NEW MEXICO
BUREAU OF MINES AND MINERAL RESOURCES

A DEPARTMENT OF THE SCHOOL OF MINES

E. C. ANDERSON
Director

BULLETIN 26

Geology of the Gran Quivira Quadrangle, New Mexico

By

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Coöperative investigation between
the New Mexico Bureau of Mines and Mineral Resources
and the Geological Survey, United States Department of the Interior

SOCORRO
1947

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THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

The New Mexico Bureau of Mines and Mineral Resources, designated as "a department of the New Mexico School of Mines and under the direction of its Board of Regents," was established by the New Mexico Legislature of 1927. Its chief functions are to compile and distribute information regarding mineral industries in the State, through field studies and collections, laboratory and library research, and the publication of the results of such investigations. A full list of the publications of the New Mexico Bureau of Mines and Mineral Resources is given on the last pages of this Bulletin.

Geology of the Gran Quivira Quadrangle, New Mexico

By
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and GEORGES VORBE[4]

INTRODUCTION

LOCATION OF THE AREA

The Gran Quivira quadrangle is a rectangular area that includes parts of Socorro, Torrance, and Valencia counties, central New Mexico (Figure 1). East and west boundaries are the 106° and 106° 30' meridians of longitude, and north and south boundaries are the 34° 30' and 34° parallels of latitude. The quadrangle covers about 980 square miles.

The town of Mountainair lies just outside the area, near the center of the north boundary. Claunch is situated on the east boundary. No large towns lie within the quadrangle. The only settlements are the small communities of Abo and Scholle in the northwest part, Chupadera in the west central part, and Gran Quivira in the east central part.

The area is served by U. S. Highway 60, which crosses the northwest corner ; by State Highway 10, connecting Mountainair and Claunch ; and by State Highway 161 from Claunch to Bingham, 6 miles south of the quadrangle on U. S. Highway 380. A large number of secondary roads serves the farms and ranches of the area. The Amarillo-Belen line of the Santa Fe Railway crosses the northwest corner.

A wide strip down the central part of the quadrangle is included in the Cibola National Forest. Gran Quivira National and State Monument, embracing about two sections of land, lies on 'the Socorro-Torrance county line in the east central part of the quadrangle. Abo State Monument is situated half a mile north of U. S. Highway 60, midway between Scholle and Abo.1

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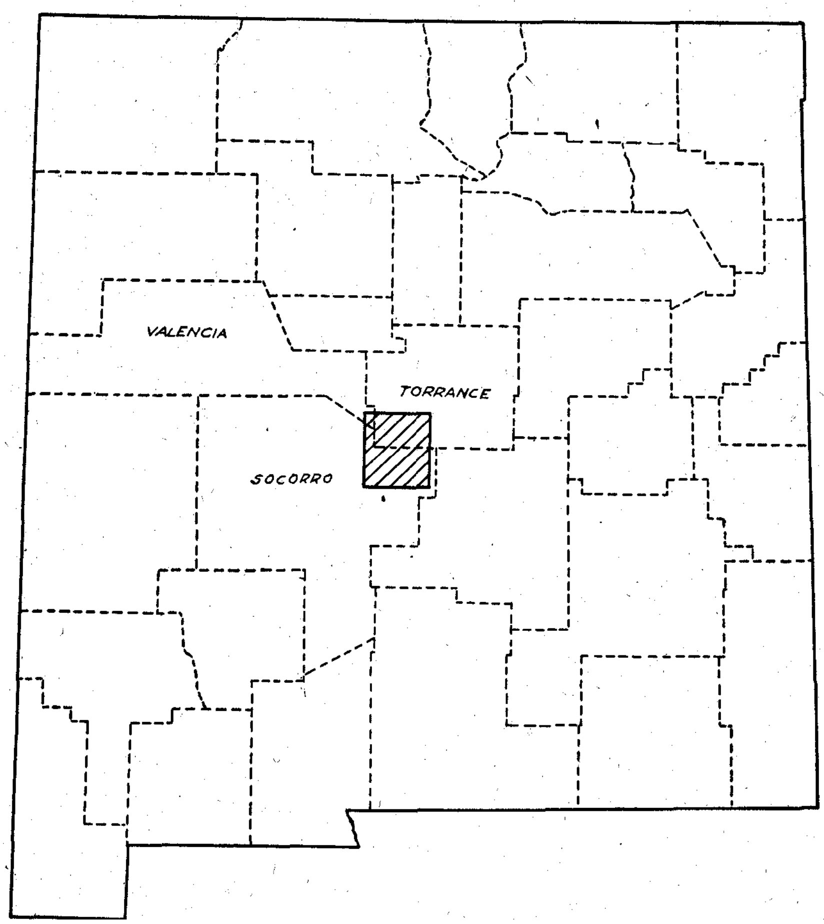


FIGURE 1. Map of New Mexico showing county boundaries and the Gran Quivira quadrangle.

TOPOGRAPHY

The Gran Quivira quadrangle includes, in its extreme northwest corner, about 1 square mile of the alluvial plain that forms the east side of the Rio Grande valley (Plate 1). The boulder-strewn surface of this plain slopes gently to the west; along its eastern margin it has been dissected into low spurs separating wide shallow arroyos. The plain supports a thin stand of grass, cactus, and yucca.

East of the alluvial plain lie the Manzano Mountains. At their southern end, in the Gran Quivira quadrangle, these mountains are only $1^1/_2$ miles in width. The surface is rough, the drainage is by intermittent streams in deep canyons, and the vegetation cover is scant. The mountains are bounded on the southeast by a deep straight canyon with a high ridge on its southeast side (Plate 2, A).

Extending very irregularly from the quadrangle's northeast corner to the center of the south boundary is a high escarpment with its steep slope on the north and west. This escarpment divides the main part of the quadrangle topographically into two parts--a relatively low, rough area to the west and north, and a relatively high, gently rolling area, Chupadera Mesa, to the east and south.

North and west of the Chupadera Mesa escarpment the surface is underlain by strata of limestone, gypsum, shale, sandstone, and arkose that dip gently southeastward except in the northwest corner where their dip is steep. These strata have varying degrees of resistance to erosion, and consequently the surface consists of alternating ridges and valleys. This condition is especially characteristic of the area west and southwest of Abo. Closer to the Chupadera Mesa escarpment the strata have in places been dissected into small erosion remnants held up by resistant beds; examples are the prominent buttes south of U. S. Highway 60, some 6 miles southwest of Mountainair.

Between the Chupadera Mesa escarpment and the Manzano Mountains are three small disconnected areas of stream-worn gravels. These gravels, which rest on surfaces that bevel the tilted bedrock strata, represent remnants of an alluvial plain or pediment that was of wide extent before erosion greatly reduced its area. The surfaces of the pediment remnants are smooth and slope gently to the southeast. They support grass and scattered pinon and juniper trees.

In the west central part of the quadrangle is a group of long narrow ridges trending northeast. They range in length from less than a mile to more than 6 miles, and in width from a few tens to a few hundreds of feet. Owing to the relatively resistant character of the intrusive igneous rocks composing them, they stand from 10 to 100 feet above the surrounding surface (Plate 2, B).

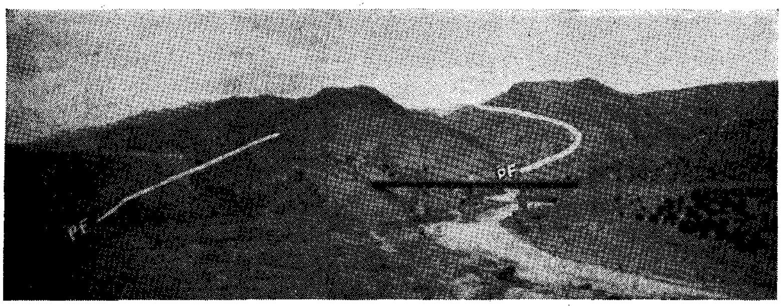
The southwest quarter of the quadrangle includes the north end of a regional physiographic feature known as the Jornada del Muerto ("journey of the dead"). This feature is an arid plain that extends more than 100 miles southward. The part of the Jornada lying in the area of this report is a nearly flat treeless desert characterized by sand dunes and dry washes. It is rimmed on the west, north, and east by a low ridge that merges on the northeast with the Chupadera Mesa escarpment.

Drainage east of Mountainair is by intermittent streams that flow from the Chupadera Mesa escarpment northward into sink holes. In the northwest part of the Gran Quivira quadrangle drainage is into Abo Canyon, which leaves the quadrangle $3^1/_2$ miles south of the northwest corner, cutting through a saddle between the Manzano Mountains to the north and the Los Pinos Mountains to the south. The canyon carries intermittent drainage westward into the Rio Grande valley. Drainage in the west central and southwest parts of the quadrangle is by intermittent streams that are not tributary to a major stream but die out in the sands and gravels of the Jornado del Muerto. Major units of this drainage are Chupadera Arroyo and Arroyo Seco.

Chupadera Mesa, east of the area just discussed, is a wide tableland with moderate to low relief that occupies some 1,700 square miles in central New Mexico. Elevations on the north range from 7,050 feet 4 miles south of Mountainair to 7,250 feet, the highest point in the Gran Quivira quadrangle, on the butte in the center of T. 1 N., R. 5 E. In the central and south central parts of the quadrangle, Chupadera Mesa consists of heavily wooded hills and ridges with intervening steep-walled canyons. Numerous prominent hills are at the top of the escarpment that bounds the mesa on the west and northwest ; the two, highest are called Grumble Knoll and Brushy Mountain. Two prominent east-trending ridges, the northern of which is named Turkey Ridge, are situated in T. 1 S., R. 7 E.

The eastern boundary of the central high forested area is a north-south bluff, the south part of which is known as Monte Prieto. This bluff extends from a point 11 miles north of the village of Gran Quivira to beyond the south boundary of the quadrangle. On the north the Monte Prieto bluff has a height of approximately 100 feet; it becomes progressively higher toward the south, so that where it passes out of the quadrangle it stands 250 feet above the lower country to the east.

To the east of the Monte Prieto bluff lie gently rolling low hills and wide valleys. Much of the surface is under cultivation ; where not broken by the plow, it supports a good stand of



A. Panorama at the northwest corner of the Gran Quivira quadrangle, looking north-northeast. Manzano Mountains extend from high point in center to left background. Abo Canyon, in foreground, swings sharply to the left beyond Santa Fe Railway trestle. Paloma Fault (PF), with pre-Cambrian rocks on west and overturned Pennsylvanian limestones on east, crosses Abo Canyon beyond trestle. Note drag-folded Pennsylvanian strata on east side of fault. White streak at left is Sais quartzite quarry.

B. Side view of dike near road one mile southwest of Chupadera.

C. Sink depression in rocks of the San Andres formation on Chupadera Mesa. Looking southwest from State Highway 10, near the southwest corner sec. 19, T. 2 N., R. 8 E. Depression contains more water than usual on account of heavy rains.

range grass. Mapping of this gently rolling country discloses a distinct east-west orientation of low ridges and wide valleys (Plate 1). The Gran Quivira ruin stands at the west end of one of these ridges. Cat Mesa, situated in T. 3 S., R. 8 E., is a group of hills that do not show the prevailing easterly trend. Some of the ridges and hills merge with the Monte Prieto bluff, whereas others are separated from it.

Drainage over all that part of Chupadera Mesa lying in the Gran Quivira quadrangle is into sink holes, the result of solution in the gypsum that constitutes much of the rock at the surface. The sink holes range in area from a few square yards to several acres. Most of them, including all those west of the Monte Prieto bluff, are shallow and dry; a few of those in the lower country to the east contain permanent pools (Plate 2, C) .

PURPOSE AND SCOPE OF THE REPORT

The purpose of this report is to present an account of the general geology of the Gran Quivira quadrangle. The exigencies of wartime limits on time, transportation, and personnel necessitated a preliminary or reconnaissance approach to the problem. Further refinements in mapping, and a more exhaustive treatment of the rock units, remain to be made. The report does, however, represent a considerable advance over the previous available information on the area.

The text has been prepared by the New Mexico Bureau of Mines and Mineral Resources. The geologic map, Plate 1, is the result of a cooperative field project between the Bureau and the U. S. Geological Survey. This map is being published by the Survey as a part of a larger map (Wilpolt and others, 1946) .[1]

Geologic mapping was done on contact prints of -aerial photographs, which were available for the west half of the quadrangle, and on re-drawn township plats in the east half. Planetabling was carried on north and northwest of the village of Chupadera and along the Chupadera Mesa escarpment from a point south of Mountainair to the northeast corner of the quadrangle. Stratigraphic sections were measured, a reconnaissance survey of the topography of the east part of the quadrangle was made, and petrographic examinations of the igneous rocks were carried out.

The stratigraphic nomenclature and classification used in this report follow the usage of the New Mexico Bureau of Mines and Mineral Resources, and differ somewhat from the usage • of the U. S. Geological Survey.

[1] References in parentheses are to the bibliography at the end of this report.

PREVIOUS WORK

No prior publications relate specifically to the Gran Quivira quadrangle. The stratigraphy and structure of Chupadera Mesa have been discussed by Darton (1922, pp. 221-223; 1928, pp. 86-94). Descriptions of the Oscura (Chupadera) anticline, in the south central part of the quadrangle, have been given by Darton (1922, p. 231), Winchester (1933, pp. 194-198), and Bates (1942, pp. 290-293). Measured sections of Permian strata in Abo Canyon have been made by Lee (1909, pp. 20-21) and by Needham and Bates (1943, pp. 1654-1657). The entire Gran Quivira quadrangle is included on the State geologic map on a scale of about 8 miles to 1 inch.

Winchester (1933, p. 190) has discussed briefly the occurrence of oil shale of Pennsylvanian age in Abo Canyon. The Scholle and Rayo mining districts have been described by Lasky (1932, pp. 135-136) and by Lasky and Wootton (1933, pp. 115, 117-118).

ACKNOWLEDGMENTS

The cooperative arrangement under which this report has been prepared was initiated by C. B. Read, U. S. Geological Survey, and John M. Kelly, formerly Director, New Mexico Bureau of Mines and Mineral Resources. To both these men, and to the Bureau's present Director, E. C. Anderson, the writers wish to express their appreciation for helpful and interested supervision.

J. T. Stark and E. C. Dapples of Northwestern University kindly in advance of publication. Aerial photographic coverage was secured through the courtesy of the Albuquerque and Mountainair offices of the U. S. Soil Conservation Service. E. W. Cottam of the U. S. Forest Service supplied information on maps and ground water. The writers wish to record the friendliness and interest of the residents of Mountainair and vicinity.

RUINS AT GRAN QUIVIRA AND ABO

The ruins of two ancient Indian pueblos and Spanish missions are situated in the Gran Quivira quadrangle. The following brief notes are inserted as a matter of general interest.

> About the time the Pilgrims were landing at Plymouth Rock, Spanish padres in the Southwest were constructing Gran Quivira Mission to serve the surrounding 10 cities of the Jumano Indians, a tribe now extinct. The older church is badly disintegrated, but the massive walls of the second church and its attached monastery and convent, on which work began about 1649, are still standing. The latter church probably was abandoned about 1670. Also included in the monument are ruined pueblos. (U. S. National Park Service, 1941, p. 4.)

According to Hewett and Mauzy (1940, p. 106), Gran Quivira is unique among ancient New Mexico ruins in having been built of limestone. The walls of the big church are 6 feet chick; some of the great timbers for the building had to be carried not less than 16 miles.

The Abo mission was founded in 1629 and dedicated to the patron saint of the old city of Abo, Finland (Hewett and Mauzy, 1940, p. 108). An elaborate religious establishment, including church and monastery, has been laid bare by recent excavations, and a considerable area of buried foundations remains to be explored. The buildings, which are constructed of red sandstone, are situated in a natural amphitheater on a tributary of Abo Canyon.

Both Gran Quivira and Abo missions were abandoned because of raids by the predatory Apache and Comanche Indians from the plains to the east.

PRE-CAMBRIAN ROCKS

Outcrops of pre-Cambrian rocks are confined to the southern Manzano Mountains, which cross the northwest corner of the quadrangle (Plate 1). Meta-sedimentary rocks and rhyolite are intruded by granite. The following lithologic descriptions are based on megascopic examination of specimens of the meta-sediments and the granite. The rhyolite is not described. Systematic petrologic descriptions and a close study of the field rela. tions await future work.

