hard, partly massive. | 80-120 | |
| | Morrison formation. | Shale, massive, palegreenish, in part maroon; thins out to south. | 150 | |
| Jurassic. | Navajo sandstone. | Sandstone, massive; upper member red, lower member gray; thins out to south. | 250 | |
| | Todilito formation. | Gypsum, white, massive; underlies northeastern part of county. | 0-60 | |
| | | Limestone, very thin bedded; thins out to south. | 0-15 | |
| | Wingate sandstone. | Sandstone, massive, mostly pink; thins out to south. | 0-150 | |
| Triassic. | | Red shales and sandstones. | 600+ | |
| Permian. | Manzano group. | Chupadera formation. | Limestone, gray sandstone, gypsum, and soft red sandstone. | 1200 |
| | | Abo sandstone. | Sandstone, brown-red, slabby. | 800 |
| Pennsylvanian. | Magdalena group. | Limestone, with some sandstone and shale, especially in lower part. | 1200-✓ | |
| Mississippian. | Lake Valley limestone. | Limestone, coarse, white; ends in Sierra Ladrones. | 0-25 | |

The strata that may possibly contain oil in this succession are the sandstones of the Mesaverde and Mancos formations, which, however, are all cut through by the valleys, and the sandstones in the Chupadera and Magdalena formations, which in part of the area lie at considerable depth. A few deep borings made in this district for water have not found any indications of oil, but apparently they have not

been sunk in places where the structural conditions are favorable. One deep hole is a mile southwest of Suwanee, and another is 11 miles west of that place. In both of these holes there is a small flow of highly mineralized artesian water. The depths are not known but are stated to be somewhat more than 1,000 feet.

LOCAL STRUCTURE.

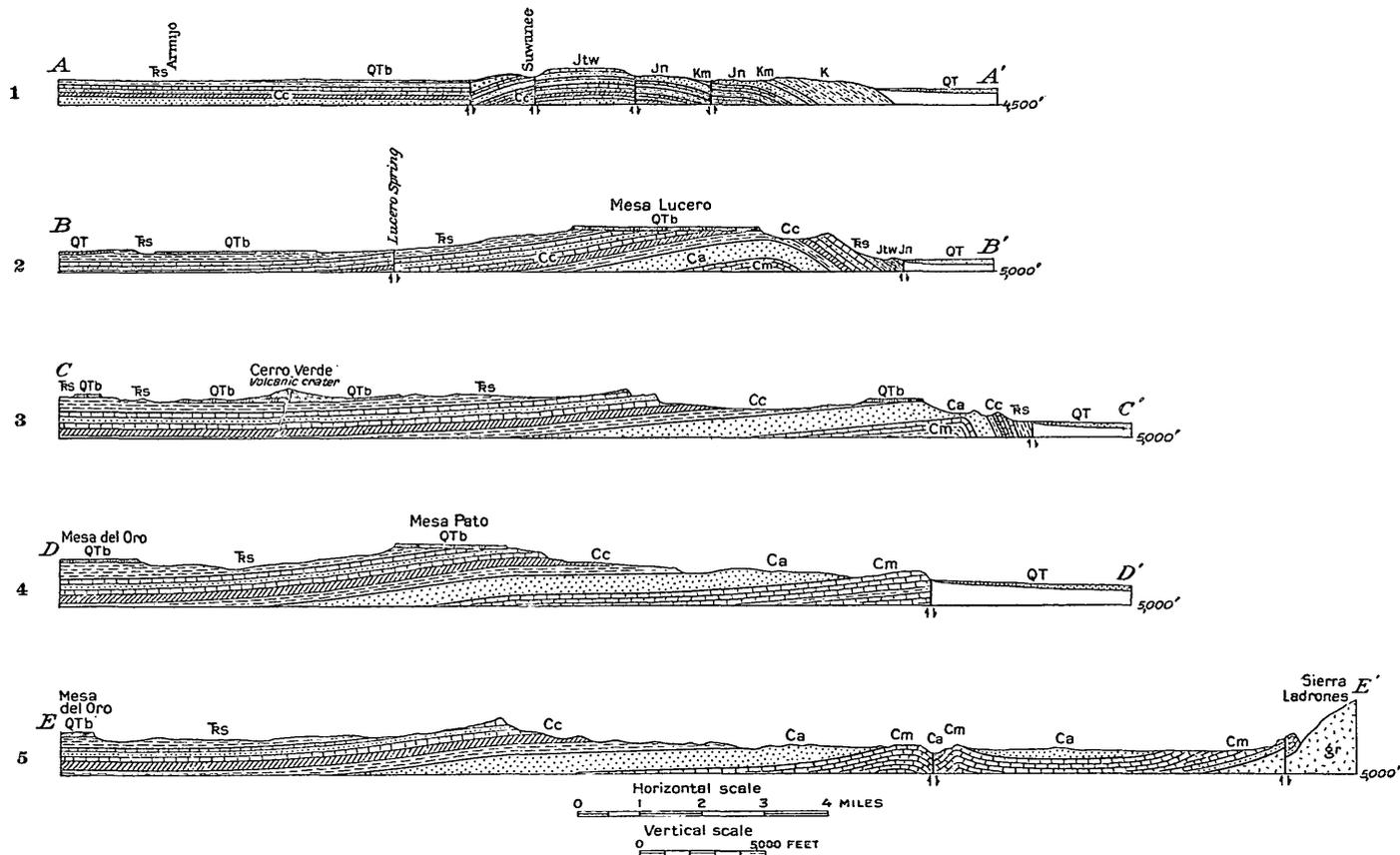
The Lucero or Ladrones anticline rises against the main fault in the vicinity of Mesa Lucero and, as shown in section 2, Plate XLIX, finally presents a complete arch of the Chupadera and the underlying Abo sandstone and Magdalena group. The top of the Magdalena is exposed on Arroyo Carrizo, 7 miles southwest of Rio Puerco station, where the overlying Abo beds dip gently westward on the west side of the axis and steeply eastward on the east side. This form is typical of the anticline with a steep eastern limb on which the higher beds are cut off by the main fault. A short distance west of Garcia siding the anticline is cut off by a fault trending northwest, with the drop on its north side, and the down-faulted block, still presenting anticlinal structure, is split by several north-south faults and cut off on the west by the Mesa Gigante fault, all well exposed north of the Rio San Jose north and east of Suwanee station. The relations in this vicinity are shown in section 1, Plate XLIX. Mesa Redonda is an outlying mass of Cretaceous sandstones preserved by a cap of old lava.

