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GEOLOGY OF REEF RIDGE COALINGA DISTRICT CALIFORNIA

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GEOLOGY OF REEF RIDGE COALINGA DISTRICT CALIFORNIA

BY

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GEOLOGY OF REEF RIDGE, COALINGA DISTRICT, CALIFORNIA

By Ralph Stewart

ABSTRACT

Reef Ridge lies along the east flank of the Diablo Range on the west side of the San Joaquin Valley south of Coalinga and west of the Kettleman Hills. The geologic section consists of Cretaceous and Tertiary fossiliferous sedimentary rocks with some volcanic ash. Some metamorphic rocks, possibly Jurassic (Franciscan), are in apparent fault contact with the Cretaceous near the west end of the area. On Reef Ridge are exposed the upturned edges of the buried strata of North Dome of the Kettleman Hills, including some of the oil sands. The general sections of the two areas are quite similar, but most of the producing sands of North Dome appear to be missing from Reef Ridge, evidently because of overlap. The Tertiary strata, which are unconformable upon the Cretaceous Panoche formation, include two prominent sandstones, the Eocene Avenal sandstone, 400 feet or less in thickness, and the Miocene Temblor sandstone, 1,000 feet or less. Indurated fossiliferous ledges of the Temblor sandstone form the crest of Reef Ridge, and the sandstone is separated from the Avenal sandstone by the Kreyenhagen shale, 1,200 feet or less in thickness. Siliceous and clay shales, 1,200 feet or less in thickness, overlie the Temblor. They correspond to the Monterey shale, and the two units into which they have been subdivided are locally designated the McLure shale member of the Monterey and Reef Ridge shale. They are overlain by 10,000 feet of Pliocene and Pleistocene sand, silt, and conglomerate constituting the Jacalitos, Etchegoin, San Joaquin, and Tulare (Pliocene and Pleistocene) formations, which have been distinguished chiefly on the basis of their molluscan and echinoid faunas.

All the formations of Reef Ridge except the Tulare contain marine fossils. The molluscan fauna of the Panoche formation is of Upper Cretaceous age. The molluscan fauna of the Avenal sandstone consists of more than 140 species and is closely related to the Domengine fauna (Eocene) of the area north of Coalinga. The Miocene Temblor sandstone has two faunal zones, the lower or *Vertipecten* zone containing a gastropod fauna, and the upper or *Aequipecten* zone that has a smaller percentage of gastropod species. These two zones, whose differences are chiefly ecologic, correspond approximately to the lower and upper members of the formation as mapped. The lower zone has a fauna that is more nearly comparable in age with that of the Temblor of Kern River; the upper zone, including the "button beds," has a molluscan fauna similar to that of the Temblor at Kern River but possibly a little younger.

The Miocene strata are unconformable upon the Eocene, and they overlap them and rest upon the Cretaceous Panoche formation at the ends of the ridge. The Big Blue serpentinous member at the top of the Temblor, which is exposed in the area north of Coalinga, does not crop out on Reef Ridge, but is known from a well core in Canoas Creek, just beneath the McLure.

Reef Ridge is part of the steep northeast flank of a major anticline, which was folded, slightly overturned, faulted, and eroded during the Quaternary period and subsequently uplifted. In spite of numerous oil seeps no oil fields have been found along the ridge.

INTRODUCTION

Oil seeps in the Tertiary rocks that form Reef Ridge led early to exploration for oil in the area, and, although the rocks of Tertiary age have received the attention of geologists for more than 30 years, interest in them has been renewed recently by the deep drilling for oil in the nearby Kettleman Hills and other parts of the Coalinga district. Reef Ridge reveals some of the rocks that yield oil in the Coalinga district and may thus provide information useful in interpreting conditions at depth in the nearby oil fields. During field work of the present investigation in 1936 and 1937 the early Tertiary rocks that contain the oil seeps were mapped; the older and younger rocks in the immediately adjoining areas were examined and mapped to some extent, but their distribution and other features as shown on plate 9 were taken for the most part from an earlier geologic map of this region.[1]

Location and topography.—Reef Ridge is a prominent narrow serrated ridge 18 miles in length that forms the easternmost escarpment of the Diablo Range and joins the west edge of the San Joaquin Valley (fig. 10) south of Coalinga and west of the Kettleman Hills. (See fig. 11.) The ridge extends in a southeasterly direction from Zapato Canyon to the Pyramid Hills, which may be regarded as representing a southeastern extension of the ridge. On the northeast the low Kreyenhagen Hills lie between the ridge and the Kettleman Plain and the Kettleman Hills beyond; to the southwest of its south end lies the McLure Valley. From northwest to southeast the ridge is crossed by Arroyo Pinoso, Beltran Creek, Reese Canyon, Canoas Creek, Garza Creek, Baby King Canyon, and Big Tar Canyon. The ridge is 1,100 feet above sea level at its southeast end and rises to more than 2,575 feet at Roundtop, its highest point. Near the northwest end of the ridge the highest point, 2,529 feet, is east of Arroyo Pinoso. Between this locality and Roundtop are numerous summits ranging from 2,100 to 2,400 feet in altitude. Arroyo Pinoso and Big Tar Canyon are 1,000 feet below adjacent summits on the ridge. In the Diablo Range south of the ridge many of the summits are relatively flat and easily traversed; their altitudes near Roundtop are about 2,700 feet, and they rise northwestward to 3,300 feet. Farther south and west Black Mountain has numerous points above 4,000 feet, the highest being Castle Mountain, altitude 4,336 feet.

Kettleman Plain is a wide valley sloping from an altitude of 765 feet at the north end of the area mapped to an altitude of 450 feet at the south end. Between the plain and Reef Ridge are the numerous low parallel ridges of the Kreyenhagen Hills.

McLure Valley has an altitude of 900 feet at the south edge of the area shown on the map.

Previous work—An account of the general geology of the region, including a cross section through Big Tar Canyon, was published in 1905 by Anderson,[2] who proposed the names Avenal and Kreyenhagen for formations of Eocene age on Reef Ridge. Later, reports on the Coalinga region by Arnold and

[1] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, pl. 1, 1910.

[2] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 155-191, pl. 34, 1905.

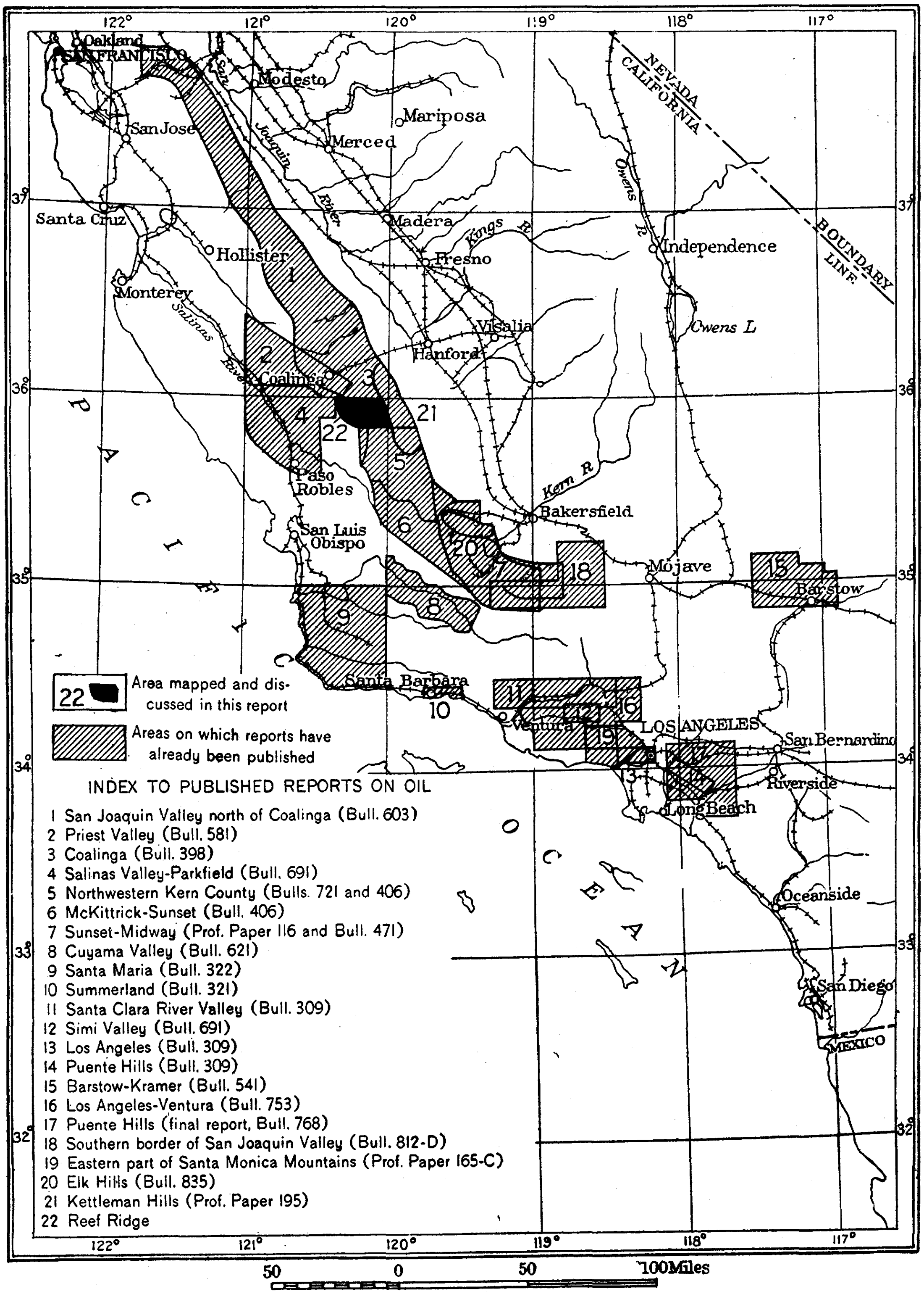

FIGURE 10.—Index map of part of California showing areas described in oil reports published by the Geological Survey.

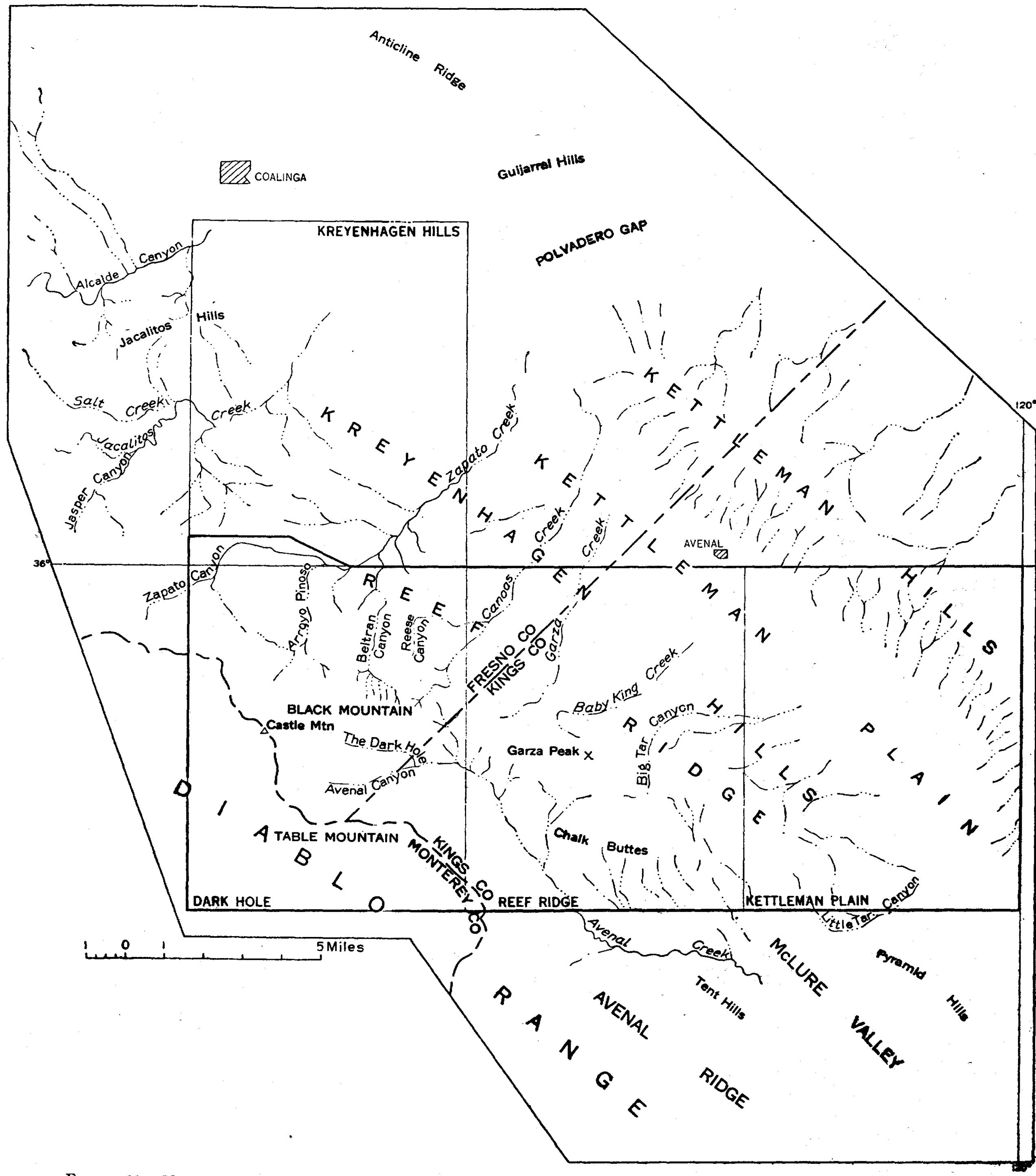

FIGURE 11.—Map showing relation of Reef Ridge to nearby geographic features. Outline of plate 9 shown by heavy line.