The meta-sedimentary rocks include quartzite, quartz-sericite schist, and chlorite schist. The quartzite is prevailingly gray, with some greenish and purplish layers. It occurs in beds 1 foot to 2 feet thick, separated by partings and thin beds of greenish gray schist. The texture is finely granular; no systematic orientation or elongation of the grains is apparent. Crystalline quartz makes up 99 percent of the rock ; the remainder consists of brown hornblende, biotite, and green chlorite.

The quartz-sericite schist is light gray when freshly broken but mottled or banded brown and green on long-exposed surfaces. Besides sericite and quartz, this schist contains a few small octahedra of a black opaque mineral, probably magnetite. Other schist layers, which show a. more pronounced schistosity and weather greenish gray with a silvery luster, consist chiefly of chlorite and quartz, with small crystoblasts of garnet and magnetite (?). The minerals and textures indicate that the schists have been produced by rather moderate dynamic metamorphism of fine-grained clastic sediments.

The bulk of the intrusive pre-Cambrian igneous rocks consists of pink slightly porphyritic biotite granite. Euhedral crystals of orthoclase 1.0 to 1.5 centimeters in diameter are sparsely distributed through a groundmass that is made up chiefly of orthoclase, with lesser amounts of a sodic plagioclase, anhedral quartz, and from 5 to 10 percent brown biotite. In places the orthoclase of the groundmass is intimately intergrown with microcline to form perthite. The sodic plagioclase is in subhedral tabular laths showing fine albite twinning; the biotite occurs as euhedral hexagonal plates. Traces of a black opaque octahedral mineral, probably magnetite, can be recognized. Small cubes of pyrite and prisms of apatite are also identifiable.

Several variants of this granite are present. Locally the proportion of quartz increases at the expense of both types of feldspar; the amount of plagioclase is especially reduced, and in composition the rock approaches an alkali granite. In other places phenocrysts are absent, and the rock has a medium-grained granitic texture and a light gray color. Dark spots are produced by partly chloritized brown biotite that forms 10 to 15 percent of the rock. The alkali feldspar is entirely orthoclase. In a third variant the color is pink and the texture is in general fine-grained granitic; a few phenocrysts up to 4.0 millimeters in diameter are present. The mineralogical composition resembles that of the coarser-grained rocks, but the alkali feldspar is entirely microcline and microcline-microperthite. Biotite forms less than 5 percent of the rock. In parts of the specimen examined the rock has a marked saccharoidal appearance. It probably occurs as dikes cutting the main mass of granite.

The pre-Cambrian rocks of the Gran Quivira quadrangle are' continuous with those of the Los Pinos Mountains to the southwest, concerning which Stark and Dapples (1941) make the following statements.

> The pre-Cambrian core . . . is composed of the Sais quartzite (oldest), Blue Springs muscovite schist (originally siltstones), White Ridge quartzite, and Sevilleta rhyolite, all intruded by the Los Pinos (pre-Cambrian) granite. The pre-Cambrian bedded rocks exceed 10,000 feet in thickness, of which nearly 4,000 feet is rhyolite flows. All dip westward (average 50°), and schistosity parallels the dip. Schistosity of the Los Pinos granite (N. 20° E.) parallels that in [the] other pre-Cambrian rocks. Granitization is pronounced along its borders, particularly along the contacts with the White Ridge quartzite.

Probably much less than 10,000 feet of pre-Cambrian rocks are exposed in the Gran Quivira quadrangle, as only a small part of the Sevilleta rhyolite is present. Dip and schistosity of the bedded rocks are essentially the same as in the Los Pinos Mountains. No marked schistosity was noted in the granite, however, nor is pronounced granitization evident at the few places where the contact between bedded rocks and granite is exposed.

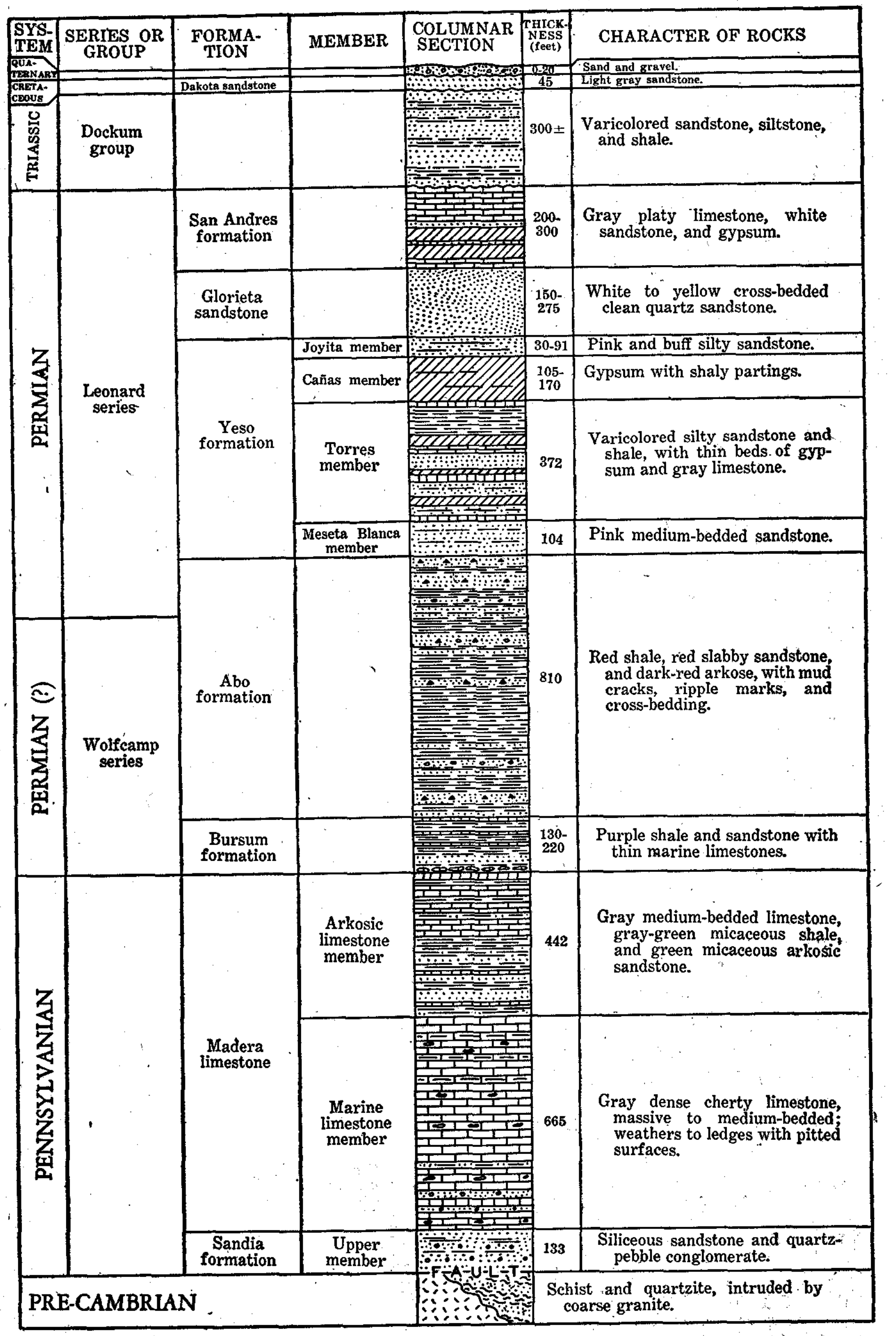


FIGURE 2. Generalized columar section of formations, Gran Quivira Quadrangle

SEDIMENTARY ROCKS

In the Gran Quivira quadrangle a total of 3,750 feet of sedimentary rocks are exposed above the pre-Cambrian basement complex. As shown on the chart, Figure 2, these rocks include nine formations of Pennsylvanian, Permian (?), Permian, Triassic, and Cretaceous ages, overlain by Quaternary deposits.

PENNSYLVANIAN SYSTEM

GENERAL STATEMENT

A number of classifications' have been proposed for the Pennsylvanian rocks of New Mexico. The most recent and by far the most detailed is that of Thompson (1942), who divides the Pennsylvanian strata into fifteen formations in eight groups. Thompson's subdivisions are based chiefly on fossil evidence, especially on that of fusulinids.

For the present map and report, time could not be taken to make and study the faunal collections necessary for the recognition and use of Thompson's formations. Consequently the Pennsylvanian rocks in the Gran Quivira quadrangle are mapped and described in three units, in ascending order the upper member of the Sandia formation and the marine limestone and arkosic limestone members of the Madera limestone (Plate 3). This classification, which is readily adaptable to reconnaissance mapping, conforms with that used by Read and others (1944) in 'the area adjoining the Gran Quivira quadrangle on the north. It is expected that future detailed stratigraphic studies in this quadrangle and adjacent areas will show some of Thompson's terminology to be applicable in treatment of faunal zones.

The three units just mentioned, together with the overlying Bursum formation of Wolfcamp age, are placed in the Magdalena group by the U. S. Geological Survey. However, there is considerable opposition to the continued use of the term Magdalena, to apply either to rocks of Pennsylvanian age or to rocks of Pennsylvanian and Wolfcamp ages. Thompson (1942, p. 22) states that the term Magdalena "seems to be essentially synonymous with the systemic term Pennsylvanian," and does not use it in his classification of the Pennsylvanian rocks of New Mexico. R. E. King (1945, p.21) objects to inclusion of beds of Wolf-camp age (Hueco formation) in the Magdalena group, and states " . . ., the unfortunate name Magdalena has become more deeply entrenched in recent geologic literature published by the U. S. Geological Survey, in which the Hueco is continued to be classed as Magdalena. The names Pennsylvanian and Hueco are fully adequate for designation of those strata, and it is recommended that the term Magdalena, a relic of an antiquated type of stratigraphic nomenclature, be permanently abandoned." On these grounds-redundancy in stratigraphic nomenclature-the New Mexico Bureau of Mines and Mineral Resources no longer uses the term Magdalena.

A section of Pennsylvanian and Permian (?) rocks measured in Abo Canyon is given below. The Pennsylvanian portion is shown in graphic form on Plate 3, together with a section measured on Mount Paloma in the central Los Pinos Mountains a few miles to the southwest.

Section of Pennsylvanian and Permian (?) rocks measured along railroad in Abo Canyon and in north tributaries to lower part of canyon, Socorro and Valencia counties, New Mexico

	Feet
Permian (?) and Permian systems-Wolfcamp and Leonard series:	
Abo formation:	
79. Sandstone, red	Not measured
Permian (?) system-Wolfcamp series:	
Bursum formation:	*Feet*
78. Redbeds, manly; poorly exposed	15.0
77. Limestone, light gray, thin-bedded, sandy, with many fossil fragments	5.0
76. Covered; probably red and gray manly beds	20.0
75. Limestone, light gray, thin-bedded, sandy, with many fossil fragments	7.0
74. Shale and sandstone, red	60.0
73. Sandstone, red, medium to coarse, arkosic	5.0
72. Shale, olive-green and red; poorly exposed	14.0
71. Conglomerate, gray and red, with pebbles of quartz, chert, and limestone less than 1 inch in diameter; and sandstone, gray and red, arkosic	3.5
(Total thickness of Bursum formation-129.5 feet)	
Pennsylvanian, system:	
Madera limestone-arkosic limestone member:	
70. Limestone, gray, massive	12.0
69. Shale, olive-green, silty, with plant fragments	10.0
68. Limestone, medium to light gray, medium-bedded, with gray chert nodules and *Triticites ventricosus*	50.0
67. Shale, yellow-gray with red streaks, in upper one-third; limestone, gray, massive, in lower two-thirds	20.0
66. Shale, light red, manly	5.0
65. Limestone, medium gray, medium-bedded, with partings of shaly limestone; fusulinids	28.0
64. Shale, red, becoming gray to yellow-buff above	6.0
63. Shale, olive-green, with gray marly nodules	5.0
62. Limestone, gray, nodular, manly; some olive-green shale	1.5
61. Shale, olive-green, with gray manly nodules	5.0
60. Limestone, medium gray, thin-bedded; weathers uniformly to yellow-green surface	1.5
59. Sandstone, olive-green, fine, micaceous, thin-bedded	5.0

58. Shale and siltstone, light olive-green, with plant fossils ---------- 12.0
57. Shale, gray, carbonaceous, fissile ---------- 1.0
56. Sandstone, olive-green, massive, fine, micaceous 4.0
55. Shale, gray, silty, grading upward into olive-green sandy shale and thin-bedded platy sandstone ---------- 10.0
54. Limestone, medium gray, silty and sandy ---------- 1.0
53. Shale, red and gray ---------- 7.0
52. Shale, olive-green, sandy ---------- 5.0
51. Limestone, medium to light gray, manly, with gray to buff clay matrix ---------- 4.0
50. Limestone, medium gray, medium crystalline, massive ---------- 20.0
49. Limestone, gray, thin-bedded, fossiliferous, interbedded with olive-green calcareous shale
48. Limestone, medium gray, medium-bedded, finely crystalline ---------- 10.0
47. Sandstone and shale, olive-green to buff ---------- 10.0
46. Limestone, medium gray, massive ---------- 6.0
45. Sandstone and shale, olive-green, with plant fragments; massive root-bearing sandstone near top ---------- 25.0
44. Shale, olive-green, sandy, crumbly, with plant fragments ---------- 10.0
43. Limestone, light gray, finely crystalline, massive 3.0
42. Shale, gray; poorly exposed ---------- 5.0
41. Sandstone, gray to buff, fine, micaceous ---------- 1 0
40. Shale, gray; poorly exposed ---------- 4.0
39. Covered ---------- 9.0
38. Limestone, light gray ---------- 1.5
37. Shale, olive-green, silty, crumbly ---------- 5.0
36. Sandstone, olive-green to buff, medium-grained, micaceous, massive, cross-bedded ---------- 11.0
35. Covered; probably shale ---------- 4.0
34. Sandstone, olive-green to gray, massive, micaceous, medium-grained; channels the underlying shale; poorly exposed ---------- 10.0
33. Shale, lower part dark gray, fissile, with iron-carbonate bands and nodules seamed with gypsum; upper part dark, carbonaceous, fissile, with plant fossils of Missouri age ---------- 27.0
32. Sandstone, olive-green to buff-gray, fine, micaceous, massive, cross-bedded; channels the underlying shale ---------- 13.0
31. Shale, gray, fissile, carbonaceous, with a few plant fossils ---------- 20.0
30. Covered. (For details of this zone, see measured section on pages 22-23.) ---------- 42.0

(Total thickness of arkosic limestone member-437.5 feet)

Madera limestone-marine limestone member:

29. Limestone, medium to dark *gray,* moderately cherty, with some limestone conglomerate; medium- to thin-bedded at base, medium-bedded with shale partings in upper 6 feet; makes ledge; carries *Neospirifer* and *Bellerophon* ---------- 56.0
28. Mostly covered; apparently shale alternating with thin-bedded limestone ---------- 20.0

27. Limestone, medium gray, and shale, gray; fossiliferous; poorly exposed ---------------------------------------26.0
26. Limestone, gray, massive, finely crystalline --------------------------4.0
25. Shale, gray and buff, calcareous -------------------------------------16.0
24. Limestone, dark gray, medium-bedded, finely crystalline; fossils include *Dictyoclostus*---------------------------- 5.0
23. Limestone, dark gray, medium- to thick-bedded, fossiliferous, alternating with calcareous gray shale--6.0
22. Shale, gray to buff; poorly exposed ----------------------------------24.0
21. Limestone, medium to dark gray, medium-bedded, fossiliferous, with some shaly beds in upper half; forms ledge --12.0
20. Limestone, medium to dark gray, dense, irregularly bedded, fossiliferous, with much yellow-brown chert as coatings; limestone weathers blue-gray----------------------------------26.0
19. Limestone, medium to dark gray, dense to finely crystalline, cherty at base and top; carries fossil fragments; in beds up to 3 feet thick---17.0
18. Limestone, medium to dark gray with some light gray beds, finely crystalline, massive at base and top, moderately cherty; in beds 2 feet thick; weathers to rough fretted surface---118.0
17. Limestone, dark blue-gray, in irregular thin beds; much yellow chert as coatings------------------------------- 10.0
16. Limestone, light and medium gray, cherty and massive at top and base; weathers to fretted surface; less resistant than beds above and below---31.0
15. Limestone, medium and dark gray, massive, cherty ---25.0
14. Limestone, medium gray, rubbly, with abundant ribbons of yellow-brown chert as coatings; forms ledge ---29.0
13. Sandstone, angular, medium to coarse, green and micaceous at top, gray and calcareous below--------------- 4.0
12. Covered; probably gray-green shale ---------------------------------- 11.0
11. Limestone, medium to dark gray with some light gray beds; in 8- to 10-foot massive beds separated by medium-bedded zones of same thickness; weathers rough; moderately cherty, with some extremely cherty zones and some chert coatings---95.0
10. Sandstone, white to gray at top, yellow-green toward base; conglomeratic and cross-bedded in upper part, with slightly weathered feldspar grains; medium-grained and micaceous in lower part--------------------------------25.0
9. Limestone, medium gray; medium-bedded and extremely crinoidal in upper one-fourth; remainder massive; weathers fretted; slightly cherty-- 26.0
8. Sandstone, yellow-gray and buff at top with granite and quartz pebbles and moderately fresh feldspars; green and micaceous in lower half, with pebble zones--------------------- 14.0
7. Limestone, medium and dark gray; massive at

top, medium-bedded below; partly cherty; carries
Fusulinella at base-- 65.0
(Total thickness of marine limestone member-665.0 feet)