The broad valley of the Arroyo Colorado contains much sand, gravel, and lava, which hide the nearly level Triassic red shales, but local terraces and arches are likely to exist. Westerly dips occur in the high plateaus of the divide between Arroyo Colorado and Arroyo Acoma, carrying the beds into the wide, shallow basin that underlies the Cebolleta Mesa region. This monocline is up-arched by a long, low anticline just north of Acoma, which exposes the Todilto limestone along the arroyo and lower slopes. There are also low domes in the sandstone slopes south of Laguna.

DEEP BORINGS.

A number of deep holes have been bored in this region, but they have not been located where the structure is favorable for oil. They were sunk for water, and some of them obtained satisfactory results. At Rio Puerco station a hole 1,015 feet deep is reported to be entirely in clay and gravel but probably penetrated Cretaceous strata. Very salty water was obtained.

At North Garcia, a siding 7 miles northwest of Rio Puerco, an 855-foot hole obtained only salt water. The record disclosed red and blue clays to 412 feet, then 20 feet of "gravel, below which was red sandstone 100 feet, white sandstone 73 feet, and blue clay 250 feet."



SECTIONS ACROSS SIERRA LUCERO IN VALENCIA AND SOCORRO COUNTIES, N. MEX.

For explanation of symbols see Plate XLVIII.

The hole starts in the valley fill east of the main fault, and it is not possible to recognize the strata penetrated.

Three holes, 235, 225, and 480 feet deep, bored in the upper red beds southwest of Suwanee found flows of salty water.

Three borings, 275, 382, and 853 feet deep, 8 miles south of Laguna were sunk in red beds in the wide flat adjoining the west fork of Arroyo Colorado. Artesian flows of salt water were found. The record of one of these wells is as follows:

Record of boring in sec. 17, T. 8 N., R. 5 W., 8 miles south of Laguna, Valencia County, N. Mex.

| | Feet. |
|---|---------|
| Red clay, sandstone, and gravel..... | 0-90 |
| Sandstone, gray; water..... | 90-160 |
| Clay, red and brown; with gray clay at 290-410 feet..... | 160-560 |
| Sandstone and shalé, red; salty water at 610 feet..... | 560-700 |
| Sandstone, hard, brown; much salty water..... | 700-705 |
| Shale, red, with sandstone layers; salty water at 737-853 feet... | 705-853 |

Apparently all the strata are the red beds overlying the Chupadera formation, and it is unfortunate that the drilling did not continue to the base of that formation.

A 942-foot hole at Armijo, after passing through a bed of lava, penetrated red sandstone and shales and at the bottom 42 feet of gray sandstone, all Triassic beds (Chinle to Moenkopi? formations) that overlie the Chupadera formation.

NORTH-CENTRAL SOCORRO COUNTY.

GENERAL RELATIONS.

There are extensive exposures of limestones, red beds, shale, and coal measures in the valleys of Rio Salado and Alamosa Creek, in north-central Socorro County. To the south and southwest, however, these rocks are unconformably overlain by the thick mass of fragmental and effusive igneous rocks of the Datil, Gallina, and Bear mountains. In general the strata in this region dip at low angles to the south and southwest, toward the mountains, but there are numerous local variations in the amount and direction of dip and several faults. The principal features are shown in Plate L, which is compiled from observations made by D. E. Winchester in a detailed survey of the coal measures.³⁵ Some underground relations are shown in the cross section, figure 42.

STRATIGRAPHY.