Anderson[3] included a structure contour map of Reef Ridge and a geologic map and description of the Ridge area. Several years later the Pliocene strata just north of the ridge were studied by Nomland.[4] Some information on the heavy minerals of the formations apparently along Reef Ridge was given by Reed.[5] The McLure shale was recognized along Reef Ridge by Henny.[6] A map of the Coalinga region compiled by Clark[7] from various sources shows the geology along Reef Ridge. In their account of the Kettleman Hills oil field, Gester and Galloway[8] gave a description of the geology and a small map of Reef Ridge. Cushman and Siegfus[9] studied this region, with particular reference to its microfauna.

The Kreyenhagen shale along Reef Ridge, including the fauna, the mineralogy, and the source of sediments and their conditions of deposition, was especially studied by Von Estorff.[10] The Kreyenhagen shale along Reef Ridge was also studied by Jenkins[11] as part of his study of the general problem of this formation. Detailed sections made by him along Reef Ridge have not been published but are given in his thesis, which is on file at Stanford University. An extensive bibliography on the Kreyenhagen was assembled and annotated by him.[12] All the differences in viewpoint on the age and boundaries of this formation, as enumerated therein by him, appear to have originated in the area north of Coalinga and not in the Reef Ridge area. The chief cause for the difference is the inclusion in the upper part of the formation north of Coalinga of strata containing fossils unlike any found in the Kreyenhagen along Reef Ridge. These strata have been designated the Tumey formation[13] including the *Leda* zone[14] and the *Uvigerina cocoaensis* zone.[15] The shale beneath the Tumey formation is equivalent to the Kreyenhagen shale of Reef Ridge. Recognition of Eocene Foraminifera at the type locality of the Kreyenhagen shale has been reported by Church,[16] and new species of Foraminifera from Reef Ridge have been described by Cushman and Siegfus.[17] The presence of volcanic material in the Kreyenhagen shales, in the general area of its exposure, has been described by Taliaferro.[18]

The Reef Ridge shale was separated from the McLure shale by Barbat and Johnson[19] and later restricted by Siegfus.[20]

In an extensive study of the correlation of the Kettleman Hills sub-surface section Goudkoff gave much information about the stratigraphy of the Reef Ridge area.[21] Comparison of the Reef Ridge and Kettleman Hills sections will also be found in the report by Woodring, Stewart, and Richards on the geology of the Kettleman Hills.[22] In his study of the mineralogy of well cores from the Kettleman Hills, Bramlette[23] described the mineralogic features of the Temblor and McLure formations of Canoas Creek and Big Tar Canyon.

The fauna of the Avenal sandstone has recently been described and correlated with that of the Domengine formation by Vokes.[24] Two new corals have been described from the Avenal sandstone at Little Tar Spring,[25] which resemble species from the Antillean Eocene and the lower Claiborne of the Gulf Coast.

Acknowledgments.—The field investigation of the geology of Reef Ridge was supervised by H. D. Miser, geologist in charge of the Section of Geology of Fuels of the Geological Survey. Many other geologists of the Survey, particularly M. N. Bramlette, have contributed toward this report. Many California geologists have likewise contributed at least indirectly, particularly Messrs. S. S. Siegfus and William D. Kleinpell, of Bakersfield; Messrs. F. A. Menken and C. C. Church, of the Associated Oil Co.; Dr. H. W. Hoots, of the Richfield Oil Co.; Messrs. D. D. Hughes, Boris Laiming, Hans Aushauer, and the late Dr. R. D. Reed, all of the Texas Co. (California); Mr. John Galloway, of the Standard Oil Co. of California; and Dr. Max Birkhauser, of the Shell Oil Co. Mrs. Irene Quinn Stewart has been of much assistance, both in the field and in the National Museum. The National Museum's collection of Recent mollusks and echinoids has been made available by Dr. Paul Bartsch and Dr. A. H. Clark. Dr. W. P. Popenoe of the California Institute of Technology has studied some of the Cretaceous fossils and kindly prepared an account for this report. The vertebrate remains were identified by Dr. Remington Kellogg of the National Museum.

3 Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga oil district: U. S. Geol. Survey Bull. 357, 142 pp., 2 pls., 1908; Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, 354 pp., 52 pls., 1910. Arnold, Ralph, Paleontology of the Coalinga district: U. S. Geol. Survey Bull. 396, 173 pp., 30 pls., 1909.

4 Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geol. Sci. Bull., vol. 10, No. 14, pp. 191-254, pls. 6-12, 1917.

5 Reed, R. D. Rôle of heavy minerals in the Coalinga Tertiary formations: Econ. Geology, vol. 19, pp. 730-749, 1924.

6 Henny, Gerard, McLure shale of the Coalinga region: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 403-410, 1930.

7 Clark, B. L., Tectonics of the Valle Grande: Am. Assoc. Petroleum Geologists Bull., vol. 13, No. 3, p. 216, 1929. Revised in 1935, Tectonics of the Mt. Diablo and Coalinga areas, middle Coast Ranges: Geol. Soc. America Bull., vol. 46, pl. 89, 1935.

8 Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists Bull., vol. 17, No. 10, pp. 1161-1184, fig. 2, 1933.

9 Cushman, J. A., and Siegfus, S. S., New species of Foraminifera from the Kreyenhagen shale of Fresno County, Calif.: Cushman Lab. Foram. Research Contr., vol. 11, pt. 4, pp. 90-95, pl. 14, 1935; Some new and interesting Foraminifera from the Kreyenhagen shale of California: Idem, vol. 15, pt. 2, pp. 23-33, pls. 6-7, 1939; Foraminifera form the type area of the Kreyenhagen shale of California: San Diego Soc. Nat. Hist. Trans., vol. 9, No. 34, pp. 385-426, pls. 14-19, 1942.

10 Von Estorff, F. E., Kreyenhagen shale at type locality, Fresno County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, No. 10 pp. 1321-1336, 1930.

11 Jenkins, O. P., Stratigraphic significance of the Kreyenhagen shale of California: Mining in California, vol. 27, No. 2, pp. 141-186, 1931.

12 Jenkins, O. P., op. cit., pp. 149-181.

13 Atwill, E. R., Oligocene Tumey formation of California: Am. Assoc. Petroleum Geologists Bull., vol. 19, No. 8, pp. 1192-1204, 1935.

14 Jenkins, O. P., op. cit., p. 145.

15 Goudkoff, P. P., Subsurface stratigraphy of the Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 4, p. 469, 1934.

16 Church, C. C., Foraminifera from the Kreyenhagen shale: Mining in California, vol. 27, No. 2, p. 204, 1931.

17 Cushman, J. A., and Siegfus, S. S., op. cit., 1935, 1939, and 1942.

18 Taliaferro, N. L., The relation of volcanism to diatomaceous and associated siliceous sediments: California Univ., Dept. Geol. Sci. Bull., vol. 23, No. 1, pp. 1-56, 17-20, 1933.

19 Barbat, W. F., and Johnson, F. L., Stratigraphy and Foraminifera of the Reef Ridge shale, upper Miocene, California: Jour. Paleontology, vol. 8, pp. 3-17, 1934; abs. in Pan-Am. Geologist, vol. 59, p. 239, 1933.

20 Siegfus, S. S., Stratigraphic features of the Reef Ridge shale in southern California: Am. Assoc. Petroleum Geologists Bull., vol. 23, No. 1, pp. 24-44, 1939.

21 Goudkoff, P. P., op. cit., pp. 435-475.

22 Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, California: U. S. Geol. Survey Prof. Paper 195, 1940 [1941].

23 Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 12, pp. 1559-1576, 1934.

24 Vokes, H. E., Molluscan faunas of the Domengine and Arroyo Hondo formations of the California Eocene, New York Acad. Sci. Annals, vol. 38, 246 pp. 22 pls., 1939.

25 Wells, J. W., Two new corals from the Avenal formation (Eocene) of California: Washington Acad. Sci. Jour., vol. 30, No. 9, pp. 374-376, figs. 1-5, 1940.

DESCRIPTIVE GEOLOGY

GENERAL FEATURES

The rocks of the Reef Ridge area are all sedimentary, with the exception of serpentine and volcanic rocks that are found in a narrow belt in the Diablo Range. The oldest rocks, which include the serpentine and the volcanic rocks, are of possible Jurassic age; they are succeeded by deposits of Upper Cretaceous, Eocene, Miocene, Pliocene, and Quaternary age. All the rocks in the area, except possibly some of late Quaternary age, have been deformed by folding and faulting, and there are some fairly large landslides associated with steeply dipping, overturned, and faulted shales.

The crest of Reef Ridge is formed by sandstone of Miocene age, with formations of Eocene age to the south separating the Miocene from the Upper Cretaceous (see pl. 15, *A*). Some 10,000 feet of Pliocene sediments are exposed north and east of the Ridge. At both the southeast and northwest ends of the area here described the Miocene overlaps the early Tertiary strata and rests upon the Upper Cretaceous. Older crystalline rocks shown on the map, as Franciscan of Jurassic (?) age, are exposed in a narrow belt north of Black Mountain (see pl. 9). The Tertiary strata that crop out on Reef Ridge have been subdivided into four formations—the Avenal sandstone and Kreyenhagen shale of Eocene age and the Temblor sandstone and Monterey shale of Miocene age. These four units contain marine fossils, but apart from their faunas they are consistently recognized by their lithologic features and their positions. The Avenal sandstone and Kreyenhagen shale together attain a thickness of about 1,500 feet in the central part of the ridge, but they decrease in thickness and thin out toward the ends of the ridge, where they are overlapped by younger Tertiary strata. The Temblor sandstone and McLure and Reef Ridge shales are together about 2,000 feet thick. The distribution of these formations is shown on plate 9. Above them are the Jacalitos, Etchegoin, and San Joaquin formations of Pliocene age and the Tulare formation of Pliocene and Pleistocene age, all of which are exposed between Reef Ridge and Kettleman Plain. These four formations were not studied during the present investigation

The character and relation of the formations exposed on and near Reef Ridge within the area shown on plate 9 are graphically shown on figure 12, and a history of their names and correlations is given in figure 13. This figure shows that there has been complete agreement in drawing the base of the Eocene and the base of the Miocene. The largest obvious divergences in age assignment are shown in the Miocene-Pliocene boundary, but this boundary has been fairly stable for the last 25 years. The boundary between the Pliocene and the Pleistocene as shown in figure 13 reveals considerable diversity of opinion.