Sandia formation—upper member:

6. Covered-- 39.0
5. Conglomerate, light gray, siliceous, with rounded quartz pebbles; silicified plant stems-- 12.0
4. Covered--- 24.0
3. Sandstone and conglomerate, pink and gray, arkosic, cross- bedded, with fresh pink angular feldspars up to one-half inch in diameter and subround to sub-angular quartz pebbles up to one inch-------------------- 25.0
2. Covered-- 33.0

(Total thickness of upper member present-133.0 feet)
Total thickness of rocks measured ---------------------------- 1,365.0 feet

PALOMA FAULT

Pre-Cambrian:

1. Schist.

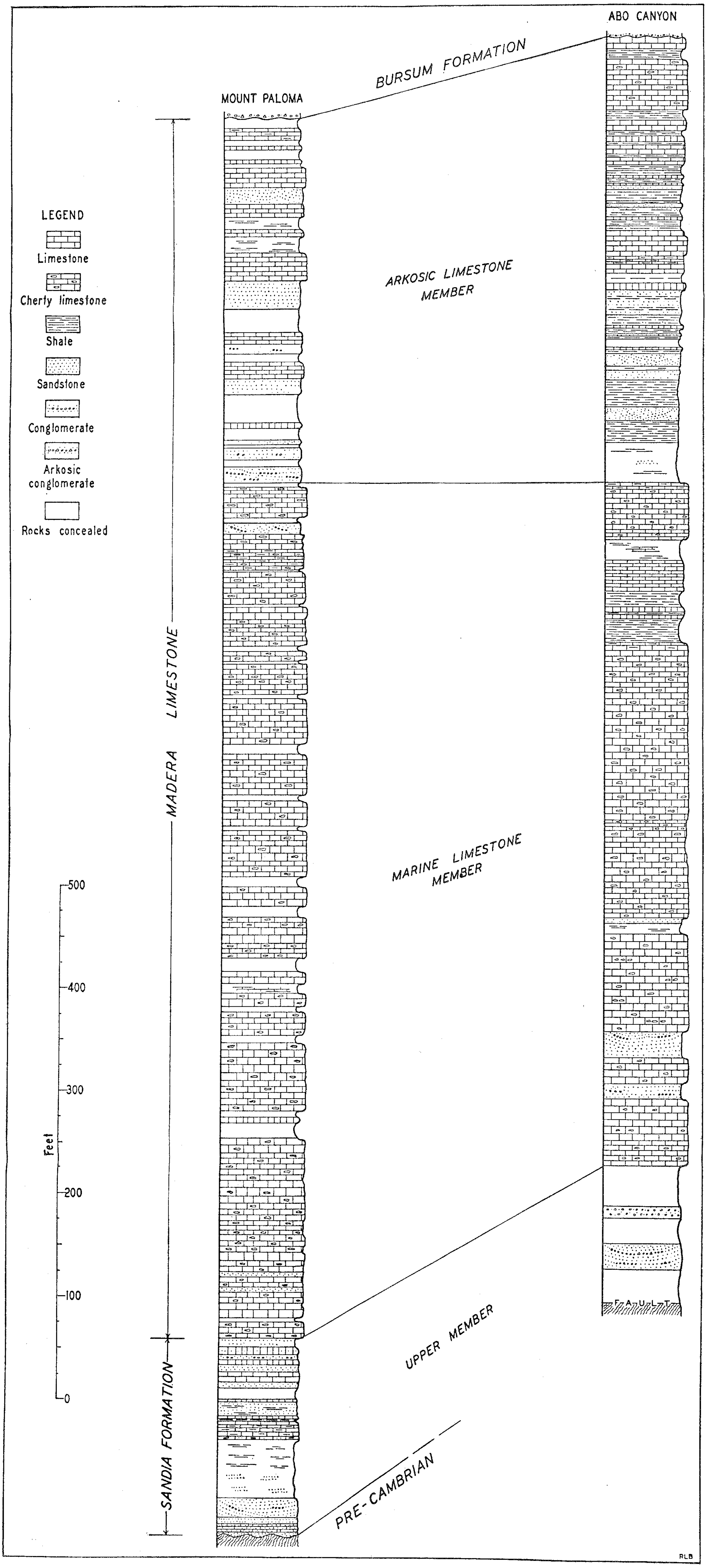
SANDIA FORMATION: UPPER MEMBER

Definition.—The term Sandia was first published by Herrick (1900). He applied it to a 150-foot section of shale, sandstone, and conglomerate that he termed a lower "series" of the Coal Measures (Pennsylvanian) of the Sandia Mountains. Keyes (1903) restricted the term to only the basal Pennsylvanian sandstones and quartzites in the Sandias. Thompson (1942, p. 22) applied the term to "the lower 127 feet of coarse-grained sandstone, conglomerates and variegated shales at the base of the Pennsylvanian in the Sandia Mountains." The usage of Thompson is essentially the same as that followed by Read and others (1944) and in the present report.

Two subdivisions of the Sandia are recognized by Read and others (1944) in north central New Mexico. These are a discontinuous lower limestone member (which may possibly be pre-Pennsylvanian in age) and an upper clastic member. Only the upper part of the upper member is present in the Gran Quivira quadrangle. Full sections of this member are exposed in the Los Pinos Mountains to the west (Plate 3).

Distribution.—The Sandia formation *is* exposed in a narrow strip along the Paloma fault in the northwest part of the quadrangle (Plate 1). The upper member, and possibly the lower, are believed to underlie that part of the quadrangle east of the outcrop.

Character and thickness.—The upper member of the Sandia formation consists of light gray siliceous quartz-pebble conglomerate containing plant fossils; pink and gray cross-bedded sandstone and conglomerate with pink angular feldspar fragments up to half an inch in diameter and subround quartz pebbles up to one



Section of Pennsylvanian rocks in Abo Canyon, correlated with section at Mount Paloma, central Los Pinos Mountains.

inch; and softer material, presumably shaly, that is largely covered. In the slopes north of Abo Canyon the member is represented by beds 133 feet thick, but as the lower beds are absent through faulting this is not a full thickness. In the Los Pinos Mountains the member has a maximum thickness of 350 feet.

Fossils and correlation.—The Sandia formation carries numerous macrofossils, including *Spirifer occidentalis, Marginif era lasallensis,* and various species of *Composita.* The upper member is characterized by the presence of *Fusulinella* and is considered to be of Lampasas age.

MADERA LIMESTONE

Definition.—The name Madera was first used by Keyes (1903), who applied it to the upper limestone of the Pennsylvanian in the Sandia Mountains. The subsequent use of the term in widely varying senses, by Keyes and others, led Thompson (1942, p. 22) to propose dropping the name Madera from Pennsylvanian nomenclature. However, in work of a relatively rapid reconnaissance nature the term is useful to designate all strata between the Sandia formation below and the Bursum formation above. This is the usage followed by Wilpolt and others (1946) and in this report. The Madera limestone is divided into a marine limestone member below and an arkosic limestone member above. These units are approximately equivalent to the Gray Mesa and Atrasado members of the Madera in the Lucero uplift (Kelley and Wood, 1946).

Distribution.—In the Gran Quivira quadrangle the Madera limestone is confined to an area of some 15 square miles in the northwest part (Plate 1). It is undoubtedly present beneath all of the quadrangle to the southeast.

Character and thickness.—The marine limestone member of the Madera consists chiefly of gray dense and finely crystalline fossiliferous cherty limestone, most of which occurs in beds from 1 foot to 10 feet thick (Plate 3). The limestone forms prominent cliffs and ledges, well developed in the lower part of Abo Canyon, and weathers to rough solution-fretted surfaces. A few zones in the upper part of the member consist of thin-bedded gray limestone interbedded with gray calcareous shale. In Abo Canyon three beds of gray-green micaceous angular coarse sandstone are found in the lower part of the member.

The arkosic limestone member (Plate 3) consists of gray fissile shale, some of which is dark and carbonaceous and carries plant fossils ; olive-green, gray, and buff arkosic micaceous sandstone; and gray finely crystalline fossiliferous limestone in part interbedded with shale. In the upper part of the member are small amounts of red calcareous shale, reddish sandstone, and gray and red marly nodular limestone. The lower two-thirds to one-half of the member, which contains the bulk of the clastics, is in general a slope-forming interval; the upper one-third to one-half, which is predominantly limestone, tends to form cliffs.

A detailed section across the contact of the two members of the Madera limestone follows. It is shown graphically in Figure **3.**

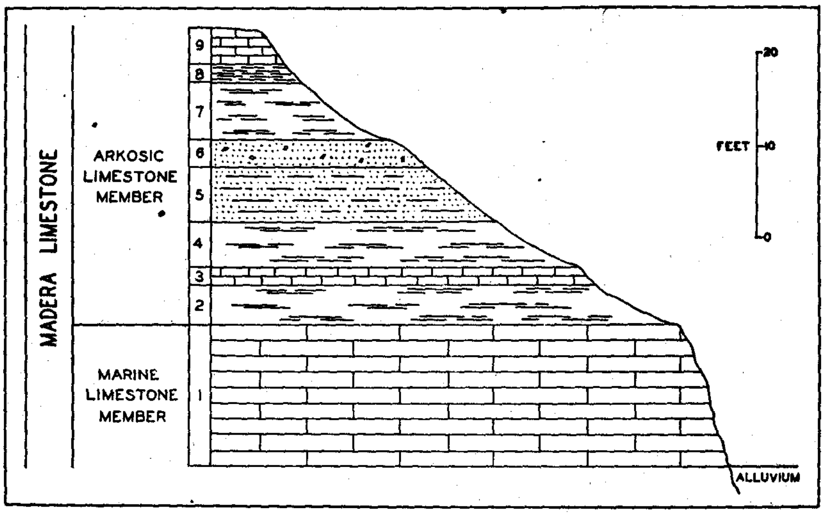


FIGURE 3. Detail of contact between marine limestone and arkosic limestone members of Madera limestone. Numbering of zones corresponds to that in measured section below.

Section across contact between the marine limestone and the arkosic limestone members of the Madera limestone, measured in Abo Canyon oneeighth mile north of third railroad bridge above mouth of canyon, on the northwest side of a sharp swing in the channel

Madera limestone:

Arkosic limestone member (only lower beds measured) : *Feet*

9. Limestone, medium to light gray when fresh, yellow-buff on weathered surface; irregularly bedded, platy; color makes bed noticeable--4
8. Shale, green-gray---2
7. Covered; probably shale--------------------------------------6
6. Sandstone, yellow-green when fresh, yellow-buff when weathered; arkosic, with angular grains of pink feldspar ---3
5. Sandstone, green and purple, thin-bedded, shaly, extremely micaceous --6
4. Covered; probably shale -------------------------------------5
3. Limestone, gray, finely crystalline, irregularly bedded---2
2. Covered; probably red shale---------------------------------- 4

Marine limestone member (only upper beds measured):

1. Limestone, medium gray, finely crystalline, in beds 1 to 3 feet thick; weathers slabby; makes ledge; base concealed by alluvium in canyon bottom -- 15+

47+

The marine limestone member is 665 feet thick in Abo Canyon, and the arkosic limestone member is 437 feet thick. Thus the total thickness for the Madera limestone is 1,102 feet.

Fossils and *correlation.*—The following macrofossils have been collected from the marine limestone member of the Madera.

Neospirifer laths, N. triplicatus
Dictyoclostus portlockianus
Squamularia perplexa
Dielasma bovidens
Campophyllum sp.
Linoproductus sp.
Composita sp.

Except for the basal 15 or 20 feet, where advanced species of *Fusulinella* are found, the member is characterized by the fusulinids *Fusulina* and *Wedekindellina.* The member is correlated with the Des Moines series of the Mid-Continent section.

The macrofossil assemblage of the arkosic limestone member of the Madera closely resembles that of the marine limestone member; the fusulinids, however, differ considerably. The lower, slope-forming interval of the arkosic limestone member contains slender cylindrical species of *Triticites,* such as *T. nebraskensis* and *T. cuchilloensis;* and the upper strata of the member are characterized by advanced, obese species of *Triticites,* such as *T. ventricosus.* The arkosic limestone member is correlated mainly with the Missouri and Virgil series of the Mid-Continent section.

PERMIAN (?) SYSTEM

WOLFCAMP SERIES

BURSUM FORMATION

*Definition.*The Bursum formation is defined by Wilpolt and others (1946) from exposures immediately west of Bursum triangulation point in the SE$^1/_4$ sec. 1, T. 6 S., R. 4 E., Socorro County, some 12 miles south of the Gran Quivira quadrangle. At its type locality the formation is 250 feet thick and consists of shale, conglomerate, and arkosic sandstone in the lower part, and marine limestone and shale in the upper part.

Distribution.—The Bursum formation crops out in an irregular strip from one-quarter mile to 2$^1/_2$ miles in width, in the northwest part of the Gran Quivira quadrangle (Plate 1). Parts of the outcrop are concealed beneath Quaternary alluvium and pediment gravels and outliers of the overlying Abo formation. The Bursum formation is well exposed just south of U. S. Highway 60, in sec. 14, T. 2 N., R. 4 E.

Character and thickness.-As indicated in the measured section, page 17, the Bursum formation in Abo Canyon consists of thick beds of red and gray shale, with thinner beds of red sandstone and gray limestone carrying marine fossils. A section measured $3^1/_2$ miles to the southwest is given below.