The sedimentary rocks in north-central Socorro County comprise strata from the Lake Valley (Mississippian) limestone to coal measures in the Upper Cretaceous, and also gravel, sand, travertine, and other

³⁵ Winchester, D. E., *Geology of Alamosa Creek valley, Socorro County, N. Mex.*: U. S. Geol. Survey Bull. 710, pp. 1-15, 1920.

deposits of late Tertiary and Quaternary age. The following table gives the principal characteristics and thickness:

Sedimentary formations in north-central Socorro County, N. Mex.

| Age. | Group and formation. | Characteristics. | Thickness (feet). | |
|-------------------|------------------------|--|---|-------|
| Upper Cretaceous. | Mesaverde formation. | Sandstone, with coal beds. | 1,800 | |
| | Mancos shale. | Shale, with several sandstone members. | 2,000 | |
| | Dakota sandstone. | Gray sandstone, hard. | 0-80 | |
| Triassic. | | Red shale. | 600 | |
| Permian. | Manzano group. | Chupadera formation. | Upper beds, limestone, gypsum, and gray sandstone; lower beds, soft red sandstone, with thin gypsum and limestone beds. | 1,200 |
| | | Abo sandstone. | Brown-red slabby sandstone and red sandy shale. | 800 |
| Pennsylvanian. | Magdalena group. | Limestone and shale, with sandstone in lower part. | 800-900 | |
| Mississippian. | Lake Valley limestone. | Limestone; thins out to north. | 0-50 | |
| Pre-Cambrian. | | Granite. | | |

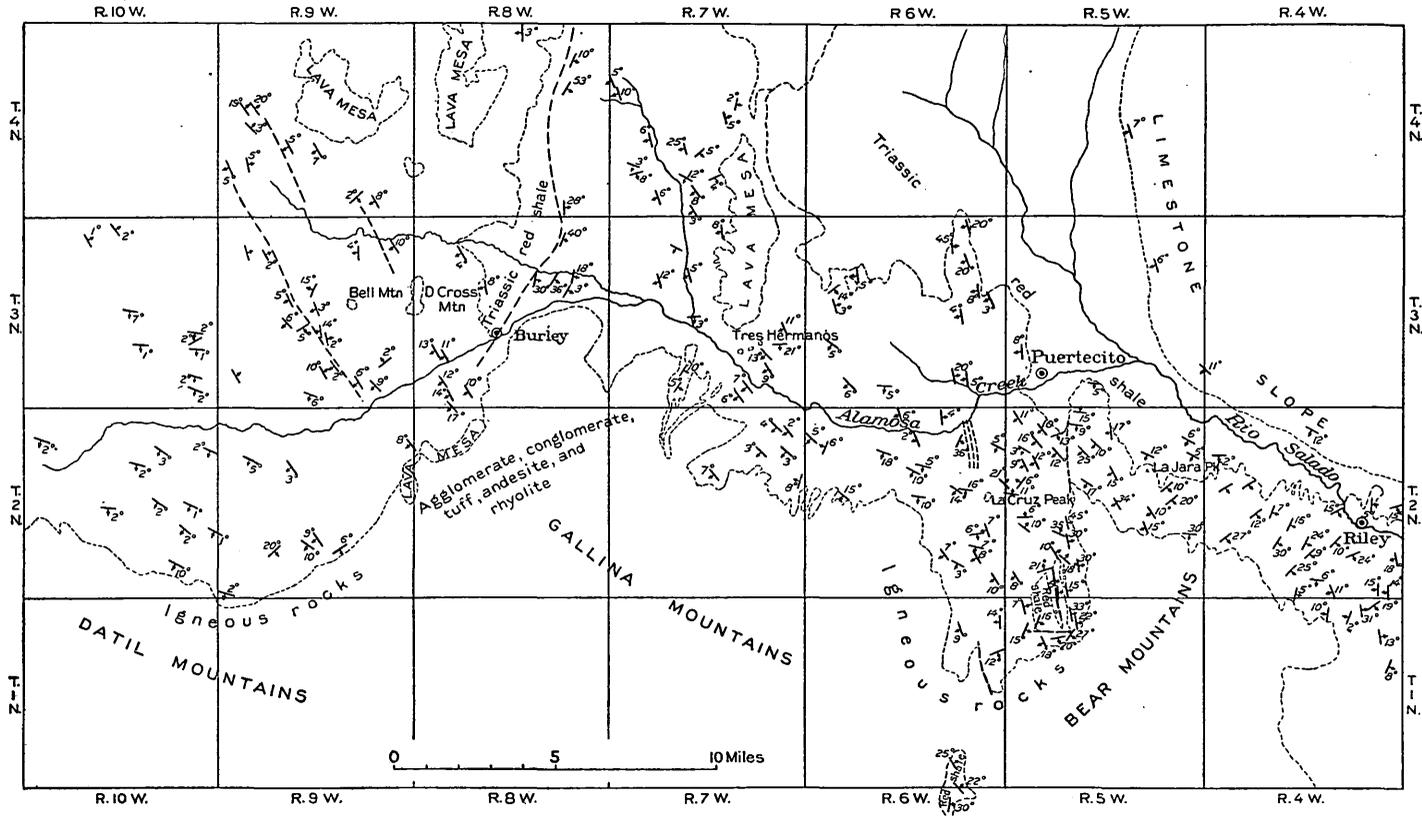
Among the more porous rocks in this succession are the sandstones in the Mancos, Dakota, Chupadera, and Magdalena formations. The Mesaverde sandstones probably do not lie at sufficient depth and in much of the area the massive sandstone of the Mancos formation also is too near the surface to be suitable as a reservoir, even where the structure may be favorable.

LOCAL STRUCTURE.