JURASSIC (?) SYSTEM

FRANCISCAN FORMATION

In the western part of the area a narrow band of metamorphic rocks follows the valley along the north base of Black Mountain. This band is the attenuated southeastern extremity of an area of Franciscan rocks described and mapped northwest of Reef Ridge by Pack and English.[26] The southeast end of this band has not been determined. It is shown on the map (pl. 9) as northwest of Yost Cabin (sec. 8, T. 23 S., R. 16 E.), but it may be a mile farther southeast. Two miles southeast of Yost Cabin is a separate lenticular outcrop of the metamorphic rocks, about 150 feet wide and 1,800 feet long, in the saddle between Blacks Corral and Bullpen Canyon in the SW$\frac{1}{4}$ sec. 15, T. 23 S., R. 16 E. The Franciscan formation in this band consists of fragments of sandstone, volcanics, serpentine, chert, and glaucophane schist, "all thoroughly kneaded together."[27] Some of the fragments are at least 10 feet long. These fragments have been subjected to much movement in a fault zone, and presumably the Franciscan formation is separated by steeply inclined faults from the Cretaceous rocks both on the north and the south sides of the belt of outcrop.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

The Cretaceous rocks exposed in the portion of the Diablo Range south of Reef Ridge consist of sandstone, shale, and conglomerate and appear to be about 7,000 feet thick. Their base has not been recognized, and the strata may be duplicated to some extent. They are overlain unconformably by the Tertiary strata. Cretaceous fossils have been found at some localities, but no mappable fossiliferous zones were recognized, and a detailed study of the rocks was not made during the present investigation. A locality in Arroyo Pinoso has yielded the largest collection of well-preserved fossils.

Many beds of conglomerate, as much as 50 feet thick, occur through the upper 2,000 feet of the formation. South of Big Tar Canyon they contain angular boulders, some 4 feet long, of chert and volcanic rocks, as well as boulders containing Cretaceous fossils (loc. 92).[28] The Cretaceous fossils at the excellent locality (loc. 97) in Arroyo Pinoso are embedded in a small lens of stratified micaceous sandstone, about 10 feet long and 2 feet thick. The sandstone lens is in a large landslide apparently just above a boulder-bearing conglomerate and about 200 feet stratigraphically below the Cretaceous-Tertiary contact. The stratigraphic position of these fossils is similar to that of the fossils found in the Big Tar Creek drainage south of Garza Peak. The fossils at the two localities may occur at the same horizon, but this cannot be determined without tracing the individual beds across the 6-mile distance between the localities.

The Cretaceous rocks of the area here described have been referred to as Knoxville-Chico rocks[29] and later as the Panoche formation[30] of the Chico group. In the Reef Ridge area these Cretaceous rocks contain coarse conglomerates, considered fanglomerates

[26] Pack, R. W., and English, W. A., Geology and oil prospects in Waltham, Priest, Bitterwater, and Peachtree Valleys, California: U. S. Geol. Survey Bull. 581, pt. 2, p. 126, pl. 5, 1914.

[27] Reed, R. D., and Hollister, J. S., Structural geology of Southern California: Am. Assoc. Petroleum Geologists, Tulsa, pp. 55,57, 1936.

[28] The fossil localities are plotted on the geologic map, plate 9, and are described on pages 111-114.

[29] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 53, 54, 58, 60, 161, fig. 6.

[30] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603, pp. 39-46, 1915.

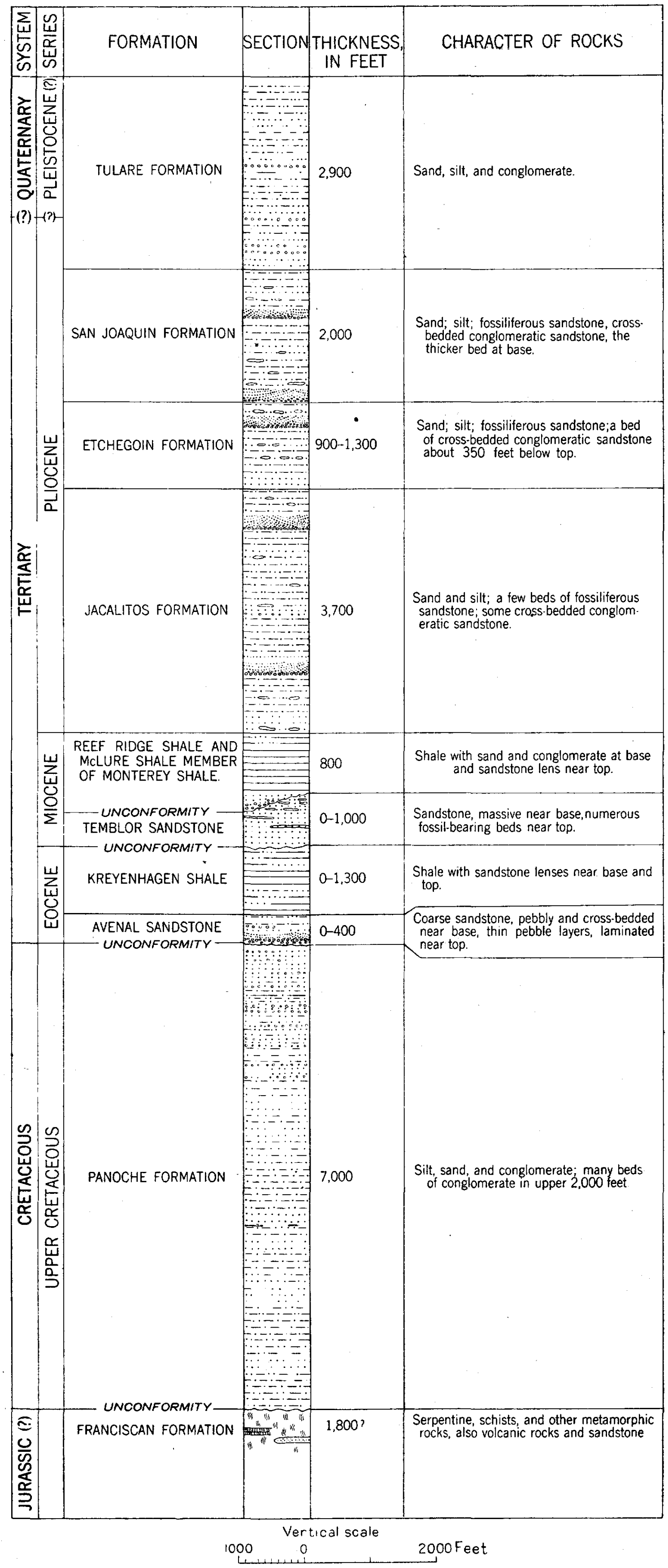

FIGURE 12.—Generalized section of rocks exposed on and near Reef Ridge.

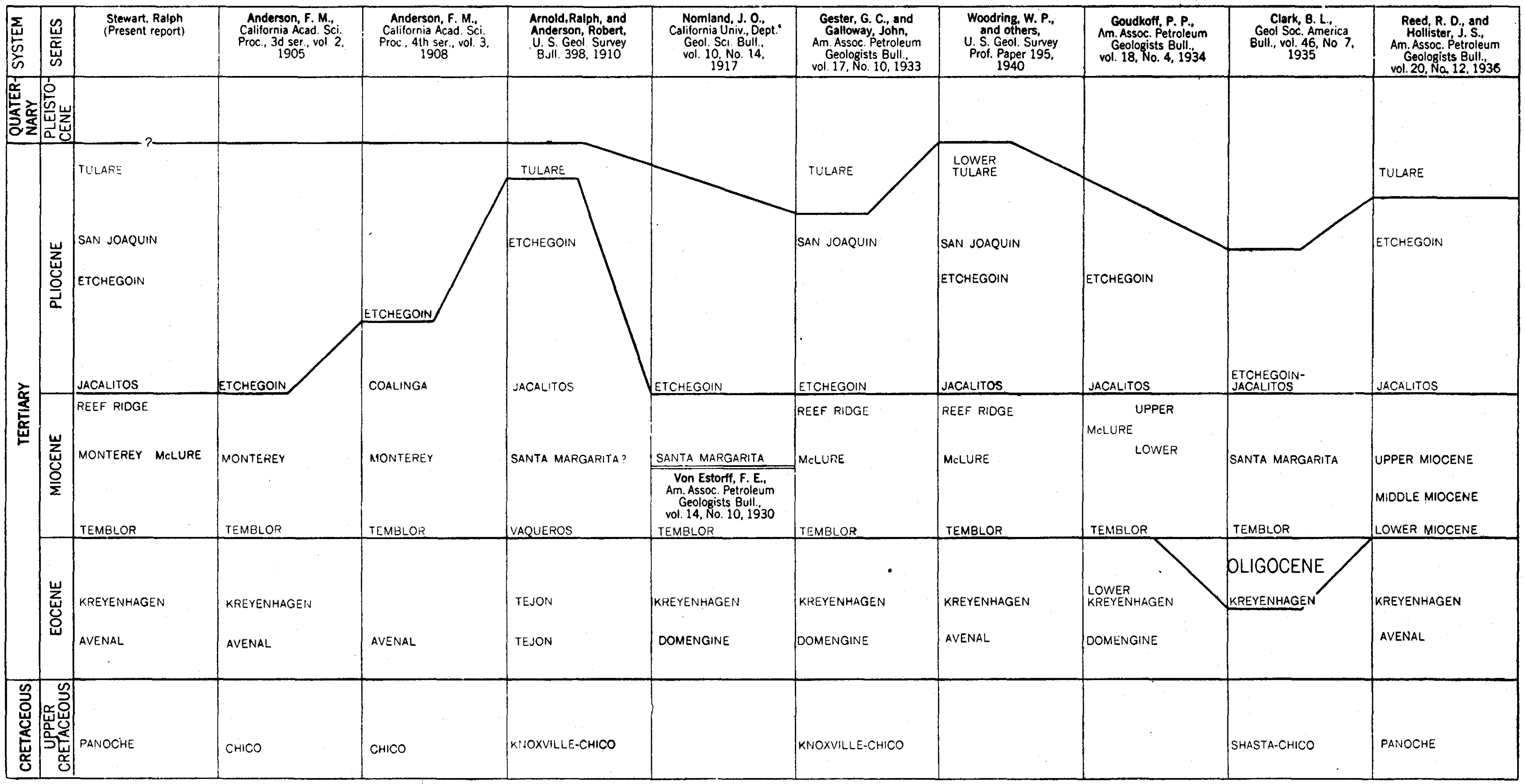

FIGURE 13.—Names and age assignments of formations as given by authors of reports on Reef Ridge.

by Clark,[31] and stratified and massive concretionary sandstones like those described in the Panoche formation at the type locality, the Panoche Hills about 40 miles north of Reef Ridge. Here, however, they are evidently thinner and contain much less shale than they do in the Panoche Hills. Some shale occurs at the top of the formation along Reef Ridge, particularly in Little Tar Canyon, where it contains Foraminifera. This foraminiferal shale apparently corresponds in stratigraphic position to the Moreno shale[32] of the area north of Coalinga. The Foraminifera from it have, however, been examined by Church, who has stated in conversation that he regards them as slightly older than the Moreno fauna.[33]

The Upper Cretaceous marine molluscan fossils were found in place above the conglomerates in Big Tar Canyon (loc. 94), and on the ridge southwest of Flattop (NW¼ sec. 20, T. 22 S., R 17 E.) a few fragments of *Glycymeris* were recognized above conglomerates. These conglomerates seem to be truncated by the angular unconformity at the base of the Avenal sandstone in McLure Valley, so that the horizon of a third locality (loc. 90) in Little Tar Canyon is probably 2,000 or 3,000 feet lower than the horizon of the fossil-bearing beds at the other localities. Likewise, presumably the foraminiferal shales above locality 90 in Little Tar Canyon are also lower than shales near the Cretaceous-Tertiary contact farther west.

The following forms from locality 90 were identified:

?"Callista" subtrigona Whiteaves
?"Cardita" veneriformis Gabb
Cymbophora cf. C. tenuissima Gabb
Corbula n. sp. (cf. C. minima Whiteaves)
Corbula cf. C. cancellifera Stoliczka
?Corbula sp.
?Glycymeris sp.
?Lembulus? translucidus Gabb
Ostrea sp.
Parallelodon (Nanonavis) cf. P. brewerianus Gabb
?Periplomya sp.
Rhectomyax cf. R. undulatus Gabb
?Yoldia diminutiva Whiteaves
?"Yoldia" nasuta Gabb
?"Acteonina" columnaris Stoliczka
?Cylichnina n. sp.
?"Discohelix" leana Gabb
?Margarites inornatus Gabb
Oligoptycha cf. O. obliqua Gabb
Solariella cf. S. occidentalis Whiteaves
Dentalium cf. D. nanaimoense Meek
Baculites cf. B. chicoensis Trask
Coral fragments

The straight cephalopod *Baculites* also was reported by Anderson[34] from a locality near the San Joaquin coal mine northwest of Coalinga and from other areas north of Reef Ridge by Arnold and Anderson.[35]

Inoceramus fragments were found in a pebble bed at locality 93, and poorly preserved fossils from locality 94 were partially identified as *?Inoceramus*, *?Gilbertwhitea*, an ammonite septum and fragments, and a large, incomplete bucciniform gastropod.