Section of Bursum, formation measured in slopes back of West Ranch headquarters in the NE¼ sec. 14, T. 2 N., R. 4 E., Socorro County

Permian (?) and Permian systems--Wolfcamp and Leonard series:
Abo formation:
32. Sandstone, purple, platy and shaly, cross-bedded, micaceous; prospect pit shows copper-oxide stain --- Not measured

Permian (?) system-Wolfcamp series:
Bursum formation: *Feet*
31. Sandstone, gray, medium-grained, quartzitic; contains limestone pebbles and a few fresh feldspar grains ------------------------------------- -----------2.0
30. Limestone, gray, rubbly, dense, sparingly fossiliferous; top layer locally covered with thin micaceous sandy coating--------------------------------2.0
29. Covered in upper one-third; shale, sandy and red, exposed and reflected in soil in lower two-thirds --------------------------------16.0
28. Sandstone, dark red, coarse, arkosic, conglomeratic, cross-bedded; contains fresh pink feldspars; makes ledge---------------------------------- 3.0
27. Covered; probably red shale--------------------------------40.0
26. Limestone, gray, dense, poorly bedded, rubbly; contains fragmental crinoid stems and spines, gastropods, and brachiopods; caps small cuesta-----------5.0
25. Covered; makes gentle slope -------------------------------25.0
24. Limestone, gray, medium-bedded, solution-pitted; contains crinoid spines, brachiopods, bryozoa; top layer has irregular paving-block fracture; caps broad cuesta ---8.0
23. Covered---24.0
22. Limestone, gray, dense, sparingly fossiliferous, in beds 3 inches, to 1 foot thick; weathers gray-brown with very rough solution-pitted surface----------------------5.0
21. Covered; probably shale -------------------------- ----------11.0
20. Shale, red, clayey; grayish purple toward top-------------15.0
19. Shale, dark red, micaceous, in part sandy -----------------6.0
18. Sandstone, dark red, medium-grained, micaceous; changes laterally within 100 feet to an 8-foot arkosic cross-bedded sandstone -----------------1.0
17. Shale, variegated, mostly red and purple, muddy; one 0.8-foot zone of limestone con-

cretions near middle -- 10.0

16. Conglomerate of limestone pebbles in shaly matrix; limestone is gray and purple, dense ----------------- 1.6
15. Covered; probably shale --------------------------------------- 1.0
14. Limestone, gray, dense, mottled with purple; in one bed; carries crinoid stems ---------------------------- 1.0
13. Shale, red, clayey, with abundant irregularly shaped nodules of red and gray limestone ---------------- 3.0
12. Shale, dark red, clayey --- 3.0
11. Sandstone, dark red, fine-grained, micaceous; upper part contains abundant nodules or pebbles of gray and purple sandy limestone ------------------------- 2.0
10. Shale, dark red, sandy, fissile, micaceous; and sandstone, dark red, hematitic, in a 4-inch bed 2.0
9. Limestone, gray and purple, dense, fossiliferous 1.0
8. Clay shale, gray to buff --- 5.0
7. Clay shale, dark red--- 3.0
6. Shale, variegated, clayey, with abundant limestone nodules carrying bryozoans and crinoid stems ------ 2.0
5. Shale, variegated, mostly purplish gray, soft ------------ 18.0
4. Sandstone, dark red, medium-grained, micaceous, with pink feldspar grains; partings of dark-red shale --- 2.0
3. Shale, dark red, sandy, micaceous, with nodules of hematite and limestone ------------------------------------ 1.8
2. Limestone, gray and purple, dense, irregularly bedded, nodular; poorly exposed --------------------- 2.0

(Total thickness of Bursum formation-221.4 feet)

Pennsylvanian system:

Madera limestone-arkosic limestone member:

1. Limestone, gray, dense ------------------------------- Not measured

The Bursum formation is 129.5 feet thick at the head of Abo Canyon, and 221.4 feet within 31/2 miles to the southwest. Abrupt changes in thickness are to be expected in such units as the Bursum, the bulk of which consists of continental redbeds (note Interval 18 in above section).

Fossils and correlation.-In addition to crinoids, bryozoans, gastropods, and brachiopods, the limestones of the Bursum formation contain well-preserved and diagnostic fusulinids. *Schwagerina,* associated with advanced forms of *Triticites ventricosus,* indicates the Wolfcamp age of the Bursum.

The stratigraphic relations of the Wolfcamp series are in question. The majority of geologists working in the Permian Basin of west Texas and southeastern New Mexico consider the Wolfcamp to be the oldest series of the Permian system; in central New Mexico, including the Gran Quivira quadrangle, a stratigraphic break is indicated at the base of the Bursum formation by the presence of a conglomerate of re-worked limestone of the underlying Pennsylvanian. However, C. B. Read (personal communication, 1945) and P. B. King (1942, pp. 556-562) of the U. S. Geological Survey consider that marine Wolfcamp strata are only questionably of Permian age, and place them in the "Magdalena group." Until the matter is finally settled, it seems advisable to designate rocks of Wolfcamp age as Permian (?).

The Bursum formation is approximately equivalent to the Red Tanks member of the Madera limestone, named by Kelley and Wood (1946) in the Lucero uplift.

Geologic history.—The Bursum formation records a history of alternating marine and continental conditions, transitional from the dominantly marine environment of the underlying Pennsylvanian to, the continental environment of the overlying Abo formation. Periods of limestone deposition were separated by intervals during which red non-fossiliferous shales, sandstones, and arkoses accumulated.

PERMIAN (?) AND PERMIAN SYSTEMS

WOLFCAMP AND LEONARD SERIES

ABO FORMATION

Definition.—A succession of dark-red coarse sandstones, exposed in Abo Canyon to an estimated thickness of 800 feet, were given the name Abo sandstone by Lee (1909, p. 12). He stated that the Abo rested unconformably on the Magdalena limestone, but did not clearly define the upper boundary. Lee termed the Abo the basal member of the Manzano group, which contained in ascending order the Abo sandstone, the' Yeso formation, and the San Andres limestone.

Lee did not designate an exact type locality for the Abo nor set up a type section. Such a locality and section have been described by Needham and Bates (1943, pp. 1654-1657). The redescribed type section lies within the Gran Quivira quadrangle, along the railroad and highway between the underpass west of Scholle and the side road to Abo Ruins (Plate 1) .

As described by Needham and Bates, the Abo in Abo Canyon consists of 914 feet of continental redbeds that overlie a thin "unnamed basal Permian limestone." Field work for the present report shows this limestone to be at the top of the Bursum formation.

The uppermost unit of the type Abo of Needham and Bates (1943, p. 1656) is a 6-foot white massive sandstone. Further field work in the Gran Quivira quadrangle has shown the presence just above this sandstone of a thin limestone that is identical with the lowest unit of the Yeso as redefined by the same authors (pp. 1657-1661) . However, as pointed out by C. B. Read (personal communication, 1945), the "basal Yeso limestone" cannot be found in Yeso sections in the northern part of the State—in

Glorieta Mesa and the Zuni Mountains, for example—and consequently it cannot serve as a universally recognizable "base of Yeso." Read further states that a 100- to 300-foot section of sandstones and shales, heretofore considered uppermost Abo, can be recognized and mapped regionally. As most of these beds are apparently of marine origin, and in many places, including Abo Canyon, have a pink color more similar to that of the Yeso than to the dark red of the Abo, Read and his co-workers on the Federal Survey have included the beds in the Yeso and have mapped the Abo-Yeso contact some distance below the basal Yeso limestone of Needham and Bates. Applied to the Abo type section, this revision lowers the Abo-Yeso contact 104 feet, to the top of Interval 32 in the Needham and Bates section (1943, p. 1656).

Distribution.—In the northwest part of the Gran Quivira ' quadrangle the Abo formation crops out in an irregular zone 4 to 6 miles wide (Plate 1), and in the subsurface underlies that part of the quadrangle southeast of the outcrop.

Character and thickness.—The Abo formation in the Gran Quivira quadrangle consists of dark-red shale (about 70 percent) and sandstone and arkose (about 30 percent). The shales are characteristically muddy, and some beds are micaceous. The sandstones range from fine-grained and micaceous to coarse-grained, conglomeratic, and arkosic. Pebbles and angular fragments of quartz and feldspar are the chief constituents of some layers. Whereas the shales have low resistance to erosion, the coarser clastics are highly resistant and form prominent ridges and cuestas.

The dark-red color of the Abo is sufficiently intense to *suggest* at first glance a high percentage of iron oxide; but microscopic examination shows the oxide to be confined to thin films around clastic grains. Laboratory tests on a typical dark-red arkose show iron oxide to make up less than 1 percent of the rock by weight. When cleaned of its iron oxide, the arkose is shown to consist of angular pieces of quartz and pink feldspar, which in the aggregate closely resemble crushed granite.

The Abo formation contains no marine limestones ; a few thin limestone-pebble conglomerates have been noted. The continental origin of the formation is shown by its clastic character and red color, by the presence of mud cracks, current ripple marks, cross-bedding, bones and tracks of land vertebrates, and plant impressions, and by the lenticularity of sandstones and arkoses.

Exclusion of the top 104 feet from the Abo as defined' by Needham and Bates (1943), as discussed above, gives the formation a thickness of 810 feet in the Gran Quivira quadrangle.

Fossils and correlation.—Recent literature contains conflicting evidence on the age and relations of the Abo formation. For a number of years it has been considered the central-New Mexico representative of the Wolfcamp series. It is reported (P. B. King, 1942, p. 677) that the Abo has been traced southward into the Deer Mountain red shale member of the Hueco limestone (Wolfcamp), and that *Pseudoschwagerina* has been collected from limestones above the Deer Mountain. Thompson (1942, Plate II) shows the Abo grading laterally into the lower Hueco limestone.

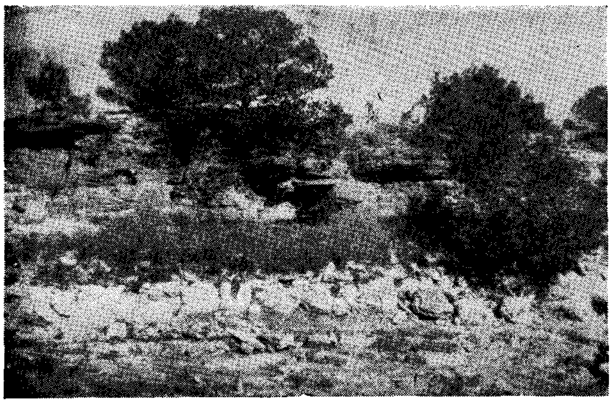
On the other hand, the possibility that much if not all of the Abo formation is of Leonard age is strongly advanced by P. B. King (1942, pp. 674-677, 689-690, 738-741), who cites Read's evidence from fossil plants and Romer's evidence from vertebrate remains, and more recently by R. E. King (1945, pp. 16-17) on the evidence of subsurface correlation from the Permian Basin northwestward. The Abo formation is here tentatively assigned in part to the Wolfcamp series of Permian (?) age and in part to the Leonard series of Permian age (Figure 2).

PERMIAN SYSTEM
LEONARD SERIES
YESO FORMATION

Definition.—The Yeso formation was named by Lee (1909, p. 12) . The name is derived from the Mesa del Yeso, a small butte 12 miles northeast of Socorro and 16 miles west of the Gran Quivira quadrangle. Lee described the type locality and the type section only in general terms, and in order to give the formation a more precise definition Needham and Bates (1943, pp. 16571661) redescribed it. They placed the top of the Yeso at the base of the overlying quartzitic blocky Glorieta sandstone and its base at the base of a 7-foot gray limestone.

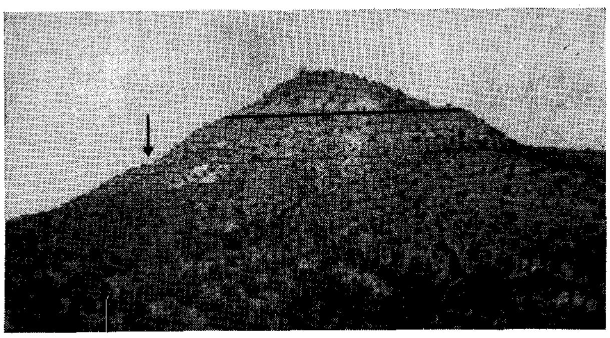
For reasons discussed under Abo formation, page 27, 104 feet of shale and sandstone called Abo by Needham and Bates, are now assigned to the Yeso ; this interval has been named the Meseta Blanca sandstone, member of the Yeso formation by Wood and Northrop (1946) . Next above is the Torres member, named by Wilpolt and others (1946) , which includes the interbedded sandstones, siltstones, limestones, and gypsums making up the main part of the formation. The Canas_gypsum and the Joyita sandstone members, both named by Needham and Bates, constitute the remainder of the formation.

Distribution.—The Yeso formation occupies large areas north and west of the Chupadera Mesa escarpment (Plates 1 and 2, A), and crops out in the breached Oscura anticline in the south central part of the quadrangle. The formation underlies all of



A. Glorieta sandstone overlain by slabby limestone of the San Andres formation. Contact is at top of grassy strip. Arroyo channel in NW% sec. 6, T. 2 N., R. 8 E.

B. Limestone of the San Andres formation overlying Glorieta sandstone. NE1/4 sec. 32, T. 1 N., R. 5 E.



C. Hill of Glorieta sandstone (below line) capped by basal beds of the San Andres formation. Arrow marks characteristic bench on Glorieta outcrop. Base of Glorieta is concealed. Looking northwest 3 miles northwest of Chupadera.

Chupadera Mesa and at least the north part of the Jornada del Muerto.

Character and thickness.--At no place in the quadrangle is a complete section of the Yeso formation exposed. However, several partial sections have been combined below, in order to give a comprehensive picture of the formation.

Composite section of the Yeso formation in the Gran Quivira *quadrangle*

I. Measured in the $E^1/_2$ sec. 32, T. 1 N., R. 5 E., on the south side of erosional outlier of Chupadera Mesa.

	Feet
Glorieta sandstone:	
Sandstone, yellow to white, medium coarse; forms rough steep slope	Not measured
Yeso formation:	
Joyita member :	
42. Siltstone and fine sandstone, pink and gray; gypsiferous in lower part	62.0
Canas member :	
41. Gypsum, white and gray	6.0
40. Siltstone, red, gypsiferous, muddy	2.0
39. Gypsum, white and gray, with partings of dark red silt that tend to stain outcrop; thin beds of poorly exposed sandstone and limestone in basal 6 feet	55.0
38. Sandstone, pink, gypsiferous	2.0
37. Gypsum, white and gray, with thin beds of sandstone and limestone	40.0
Torres member:	
36. Limestone, dark gray, silty; weathers blocky; caps small bench	8.0
35. Gypsum, white	8.0
34. Siltstone and fine sandstone, pink, gypsiferous	32.0
33. Gypsum, white and gray, with beds of pinkish gray coarse clean well-sorted sandstone that consists of rounded quartz grains in a selenite matrix	24.0
32. Limestone, brownish *gray, silty* and sandy, gypsiferous, medium- to thin-bedded, with few thin shale partings; weathers blocky	20.0

II. Measured in the prominent escarpment in the $S^1/_2$ sec. 28, T. 3 N., R. 6 E., 0.5 mile southeast of the village of Abo. (Intervals 28-31 below are equivalent to Interval 32 above.)

	Feet
31. Limestone, gray, medium crystalline, finely porous, with fossil fragments; weathers to angular blocks; yields oil odor when struck; *caps* butte	4.0
30. Limestone, gray, medium-bedded, sandy	5.0
29. Limestone, gray, medium crystalline, with many fossil fragments; weathers to angular blocks; yields oil odor when struck; lower half forms prominent ledge	3.0
28. Limestone, gray, medium-bedded, sandy	4.0

27. Sandstone, fine, clean; light gray in lower half, buff in upper; with thin gray shale beds ----------------- 9.0
26. Sandstone, orange, fine, very silty, soft; with some shale -- 27.0
25. Gypsum, gray -- 3.0
24. Limestone, gray, impure, interlaminated with gypsum; laminae are crumpled toward top; forms cliff --- 9.5
23. Sandstone, gray-buff, fine, with thin partings of gray-green shale -- 5.5
22. Sandstone, bright orange, medium to fine, silty, angular, soft; contains several thin beds of sandy sugary gypsum --45.0
21. Gypsum, predominantly gray, with zones containing small disseminated fragments of red *gypsum;* some beds are laminated red and gray gypsum; makes sheer cliff ----------------------------------- 17.0
20. Limestone, *gray,* irregular bed------------------------------- 0.5
19. Sandstone, buff and orange, medium-grained, silty, angular, with thin zones of gypsum and shale --- 29.0
18. Gypsum, greenish-gray and red, laminated---------------3.0
17. Sandstone, buff and orange, fine, silty, with thin gray-green shale and selenite partings and coarse rounded quartz grains; makes sheer cliff at base of escarpment; base not exposed ---------------- 53.0

III. Measured on south side of Abo Canyon arroyo, south of U. S. Highway 60, in the N1/2 secs. 31 and 32, T. 3 N., R. 6 E. (Intervals 16 and 17 cannot be found in contact. However, field traverse shows the top of Interval 16 to be within a few feet of the base of the cliff formed by Interval 17.)

16. Limestone, medium gray, argillaceous; weathers into small angular blocks; does not make clean-cut ledge--- 4.0
15. Covered --- 42.0
14. Limestone, medium to light gray, argillaceous, poorly bedded; weathers to angular blocks in lower 1 foot, to irregular thick wavy slabs-above; caps cuesta-- 7.0
13. Silt, gray and yellow, sandy, soft ---------------------------- 6.0
12. Covered; gypsite and pink silty soil ----------------------- 54.0

Meseta Blanca member:

11. Sandstone, light yellow-gray, medium-grained-----------3.0
10. Sandstone, pink and red, fine- to medium-grained, thin-bedded and shaly ----------------------------- 9.0

IV. Measured in low hill in the N1/2 sec. 36, T. 3 N., R. 5 E., just northeast of junction of U. S. Highway 60 and road to Abo State Monument (This comprises Intervals 33-40 of the Abo type section of Needham and Bates (1943, p. 1656.) Interval 11 above is equivalent to Interval 9 below, and Interval 10 above to the upper beds of Interval 8.)