The best-defined anticline in the area extends northward from Burley post office. It brings up the Triassic red shale in an outcrop area about 10 miles long, cut off on the east side by a fault with a displacement of several hundred feet. A smaller uplift, with a similar fault on the east side, occurs $5\frac{1}{2}$ miles west of Burley. A small faulted dome brings up red beds again 3 miles southeast of La Cruz Peak. Some fainter structural disturbances appear in the center of T. 4 N., R. 7 W., and 3 miles southwest of Puertocito, extending southeastward nearly to La Cruz, possibly connecting with the dome above mentioned 3 miles southeast of that peak.

BORINGS.

The only boring reported in the region is a test for oil or gas made at a point about 3 miles east of La Jara Peak. It had reached a depth of about 300 feet in 1916.



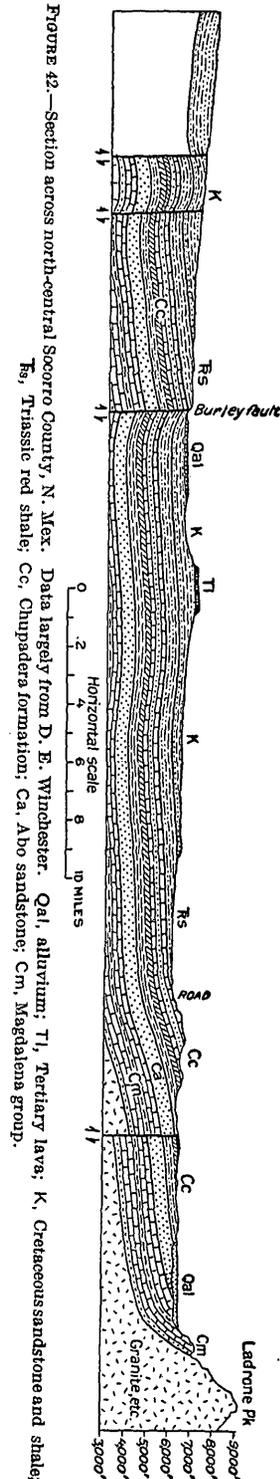
MAP SHOWING STRUCTURE OF VALLEYS OF RIO SALADO AND ALAMOSA CREEK, N. MEX.

Mainly from data furnished by Dean E. Winchester.

WEST-CENTRAL VOLCANIC AREA.

The central and western parts of Socorro County, the northwestern part of Sierra County, and the northern part of Grant County are occupied by a large area of Tertiary volcanic rocks which appear to mask the underlying formations completely. These volcanic rocks consist of widespread sheets of agglomerate and tuff, interbedded with extensive flows of latite, andesite, rhyolite, and basalt, lying mostly level but locally tilted and faulted to a greater or less extent. Very few data have been obtained as to the succession or structure of these rocks, and they present no possibility whatever for oil or gas. It has been stated that underlying Cretaceous sandstone appears near Reserve, but this statement has not been verified. To judge from the complex faulting and flexing of the strata in the Silver City-Hanover region, it appears likely that the sedimentary rocks, which no doubt underlie the igneous rocks, may present many complexities of structure, especially to the south. At the north end of the area, however, in the vicinity of Salt Lake and in the valley of Alamosa Creek, in the northern part of Socorro County, the Cretaceous rocks pass under the northern edge of the volcanic series in a widely extended, gently southward-dipping monocline. How far south this structure or these relations extend can only be surmised. If borings are sunk in the great area of igneous rocks and specimens of the borings are preserved it may be possible to ascertain some of the structural and stratigraphic conditions, but until this is done no oil predictions will be justified in the area indicated.

In 1920 a boring was in progress in sec. 17, T. 3 N., R. 14 W., about 16 miles north-east of Quemado.



PLAINS OF SAN AGUSTIN.

The Plains of San Agustin occupy an area of about 300 square miles in the central part of Socorro County. Their average width is about 12 miles. On nearly all sides are ridges and mountains of igneous rocks. The general altitude of the remarkably level valley floor is about 6,850 feet.

Very little has been ascertained as to the structural relations in this area, but the rocks of the adjoining ridges lie nearly horizontal, and although there are many faults the plains are not bounded by them and apparently consist of much younger beds, which comprise several hundred feet of loam, sand, and gravel derived from the adjoining mountains and partly filling an old valley between them. Several wells have been sunk in this filling, apparently without reaching bedrock.

The following data, supplied by Dean E. Winchester, are all that are available:

Data on wells in Plains of San Agustin, Socorro County, N. Mex.

| Location. | Depth (feet). | Results. |
|---|---------------|--|
| Northeastern part of T. 1 S., R. 8 W. | 300 | Plenty of good water. |
| Southwest corner of T. 2 S., R. 7 W. | 171 | |
| South-central part of T. 3 S., R. 7 W. | 292 | Plenty of good water; 100 feet of gravel, then red clay and pebbles. |
| Northeastern part of T. 3 S., R. 6 W. | 335 | |
| Center of T. 3 S., R. 9 W. | 280 | |
| Center of T. 4 S., R. 11 W. | 125 | Plenty of good water. |

In 1920 a boring for oil was in progress in sec. 8, T. 2 S., R. 8 W., about 10 miles east of Datil.