The fauna in Arroyo Pinoso (loc. 97) has been identified by Dr. W. P. Popenoe of the California Institute of Technology, who kindly prepared the following list and statement.

Aphrodina? sp.
Clisocolus sp.
Cucullaea cf. C. gravida (Gabb)*
Cymbophora? sp.*
Flaventia n.sp.*
Glycymeris pacificus (Anderson)*
"Pachycardium" cf. P. remondianum (Gabb)*
Trigonia sp. undet.
Volsella? sp.
Anchura n.sp.*
Cylichnina? sp.
Gyrodes dowelli White*
Margarites cf. M. inornatus (Gabb)*
Volutoderma? sp.
Desmoceratid, small specimen
Lytoceratid, small specimen

The species marked by an asterisk are identical with or very close to species found in the early Upper Cretaceous fauna of Little Cow Creek Valley, Redding, Shasta County, and the lower fauna of the Upper Cretaceous beds of the Santa Ana Mountains, Orange County, Calif. The assemblages of these early Upper Cretaceous horizons are distinct from and stratigraphically lower than the typical "Chico" fauna of Chico and Butte Creeks and Penz Ranch, Butte County. On the basis of this comparison, it is believed that the fauna from locality 97 is of an early Upper Cretaceous, probably early Cenomanian, age and is older than the Cretaceous of Chico Creek and Penz Ranch.

Cretaceous fossils found in boulders in the conglomerates near the head of McLure Valley (locs. 91 and 92), Beltran Canyon (loc. 95), and Arroyo Pinoso (locs. 96 and 98) represent a fauna that has not been recognized in any section in this area. It appears, however, to be an Upper Cretaceous fauna, possibly not much older than the Cretaceous fossils of locality 97, and it perhaps corresponds in age to the Upper Cretaceous at Martinez, Calif.; not enough, however, is known about the stratigraphic range of the forms to justify a direct correlation with the section at Martinez. Recently similar boulders have been tentatively identified as of the Chico formation.[36]

The largest fauna from a boulder was found at locality 92. It contained the following:

?Anomia sp.
Corbula cf. C. traski Gabb
Cymbophora ashburnerii Gabb
?Legumen ooides Gabb
Myrtaea? cf. M. gabbi Stewart
"Mytilus" cf. M. quadratus Gabb
?Ostrea sp.
Pachycardium? cf. P. rémondianum Gabb
?Tellina ashburnerii Gabb
Trigonia cf. T. evansana Meek
Trigonarca n. sp.
Acteonella cf. A. oviformis Gabb
"Acteonina" cf. A. californica Gabb
Ampullina cf. A. avellana Gabb
?Arrhoges californicus Gabb
Gyrodes cf. G. conradiana Gabb
?Margarites inornatus Gabb
?Metacerithium sp.
Polinices? cf. P. shumardianus Gabb
Pugnellus cf. P. manubriatus Gabb
?Volutoderma sp.
?Neocardioceras sp.

[31] Clark, B. L., Tectonics of the Mount Diablo and Coalinga areas, middle Coast Ranges of California: Geol. Soc. America Bull., vol. 46, No. 7, p. 1073, 1935.
[32] Anderson, Robert, and Pack, R. W., op. cit., p. 46.
[33] Cushman, J. A., and Church, C. C., Some Upper Foraminifera from near Coalinga: California Acad. Sci. Proc., 4th ser., vol. 18, No. 16, pp. 497-530, 1929.
[34] Anderson, F. M., op. cit., p. 161.
[35] Arnold, Ralph, and Anderson, Robert, op. cit., p. 60.
[36] Taff, J. A., Hanna, G. D., and Cross, C. M., Type locality of the Cretaceous Chico formation: Geol. Soc. America Bull., vol. 51, p. 1319, 1940.

The fauna of another boulder from these conglomerates, at locality 91, has been identified by Dr. Popenoe, who has kindly prepared the following list and statement.

Anomia sp.
"Astarte" n.sp.
Clisocolus cf. C. cordatus Whiteaves
Corbula sp.
Cucullaea sp, undet. (juvenile)
Cymbophora? sp. undet.
Martesia? sp.
Trigonia sp. undet.
Trigonocallista n.sp.
Arrhoges? n.sp.
Gyrodes cf. G. expansa Gabb (juvenile)
Oligoptycha obliqua (Gabb)
"Scaphander" sp.
Dentalium sp.

The fauna from locality 91 is peculiar in that it is composed almost entirely of specimens of small species and of small juvenile forms of normally large species. It probably represents a special ecologic or depositional condition. The fauna has few species in common with any other assemblage known to me. *Oligoptycha obliqua*, the only described species definitely recognized in the assemblage, is a species with a long time range in the West Coast Cretaceous and is almost worthless as an aid to age determination. The species of *Trigonocallista*, *Corbula*, *Gyrodes*, and *Clisocolus* all appear to be more closely related to species from the Chico Creek fauna than to species from the earlier Cretaceous fauna from Little Cow Creek [mentioned above]. The remaining species have no present known correlation value. The fauna suggests an age later than that of locality 97, but this cannot be considered as more than a suggestion.

Another fauna in a boulder from locality 96 was identified as follows:

Agnomyax cf. A. monilifer Gabb
Anomia sp.
Astarte? cf. A. sulcata Packard
Trigonocallista cf. T. varians Gabb
T. cf. nitida Gabb
Corbula cf. C. traski Gabb
?Cymbophora gabbiana Anderson
?Meekia sella Gabb
Myrtea? cf. M. gabbi Stewart
Pachycardium? cf. P. rémondianum Gabb
Trigonia cf. T. evansana Meek
Volsella cf. V. siskiyouensis Gabb
Acteon politus Gabb
Lacunaria cf. L. striata Gabb
"Margaritella" cf. M. globosa Gabb
"Scobinella" aff. S. dilleri White = ? Volutoderma mitraeformis Gabb

Lacunaria striata[37] is a Paleocene species, and its presence, or that of a similar form, in this fauna suggests that it is rather late in the Cretaceous, or that *Lacunaria* occurs considerably earlier than hitherto known.

A boulder from locality 95 contained *Meekia* cf. *M. sella*, and one from locality 98 contained *"Acteonina"* cf. *A. californica* and *Trigonia* cf. *T. evansana* Meek.

Avicula linguaeformis Evans and Shumard was reported from the head of Canoas Creek by Arnold and Anderson.[38]

[37] Stewart, Ralph, Gabb's California fossil type gastropods: Acad. Nat. Sci. Philadelphia, Proc., vol. 78, p. 339, pl. 25, fig. 12, 1927.
[38] Arnold, Ralph, and Anderson, Robert, op. cit., p. 60.

TERTIARY SYSTEM

EOCENE SERIES

AVENAL SANDSTONE

DEFINITION

The Avenal sandstone, named for its exposure near the Avenal wells in Big Tar Canyon,[39] is a light-gray sandstone, 300 to 400 feet thick. (See pl. 10.) It was described and mapped with the overlying Kreyenhagen by Arnold and Anderson;[40] it was shown separately as the Domengine on a small map by Clark;[41] and later it was described by Gester and Galloway[42] as Domengine and shown by them as Domengine on a small map.

DISTRIBUTION

The Avenal sandstone forms a narrow band of conspicuous outcrops (see pl. 15, *A*) just southwest of and parallel to the crest of Reef Ridge. Near both ends of the ridge the Avenal is overlapped by Miocene strata, by the McLure shale to the southeast and by the Temblor sandstone to the northwest. A small remnant of Eocene strata, including Avenal sandstone, has recently been discovered, by geologists of the Associated Oil Co., between the McLure and Panoche formations on the Chalk Buttes northwest of McLure Valley.

CHARACTER

The lower part of the sandstone is generally massive but displays some irregular bedding; the upper part is more evenly bedded and contains thin layers of silty sand. The sandstone is fairly soft, except where cemented in concretionary ledges. Many of the beds, particularly the ledges, have an almost horizontal jointing and exhibit some minor faulting with displacements of less than 1 foot. The sandstone consists dominantly of quartz and feldspar with minor amounts of other minerals, including mica, the flakes of which are not so large as those in some of the underlying Cretaceous sandstones. The sandstone is generally gray but locally yellow and variously tinted, particularly in the more laminated upper part. Some oil stains are also present in the upper part.

A thin conglomerate of well-rounded quartz, metamorphic, and volcanic pebbles is present at the base in some outcrops, and lenses of pebbles are found also higher in the sandstone. The basal conglomerate is 30 feet thick in Reese Canyon. In Zapato Canyon, where the beds are overturned, some 30 feet of massive sandstone is stratigraphically above about 20 feet of basal sandstone and conglomerate; on the west side of the canyon, where the beds are not overturned, only the massive sandstone was found.

On the ridge between Garza Creek and Baby King Canyon the conglomerate is 5 feet thick, and the cobbles in it, some of them 4 inches long, are well rounded. Pebbles of crystalline and volcanic rocks and some quartz pebbles are abundant, but no pebbles of definitely Cretaceous rocks were recognized.

[39] Anderson, F. W., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 164, pl. 34, fig. 1, (section), 1905.
[40] Arnold, Ralph, and Anderson, Robert, op. cit., pl. 1, pp. 67-70, fig. 3.
[41] Clark, B. L., Tectonics of the Valle Grande of California: Am. Assoc. Petroleum Geologists Bull., vol. 13, No. 3, p. 216, 1929.
[42] Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists Bull., vol. 17, No. 10, pp. 1167, 1184, 1933.

Above the conglomerate are at least 7 beds of fossiliferous sandstone, one of which contains pebbles 2 inches long (see pl. 10). Septarian concretions about a foot in diameter were found in silt near the middle part of the formation in McLure Valley, in the next canyon southeast of Roof Spring (sec. 21, T. 23 S., R. 17 E., 2,100 feet east, 1,300 feet north).[43]

The Eocene on the Chalk Buttes northwest of McLure Valley, as described by geologists of the Associated Oil Co., includes in its lower part 31 feet of sand resting upon green clay of probable Cretaceous age. The lowest 3 feet is red-brown sand containing *Spiroglyphus? tejonensis;* the next 24 feet is light, fine, clean, friable sand, weathering red; and the upper 4 feet is a fossiliferous sand with small *Turritella* sp. and small *Plagiocardium* (*Schedocardium*) cf. *P. brewerii.* The sand is overlain by 40 feet of green clay and silty clay with some thin sandstone lenses. The lower 10 feet of this clay contains Foraminifera characteristic of the Avenal and Domengine formations, and the upper 25 feet contains the foraminiferal fauna of the green clay member of the Kreyenhagen shale. The clay is overlain by 15 feet of greenish-gray sand with black chert pebbles presumably of Kreyenhagen age. The Eocene strata extend for about 2,000 feet along the strike, and the fossils were reported from the second knoll of the Chalk Buttes east of Willow Spring (sec. 26, T. 23 S., R. 16 E., 3,100 feet north and 1,000 feet west). Mr. Fred A. Menken of the Associated Oil Co. has kindly granted permission to place this information on record. These Eocene strata were discovered by Mr. Earl Dillon, and the fossils of Avenal and lower Kreyenhagen age were identified by Mr. C. C. Church.

STRATIGRAPHIC RELATIONS

The Avenal sandstone rests with angular unconformity on the sands and shales of the Panoche formation (Upper Cretaceous). Some subsequent faulting has occurred along this contact, particularly at localities where the Avenal overlies silty shales. Ordinarily the contact between the Avenal and Panoche formations is not exposed, but it is exposed at two places, one at the head of Big Tar Creek just east of Garza Peak and the other in Canoas Creek Canyon. At locality 80 on Big Tar Creek a hand specimen shows the unconformable contact and a difference in dip of 15°.