Meseta Blanca member:

9. Sandstone, white, one massive bed; upper part weathers limy -- 6.0
8. Sandstone, pink, medium-grained, in beds of medium thickness -- 43.0
7. Sandstone, light-colored, coarse ------------------------------ 3.0

6. Shale, pink, sandy, with sandstone parting--------------7.0
5. Sandstone, light-colored, coarse ---------------------------5.5
4. Sandstone, pink and buff, with shale partings---------21.0
3. Sandstone, red --7.0
2. Sandstone, pink, shaly; and sandy shale --------------- 12.0
(Total thickness of Yeso formation-678 feet)

Abo formation:

1. Shale, red ---3.0

As indicated in the above section, the gypsums of the Yeso formation are white and gray and generally contain thin partings of shale and silt; the sandstones are mostly buff to orange-pink and are fine and silty; and the silts and shales are variegated. A typical limestone of the Torres member is described in the following field notes, taken in the $E^1/_2$ sec. 29, T. 2 N., R 5 E. "Lowermost Yeso limestone; good exposure. Here the limestone is 12 feet thick and caps a small isolated hill. This thickness appears to exceed the average for this limestone in the quadrangle; in many places it is either thin or poorly resistant, or both, making low inconspicuous benches or none at all. Here the limestone is buff-gray on fresh surface, and weathers to platy slabs 2 to 8 inches thick. Limestone is silty and muddy ; some layers probably approach calcareous siltstone in composition. Has thin shale partings. Is underlain by yellow friable sandstone, medium to fine, about 5 feet thick, and this in turn by soft greenish gray shale."

The Meseta Blanca and Joyita sandstone members, and some of the, limestones of the Torres member, are moderately resistant to erosion ; the remainder of the strata are much less resistant and consequently the Yeso formation is characterized by a gently rolling surface of low relief. The silts and fine sandstones of the Yeso produce a mealy soil that supports, a good stand of range grass and is readily cultivated.

The composite section given above shows the Yeso to be approximately 680 feet thick in the north half of the Gran Quivira quadrangle. It thickens markedly toward the south; the Rio Grande Oil Co. No. 1 Stackhouse, a dry hole in sec. 14, T. 3 S., R. 6 E., started below the top of the Yeso and penetrated 1,580 feet of Yeso beds. This figure doubtless exceeds the true thickness, as the test is situated in an area of close folding and the drilling was probably not all at right angles to the bedding.

Thickness of the Joyita sandstone member where measured at eight localities along the Chupadera Mesa escarpment ranges from 30 to 91 feet and averages 64 feet; the thinnest section of the Canas gypsum member measures 105 feet, and the thickest is over 170 feet.

Stratigraphic relations.—As the Yeso formation is devoid of diagnostic fossils, its relations must be determined on the basis of lithology and stratigraphic position. Its high proportion of evaporites and the distinctive pink or orange color of many of the associated clastics make the formation readily recognizable, and its position between the Abo redbeds and the Glorieta sandstone makes correlation relatively simple in central New Mexico.

Toward the north from the latitude of the Gran Quivira quadrangle the Yeso loses its evaporites and most of its limestones and becomes essentially a unit of orange silty sandstone. It is correlated with the upper member of the Supai formation of northeastern. Arizona (Huddle and Dobrdvolny, 1945) . To the south and east in the subsurface the Yeso thickens to as much as 2,350 feet (R. E. King, 1945, p. 11), and includes large amounts of anhydrite, salt, and dolomitic limestone. King shows by means of cross sections based on well logs that the Yeso is traceable into beds of Leonard age in the Permian Basin.

GLORIETA SANDSTONE

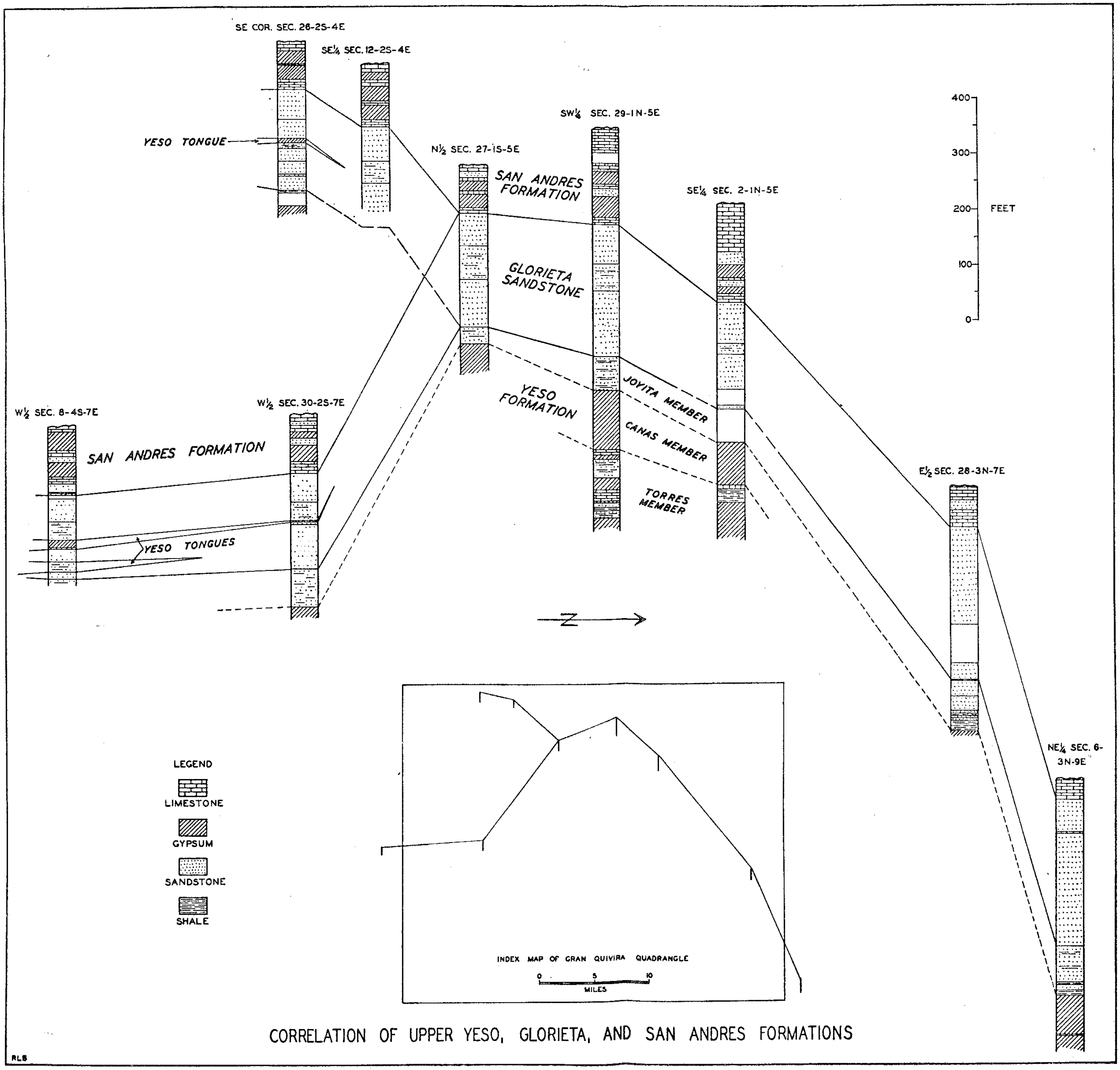
Definition.—The following statements are quoted from Needham and Bates (1943, p. 1662).

> The name Glorieta was first used by Keyes (1915, pp. 2, 7), who applied it to the main body of the Dakota sandstone (Cretaceous) around the south end of the Rocky Mountains. Although Keyes gave no type locality, presumably the sandstone was named from Glorieta Mesa in Santa Fe and San Miguel Counties, New Mexico, or from the town of Glorieta at the north end of the Mesa. Cretaceous formations do not crop out at either of these places. Common usage has determined the Glorieta to be the prominent sandstone, well developed and exposed on Glorieta Mesa, that separates the Yeso and San Andres formations.
>
> The Glorieta was first designated Permian by Hager and Robitaille (1919). . .

Although the U. S. Geological Survey classifies the Glorieta sandstone as a member of the San Andres formation, the New Mexico Bureau of Mines and Mineral Resources considers that the unit has sufficient thickness, regional distribution, and distinctive character to warrant formational rank.

Distribution.—The Glorieta sandstone crops out in an irregular band along the north and west edges of Chupadera Mesa and on the flanks of the Torres syncline (Plate 1). In areas of steep dip or abrupt slope, the width of Glorieta outcrop is only a few hundred feet; where the dip is gentle and erosion has stripped back the overlying San Andres formation the outcrop is more than 2 miles in width.

Character and thickness.—The Glorieta is a white and yellow clean sandstone (Plate 4, A) composed of angular to sub-round quartz grains of medium size. Distinguishing characters include thick bedding, cross-bedding, moderate friability, and a high resistance to erosion that generally results in cliffs and steep slopes with rounded ledges. Zones of iron-oxide concre-



CORRELATION OF UPPER YESO, GLORIETA, AND SAN ANDRES FORMATIONS

tions are common. The middle part of the formation is thinner-bedded and slightly less resistant than the upper and lower parts; this condition produces a bench about midway across most steep exposures (Plate 4, C).

As measured at nine localities in the quadrangle, the Glorieta ranges in thickness from 275 feet in the northern part to 150 feet in the southern.

Stratigraphic relations.—The relations of the Glorieta sandstone to the San Andres formation above and the Yeso formation below are shown graphically on Plate 5. At most places the upper contact is regular and conformable (Plate 4, B) . At one locality a gradation occurs from friable yellow Glorieta sandstone through limey sandstone and sandy limestone to dark gray limestone of the San Andres formation.

Silty sandstone of the Joyita type, and thin beds of gypsum and limestone, are found in the Glorieta sandstone in the southwest part of the quadrangle (Plates 1, 5), and field work by members of the U. S. Geological Survey shows that these beds thicken southward. They are considered to be tongues of the Yeso, indicating alternating transgression and regression of Yeso seas from the south. Further work may show that the thinning of the Glorieta toward the Permian Basin on the southeast is the result of the lateral gradation of the Power part of the formation into Yeso/beds.

According to R. E. King (1945, p. 10), "The Glorieta is a wedge of clastic sediments derived from islands in the Permian sea, the remnants of the Ancestral Rocky Mountains, in north central New Mexico. It is generally correlated with the San Angelo sandstone of the central Texas section. . . " On the northwest the Glorieta is considered the equivalent of the De Chelly and Coconino sandstones of Arizona (Huddle and Dobrovolny, 1945).

SAN ANDRES FORMATION

Definition.—The San Andres limestone was named by Lee (1909, pp. 12, 29), from the San Andres Mountains in southern Socorro County. At the type section, located and described by Needham and Bates (1943, pp. 1664-1666), the formation consists of 593 feet of dark gray thick-bedded limestone. As used in the present report, the San Andres formation does not include the underlying Glorieta sandstone, and is thus equivalent to the limestone member of the San Andres formation of the U. S. Geological Survey.

Distribution.—The San Andres is the surface formation over more than 450 square miles on Chupadera Mesa and its erosional outliers (Plate 1). It is also present around the margins of the Torres syncline.

Character and thickness.—In the Gran Quivira quadrangle the San Andres formation contains limestone, gypsum, and sandstone (Plate 5). The limestone is gray, finely crystalline, and thick-bedded to slabby (Plate 6, A) . Solution cavities are common and the beds tend to weather to rough fretted surfaces. Finely porous sandy and oolitic beds are numerous. A dark brownish gray blocky bed at the base of the formation gives off a strong oil odor when struck with the hammer. Small lenses, up to 1 inch in diameter, of silicified shell fragments resembling coquina have been noted. A few beds are moderately cherty, although in general chert is not diagnostic. Fossil fragments are abundant in some layers.

The gypsum of the San Andres is white and massive like that in the Yeso formation. It may be seen along the top of the Chupadera Mesa escarpment and also around sink holes on the Mesa (Plate 6, B). The sandstone is white to yellow, medium-grained, and friable; it closely resembles the Glorieta.

The ease with which the gypsum in the formation is dissolved by ground waters accounts for the uneven surface of the Mesa and the abundant sink holes (Plates 2, C and 6, C).

The greatest measured thickness of the San Andres *is* 180 feet, on the Mesa escarpment in the $S^1/_2$ sec. 2, T. 1 N., R. 5 E., and it is doubtful if more than 200 to 300 feet of the formation is present in the quadrangle. A water well in sec. 25, T. 2 S., R. 8 E., penetrated 385 feet before encountering the Glorieta; but of this total, 95 feet is igneous rock in the form of sills.

Stratigraphic relations.—The lower contact of the San Andres formation is conformable and in some places gradational. Although younger beds cannot be seen resting on the San Andres, it is highly probable that Triassic strata directly overlie it in the Torres syncline. If so, several hundred feet of younger Permian strata that overlie the San Andres in the subsurface of southeastern New Mexico are missing, and the San Andres surface is thus an unconformity of some magnitude.

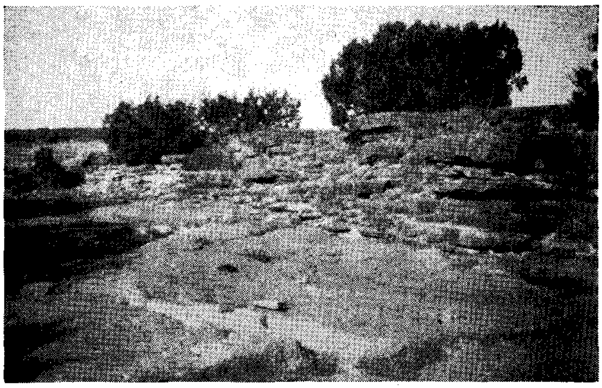
The San Andres is considered to constitute the upper part of the Leonard series.

TRIASSIC SYSTEM

DOCKUM GROUP

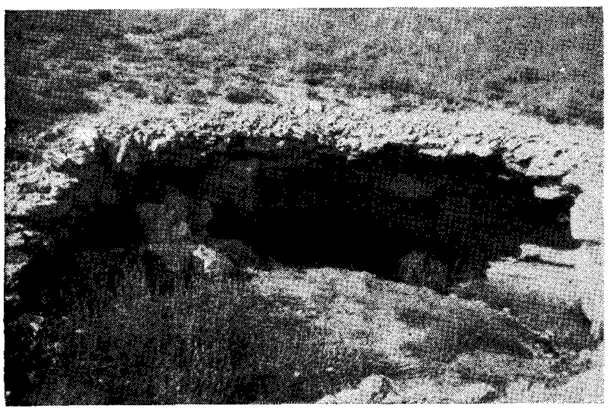
Small scattered exposures of rocks assigned to the Dockum group are found in the Torres syncline (Plate 1). Correlatives of the Chinle formation and the Santa Rosa sandstone are probably present. It is likely that these strata were once present over the entire Gran Quivira quadrangle, from the higher parts of which they have been removed by erosion.

The rocks consist of maroon, light green, and light gray



A. Limestone of the San Andres formation exposed in arroyo in the NE1/4 sec. 32, T. 2 N., R. 8 E.

B. Ten-foot bed of laminated gypsum in the San Andres formation. Wall of large sink depression in the NE 1/4 sec. 14, T. 1 N., R. 8 E.



C. Small sinkhole in San Andres limestone that is underlain by 10-foot gypsum bed. Same locality as Plate 6, B.

sandstone, siltstone, and shale, with local lenses of limestone conglomerate. The thickness is estimated at 300 feet; a stratigraphic section could not be measured.

The Dockum group rests disconformably on the San Andres formation. At all exposures in the Torres syncline it is overlain unconformably by Quaternary alluvium.

CRETACEOUS SYSTEM

DAKOTA SANDSTONE

At an isolated small outcrop in sec. 31, T. 3 S., R. 5 E., in the Torres syncline (Plate 1), 40 to 45 feet of light gray fine to coarse sandstone is exposed. On lithologic grounds this rock is assigned to the Dakota sandstone. Owing to extensive cover by Quaternary alluvium, the relations of this bed to underlying and possible overlying strata are impossible to determine.