FAIRVIEW TO LAKE VALLEY.

Limestones and sandstones of Carboniferous to Cambrian age crop out at intervals along the east slope of the Black Mountains and Mimbres Range, and the pre-Cambrian granite appears near Hillsboro Peak. The rock outcrops are separated by an extensive overlap of talus and other younger formations, and there is much faulting, so that the structural relations are difficult to ascertain.

The section in figure 43, by C. H. Gordon,³⁰ shows the complex relations in the Hillsboro region. East of Fairview I found an eastward-dipping succession of limestone of the Magdalena group, red Abo sandstone, and limestones and sandstones of the Chupadera formation, and on Palomas Creek, 10 miles southwest of Chuchillo, the Abo sandstone reappears. At Hermosa there are very extensive exposures of the Magdalena group underlain by the Lake Valley limestone and Percha shale. The greater part of the high mountains west of these

³⁰ U. S. Geol. Survey Prof. Paper 68, fig. 16, p. 224, 1910.

places consists of the Tertiary igneous succession described on page 186, and the igneous rocks also appear in a zone of ridges extending through the eastern parts of Tps. 10 to 17 S., R. 7 W. At Lake Valley there appears in the center of this ridge zone an eastward-dipping succession of rocks of Ordovician to Mississippian (Lake Valley) age. Owing to the complexities of structure and interruptions of outcrops by igneous rocks and superficial deposits it was not possible to ascertain the structural conditions. Locally there may be anticlines and domes in which oil or gas could accumulate if they were present.

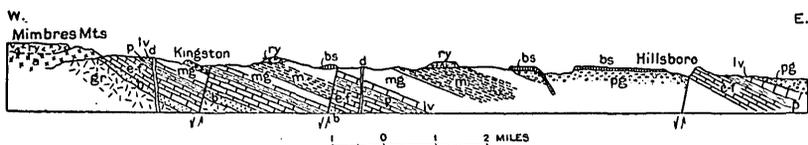


FIGURE 43.—Section from the Mimbres Mountains eastward through Kingston and Hillsboro, N. Mex. (After Gordon.) gr, Granite; b, Bliss sandstone; e-f, Mimbres limestone [El Paso, Montoya, and Fusselman limestones]; p, Percha shale; lv, Lake Valley limestone; mg, Magdalena group; m, Manzano group; pg, Palomas gravel; bs, basalt sheet; a, andesite; ry, rhyolite; d, dike.

SOUTHWESTERN COUNTIES.

GENERAL RELATIONS.

Luna, Grant, and Hidalgo counties consist of detached ridges made up largely of volcanic rocks, with wide desert valleys containing thick deposits of sand and gravel. The structure of many of the ridges has been determined,³⁷ but the conditions under the wide, flat-floored deserts between them are not known, and few borings have been deep enough to reach the bedrock. The sedimentary rocks of the region range from Cambrian sandstone (Bliss) to late Cretaceous and Tertiary deposits and have an aggregate thickness of several thousand feet. The underlying pre-Cambrian granite and schist appear in a few places, and large bodies of Tertiary volcanic rocks, both effusive and fragmental, overlap the other rocks with a great variety of relations. The sedimentary rocks exposed in the ridges are tilted and flexed and in most places greatly faulted, and undoubtedly similar flexing and faulting prevails under the deserts and under the wide covers of igneous rocks, most of which were accumulated since the principal flexing and faulting. The igneous masses, are, however, also tilted, flexed, and faulted to a considerable extent. In many parts of the region there are rocks that might possibly contain petroleum, and at a few places the structural conditions appear favorable, but no authentic evidence of the existence of oil or gas has been obtained. In many areas the large amount of fault-

³⁷ Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), 1916. Darton, N. H., *idem*, Deming folio (No. 207), 1917; *Geology and underground water of Luna County, N. Mex.*: U. S. Geol. Survey Bull. 618, 1916.

ing and the former heat of igneous rocks may be unfavorable. Deep borings for oil near Lordsburg and Columbus appear to have been located without any consideration of geologic conditions. It is reported that the hole at Columbus had reached a depth of 1,900 feet early in 1919. Many of the ridges showing sedimentary rocks are tilted blocks rising out of the desert on one side and showing steep faces on the other, most of them traversed by numerous faults, an unfavorable structural condition. A brief description of some of these mountains may be of interest, especially as the rocks which they represent undoubtedly underlie some of the adjacent valleys. Detailed descriptions of the ridges in Luna County will be found in the two reports above cited.

COOKS RANGE.

Cooks Range, a southern extension of the Mimbres Range, is a conspicuous feature in the northern part of Luna County. It consists of an uplifted block of limestone and sandstone, from Cretaceous to Cambrian in age, traversed by a large stock of porphyry constituting Cooks Peak. The basement of old granite appears in places. Along the east side and at the north and south ends of the range are thick bodies of the Tertiary igneous series, consisting of agglomerate, tuff, and lava flows of various kinds. The fault along the east side of the range has a drop of about 1,000 feet on the east.

FLORIDA MOUNTAINS.