East of Beltran Canyon and on the west side of the hill, at an altitude of 2,526 feet (loc. 95), the massive Cretaceous sandstone and conglomerate that are in contact with the Avenal appear to be faulted. There the base of the apparently continuous Avenal is formed by a 10-foot pebble bed that cuts across 50 feet of Cretaceous strata. On the west side of the canyon the Cretaceous sandstone and conglomerate are absent, and the Avenal lies against Cretaceous shales like those beneath the Cretaceous conglomerate on the east side. If the sandstone and conglomerate have not changed to shale the base of the Avenal at this locality cuts across some 300 feet of Cretaceous strata because of pre-Avenal erosion or faulting.

The Avenal sandstone is overlain by the Kreyenhagen shale, and, although the contact is seldom well-exposed, it is probably gradational. At locality 55, on a tributary of Garza Creek, the contact is even and is marked by thin plates of gypsum, which separate laminated sand from overlying green clay. The highest Avenal fossils found in this section are in a hard ledge-forming bed 40 feet below the contact. Greensand has been found at some outcrops of the lower part of the Kreyenhagen, and at one of these, in Baby King Canyon, a 2-foot bed of glauconitic greensand is exposed; although faulting and landslides obscure the exact stratigraphic position of this bed, it is evidently near the base of the Kreyenhagen.

[43] The figures following the land-net data represent distances within the section from its boundaries to the fossil locality.

FOSSILS

Fossils are abundant in the Avenal sandstone (see pl. 11), particularly in the eastern half of the area. The fossils are preserved in more or less indurated lenses a few feet thick, which appear to become longer toward the east, where they form outcropping beds that may be traced for distances of about a mile. Small lists of these fossils have been published by different authors.[44] These include an orbitoid (Foraminifera), possibly the same species as *Orthophragmina clarki,* which was later described by Cushman[45] from the Coalinga anticline and has also been reported by Cole[46] as *Discocylina clarki* (Cushman) from the Guayabal formation, Eocene of Mexico. The smaller Foraminifera have also been found with the orbitoid near the middle of the formation in McLure Valley, where the formation is only about 150 feet thick.

The fauna obtained and identified by the writer is listed in table 1.

Recently a fauna of 105 Mollusca from Reef Ridge has been described by Vokes[47] in a general and useful account of the Domengine fauna. About 43 of the Reef Ridge forms were illustrated by him, and most of the others were illustrated with specimens from other localities, mostly north of Coalinga. His faunal list contains the following species not found in the course of this investigation: 5 species of bivalves, *Gari eoundulata, Nucula cooperi, Solen parallelus, Solena* (*Eosolen*) *coosensis,* and *S.* (*E.*) *subverticala* and 4 species of gastropods, *Acmaea* n. sp., *Harpa* (*Eocithara*) *clarki, Nerita* (*Amphinerita*) *eorex,* and *Velates californicus.* The absence from table 1 of other names in Vokes' list is due to nomenclatorial differences. His faunal list contains many of the species in table 1, and the combined lists of Vokes and the writer indicate at least 144 species of mollusks for Reef Ridge.

Placunanomia inornata and *Barbatia morsei,* listed by Arnold[48] as from Reef Ridge, are questionable. They are probably based on a Cretaceous *Anomia* and a Cretaceous taxodont, possibly *Trigonarca,* for the collection, which is now in the National Museum, contains the Cretaceous bivalve

[44] Anderson, F. M., op. cit., p. 164. Arnold, Ralph, and Anderson, Robert, op. cit., pp. 70, 71, locs. 4615, 4617. Von Estorff, F. E., Kreyenhagen shale at type locality, Fresno County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, No. 10, p. 1327, 1930.

[45] Cushman, J. A., The American species of *Orthophragmina* and *Lepidocyclina*: U. S. Geol. Survey Prog. Paper 125-D, p. 41, pl. 7, figs. 4, 5, 1920. Northeast side of Domengine Creek.

[46] Cole, W. S., A foraminiferal fauna from the Guayabal formation in Mexico: Am. Paleontology Bull., vol. 14, No. 51, pp. 10, 36, pl. 2, fig. 31, 1927.

[47] Vokes, H. E., Molluscan faunas of the Domengine and Arroyo Hondo formations of the California Eocene: New York Acad. Sci. Annals, vol. 38, 246 pp., 22 pls., 1939.

[48] Arnold, Ralph, and Anderson, Robert, op. cit., p. 70, loc. 4615.

Meekia and is probably from a fossiliferous boulder in the Cretaceous conglomerate. Such boulders have been found in the conglomerate (loc. 96) near the locality cited.

The molluscan fauna of the Avenal sandstone is marine and is characterized by small forms. More gastropods than bivalves have been identified, the ratio being 78 to 51, and of the 25 species found at most localities 15 were gastropods. The bivalves are represented by single valves, very few double-valved specimens having been found. The abundance of gastropods is in contrast with nearly all later marine molluscan faunas of the Tertiary of the region, which usually have more bivalves than gastropods.

About a quarter of the species are not listed from more than a single locality, and half of the species are not listed from more than three localities. Twenty-five species are listed at 11 or more of the 41 localities, and they are also represented by numerous individuals; they will therefore be referred to as the abundant species of this fauna. *Ectinochilus* was found at 27 localities, and *Turritella buwaldana* was found at 29 localities; these are the largest number of localities having a species in common. *Nemocardium* was found at 25 localities, the largest number of localities having a bivalve species in common.

Of the 25 abundant forms (see pl. 11) the *Nemocardium, Glycymeris perrini, Venericardia sandiegoensis, Pitar? joaquinensis,* the *Etinochilus,* the *Globularia* (*Eocernina*), *Turritella uvasana, Ficopsis crescentensis,* and the *Spiroglyphus?* are fairly well scattered, but for *Pitar uvasanus kelloggi,* the *Plagiocardium* (*Schedocardia*), the *Spisula, Glycymeris sagittata,* the *Agaronia,* the *Calyptraea,* the *Euspira,* the *Conus,* the *Cylichnina,* the *Olequahia,* and *Amaurellina* (*Euspirocrommium?*) *clarki* a preponderance of the localities lies north of Roof Spring (loc. 76). The fairly abundant species of *Pseudoliva, Ranellina, Scaphander, Terebellum,* and *Pleurofusia* have also a similar distribution. The abundance of these forms north of Roof Spring may be due partly to the larger collections made from Roof Spring northward, and the larger size of the collections may also be the explanation for the record of the less abundant species found only north of Roof Spring. At the northern localities, however, the absence of such forms as the *Trachycardium* (*Agnocardia*), the *Spondylus, Turritella lawsoni, Ficopsis packardi, the Moniliopsis,* the *Ancilla,* and the foraminifer *Discocyclina,* whose localities are chiefly south of Roof Spring, cannot be attributed to the size of the collections at the northern localities. Evidently a change of facies is indicated, which was possibly due to deepening of the water southward or a decrease in the mobility of the water southward. The increase in species does not continue northward, and at Zapato Canyon no fossils were found in the Avenal sandstone. *Venericor* is listed only from localities north of Roof Spring, and it is more abundant there, particularly near the base of the formation, but one specimen was noted about 800 feet southeast of locality 69—almost within a mile of the easternmost outcrop of the formation at Little Tar Canyon. The most widely separated collections of considerable size are from Reese Canyon (loc. 87c) and Little Tar Spring (locs. 66 and 66a), near the southernmost outcrop of the Avenal sandstone. The two localities near Little Tar Spring together have yielded 49 species, including 16 of the abundant species. The Reese Canyon locality has yielded 19, of which 11 are also found at Little Tar Spring. The smaller fauna has more of the abundant species than the larger, presumably because the larger collections from the more northern localities have had a greater part in indicating the abundant species. In addition to the 11 abundant species, species of *Gari, Akera, Falsifusus?, Lyria, Moniliopsis, Personella, Pleurofusia,* and *Sinum* are also common to both localities. Sixty-six forms were recognized near Roof Spring (locs. 76 and 76a). The collections contained all the abundant forms except the *Agaronia, Amaurellina lajollaensis* and the *Architectonica* (*Stellaxis*). The largest collection is from locality 78, north of Roof Spring. Sixty-nine forms are listed, and there are about 20 more that have not been identified, including small questionable *Corbis* and *Tivela* and a new species evidently near *Pleurofusia.* This fauna contains many small specimens, and its large size is probably due chiefly to a greater length of time spent on collecting and preparing the fauna. It contains all the abundant species except the *Spisula* and *Amaurellina lajollaensis,* both of which occur in the underlying basal conglomerate (loc. 78b). Even this fauna, however, lacks 18 of the 49 forms known from Little Tar Spring.

No consistent stratigraphic change has been recognized in the collections of the fauna. Three collections were obtained in the same section at locality 81, south of Garza Peak. The lowest collection was from the conglomerate at the base of the formation, the middle collection 80 feet above the conglomerate, and the upper collection was 100 feet above the conglomerate. Eight species are present in all three beds. Seven of these are abundant species, and the other is the *Bonellitia.* The lowest collection contains the smallest number of species and has more bivalves than gastropods, the ratio being 18 to 16; the middle collection has only 11 bivalves to 32 gastropods; and the upper has 18 bivalves and 22 gastropods. The gastropods *Molopophorus, Neverita, Terebra,* and *Umpquaia* were found only in the lowest bed; the bivalves *Donax, Taras? unisulcatus,* the *Saccella,* a solenid, and an oyster fragment were likewise not found above the conglomerate in this section. The uppermost collection (loc. 8b) is only 20 feet above the middle one (loc. 81a) and has at least 11 species also known from the middle collection but not found in the conglomerate. The uppermost collection has four bivalves, *Acila, Brachidontes, Crassatella* and *Glycymeris perrini,* and the gastropod *Calyptraea,* which were found in the conglomerate but not in the middle collection. The *Gyrineum, Mitra* cf. *M. cretacea,* the *"Pleurotoma,"* the *Pleurofusia,* the *Spiroglyphus?,* and the *Lucina* were found in only the uppermost collection.

Molopophorus has been found at only five localities along Reef Ridge; three of these are in the basal conglomerate (locs. 78b, 81, and 83), and others are in the lower part of the formation (locs. 79 and 85). *Venericor* is also most abundant near the base of the formation, but in the section at locality 81 it was found only in the middle collection.

In the basal conglomerate (loc. 78b) below the largest collection (loc. 78) 37 forms were recognized. Eleven of these, including the abundant species *Amaurellina lajollaensis* and possibly *Spisula merriami,* were not found higher in the section.

RELATION OF AVENAL FAUNA TO SIMILAR FAUNAS

The fossils of the Avenal sandstone were considered to be of Tejon age, and the sandstone was called the Tejon formation by Arnold and Anderson.[49] Subsequently the name Tejon was restricted by Clark.[50] The approximate correspondence of the strata now included in the Avenal sandstone to the strata of the Coalinga anticline now called the Domengine,[51] a correlation which was first pointed out by Arnold and Anderson, is now generally recognized.

A few miles north of Reef Ridge, fossiliferous sandstones of Eocene age crop out below the Kreyenhagen shale at Coal Mine Creek. About 40 forms have been listed from one of these sandstones by Vokes.[52] This fauna is beneath a fossiliferous ledge of gritty sandstone, which appears to be the base of the Domengine formation in this section. The fauna is therefore older than the Domengine fauna, and it is here suggested that it is to be correlated with that of the Avenal. Inasmuch as the Avenal fauna of Reef Ridge has more than three times as many forms as the fauna on Coal Mine Creek, the two faunas are very distinct. Only 5 of the 25 abundant forms from Reef Ridge were reported from Coal Mine Creek, and only one-fourth of the fauna at Coal Mine Creek is known from Reef Ridge. The presence of brackish-water forms in the smaller fauna and the occurrence of coal beds in the sequence on Coal Mine Creek suggest that the difference in the two faunas may be attributed principally to a difference in facies. The smaller fauna is a bivalve fauna having twice as many bivalves as gastropods, and it evidently lived in more brackish water and shallower water than the larger fauna. The fauna on Coal Mine Creek might, of course, be slightly older or younger than the Avenal.