QUATERNARY SYSTEM

PEDIMENT GRAVELS

The gravels that cap the pediment remnants in the northwest part of the quadrangle (Plate 1) consist of coarse rounded and platy fragments of pre-Cambrian rocks—schist, quartzite, and granite—and of Pennsylvanian limestone and red Abo sandstone. They are found in loose form except locally where they are cemented by calcium carbonate to form a very coarse conglomerate. The gravels are 3 to 4 feet in thickness. They originated from the wearing-down of the pre-Cambrian masses and flanking Paleozoic sediments in the Manzano Mountains.

ALLUVIUM

The alluvial material of the Rio Grande valley, a portion of which crops out at the extreme northwest corner of the quadrangle (Plate 1), and also the material in local alluvial fans, consists of unsorted cobbles and pebbles mixed with sand and finer material. It is unconsolidated, is generally but a few feet thick, and represents the products of recent stream flow of the flash-flood type.

Besides these arroyo ravels, there are in the Torres syncline a considerable number of sand dunes. The sand has been winnowed out of the stream-wash material by the prevailing westerly winds.

CALICHE AND GYPSITE

Local thin accumulations of calcareous and gypsiferous material are found in the extensive areas underlain by the Yeso and San Andres formations.

TERTIARY (?) IGNEOUS ROCKS

OCCURRENCE

A number of dikes and sills intrude the sedimentary rocks of the Gran Quivira quadrangle (Plate 1) . The dikes are confined to the west central part. Sills are present along the west edge of Chupadera Mesa, and in the east central part of the quadrangle in Tps. 1 N. and 1 S., Rs. 8 and 9 E. A sill makes an isolated outcrop 3 miles southwest of Abo, and a sill remnant occurs at the northeast end of a dike near the west edge of the quadrangle, in the NE 1/4 sec. 23, T. 1 N., R. 4 E.

The dikes are in rocks of the Yeso formation. Most of them trend northeast; one, in secs. 23, 26, and 35, T. 1 N., R. 5 E., trends slightly west of north. They reach a maximum length of $6^1/_2$ miles and a maximum thickness of nearly 500 feet. The arching that these intrusives have produced in the sedimentary rocks, and the inferred manner of emplacement of the dikes, are discussed under Geologic Structure, page 40.

The sill southwest of Abo and the sill remnant in sec. 23, T. 1 N., R. 4 E., are in the Yeso formation. Those on the Chupadera Mesa escarpment are along the Yeso-Glorieta contact and in the lower part of the Glorieta sandstone; and those in the east central part of the quadrangle are in the San Andres formation. The largest sill, on the Chupadera Mesa escarpment east of the settlement of Chupadera (Plate 1), has an extremely irregular outcrop pattern with an airline length of more than $4^1/_2$ miles. Its thickness ranges from a few feet near its northern end (Plate 7, B) to as much as 50 feet in its central part. Other sills, such as those near Gran Quivira, are exposed only at isolated points (Plate 7, C), and hence their thickness and continuity beneath the soil cover are impossible to determine. Six sills, from 5 to 45 feet thick, were penetrated in a water well on the Phipps property in sec. 25, T. 2 S., R. 8 E., between depths of 65 and 310 feet. As all the sills have an attitude approximately parallel with that of the sedimentary rocks, they are nearly horizontal.

Evidence on the relation of sills to country rock is provided by the small sill remnant in the NE 1/4 sec. 23, T. 1 N., R. 4 E. Sill rock caps a prominent knob that is roughly oval in plan and has a maximum length of about 300 feet. Underlying the sill is yellowish gray silty shale and purple shale, from 4 to 6 feet thick, below which is orange-pink siltstone and fine sandstone forming the lower slopes of the knob. All these sedimentary rocks are in the lower part of the Yeso formation. The contact between sill rock and sediments is exposed at several places. The sill rock, which is gray and medium-grained, lies on the shale with no evidence of baking, soaking, or replacement. The lower surface of the sill conforms to the dip of the strata beneath. Local irregularities in this surface occur, however, as on the west side of the knob where the igneous rock cuts down through 2 feet of yellowish gray silty shale and is in irregular contact with purple shale. Lenses of yellowish gray silty shale are here embedded in the sill material. At other points the purple shale has a contorted or "pillowy" structure beneath sill rock that contains wedges of yellowish gray shale at the base. Although locally the dip of bedding and contact is as high as 19°, at most places the dip is gently to the southeast in general conformity with the regional dip. The sill of which the knob is a remnant was probably fed from the dike that lies immediately to the southwest. Original thickness and lateral extent of the sill are unknown.

The rock that composes the dikes is in general more resistant than the surrounding sediments of the Yeso formation, and hence the dikes stand several feet above the general ground level (Plate 2, B). Some of the dike material tends to spall or exfoliate (Plate 7, A). Both dike rock and sill rock are deeply weathered, and their granular disintegration produces loose grains of coarse sand ; angular blocks of fresh igneous rock are entirely lacking. The coarse sand accumulates below the dikes and sills and is carried downstream in the arroyos. As the gray and faintly greenish gray color of the products of igneous-rock weathering differs markedly from the color of the sedimentary rocks and their residual soil, the presence of a dike or sill can readily be detected from inspection of soil or arroyo sand.

PETROGRAPHY

The Tertiary (?) igneous rocks of the quadrangle may be divided on megascopic examination into two general textural types—medium-grained or phaneritic, and dense or aphanitic. Porphyritic textures are known but are not common. The phaneritic rocks have a speckled appearance, owing to the presence of black or dark-green ferromagnesian minerals scattered through white or light gray feldspathic components. There is considerable variation in the size of the dark crystals. Hornblende prisms more than 3 centimeters long were measured in a specimen from the sill in the NE1/4 sec. 23, T. 1 N., R. 4 E., but more commonly the length of the hornblende crystals is 1 to 2 millimeters. The rocks that contain the. long prisms are not truly porphyritic, as the short diameter of the prisms is about one-tenth of the long diameter and therefore the basal sections of hornblende are commensurate in size with the other components of the rock.

The grain size may differ markedly in one specimen. The boundary between the texturally different parts is irregular but sharp, and was not found in any specimen to be traversed by the hornblende prisms.

A thin section from the sill in sec. 23, T. 1 N., R. 4 E., shows a rock of medium-grained granular texture. Plagioclase, which forms about 60 percent of the rock, is present in broad tabular subhedral laths that are commonly zoned. The zoning is strikingly brought out by the much greater degree of alteration of the core than of the peripheral zone. Alteration has progressed so far that optical measurements using the albite twinning striations are difficult in the peripheral zones and impossible in the cores. Such measurements indicate the peripheral zones to have the composition of a calcic oligoclase ($Ab_{25-30}An_{75-70}$). By anal. ogy with the results obtained from other thin sections, composition of the core is assumed to lie within the andesine range.

Orthoclase and quartz are both present in anhedral grains. The orthoclase is little altered; the quartz is clear except for minute unidentified inclusions. Each of these minerals forms less than 5 percent of the rock.

Hornblende, which is the chief melanocratic mineral, forms about 30 percent of the rock. A occurs as long prisms with ragged terminations, or as symmetrical rhombs with well-defined prismatic cleavage. Many of the rhombs are twinned, with the front pinacoid as the twinning plane. The angle 2V is large, the optic sign is negative, and ZA c is 17°; pleochroism is X = pale brown, Y= Z= dark brown. The hornblende is in part altered to a pale green, weakly pleochroic chlorite.

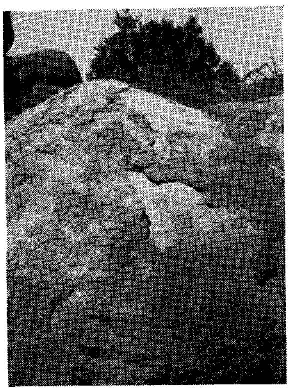
The mica group is represented by biotite, pleochroic in dark shades of brown, in euhedral hexagonal flakes. Some of these crystals, like those of the hornblende, include small apatite prisms. The biotite makes up less than 5 percent of the rock. Other primary minerals are apatite, rutile, zircon, and possibly magnetite.

The most common secondary mineral is magnetite. It occurs chiefly as irregular flakes, although crystal sections of octahedra are common. Calcite occurs as grains reaching a diameter of 1 millimeter and as part of an intimate mixture with a flaky mineral that is probably kaolinite resulting from decomposition of the plagioclase. Epidote, chlorite, and perhaps a part of the quartz are other secondary minerals.

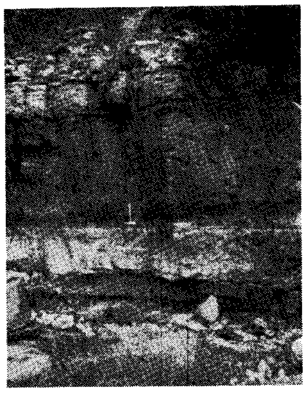
In sections of intrusives from other localities in the quadrangle, orthoclase is entirely absent and quartz and hornblende are much less abundant. Plagioclase forms as much as 90 percent of the primary constituents. Rocks of a composition intermediate between this type and the one discussed above are also present.

The phaneritic intrusives are thus all hornblende diorites; some of them approach the composition of syenodiorites as that family is described by Johannsen (1937).

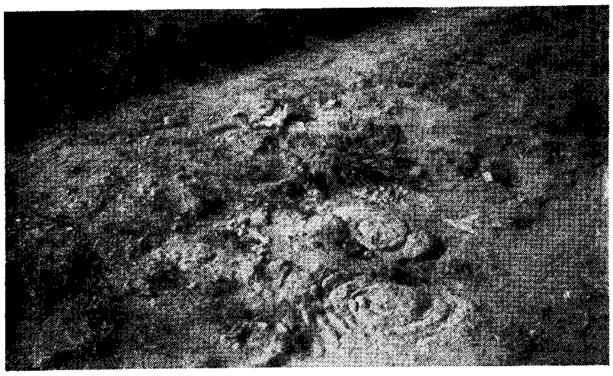
The apahanitic rocks are dark gray on fresh surfaces but



A. Spheroidally weathered dike rock near road one mile southwest of Chupadera. Exposure is 6 feet in height.



B. Sills in Glorieta sandstone. Head of hammer is at base of thicker sill; thinner one is at base of cliff. In canyon 2 1/2 miles northeast of Chupadera.



C. Spheroidally weathered igneous rock in section line road between secs. 34 and 35, T. 1 N., R. 8 E. Tire impressions *give* scale. A typical exposure in the area around Gran Quivira.

weather to a lighter brownish gray. Under the hand lens a few small laths of plagioclase, with a maximum length of 1 millimeter, are distinguishable. The groundmass, which can be recognized as crystalline, is shown to have a finely mottled dark greenish gray and light gray color.

Under the microscope these rocks are found to consist largely of a felt-like groundmass of feldspar laths with an interstitial ferromagnesian mineral. Both these minerals are cut through by grains and long needles of a black opaque mineral that is probably magnetite. The feldspars and the ferromagnesian mineral are both so altered that specific determinations are difficult and uncertain. Maximum extinction angles measured against albite twinning striations indicate that the feldspar is probably labradorite. The ferromagnesian mineral has been completely altered to shreds of a greenish yellow mineral, probably chlorite, with weak birefringence and no perceptible pleochroism.

The plagioclase and the ferromagnesian mineral, together with their alteration products, form 80 to 90 percent of the groundmass. From 10 to 20 percent consists of the needles and grains of magnetite; the smaller percentage is characteristic of rocks in which the magnetite is present almost entirely in grains, and the larger percentage represents the rocks in which needles are common.

Phenocrysts constitute less than 10 percent of the rock. Labradorite (?), largely altered to a fine granular mixture of calcite and kaolinite but still showing indistinct twinning, occurs in lath-shaped outlines from 1/4 to 1 millimeter in length. A ferromagnesian mineral, possibly originally a pyroxene, has been completely altered to an intimate granular mixture containing mica, calcite, and iron oxide.

On the basis of texture and recognizable mineral constituents, the aphanitic intrusives are considered to be diabases.

AGE

The assignment of Tertiary (?) age to the dikes and sills of the Gran Quivira quadrangle is based on evidence provided by intrusives of like character in other parts of New Mexico. Dikes of similar composition intrude the Baca formation, of Eocene (?) age, in the northern Bear Mountains 30 miles northwest of Socorro (Wilpolt and others, 1946). Stocks of monzonite and granite in the Magdalena mining district, and the monzonite batholith of the Organ Mountains, invade pyroclastics and flows considered to be Tertiary in age (idem). It seems likely that the period of widespread Tertiary igneous activity that formed these intrusives also produced the diorites and diabases of the Gran Quivira quadrangle.

GEOLOGIC STRUCTURE

LOCAL FEATURES

FOLDS ASSOCIATED WITH DIKES

At several places along the escarpment of Chupadera Mesa and its erosional outliers in Tps. 1 and 2 N., Rs. 5 and 6 E., the strata have been arched into open folds that are as much as one-half mile across. This arching is prominently shown by the Glorieta sandstone.

A plane-table survey was made in order to determine whether the folds are associated with, or independent of, the swarm of dikes present in the area. The results, shown in Plate 8, indicate a definite association. The presence of large dikes below observed arches, the absence of arches away from the dike areas, and the parallelism of folds and dikes, indicate that the folds were produced by dike intrusion.

Figure 4 shows the way in which the folds are believed to have been formed. A sheet-like mass of igneous rock, oriented approximately vertically, pushed its way upward through the soft sediments of the Yeso formation, dragging some of the more competent layers as it moved. As the mass was unable to penetrate the thick Glorieta sandstone, it spread laterally, forming a small laccolith that arched the Glorieta and penetrated considerable distances along the Yeso-Glorieta contact. Subsequent erosion removed all the laccolith except a part that now appears as a sill, and left the "feeder" as a dike flanked by, steeply dipping limestones of the Yeso.

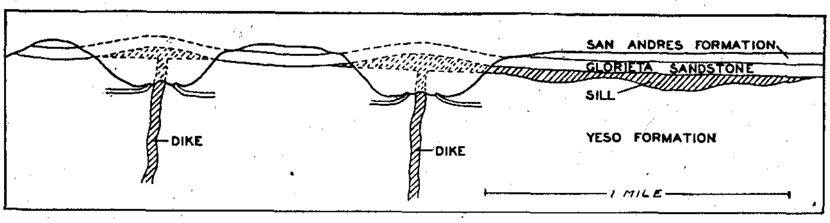


FIGURE 4. Schematic cross section along Chupadera Mesa escarpment in T. 1 N., R. 6 E., showing inferred manner of dike and sill emplacement. Arching of Glorieta sandstone, shown by dashed lines, can be observed at heads of re-entrant valleys in escarpment.

FOLDS ASSOCIATED WITH SILL

A small anticline and syncline were mapped in secs. 8 and 17, T. 2 N., R. 6 E. (Plate 1). They are in rocks of the Yeso formation and can be traced by exposures of a thin limestone. They trend slightly west of north and the limestone has local dips of nearly 90°. It is believed that these folds were produced in the incompetent Yeso strata by compression incident to the intrusion of the sill one-half mile to the west, or to the intrusion of a larger body of which the sill is the part now exposed.

FOLDS PRODUCED BY SOLUTION

Structure contours on the top of the Glorieta sandstone along the Chupadera Mesa escarpment in T. 3 N., Rs. 7-9 E., show a series of gentle anticlines and synclines trending northwest (Plate 1). The origin of these folds is not clear. Their general trend is at a considerable angle to the structural "grain" of the region (Plate 9), and no other folds with similar trends have been observed; lateral compression therefore seems to be ruled out as a causal factor. It is not likely that the folds are reflections of buried pre-Cambrian ridges, as they are too well defined to reflect a surface that is believed to be at least 2,500 feet below the ground. Intrusion of dikes might be a possibility, but no dikes are known in the area of the folds.

The folds involve rocks of the San Andres, Glorieta, and Yeso formations. The known presence of thick beds of gypsum in the buried part of the Yeso suggests that the folding may be the result of differential solution, and this is the origin tentatively assigned to them. It is realized, however, that this hypothesis fails to explain the fact that the major drainage lines are in anticlines and the intervening divides are synclinal. It has been suggested that the beds below the stream channels may have been arched as a result of hydration of anhydrite to gypsum in the buried strata, with a volume increase of 40 percent, owing to downward-percolating waters; but this hypothesis involves several assumptions that are not warranted on present information.