The Florida Mountains are a high and exceedingly rugged ridge a few miles southeast of Deming. The northern half of the ridge and the outlying Little Florida Mountains consist of agglomerate and other igneous rocks, and the southern half is pre-Cambrian granite overlain in the small central area by sandstones and limestones of Cambrian to Permian age. The rocks are tilted in the same direction and traversed by great faults. The principal structural features are shown in figure 44, introduced here because it shows also the relations in parts of the adjoining plains.

FLORIDA PLAINS.

The structural relations under the wide desert plains on each side of the Florida Mountains are not known. A few widely scattered rock outcrops are of very diverse character. The Snake Hills (see section, fig. 45), 10 miles southwest of Deming, consist of limestone (El Paso and Montoya) dipping gently westward, possibly on the west slope of an anticline, the location of whose crest, however, is not indicated. On the crest there would probably be only a small thickness of the El Paso limestone and Bliss sandstone lying on granite. It may be that the strata on the northwest slope of the Florida Mountains are on the east slope of the arch, and under this

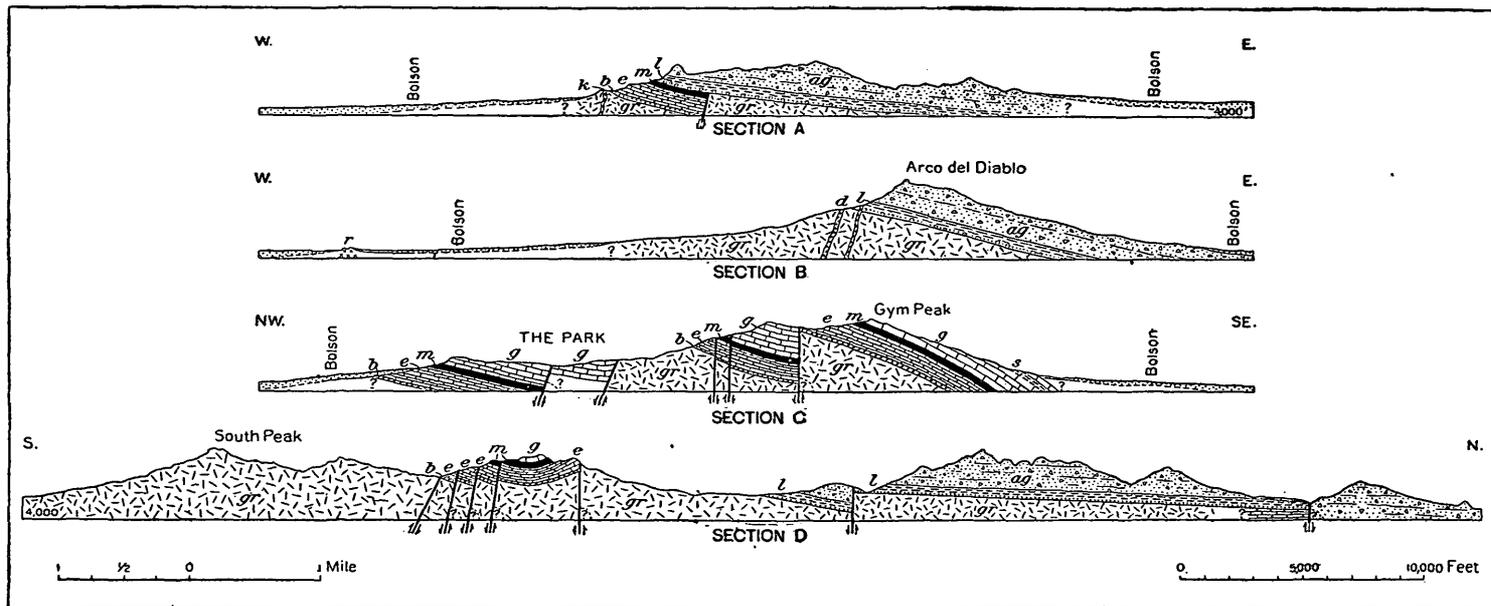


FIGURE 44.—Sections across the Florida Mountains, Luna County, N. Mex. A, From Capitol Dome; B, from Arco del Diablo; C, through The Park and Gym Peak; D, from south to north along the higher part of the range. *b*, Bliss sandstone; *e*, El Paso limestone; *m*, Montoya and Fusselman limestones; *r*, felsitic rhyolite in White Hills; *d*, rhyolite porphyry dikes; *l*, Lobo formation; *g*, Gym limestone; *s*, black shale member; *k*, keratophyre; *gr*, granite; *ag*, agglomerate.

condition the crest would be granite under the deep valley south of Deming. Several deep holes sunk for water in this general region were entirely in valley fill. One in sec. 20, T. 24 S., R. 8 W., 6 miles southeast of Deming, was 1,665 feet deep; another in Deming was 980 feet deep; and a third $3\frac{1}{2}$ miles east of Deming was 710 feet deep. A boring for oil in T. 23 S., R. 10 W., 6 miles northwest of Deming, had reached a depth of 1,565 feet in 1920. Clay and sand were found to a depth of 430 feet, then limestone, shale, sandstone, and "gravel" to 1,430 feet, white limestone to 1,515 feet, and red shale to the bottom.