From the type area of the Domengine about 95 species were reported by Vokes,[53] including 45 bivalves and 45 gastropods, 71 of which (34 bivalves and 37 gastropods) are also known from Reef Ridge. Three-fourths of the Domengine fauna is known from Reef Ridge, in contrast with the one-fourth of the Coal Mine Creek fauna that is known from Reef Ridge. All the 25 abundant species of Reef Ridge were reported from the Domengine area. If the Avenal, as now generally recognized, is to be correlated with the Domengine, the implication is that the fauna at Coal Mine Creek is somewhat older than the Avenal. The available paleontologic evidence does not, however, appear sufficient to warrant such an exact correlation. Also, the characteristic black pebble bed that forms the base of the Domengine formation north of Coalinga has not been definitely identified along Reef Ridge either as the basal conglomerate of the Avenal or as one of the several higher beds of black pebbles. It, therefore, seems quite likely that the Avenal includes equivalents of both the Domengine and the sandstones below the Domengine on Coal Mine Creek.

The fauna near the top of the Lodo formation of R. T. White and just beneath the Domengine formation is not well-known, but the fauna about 1,800 feet lower and near the base of the Lodo formation of the Domengine area, known chiefly from locality 1817 of Dickerson, has recently been revised.[54] Sixty-four forms were recognized, about half of which are known from Reef Ridge. This is a peculiar fauna containing many small forms. Comparisons of this fauna with more general or less restricted faunas are difficult to interpret. It contains about half of the abundant species of Reef Ridge, and it was considered closely related to the overlying Domengine fauna (loc. 672 Univ. California) by Dickerson[55] but was recognized as a separate zone slightly higher than his *Turbinolia* zone south of Mount Diablo. This fauna, called the *Turritella andersoni* zone (loc. 1817 Univ. California), has been correlated with the fauna of the Meganos formation,[56] and recently it was correlated with that of the Capay formation of northern California and with the fauna (*Siphonalia sutterensis* zone of Dickerson[57]) at Marysville Buttes.[58] The coral *Turbinolia dickersoni* of locality 1817 has been found quite distinct from *T. clarki* of locality 672.[59] Nine mollusks from locality 1817 have been cited as morphologically distinct from relatives in the overlying Domengine formation.[60] The *Turritella andersoni* and *T. lawsoni* lineage is probably the most important, *T. lawsoni* being the later form. *T. andersoni* has not been recognized on Reef Ridge, and the abundance of *T. lawsoni* there suggests that the Avenal sandstone is later than the *T. andersoni* zone north of Coalinga. This suggestion is further borne out by the presence of a fauna similar to the Avenal fauna, namely the Domengine, stratigraphically above the *T. andersoni* zone.

From the La Jolla formation of Hanna near San Diego and the Tejon formation of the Tejon Ranch at the south end of the San Joaquin Valley, faunas have been described that are large enough and similar enough to be compared profitably with the Avenal. About 22 species are known to occur in all three formations. Nine of the abundant species from Reef Ridge occur in all three formations, *Glycymeris perrini, G. sagittata,* the *Nemocardium,* the *Agaronia, Amaurellina* (*E.?*) *clarki,* the *Cylichnina,* the *Calyptraea, Turritella buwaldana,* and *T. uvasana.*

In the La Jolla fauna,[61] of 150 forms about 60 have

[49] Arnold, Ralph, and Anderson, Robert, op. cit., p. 63.

[50] Clark, B. L., Meganos group, a newly recognized division in the Eocene of California: Geol. Soc. America Bull., vol. 29, pp. 281-296, 1918; Stratigraphic and faunal relationships of the Meganos group, middle Eocene of California: Jour. Geology, vol. 29, pp. 123-165, 1921; Domengine horizon, middle Eocene of California: California Univ., Dept. Geol. Sci., Bull., vol. 16, pp. 104-106, 1926. Domengine separated from Tejon.

[51] Von Estorff, F. E., op. cit., p. 1325. Clark, B. L., and Vokes, H. E., Summary of marine Eocene sequence of western North America: Geol. Soc. America Bull., vol. 47, No. 6, p. 856, fig. 2, 1936. Vokes, H. E., Faunas of the Domengine and Arroyo Hondo formations: New York Acad. Sci. Annals, vol. 38, pp. 21, 1939.

[52] Vokes, H. E., op. cit., pp. 24-26.

[53] Vokes, H. E., op. cit., pp. 24-26.

[54] Vokes, H. E., op. cit., pp. 29-32, as Arroyo Hondo formation.

[55] Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California: California Univ., Dept. Geol. Sci., Bull., vol. 9, No. 17, pp. 425-429, 1916.

[56] Clark, B. L., Domengine horizon, middle Eocene of California: California Univ., Dept. Geol. Sci., Bull., vol. 16, No. 5, p. 104, 1926.

[57] Dickerson, R. E., op. cit., pp. 403-409.

[58] Merriam, C. W., and Turner, F. E., The Capay middle Eocene of northern California: California Univ., Dept. Geol. Sci., Bull., vol. 24, p. 94, 1937.

[59] Quayle, E. H., Fossil corals of the genus *Turbinolia* from the Eocene of California: San Diego Soc. Nat. Hist. Trans., vol. 7, No. 10, pp. 98-101, pl. 6, figs. 1-8, 1932.

[60] Vokes, H. E., op. cit., p. 32.

[61] Hanna, M. A., An Eocene invertebrate fauna from the La Jolla quadrangle, California: California Univ., Dept. Geol. Sci., Bull., vol. 16, No. 8, check list following pl. 57, 1927.

been recognized on Reef Ridge. Thirteen species were listed from more than ten La Jolla localities. Of these, the *Nemocardium*, the *Calyptraea*, the *Scaphander* (*Mirascapha*), *Amaurellina lajollaensis* (as *Amauropsis alveata*), *Ficopsis crescentensis*, and *Turritella buwaldana* are also abundant species of Reef Ridge. *Turritella applini* is probably very close to *T. uvasana* of Reef Ridge. Three more of the 13 forms are known from Reef Ridge, the *Acila*, the *Brachidontes*, and *Ostrea idriaensis*, but 4 have not been found on Reef Ridge. They are *Venericardia* (*Venericor*) cf. *V. hornii*, *Cerithium? cliffensis*, *Ectinochilus* (*Cowlitzia*) *canalifer supraplicatus* (as *C. simplex*), and *"Pitaria" soledadensis*, which may be a form of *Macrocallista hornii*, small forms of which are present on Reef Ridge.

Besides the 6 or 7 abundant forms that are common to both the Avenal sandstone of Reef Ridge and the La Jolla formation, 9 of the abundant forms from Reef Ridge are also known from the La Jolla. These are *Corbula parilis*, *Glycymeris perrini*, *G. sagittata* (as *G. tecolotensis*), *Venericardia sandiegoensis* (as *Cardita*), the *Globularia* (*Eocernina*) (as *Ampullina*), the *Euspira* (as *Natica nuciformis*), the *Agaronia*, *Amaurellina* (*Euspirocrommium?*) *clarki* (as *Amauropsis alveata*), the *Calyptraea*, and possibly *Corbula complicata*, and *Spisula merriami*. Thus, half the abundant forms from Reef Ridge are known from the La Jolla formation, and a fourth of them are abundant species there.

Nine of the 13 abundant La Jolla species are also known from the Tejon formation, either as the same species or closely related varieties, such as the corresponding forms of *Ectinochilus* (*Cowlitzia*). Most of these are also known from Reef Ridge, except *Venericardia* (*Venericor*) cf. *V. hornii*, *Conus remondii*, and the *Cowlitzia*. Twenty-nine species have been listed as common between the Tejon and La Jolla formations,[62] but about half of these (13) are not known from Reef Ridge.

Forty of the 130 forms of the Tejon formation[63] are represented in the Avenal sandstone at Reef Ridge. The fauna includes about half the abundant species of Reef Ridge, either as identical forms or forms so similar that they are distinguishable with certainty only after a large number of specimens have been studied. These forms are the *Nemocardium*, *Glycymeris perrini*, *G. sagittata*, *Spisula merriami*, the *Agaronia*, the *Calyptraea*, *Turritella uvasana*, the *Euspira*, *Amaurellina* (*Euspirocrommium?*) *clarki*, the *Cylichnina*, the *Plagiocardium* (*Schedocardia*), and the *Olequahia*. Naturally these forms give the Avenal sandstone fauna of Reef Ridge a Tejon aspect. One of the most abundant forms along Reef Ridge, however, is *Ectinochilus macilentus*, which is not yet known from the Tejon. The *Globularia* (*Eocernina*), *Architectonica cognata*, *Pitar? joaquinensis*, *Venericardia sandiegoensis*, and *Ficopsis crescentensis* are also abundant forms on Reef Ridge easily distinguished from anything at present known from the Tejon. Except *Pitar? joaquinensis*, these forms or very similar ones are known from the La Jolla formation. Other species in common with the La Jolla or represented there by very similar forms, but apparently absent from the Tejon, are *Turritella lawsoni*, the *Trachycardium* (*Agnocardia*), *Microcallista tecolotensis*, *Amaurellina lajollaensis*, *Fusinus? teglandae*, *Terebellum erraticum*, *Surcula praeattenuata*, *Tornatellaea rosa*, and *Xenophora stocki*.

As there are species common to any two of the Avenal, La Jolla, and Tejon faunas and absent from the third, and conclusive stratigraphic evidence is not available, it is possible to find evidence for grouping the Avenal fauna with either the Tejon or La Jolla, or both. The species common to the Avenal and La Jolla are the basis for the correlation of these two formations, and the present emphasis on those species is, at least, partly justified by the presence of some of them in a similar fauna in the Llajas formation of McMasters in Simi Valley, northwest of Los Angeles. On such a basis the Tejon forms in the La Jolla serve to suggest that the La Jolla fauna is nearer the Tejon than is the Llajas or Avenal faunas. It has been suggested that the La Jolla fauna is a little closer to the Tejon than is the Llajas.[64] Partial lists of the Llajas fauna have been published,[65] but thus far it has not been described. Of 30 species cited as present in the La Jolla and the Llajas,[66] 21 are known from the Avenal.

The abundant *Ectinochilus*, *E.* (*Cowlitzia*) *canalifer supraplicatus*, in the La Jolla formation is quite a different species from that in the Avenal. In fact it has even been described as a different genus, *Cowlitzia*.[67] It is the *Cowlitzia* form which is also known from the Tejon. The Tejon and La Jolla forms have been considered at least subspecifically distinct,[68] but a large collection of each was not available for comparison. Although a typical *Ectinochilus*, that is, a species similar to *E. macilentus*, has not been found in the Tejon, it is probably represented in the La Jolla fauna by *E? problematicus* Hanna.[69] This species is not well known, but it has the narrow spiral interspaces and numerous spiral lines of *E. macilentus*, and at least the Avenal specimens of that species also have the first four or five whorls smooth. Two specimens of *E. macilentus* also have pseudovarices on their smooth early whorls.

Recent attempts by some paleontologists[70] to associate *Ectinochilus* with *Rimella* do not seem to be justified. In this connection it may be recalled that Lamarck and Deshayes placed them in different genera—*Ectinochilus* in *Strombus* and *Rimella* in *Rostellaria*. *Rimella* has an attenuated columella; on *Ectinochilus* the columella is truncated. Probably the North American form nearest to *Rimella* is

[62] Hanna, M. A., op. cit., p. 259.

[63] Anderson, F. M., and Hanna, M. A., Fauna and stratigraphic relations of the Tejon Eocene at its type locality in Kern County, Calif.: California Acad. Sci., Occ. Papers, vol. 11, 249 pp., 16 pls., 1925.

[64] Stewart, Ralph, Gabb's California fossil type gastropods: Acad. Nat. Sci. Philadelphia Proc., vol. 78, 1926, p. 301, 1927 (as the Domengine fauna at Simi). Clark, B. L., and Vokes, H. E., Summary of marine Eocene sequence of western North America: Geol. Soc. America Bull., vol. 47, No. 6, p. 863, 1936 (called "transition stage").

[65] Clark, B. L., Domengine horizon, middle Eocene of California: California Univ., Dept. Geol. Sci., Bull., vol. 16, pp. 114-116, 1926. Turner, F. E., Stratigraphy and Mollusca of the Eocene of western Oregon: Geol. Soc. America Special Papers. No. 10, pp. 33-37, 1938. Vokes, H. E., Molluscan faunas of the Domengine and Arroyo Hondo formations of the California Eocene: New York Acad. Sci. Annals, vol. 38, pp. 24-26, 29-31, 1939.

[66] Hanna, M. A., op. cit., p. 260.