At numerous places on Chupadera Mesa, limestones of the San Andres formation are steeply tilted into attitudes that locally suggest folding. Furthermore, many of the hills on the Mesa are capped by thin limestones of the San Andres that are essentially horizontal along the summits but dip toward the valleys along the hillsides, thus giving the hills a superficially anticlinal appearance. An example is Turkey Ridge, in T. 1 S., R. 7 E. (Plate 1). A study of the field relations shows that the steep dips are confined to the vicinity of sink holes and have no consistent orientation, and that the limestones on the hills have been "draped" over the underlying strata by removal of gypsum in solution.

FAULT PRODUCED BY SOLUTION

A normal fault trending N. 65° W. is exposed in sec. 14, T. 3 N., R. 8 E. (Plate 1). It can be recognized where it crosses the outcrop of the Glorieta sandstone, but apparently disappears in the Yeso strata to the west and in the San Andres strata to the east. Displacement of the Glorieta sandstone is 100 feet; the downthrown side is on the north. The fault is considered to be a "gravity fault" resulting from differential solution in the gypsums of the underlying Yeso formation.

REGIONAL FEATURES

PALOMA AND MONTOSA FAULTS

A thrust fault more than 25 miles in length, named the Paloma fault by Stark and Dapples (1941), crosses the northwest corner of the Gran Quivira quadrangle (Plates 1, 9). In a railroad cut one-half mile west of the quadrangle the fault strikes N. 40° E. and dips 48 ° NW. The pre-Cambrian Sais quartzite is on the west or upthrown side of the fault, and the marine limestone member of the Madera limestone, with an overturned dip of 50° NW., is on the east side (Plate 2, A). The fault is marked by a 5-foot zone of quartzite-limestone breccia.

The Paloma fault, together with the Montosa fault to the southwest (Plate 9) , marks the eastern structural boundary of the Los Pinos and Manzano Mountain masses. Eastward thrusting on both these faults took place in Laramide time. Later movement on the Montosa fault was in a direction opposite to the thrusting; traced several miles to the southwest, the Montosa is the normal fault that now bounds the Rio Grande depression on the east.

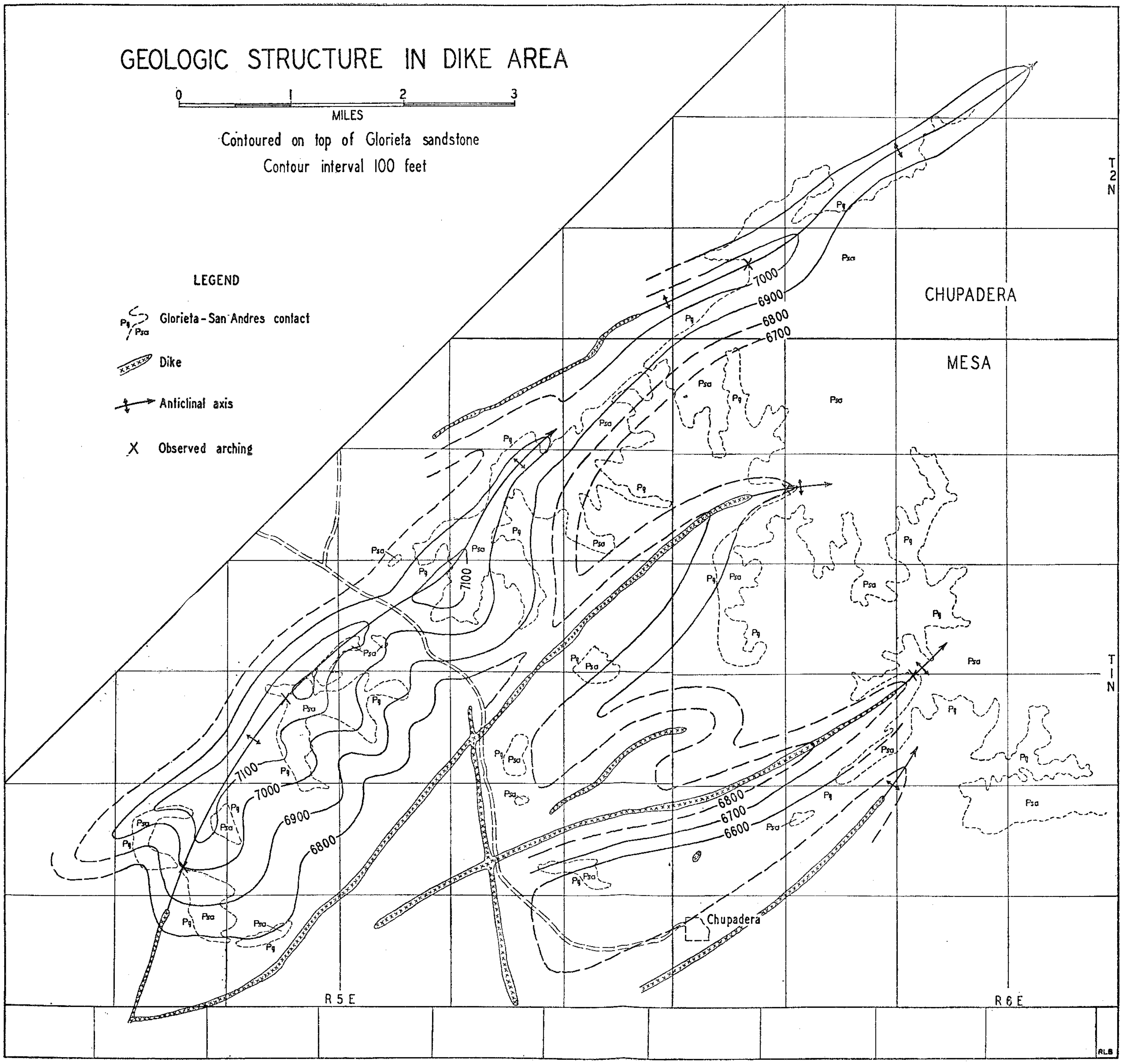
OSCURA ANTICLINE

The Oscura anticline was so named by Darton (1922, p. 239). It has been termed the Chupadera anticline by Winchester (1933, pp. 194-198), but *as* it passes southward into the Oscura Mountains Darton's term is considered more appropriate.

The Oscura anticline is a fold some 20 miles in exposed length that plunges northward in the south central part of the Gran Quivira quadrangle (Plates 1, 9). The anticline has been breached by erosion, so that its surface expression is a valley. The Yeso formation is exposed in this valley, flanked on the west by the Glorieta sandstone dipping westward in a low ridge and on the east by the same sandstone dipping eastward into the Chupadera Mesa escarpment. A low hill in sec. 35, T. 2 S., R. 6 E., with Glorieta sandstone in the slopes and strata of the San Andres formation at the top, is the erosional remnant of a subsidiary syncline (structure' section C-C', Plate 1).

In the words of Wells (1929):

> Throughout the valley which follows the axis of the anticline the beds of the lower Chupadera [Yeso] formation present many unusual and at first puzzling features. In numerous areas of considerable extent the out-


GEOLOGIC STRUCTURE IN DIKE AREA
0 1 2 3
MILES
Contoured on top of Glorieta sandstone
Contour interval 100 feet
LEGEND
Glorieta-San Andres contact
Dike
Anticlinal axis
Observed arching
CHUPADERA
MESA
Chupadera
T 2 N
T 1 N
R 5 E
R 6 E
7100
7000
6900
6800
6700
6600
Pg
Psa
RLB

cropping limestone beds stand with dip angles of 60° to 90°, In the main the strike of these sharply upturned beds is north but in part they strike in many different directions. . . .

Wells explains these steep anamalous dips as resulting from two factors: "weathering, erosion and solution of the gypsum strata", and the incompetent character of the Yeso formation. This explanation is considered correct. Whereas the formations above and below the Yeso accommodated themselves to the compressive stress in relatively open simple folds, the Yeso strata were plicated into hundreds of small wrinkles. This intense crumpling would be expected of a heterogeneous assemblage consisting chiefly of soft silt, shale, and gypsum. Quite possibly the crumpling was accentuated by the volume increase incident to the change of anhydrite to gypsum in the zone of weathering in the Yeso formation.

Dips on the west side of the anticline in the Gran Quivira quadrangle range from 7 to 25 degrees and average 14.4 degrees; those on the east side range from 2 to 20 degrees and average 8.1 degrees. Thus the anticline is slightly asymmetrical.

It will be noted from the regional structure map, Plate 9, that south of the Gran Quivira quadrangle the Oscura anticline is broken longitudinally by the normal fault on the west front of the Oscura Mountains, and also that the part of the fold displaced downward is more complex than the main anticline farther north. No attempt is made here to give a detailed tectonic history of the structures, but it seems apparent that the folding preceded the normal faulting. Thus a reconstruction of the pre-faulting picture shows a major anticlinal fold, with a minor longitudinal syncline at the crest—this syncline being reflected by the remnant in sec. 35, T. 2 N., R. 6 E., and possibly by the syncline now dipping into the fault in the N 1/2 T. 6 S., R. 5 E. and the S1/2 T. 5 S., R. 5 E. The major anticline was flanked on the east by nearly horizontal beds without appreciable folding, and on the west by the shallow Torres syncline.

The asymmetrical form of the Oscura anticline, reflected in steeper dips on the west flank, might be taken to indicate that the causal compressive stresses came from the east. However, the dips on the west are only a few degrees steeper than those on the east, and it is considered likely that the west flank was steepened after the folding, by dragging along and north of the normal fault west of the Oscura Mountains. It is thought that the stresses that produced both the Oscura anticline and the Torres syncline were Laramide in age. As the Paloma and Montosa thrust faults were also formed during Laramide time, it is logical to assume that the stresses forming the folds, like those that produced the faults, were from the west or northwest.

TORRES SYNCLINE

The name Torres is here given to the wide shallow syncline, trending north, in the southwest part of the Gran Quivira quadrangle (Plates 1, 9). The syncline, which marks the northwesternmost extension of the structurally depressed region known as the Jornada del Muerto, is floored with arroyo gravels and windblown sand, beneath which lies Triassic bedrock. Beds of the San Andres formation are exposed around the edges of the syncline, within the enclosing rim of Glorieta sandstone.

The Torres syncline is situated between two anticlines, the Oscura on the east and the Prairie Spring on the west. Dips from both these anticlines are approximately equal, and the Torres syncline is therefore symmetrical. All three folds were probably formed by regional compressive stresses of Laramide age.

CANYONCITO AXIS AND ROWE-MORA BASIN

Two regional structural features that extend into Torrance County from the north and may continue into the Gran Quivira quadrangle are the Canyoncito axis and the Rowe-Mora basin (Plate 9), named and discussed by Read and Andrews (1944). The Canyoncito axis is a late Paleozoic positive area and the Rowe-Mora basin is a deep sedimentary trough. The positive area stood high and was eroded, and the basin received the resulting sediments, from late Pennsylvanian until the beginning of Yeso time. Seas then spread over most of the region and deposited fine clastics and evaporites that blanketed the earlier sediments.

From a study of the geologic map of. central New Mexico it would appear logical to assume that the Cerrito del Lobo, a pre-Cambrian mass west of the Pedernal Hills (Plate 9), is connected with the main Pedernal mass beneath only a thin sedimentary cover. However, a deep test well drilled in the intervening area, in sec. 20, T. 6 N., R. 10 E., penetrated 5,321 feet of sedimentary rock and did not encounter the pre-Cambrian. A deep basin between the two pre-Cambrian masses is thus inferred.

Although the axis and basin are so aligned that if projected southward they would extend into the Gran Quivira quadrangle, there is no conclusive evidence of their presence there. It may be pointed out that the Canyoncito axis is approximately in line with the most prominent of the anticlines along the north edge of Chupadera Mesa (Plates 1, 9) and with the Monte Prieto bluff (page 10) to the south, and that the Rowe-Mora basin is approximately in line with the most prominent of the synclines. Evidence from deep drilling on Chupadera Mesa is entirely lacking, and final information on the presence or absence of these major features in the subsurface of the Gran Quivira quadrangle will have to await future exploration with, the drill.

STRUCTURAL HISTORY

The structural history of the Gran Quivira area can be recon-. structed as follows. Toward the end of the Cretaceous period, when several thousand feet of sediments had accumulated upon an uneven surface of pre-Cambrian crystalline rocks, great regional stresses were exerted from the west and the mass ruptured. Along surfaces dipping west, a part of the pre-Cambrian basement complex with its superimposed sediments moved upward and toward the east over the part on the opposite side of the fractures. The partly worn-down upthrust masses are now seen as the Los Pinos and Manzano Mountains, and the fractures are termed the Montosa and Paloma thrust faults. At the same time, the essentially flat-lying sediments to the southeast were being gently folded into what are now called the Prairie Spring and Oscura anticlines and the Torres syncline.

In medial or late Tertiary time, a regional relaxation of stresses resulted in normal faulting along trends, or actually along faults, that were previously compressional. Thus the Los Pinos fault came into being, movement was reversed on the Paloma fault, and the Oscura anticline was fractured so deeply that its pre-Cambrian core was exposed in what, is now the Oscura Mountains. Probably during this same period, extensive igneous activity resulted in the formation of dikes and sills and their associated structures in the intruded sediments. Final event was the Quaternary outpouring of lavas to the west and southeast of the Gran Quivira quadrangle (Plate 9) . Erosion during and after the above events exposed the present arrangement of rocks and structures.

ECONOMIC GEOLOGY

GROUND WATER

Records of drilling for water are so scanty that it is impossible to present a detailed picture of the ground-water resources of the quadrangle. Water is known to have been found in recent sands and gravels, in the Joyita sandstone member of the Yeso formation, and in a sandstone of the Abo formation.

Shallow wells reaching only into unconsolidated arroyo sands and gravels have been dug or drilled at numerous places, especially to the west of Chupadera Mesa. The volume of water produced is low but is generally sufficient for a family's domestic needs and for watering a small number of cattle.

Although several wells on Chupadera Mesa have been drilled through the San Andres formation, it has been found that the underlying Glorieta sandstone is not a water-bearer and the wells have been carried deeper into the upper beds of the Yeso formation. It is not clear why the Glorieta is non-productive of water; possibly the sandstone is too tightly cemented, or its narrow outcrops may provide an insufficient catchment area. Fair volumes of "gyppy" water, suitable for watering stock, are reported from what is apparently the upper Yeso.

A water well of 'the Santa Fe Railway at Abo station is producing water from a red sandstone of the Abo formation at a depth of 1,080 feet. Character of the water and volume of flow are unknown.

SCHOLLE MINING DISTRICT

The following statements are quoted from Lasky, and Wootton (1933, pp. 117-118).

> The Scholle district is at the junction of Socorro, Torrance and Valencia counties and embraces parts of all three. The ore deposits are in the Abo sandstone and are similar to the general type of copper deposits in "Red Beds." The copper occurs as carbonates in the shale beds; *as sulphides,* chiefly chalcocite, associated with plant remains and fossil wood in arkose; and as nodules and lenses of sulphides which replace the cement and feldspar of the arkose. Silver is 'present in small amounts. In places the oxidized ores contain vanadium, probably as a copper vanadate.
>
> This district produced a small tonnage of ore steadily from 1915 to 1919, but production since then has been desultory. The latest recorded production was for the year 1930. The approximate entire production of the district, all of which is credited to Torrance County in official reports, consists of 10,380 tons of ore carrying 1,006,068 pounds of copper, 7,872 ounces of silver, and $200 worth of gold, having a total value of $224,143. A negligible quantity of lead was reported in the shipments for 1917. Several small leaching plants were built in the district, but they were unsuccessful.

RAYO MINING DISTRICT

The ore at Rayo, an abandoned settlement 12 miles south of Scholle, consists of copper carbonates and nodules of chalcocite in gray, loosely cemented Abo sandstone that is locally overlain by barren red sandstone (Lasky, 1932, p. 135). Carbonaceous matter is apparently absent. Workings consist almost entirely of trenches and cuts. A trifling amount of ore that may have been taken out in the course of prospecting constitutes the only production.