Another well 22 miles southeast of Deming, in the SW. $\frac{1}{4}$ sec. 8, T. 25 S., R. 6 W., is being drilled for oil. The strata reported are

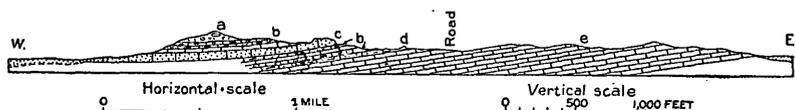


FIGURE 45.—Section through the Snake Hills, southwest of Deming, Luna County, N. Mex. a-d, Montoya limestone (a, limestone with chert in large bodies; b, cherty members; c, massive dark-gray sandy limestone; d, massive dark limestone at base); e, El Paso limestone.

alternations of gravel, clay, and sand. The sand contains a large amount of water. Notable artesian flows were found at 580, 594, 650, and 670 to 700 feet.

GOODSIGHT MOUNTAINS.

The Goodsight Mountains, which extend southward from Sunday Cone, in Sierra County, to a point about 10 miles northwest of Cambray, consist entirely of volcanic rocks. The principal feature is a thick cap of basalt on agglomerate, both tilted to the east at a low angle.

TRES HERMANAS MOUNTAINS AND ADJOINING PLAINS.

The prominent peaks of the Tres Hermanas Mountains, in the south-central part of Luna County, consist of porphyry intruded in the Gym limestone. This limestone crops out here and there on the slopes of the ridges, in most places dipping away under the adjoining plains. How far it extends under the plains and what are its underground relations can not even be suggested. Wells in the country near Columbus indicate that these plains are underlain by a thick body of valley fill. The deepest hole reported is one 975 feet deep on the Shay ranch, in sec. 6 or 7, T. 28 S., R. 7 W. Another well in sec. 26, T. 27 S., R. 7 W., was 500 feet deep. One in the NE. $\frac{1}{4}$ sec. 26, T. 28 S., R. 7 W., is 510 feet deep; one in the SW. $\frac{1}{4}$ sec. 4, T. 29 S., R. 9 W., is 500 feet deep; and one in sec. 9, T. 29 S., R. 7 W., is 500 feet deep. A deep boring for oil in the NW. $\frac{1}{4}$ sec. 16, T. 29 S., R. 7 W., was unsuccessful. The occurrence of oil in this region is improbable, and there is no evidence whatever as to the underground structure.

CEDAR GROVE MOUNTAINS AND CARRIZALILLO HILLS.

The high ridge that extends across the southwest corner of Luna County and is crossed by the El Paso & Southwestern Railroad just west of Hermanas, including the Cedar Grove Mountains and the Carrizalillo Hills, consists entirely of volcanic rocks in thick sheets. The sheets dip to the northeast at low angles and undoubtedly underlie the plains for some distance toward the Tres Hermanas Mountains and Iola.

KLONDIKE HILLS.

The small outlying ridge in T. 26 S., R. 13 W., known as the Klondike Hills, consists mainly of Ordovician limestones, which are domed as shown in figure 46. This dome, with its granite outcrop

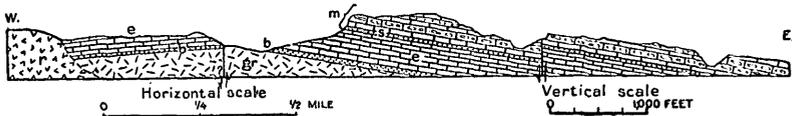


FIGURE 46.—Section through the Klondike Hills, Luna County, N. Mex. *gr*, Granite and gneiss; *b*, Bliss sandstone; *e*, El Paso limestone; *m*, Montoya limestone, with sandstone (*s*) at its base; *r*, rhyolite.

in the center, is not favorable for oil or gas. Possibly other domes less uplifted and eroded exist under the wide plains of Luna and Grant counties, but they are buried by gravel and sand.

VICTORIO MOUNTAINS.

The isolated group of hills known as the Victorio Mountains lie just south of Gage, 20 miles west of Deming. The main ridge consists of a sheet of andesite dipping 20° – 25° NNE. In the hills just

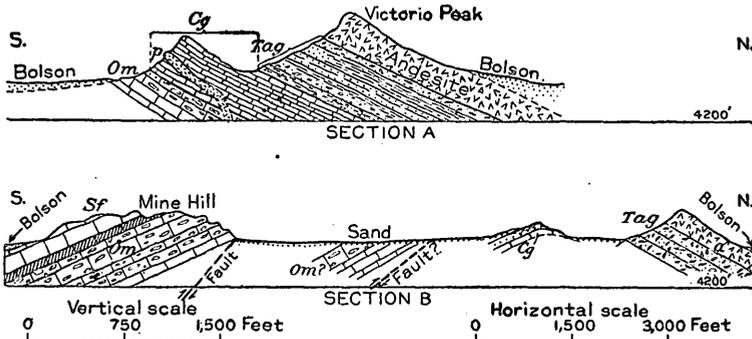


FIGURE 47.—Sections across the Victorio Mountains, south of Gage, Luna County, N. Mex. *a*, Andesite; *Tag*, agglomerate, shale, and sandstone; *Cy*, Gym limestone; *Sf*, Fusselman limestone; *Om*, Montoya limestone; *Oe*, El Paso limestone; *p*, porphyry.

south of it are Ordovician, Silurian, and Carboniferous limestones, cut by igneous rocks and dipping in various directions. Faulting also complicates the relations. The two sections in figure 47 show that there is a dome in the center of the area, but the depth to the granite is very small, and there has been much metamorphism, mineralization, and faulting, so that there appears to be no chance for petroleum.