[67] Clark, B. L., and Palmer, D. K., Revision of the **Rimella**-like gastropods from the west coast of North America: California Univ., Dept. Geol. Sci., Bull., vol. 14, No. 7, p. 283, pl. 51, figs. 11-14, 1923.

[68] Stewart, Ralph, op. cit., p. 369, pl. 28, fig. 12.

[69] Hanna, M. A., op. cit., p. 13, pl. 50, figs. 9, 10, 12 (as *Cowlitzia*).

[70] Rutsch, R., Einige interessante Gastropoden aus den Tertiär der Staaten Falcón und Lara, Venezuela: Eclogae geol. Helvetiae, vol. 23, No. 2, pp. 605-607, 1930. Clark, B. L., and Vokes, H. E., op. cit., p. 863. Turner, F. E., op. cit., p. 94 (*Macilentus* as a subgenus of *Rimella*). Vokes, H. E., op. cit., p. 155 (*Macilentus* as a subgenus of *Rimella*).

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Calyptrophorus, judging from the development of its ornamentation and its attenuated columella. However, the columella of *Calyptrophorus* is longer than that of *Rimella*. A species of *Chedevillia* from the Eocene of Simi Valley is presumably also nearer *Rimella* than is *Ectinochilus*.

In summary, from the faunal relationships it appears to the writer that: (1) The Avenal sandstone probably has in it equivalents of the Domengine formation and the sandstone below the Domengine in Coal Mine Canyon; (2) the Avenal is probably later than the lower part of the Lodo formation; and (3) the Avenal appears to be more nearly equivalent to the La Jolla formation than to the Tejon formation, though it is possible to find opposing faunal relations, and the matter must be left undecided at this time.

KREYENHAGEN SHALE

CHARACTER AND DISTRIBUTION

The Kreyenhagen shale was named for its occurrence at the Kreyenhagen wells, on Canoas Creek in the Reef Ridge area.[71] It forms a band of rounded grass-and-weed-covered slopes on the west side of Reef Ridge (see pl. 15, *B*) between the rugged outcrops of the underlying Avenal sandstone and the overlying Temblor sandstone. Near both ends of the ridge it is overlapped by the Temblor sandstone to the west and the McLure shale to the east. A small remnant of lower Kreyenhagen has recently been found on the Chalk Buttes and is briefly described with the Avenal sandstone on page 90. The Kreyenhagen is about 1,000 feet thick, and interbedded with the shale are some light-colored sandstone lenses and limy and bentonitic clay layers. (See pl. 13.) Sandstone dikes are present in the upper part, particularly east of the Big Tar Canyon. (See pl. 9.)

The shales of the Kreyenhagen are typically dark, thin-bedded, rather brittle, more or less siliceous, and silty. At fresh outcrops they are much fractured and stained with a sulfur compound (jarosite?).

An opaline shale, composed chiefly of opal, a few angular quartz grains, and many radiolarians, was described by Von Estorff[72] at the top of his generalized section of this formation, which is apparently largely based on the section exposed south of Flattop, a mile southeast of Big Tar Canyon. A section revealing such shale has also been described by Gester and Galloway.[73] Most of the shale is not so siliceous as the topmost part near Flattop and does not form fresh outcrops. It slides considerably on slopes, for, although little bentonite is exposed, there is probably a good deal of it interbedded with this shale. A bed of bentonitic clay 9 feet thick is exposed near the top of the formation in a prospector's pit on the west side of Big Tar Canyon. In a nearby pit is a 6-foot bed of bentonite, and 18 feet above it is a 1-foot bed. The pits revealing these bentonite beds show slickensided fault surfaces and gouge. Wells on the Jacalitos anticline, at the southeast end of Reef Ridge, and near Devil's Den,[74] have shown the presence of bentonitic layers in the Kreyenhagen.

STRATIGRAPHIC RELATIONS

The Kreyenhagen shale is apparently conformable upon the Avenal sandstone. An exact base for the Kreyenhagen was not identified, but the green clay just above the Avenal sandstone is considered to be a basal member. The placing of the green clay in the Kreyenhagen accords with the occurrence below the clay of all the present known molluscan fossils (megafossils) of the Avenal. The foraminiferal evidence for the classification of the clay member is discussed below. The green clay member is not named as a separate unit, because neither its base nor top has been well established.

The top of the Kreyenhagen is marked by a surface of erosion overlain by a layer of pebbles of the succeeding Temblor sandstone. The contact is generally not exposed but may be observed west of Garza Creek, on the road into Garza Canyon, in Baby King Canyon, south of Roundtop, and particularly south of Flattop. South of Roundtop some displacement by faulting has apparently occurred along the contact. The overlying lower member of the Temblor is a massive sandstone, but just above the layer of pebbles at the contact the sandstone is silty.

Limy concretions and limy layers occur in the shale, and yellow limestone in beds about 3 feet thick is present in the lower part. Near the west end of Reef Ridge, just east of Arroyo Pinoso, a bed of limestone is exposed about 200 feet above the base of the formation. Five miles farther east, on the divide east of Canoas Creek, is a bed about 400 feet above the base and another about 150 feet higher. In McLure Valley a limestone layer occurs about 550 feet above the base. Some of the limestones were examined under the microscope by Von Estorff,[75] who reported small angular quartz grains, a few fine feldspar grains, and many radiolaria in a fine crystalline calcite. Some of the limestones are banded, with about 15 light and 15 dark bands to the inch, as shown in a specimen from the McLure Valley, Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 26, 690 feet east, 300 feet north. This banding is not conspicuous on a fresh surface but is emphasized on weathered surfaces. Other hard layers are limy shales, which weather into slabs.

In the upper part of the Kreyenhagen, in the Garza Creek drainage basin, a sandstone lens about 80 feet thick is separated from underlying and overlying shales by alternating layers of sand and silty shale. Three distinct sandstone lenses, each about 25 feet thick, occur near the base of the formation just east of Garza Peak (pl. 15, *A*, *B*), in the upper Big Tar Creek drainage basin. Just south of Roundtop the highest sandstone has large cylindrical concretions about 10 feet high, 6 feet in diameter, and about 50 feet apart.

A white unconsolidated and poorly sorted sandstone in the lower part is stated by Von Estorff[76] to be composed of angular grains, mostly fine and medium-sized, of plagioclase, orthoclase, microcline, quartz, muscovite, and possibly magnetite; it is com-

[71] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 163, 1905. Arnold, Ralph, and Anderson, Robert, op. cit., pp. 67-70 (called Tejon).

[72] Von Estorff, F. E., Kreyenhagen shale at type locality, Fresno County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 1326, fig. 3, 1930.

[73] Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists Bull., vol. 17, No. 10, p. 1183, 1933.

[74] Goudkoff, P. P., Subsurface stratigraphy of the Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 4, p. 472, 1934.

[75] Von Estorff, F. E., op. cit., p. 1330.

[76] Von Estorff, F. E., op. cit., p. 1328, fig. 5-A, histogram.

posed mostly of fresh feldspar and quartz in about equal amounts. Indurated grayish-white sandstone, interbedded with the Kreyenhagen shale, was found by him[77] to have fine well-sorted angular grains of quartz, orthoclase, plagioclase, microcline, antigorite, chert, and hornblende. The antigorite was said to be absent from "the Domengine sandstone" (now Avenal sandstone) of Reef Ridge, and Von Estorff suggested that it may have come from Franciscan rocks from the west.[78]

Sandstone dikes occur, particularly east of Big Tar Canyon (see pl. 9). Some of them are as much as 4 feet thick. Most of them stand practically vertical and strike about north. The sandstone of the dikes is impregnated with dark oil, but on weathered surfaces it is white. The dikes in the Reef Ridge area are apparently similar to those found north of Coalinga.[79]

The basal beds of the formation, here designated the green clay member, have been mapped separately (see pl. 9). This member is less resistant to erosion than the adjacent strata and is recognizable in the field as a greenish band about 75 feet wide, just above the Avenal sandstone. It is a clay shale with irregular dark spots and contains numerous well-preserved Foraminifera. In the western part of the Reef Ridge area the clay is only a few feet thick, but eastward in McLure Valley it is locally about 30 feet thick. Fragments of greensand, possibly marking the base, have been found along this green band. The member contains laminated silts and sands and evidently grades downward into the Avenal and upward into the typical shale of the Kreyenhagen. At many places a white sandstone about 25 feet thick separates this member from the typical Kreyenhagen shale. On the north fork of Garza Creek (loc. 55) the member consists of about 50 feet of alternating sands and clays, which become more sandy upward and change to a white sandstone. Here the contact with the underlying Avenal is straight and even and is marked by a thin layer of gypsum. Fragments of greensand were found near the contact, but none were in place. The topmost portion of the underlying Avenal is about 40 feet of thin-bedded sands above a hard fossiliferous ledge. The green clay was placed by Arnold and Anderson[80] in the transition zone between the Avenal and Kreyenhagen, and Jenkins[81] suggested that it and the overlying white sandstone (of local extent) might better be considered as upper Avenal rather than lower Kreyenhagen. The green clay member has also been called "the green mud," "the Canoas silt," and "the J zone."[82] Since this report was written it has been named the Canoas siltstone member of the Kreyenhagen shale by Cushman and Siegfus.[83]

The unconformity at the top of the Kreyenhagen appears to truncate the shale, and thus accounts for the thinning toward the easternmost and westernmost outcrops in the Reef Ridge area. In Little Tar Canyon at the east end of Reef Ridge the Kreyenhagen is about 150 feet thick near the place where it is overlapped by the McLure shale, but 1½ miles to the northwest along the strike it is about 1,200 feet thick. At the west end of the Kreyenhagen outcrop the decrease in thickness is more gradual. Just east of Arroyo Pinoso the shale is about 200 feet thick, and it apparently decreases gradually westward until it disappears within a distance of about 2 miles, or 1 mile east of Zapato Canyon. These differences in thickness are probably all due to erosion during the Kreyenhagen and Temblor interval.

Also the rapid thinning of the Avenal sandstone at the west end of Reef Ridge is apparently due to pre-Temblor erosion, for where it is overlain by the Kreyenhagen west of Arroyo Pinoso it maintains a thickness of about 400 feet, but farther west where the Kreyenhagen is absent the Avenal thins out within a distance of 1 mile.

FOSSILS AND CORRELATION

The only molluscan fossil found in the Kreyenhagen shale is the small pecten *Propeamusium interradiatum* (Gabb) (see pl. 12, figs. 8, 9), which has been regarded as of Eocene age.[84] This species was found in limy shale layers that generally occur in the lower half of the formation. It was not noted in the underlying green clay. At the type locality of the Kreyenhagen on Canoas Creek,[85] the species occurs near the middle of the formation and was reported from the top of the formation in a core of a nearby well (p. 109). This species has also been found in the lower half of the formation by Von Estorff.[86] It was obtained at localities 99 to 105, which are west of Roundtop.