Faint showings of copper carbonate are commonplace in the Abo formation of the Gran Quivira quadrangle, especially in the lower beds, and small prospect pits are numerous in the area of Abo outcrop. No evidence of appreciable ore bodies was seen and it is very doubtful if copper deposits of the "redbeds type" are present in commercial sizes.

No mining other than that for copper has been done in the quadrangle, and no indications of other minerals were seen.

OIL AND GAS POSSIBILITIES

Although the San Andres formation produces large amounts of oil and *gas* where it is deeply buried in southeastern New Mexico, it is at the surface over much of the Gran Quivira quadrangle and is only thinly buried in the Torres syncline. For this reason alone—disregarding the facts that the formation is thin and contains much gypsum—the San Andres is not considered a possible source or reservoir rock for oil and gas. The Yeso and Abo formations consist mainly of shallow-water or continental deposits and are likewise considered unfavorable. The strata of Pennsylvanian age, however, are under a relatively thick cover of sedimentary rocks, consist of marine limestones and shales interbedded with arkosic material, and are thick enough to produce oil and gas. The Pennsylvanian strata are considered to be the only ones in the quadrangle to have appreciable oil possibilities.

The following paragraph is quoted from Winchester (1933, p. 190).

> A small sample of black shale from the upper part of the Magdalena formation "near Scholle," . . . was subjected to distillation and found to yield oil at the rate of 41 gallons per ton. This is exceptionally rich for shales of Pennsylvanian age. Several of the black shale beds of the section were tested by the writer and found capable of yielding oil on distillation. Coal found by the writer in the Magdalena formation on the west side of the Estancia Valley showed by analysis that it had not been greatly metamorphosed and devolatilized. It is evident, therefore, that the Magdalena formation on the west side of the Estancia Valley and in Abo Canyon west of Scholle includes organic material in considerable amount and that the formation has not been subjected to heat or pressure sufficient to devolatilize and drive off all the oil-forming substance. It appears, therefore, that where structural conditions are favorable the Magdalena formation in central New Mexico is worth testing for oil and *gas*.

The presence of commercial amounts of carbon-dioxide gas in the Sandia formation in the Estancia area, T. 7 N., R. 7 E., shows that conditions of porosity and permeability are favorable for the accumulation of fluids at some places in Pennsylvanian rocks.

A structure in which oil and gas might be found is the Oscura anticline (Plates 1, 9), the pertinent features of which are well summarized by Winchester (1933, p. 196) as follows.

> Structural closure on the east, west and north is well defined. To the south structural closure is weak or absent, but is augmented and probably made effective by the dike which crosses the structure from east to west through the north tier of sections of T. 4 S. [Plate 9]. This dike probably is continuous and cuts all of the sedimentary formations, and should ford an adequate seal against the migration of oil and gas up the dip to

the south. Along the terraced part of the axis of the structure there may be slight undulations, although the beds continue essentially level for long distances.

An incomplete test of the Pennsylvanian rocks of the Oscura anticline was made in 1929-30, when the Rio Grande Oil Co. drilled its No. 1 Stackhouse in the NE1/4 SE1/4 sec. 14, T. 3 S., R. 6 E. Examination of the samples from this test shows that Yeso beds were penetrated from the surface to 1,580 feet; Abo beds from 1,580-to approximately 2,500 feet; and Pennsylvanian strata, presumably the Madera limestone, from 2,500 to 2,772 feet, the total depth. Thus only about 272 feet of the Pennsylvanian section was drilled. As this section should be some 1,000 feet thick in this area, there are at least 725 feet of potentially oil-bearing rocks yet to be tested in the Oscura anticline.

As no structures are known to be present on Chupadera Mesa in the area of this report, and as no test wells have been drilled, oil and *gas* possibilities are problematical. If it can be demonstrated that the Canyoncito axis (Plate 9) extends into the Gran Quivira quadrangle, exploration for accumulations in stratigraphic traps along its flanks should be in order. The possibilities of accumulation against intrusions are unknown; but it may be pointed out that the majority of the intrusions in the east half of the quadrangle seem to occur as sills rather than *as* dikes.

BIBLIOGRAPHY

BAKER, C. L., 1920, Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 99-126.

BATES, ROBERT L., and others, 1942, The oil and gas resources of New Mexico, second edition: N. Mex. School of Mines, State Bur. Mines and Min. Res. Bull. 18.

DARTON, N. H., 1922, Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726-E.

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

HAGER, D., and ROBITAILLE, A. E., 1919, Geological report on oil possibilities in ,eastern New Mexico (unpublished). Cited by Wilmarth (1938), Lexicon of geologic names of the United States, U. S. Geol. Survey Bull. 896, p. 831.

HERRICK, C. L., 1900, The geology of the White Sands of New Mexico: Jour. Geology, vol. 8, pp. 112-128.

HEWETT, EDGAR L., and MAUZY, WAYNE L., 1940, *Landmarks of New Mexico:* University of New Mexico Press, Albuquerque.

HUDDLE, J. W., and DOBROVOLNY, E., 1945, Late Paleozoic stratigraphy of central and northeastern Arizona: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary Chart 10.

JOHANNSEN, ALBERT, 1937, *A descriptive petrography of the igneous rocks, Vol. In, The intermediate rocks:* University of Chicago Press, pp. 102-131.

KELLEY, V. C., and WOOD, G. H., 1946, Lucero uplift, Valencia, Socorro, and Bernalillo counties, New Mexico: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary. Map 47.

KEYES, C. R., 1903, Geological sketches of New Mexico: Ores and Metals, vol. 12, p. 48.

KEYES, C. R., 1915, Foundation of exact geologic correlation: Iowa Acad. Sci., Proc., vol. 22, pp. 249-267.

KING, PHILIP B., 1942, Permian of West Texas and southeastern New Mexico: Bull. Amer. Assoc. Petrol. Geol., vol. 26, no. 4, pp. 535-763.

KING, ROBERT E., 1945, Stratigraphy and oil-producing zones of the pre-San Andres formations of southeastern New Mexico: N. Mex. School of Mines, State Bur. Mines and Min. Res. Bull. 23.

LASKY, SAMUEL G., 1932, The ore deposits of Socorro County, New Mexico: N. Mex. School of Mines, State Bur. Mines and Min. Res. Bull. 8.

LASKY, SAMUEL G., and WOOTTON, THOMAS P., 1933, The metal resources of New Mexico and their economic features: N. Mex. School of Mines, State Bur. Mines and Min. Res. Bull. 7.

LEE, WILLIS T., 1909, The Manzano group of the Rio Grande valley, New Mexico: U. S. Geol. Survey Bull. 389.

NEEDHAM, C. E. and BATES, ROBERT L., 1943, Permian type sections in central New Mexico: Bull. Geol. Soc. Amer., vol. 54, no. 11, pp. 1653-1667.

READ, C. B., and others, 1944 Geologic map and stratigraphic sections of Permian and Pennsylvanian rocks of parts of San Miguel, Santa Fe, Sandoval, Bernalillo, Torrance, and Valencia counties, north central New Mexico: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary Map 21.

RICH, J. L., 1921, The stratigraphy of eastern New Mexico—a correction: Am. Jour. Sci., 5th ser., vol. 2, pp. 295-298.

STARK, J. T., and DAPPLES, E. C. 1941, Structure of the Los Pinos Mountains, New Mexico (abstract) : Bull. Geol. Soc. Amer., vol. 52, no. 12, p. 1936.

THOMPSON, M. L., 1942, Pennsylvanian system in New Mexico: N. Mex. School of Mines, State Bur. Mines and Min. Res. Bull. 17.

U. S. NATIONAL PARK SERVICE, 1941, Southwestern National Monuments.

WELLS, E. H., 1929, The geology and oil and *gas* possibilities of the Chupadera anticline, Socorro County, New Mexico: (unpublished report).

WILMARTH, M. GRACE, 1938, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896.

WILPOLT, R. H., and others, 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro counties, New Mexico: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary Map 61.

WINCHESTER, DEAN E., 1933, The oil and gas resources of New Mexico: N. Mex. School of Mines, State Bur. Mines and Min. Res. Bull. 9.

WOOD, G. H., and NORTHROP, S. A., 1946, Geology of Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba counties, New Mexico: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary Map 57.

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PUBLICATIONS

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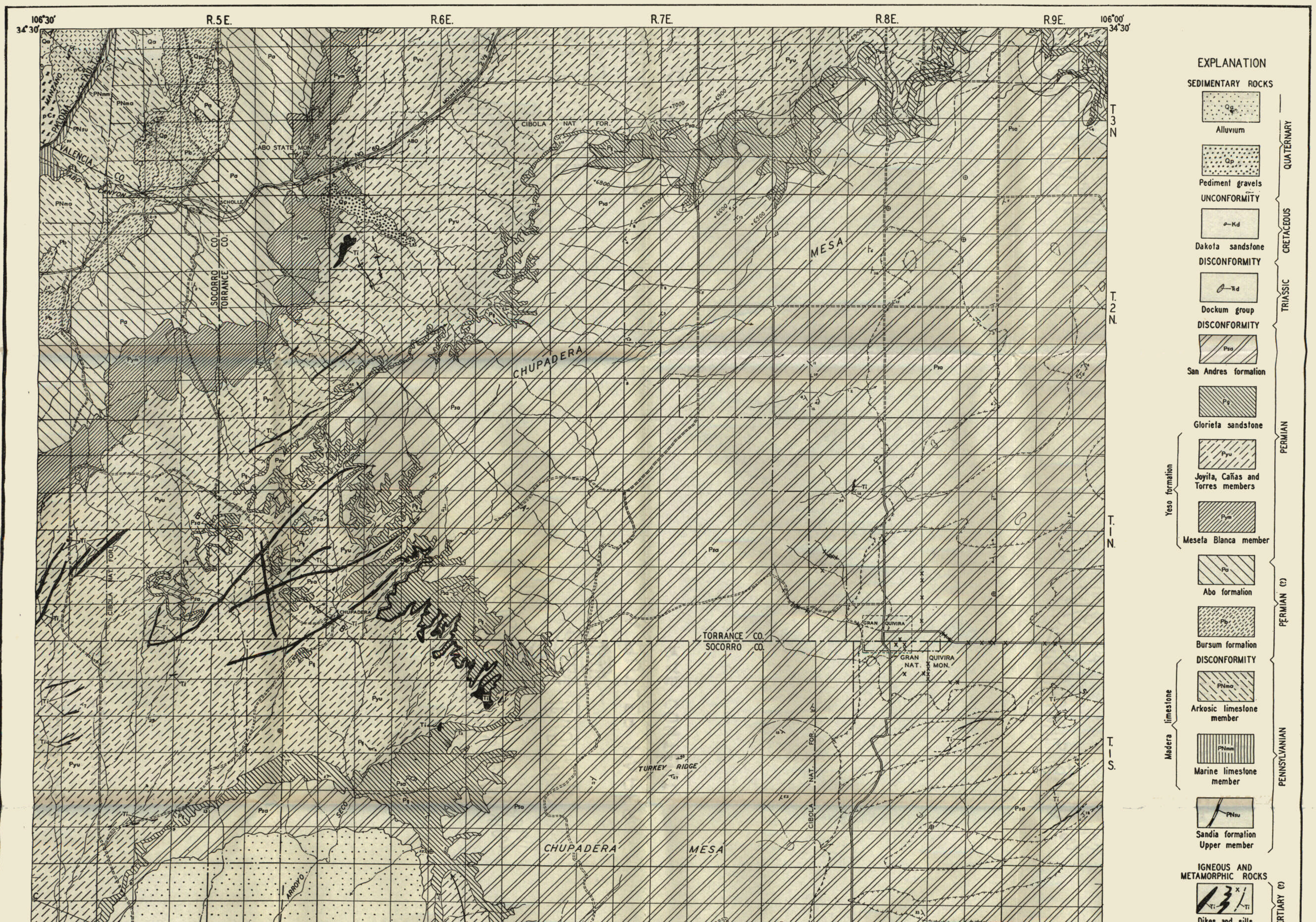
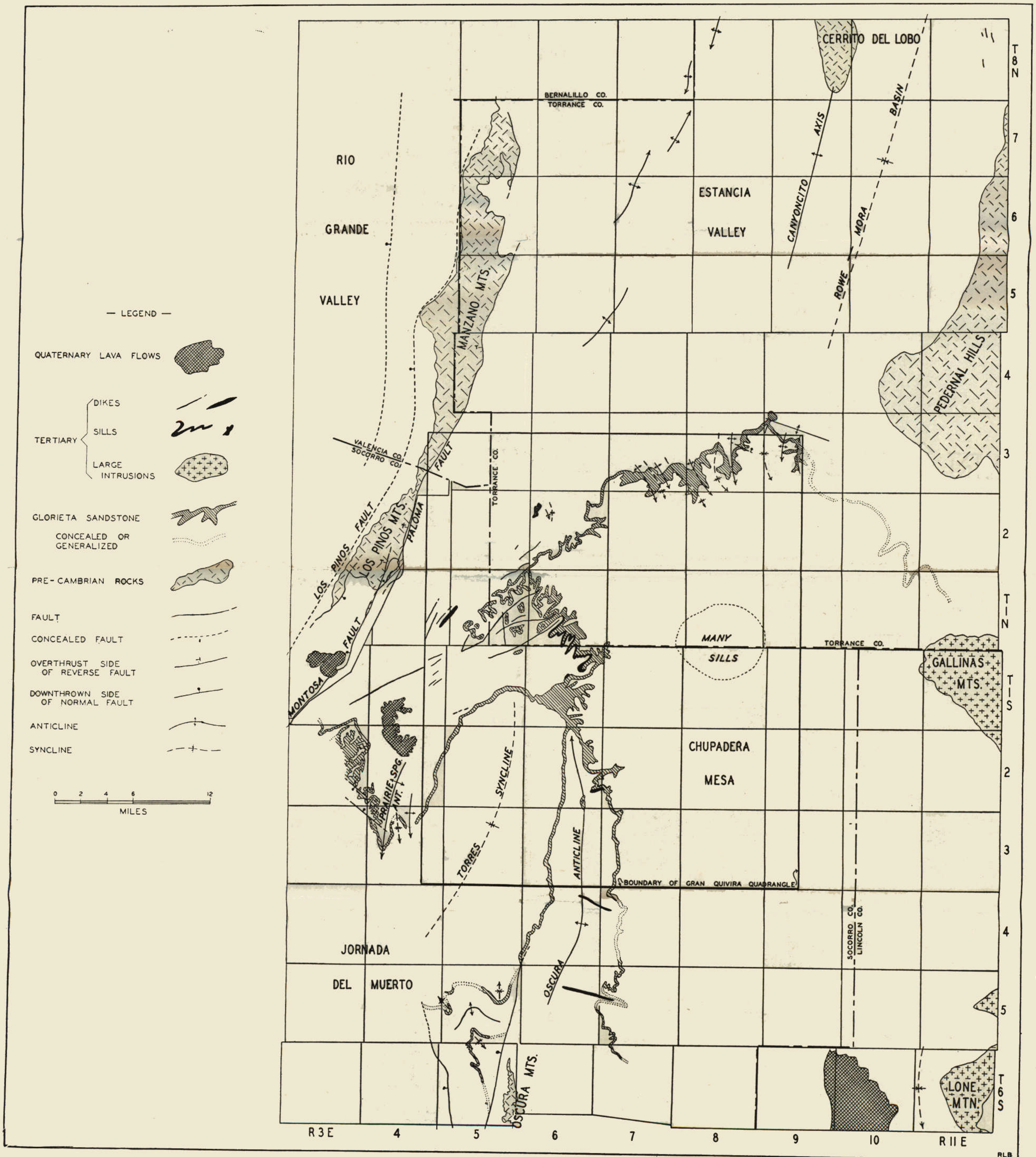
* Prepared in cooperation with the New Mexico Bureau of Mines and Mineral Resources.



GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE GRAN QUIVIRA QUADRANGLE, NEW MEXICO



Map showing major structural features of Gran Quivira quadrangle and adjacent areas. Information has been assembled from the following sources: north of T. 3 N., from U. S. Geological Survey, Oil and Gas Investigations, Preliminary Maps 8 and 21; east and southeast of the Gran Quiviraquadrangle, from the geologic map of New Mexico; south and southwest of the Gran Quivira quadrangle, from unpublished data of the U. S. Geological Survey; Los Pinos Mountains area, from U. S. Geological Survey, Oil and Gas Investigations, Preliminary Map 61.