RIDGES IN NORTHWEST CORNER OF LUNA COUNTY.

Cow Cone, Grandmother Mountain, Red Mountain, Gray Butte, and other hills and ridges in the northwest corner of Luna County all consist of rhyolite of various kinds, with small showings of basalt and agglomerate. No evidence is revealed as to the nature or structure of the sedimentary rocks, and moderately deep holes to the south and near Spaulding and Red Mountain show that the valley fill is more than 300 feet thick in places.

BIG HATCHET MOUNTAINS.

The Big Hatchet Mountains consist of Ordovician to Carboniferous formations flexed in various directions and lying on granite, which is exposed in several places. At the north end of the range there is a fine dome, in which, however, the underlying granite is lifted so high that there is no prospect for an oil reservoir. The relations of this area are shown by the cross section in figure 48. This section is

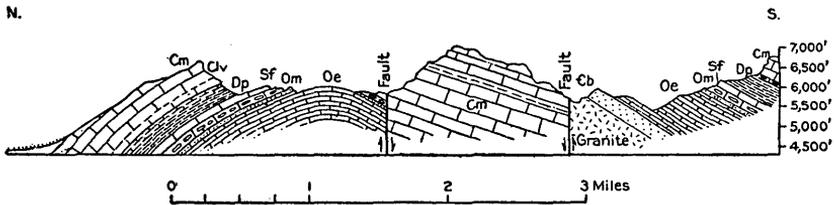


FIGURE 48.—Sketch section across the north end of the Big Hatchet Mountains, Hidalgo County, N. Mex. Cb, Bliss sandstone; Oe, El Paso limestone; Om, Montoya limestone; Sf, Fusselman limestone; Dp, Percha shale; Cv, probable Lake Valley limestone; Cm, Magdalena group.

important in showing for the first time a succession of the strata constituting the Paleozoic rocks of the region. To what extent these rocks underlie the surrounding basins and the thick accumulations of volcanic materials in the adjoining ridges is not known. At the southwest end of the range are thick beds of limestone, sandstone, and shale of Comanche age, which are also conspicuous in some of the adjoining ridges, notably in the Sierra Rica and Apache Hills, in and adjoining the extreme southwest corner of Luna County. These strata are extensively cut and overlain by a variety of igneous rocks.

LITTLE HATCHET MOUNTAINS.

The Little Hatchet Mountains, 6 to 12 miles west of Hachita, present a considerable variety of rocks and structural conditions. Only a portion of the range was examined. At Old Hachita there are exposures of light-colored limestones of Comanche age forming an anticline or dome, and these beds, with associated shales and sandstones, are extensively exposed in some of the ridges to the southwest, notably in the Sylvanite mining district. They are cut by igneous rocks and overlain by tuffs, agglomerates, and lava flows of various kinds. The general dip is to the southwest, and the

structural relations are complex. In places the strata are considerably altered by the igneous rocks.

ANIMAS MOUNTAIN AND SAN LUIS RANGE.

The wide, high ridge known as Animas Mountain, extending from a point near the El Paso & Southwestern Railroad in the southwestern part of Hidalgo County 40 miles southward to the Mexican line, so far as examined consists mainly of Tertiary igneous rocks, with some limestones and shales of Comanche age on the central eastern slope. These sedimentary rocks appear in an irregular dome faulted on several sides just south of Gillespie Mountain, and although they may be wholly included in igneous rocks they may possibly be underlain by 1,800 feet or more of Paleozoic limestone. Some portions of the adjacent San Luis Range are limestone, and limestones are reported at the north end of Animas Mountain.

PELONCILLO MOUNTAINS.

The high range of the Peloncillo Mountains, extending southward to the Mexican boundary from the gap through which the El Paso & Southwestern Railroad passes west of Pratt, apparently consists entirely of Tertiary igneous rocks, and nothing is known of the underlying beds. The southern continuation of the range past Pratt and Steins Pass shows a variety of rocks, mostly volcanic but including Paleozoic limestones and supposed pre-Cambrian granite, all very greatly disturbed and faulted. Granite Gap evidently marks an east-west fault with granite on the north side and lower Paleozoic limestones on the south. Gilbert³⁸ reported that limestones and sandstones of probable Paleozoic age, in which Carboniferous fossils were noted, occur in Gabilan Peak. "The strata dip at a high angle toward both flanks of the range, and upon their upturned edges rests the granite which constitutes the peak." On account of this relation and much metamorphism of the strata the granite was regarded as igneous.

The only hole reported in this region is one on the plain 10 miles west of Lordsburg. It attained a depth of 700 feet—the first 340 feet in clay and gravel and the lower part in blue clay, gravel, and "cement" of unknown age.

PYRAMID MOUNTAINS.

The irregular high ridge area extending northward from Little Pyramid Peak to Lordsburg shows only Tertiary igneous rocks. Possibly there is an underlying core of sedimentary beds, but the nature of these beds and their relations and structure under the adjoining valleys can not be determined.

³⁸ Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 514, 1875.