Propeamusium apparently occurs with *Delectopecten* north of Coalinga, as *Delectopecten* and one specimen of *Propeamusium* (Catalog No. 165634) in the National Museum have been figured as from locality 4616.[87] On the label of this *Propeamusium,* however, the locality has been changed to 5013, the same as that of the other figured *Propeamusium* (Catalog No. 165667) in the Museum. Therefore this evidence is not sufficient proof of the association of *Propeamusium* and *Delectopecten.*

The genus *Propeamusium* is living along the California Coast and in Bering Sea,[88] but the single living species, *P. alaskense* Dall, is probably not closely related to the fossil species *P. interradiatum,* because it has many more internal radiating ribs than the fossil form. A species similar to this fossil, however, is living in the Gulf of Panama, where it has been dredged from 1,471 to 1,873 fathoms, and in the mid-Pacific in ooze at 2,463 fathoms.[89] The

[77] Von Estorff, F. E., op. cit., pp. 1329-1330, fig. 5-B, histogram.
[78] Von Estorff, F. E., op. cit., p. 1330.
[79] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California: U. S. Geol. Survey Bull. 398, p. 66, pl. 6-A, 1910. Jenkins, O. P., Sandstone dikes as conduits for oil migration through shales: Am. Assoc. Petroleum Geologists Bull., vol. 14, No. 4, p. 415, fig. 2, 1930.
[80] Arnold, Ralph, and Anderson, Robert, op. cit., p. 69, fig. 3.
[81] Jenkins, O. P., Stratigraphic significance of the Kreyenhagen shale of California: Mining in California, vol. 27, No. 2, pp. 143, 181, 1931.
[82] The term "J zone" was used by Stanley Siegfus in a privately distributed description of the section on Garza Creek.
[83] Cushman, J. A., and Siegfus, S. S., Foraminifera from the type area of the Kreyenhagen shale of California: San Diego Soc. Nat. Hist. Trans., vol. 9, No. 34, pp. 390-391, 1942.
[84] Stewart, Ralph, Gabb's California Cretaceous and Tertiary type lamellibranchs: Acad Nat. Sci. Philadelphia, Spec. Pub. No. 3, p. 123, pl. 8, fig. 10, 1930. Arnold, Ralph, Tertiary and Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, p. 53, pl. 2, figs. 9, 10, 11, (after Gabb), 1906. Arnold, Ralph, and Anderson, Robert, op. cit., pl. 25, fig. 7, 11 (as *Pecten*).
[85] Hanna, G. D., The age and correlation of the Kreyenhagen shale in California: Am. Assoc. Petroleum Geologists Bull., vol. 9, No. 4, p. 995, 1925 (as *Pecten interradiatus*).
[86] Von Estorff, F. E., Kreyenhagen shale at type locality, Fresno County, Calif.; Am. Assoc. Petroleum Geologists Bull., vol. 14, No. 10, pp. 1326, 1331, 1930 (as *Pecten interradiatus*).
[87] Arnold and Anderson, op. cit., pl. 25, fig. 2 (*Delectopecten*), figs. 7, 11 (*Propeamusium*).
[88] Grant, U. S., IV, and Gale, H. R., Pliocene and Pleistocene Mollusca of California; San Diego Soc. Nat. Hist. Mem., vol. 1, p. 234, 1931. Arnold, Ralph, op. cit., p. 133, pl. 53, figs. 2a, 3; Bering Sea, 80 fathoms.
[89] *Propeamusium malpeolonium.* Dall, W. H., The Mollusca and the Brachiopoda: Harvard Coll. Mus. Comp. Zoology Bull. 43, No. 6, p. 405, pl. 6, fig. 7, 1908.

presence of these fossils in the limy layers of the Kreyenhagen shale, and also the absence of other Mollusca, may be due to the deposition of the limy layers in deep water, possibly as deep as a thousand fathoms.

A fossil leaf has been reported from the Kreyenhagen shale in the Reef Ridge area.[90]

The microfauna consists chiefly of Foraminifera and Radiolaria. The Radiolaria are most abundant in the upper part of the shale, and the Foraminifera are most abundant in the lower part. One of the most accessible localities for Foraminifera is immediately below the contact of the Kreyenhagen with the Temblor on the road into Garza Canyon. That fauna, however, is said to resemble the green clay fauna rather than the typical Kreyenhagen fauna, though it occurs about 800 feet above the basal green clay.

A brief study of the Kreyenhagen microfauna by Von Estorff[91] has yielded a list of eight genera of Foraminifera from a locality half a mile west of Canoas Creek but a larger fauna from the lower part of the Kreyenhagen in the canyon south of Flattop and 1 mile east of Big Tar Canyon. The fauna was described by him as lower Tertiary. Later it was referred to the upper Eocene by Church.[92]

The green clay member is not well exposed in Canoas Creek but was there described by Church[93] as "silty clay shale." The foraminiferal fauna in this clay shale was found to correspond to that in a similar clay shale in the lower part of the Kreyenhagen at Coal Mine Canyon, northwest of Coalinga. The fauna of the clay shale near the base of the Kreyenhagen at the Coal Mine Canyon locality was found to correspond to that in a clay shale near the base of the Kreyenhagen shale in Oil Canyon, northeast of Coalinga. In Oil Canyon a 20-foot foraminiferal "clay shale" lies 8 feet above a gypsiferous clay and glauconitic sand taken as the base of the Kreyenhagen shale. The presence in the 8-foot interval beneath the clay shale of chocolate-brown radiolarian shale seems to justify the inclusion of the "clay shale" with the Kreyenhagen. Although Church cited the "clay shale" fauna as being more closely related to the reef beds of Eocene age in Coal Mine Canyon than to the Kreyenhagen,[94] he has since stated in conversation that this "clay shale" fauna is probably very closely related to overlying faunas in the Kreyenhagen and might, therefore, be considered part of the Kreyenhagen.

The Foraminifera of the Kreyenhagen were later described by Hughes and Laiming[95] and by Goudkoff.[96] According to Goudkoff two faunas are recognizable in the Kreyenhagen of Reef Ridge, an upper and a lower *Spiroplectammina* fauna. The lower occurs in the green clay member of this report and some 200 feet of sands and shales above that member, all of which constituted the transitional zone of Jenkins. The lower fauna was said by Goudkoff to be quite distinct from the fauna of the type Domengine but closely related to that in the type Tejon determined by Huges and Laiming.

A new species of Foraminifera, *Pulvinulinella tenuicarinata*, has recently been described by Cushman and Siegfus[97] from the type locality of the Kreyenhagen shale on Canoas Creek, and seven other new species have been described from Garza Creek, 3 miles southeast of the type locality where the formation is better exposed. Although the age of the fauna was not discussed, attention was called to a number of Eocene species in the fauna as well as the Eocene and Cretaceous genus *Hantkenina*.

Later Cushman and Siegfus[98] described four new species from the Kreyenhagen shale at Little Tar Canyon, probably from the green clay member, and six species from the Kreyenhagen of Garza Creek. The lower part of the section on Garza Creek, according to them, was said to contain species known elsewhere only in the Eocene Aragon formation of Mexico, and the higher beds were said to contain species that are known from the Guayabal formation of Mexico and the Claiborne group of the Gulf Coastal Plain. According to Cushman and Siegfus the upper part of the section has species identical with those from the Chapapote formation of Mexico, of upper Eocene (Jackson) age. Nineteen Foraminifera have been reported from the Avenal and Kreyenhagen formations near the south end of Reef Ridge.[99] The faunas are said to lack marked change in composition and are not differentiated.

In the most recent description of the Kreyenhagen Foraminifera at the type locality, by Cushman and Siegfus,[1] 78 forms are listed, 66 of which are recorded from the green clay. Detailed correlations with other sections are discussed, and it is suggested that the upper part of the Kreyenhagen is to be correlated with the *Uvigerina cocoaensis* zone.

The Kreyenhagen shale has been described and correlated with similar shales at other localities along the west side of the San Joaquin Valley by Jenkins,[2] whose report also contains an annotated bibliography. Measured sections made during the course of his study are on file at Stanford University. Apparently the Kreyenhagen shale is recognizable at a number of localities along the west side of the San Joaquin Valley from the vicinity of Maricopa to Mount Diablo. It is of upper Eocene age as indicated by the Foraminifera,[3] and it probably corresponds to part of the Tejon formation at its type locality.[4] It has also been correlated with the Domengine formation.[5]

Diatoms, radiolarians, and sillicoflagellates described from the Kreyenhagen shale north of Coalinga and elsewhere by Hanna[6] were considered by

[90] Von Estorff, F. E., op. cit., p. 1334.

[91] Von Estorff, F. E., op. cit., p. 1327. Locality IV is evidently from the green clay member.

[92] Church, C. C., Foraminifera of the Kreyenhagen shale: Mining in California, vol. 27, No. 2, p. 204, 1931.

[93] Church, C. C., op. cit., p. 204.

[94] Church, C. C., op. cit., p. 204.

[95] Hughes, D. D., and Laiming, Boris, Notes on the distribution of the Kreyenhagen foraminiferal fauna along the western border of the San Joaquin Valley, paper read before the Pacific Section, Soc. Econ. Paleontologists and Mineralogists, April 3, 1933, quoted by Goudkoff, P. P., op. cit., p. 470.

[96] Goudkoff, P. P., op. cit., pp. 470-472.

[97] Cushman, J. A., and Siegfus, S. S., New species of Foraminifera from the Kreyenhagen shale of Fresno County, California: Cushman Lab. Foram. Research Contr., vol. 11, pp. 90-95, pl. 14, 1935.

[98] Cushman, J. A., and Siegfus, S. S., Some new and interesting Foraminifera from the Kreyenhagen, State of California: Cushman Lab. Foram. Research Contr., vol. 15, pt. 2, pp. 23-33, pls. 6, 7, 1939.

[99] Crume, R. W., Foraminiferal faunule from the Avenal sandstone (middle Eocene) of Reef Ridge, California: Abs. in Geol. Soc. America Bull., vol. 51, No. 12, pt. 2, p. 1982, 1940.

[1] Cushman, J. A., and Siegfus, S. S., Foraminifera from the type area of the Kreyenhagen shale of California: San Diego Soc. Nat. Hist. Trans., vol. 9, No. 34, pp. 385-426, pls. 14-19, table opposite p. 416, 1942.

[2] Jenkins, O. P., The stratigraphic significance of the Kreyenhagen shale of California: Mining in California, vol. 27, No. 2, pp. 141-186, 1931.

[3] Church, C. C., op. cit., p. 206.

[4] Goudkoff, P. P., op. cit., p. 472.

[5] Hughes, D. D., and Laiming, Boris, in Reed, R. D., Geology of California, p. 162, Am. Assoc. Petroleum Geologists, Tulsa, 1933.

[6] Hanna, G. D., Diatoms and sillicoflagellates of the Kreyenhagen shale: Mining in California, vol. 27, No. 2, pp. 187-201, 1931.

him to be of probable Eocene age and to indicate open and deeper water conditions than the underlying sands.

MIOCENE SERIES

TEMBLOR SANDSTONE

DEFINITION

The Temblor sandstone received its name from the Temblor Ranch of the Temblor Range and was recognized on Reef Ridge by Anderson.[8] This formation was first described and mapped along Reef Ridge as Vaqueros,[9] but it is now generally designated as Temblor[10]. In this report it is divided into two unnamed members, which are separated by a thin layer of pebbles and fossils in which a large pecten is particularly common. The lower member is about 150 feet thick and the upper member 850 feet thick.

DISTRIBUTION

The Temblor sandstone forms the crest of the conspicuous, rugged Reef Ridge. (See pl. 15.) At the southeast end of the area here described, however, the Temblor is overlapped, and the crest of the ridge is then formed by the McLure shale, and at the northwest end of the area the crest on the south wall of Zapato Canyon is formed by the Avenal sandstone (pl. 16, A).

CHARACTER

The lower member of the formation is a light-colored massive sandstone with few fossils. Oil seeps are present in it in the southeastern part of the area, the best known being those in Big Tar Canyon. In Little Tar Canyon the sandstone of the lower member weathers white at the surface, although a fresh fracture is black with oil.

The upper member is more stratified and fossiliferous (see pl. 14) and in general consists of coarse sandstone with numerous pebble conglomerates and resistant fossiliferous ledges, which may be traced for a few miles along the strike and which form steep dip slopes on the north face of the ridge. Some fine-grained silty beds are also present. A sample of the Temblor sandstone studied by Reed[11] was reported to have more large grains, more turbid feldspars, and more muscovite than Eocene sandstone of this area. In their studies of the oil-producing zones of the Kettleman Hills Goudkoff[12] and Bramlette[13] have made studies of the mineralogy of the Temblor sands along Reef Ridge according to Bramlette.

The major part of the Temblor (middle Miocene) sandstones along Reef Ridge consists of a distinctive andesitic sand zone. In Canoas Creek and Big Tar Canyon this zone is about 500 feet thick and includes the "reef beds" containing *Turritella ocoyana* and most of the sand containing "buttons" or *Scutella Merriami* * * *. The mineral tabulations indicate that this zone is characterized by abundant andesine, much of which shows a good euhedral form with distinct zonal growth, many andesitic rock grains of finer texture, varying amounts of more or less altered shards of volcanic glass, and among the heavy minerals considerable amounts of green and basaltic (brown) hornblende, augite, and actinolite—the actinolite perhaps derived from hornblende. From the composition it is estimated that parts of this zone contain nearly 50 percent of andesitic pyroclastic materials, mixed with the ordinary clastic sands. This mineral zone is sharply delimited from the basal Temblor and from overlying strata in the outcrops.

The uppermost 60 feet of Bramlette's Temblor in Big Tar Canyon is distinct from the underlying andesitic zone and is characterized by an abundance of chromite, and near the top serpentine and uvarovite were found.[14] At least some of this zone is considered basal McLure in this report (see below).

The mineral tabulations[15] list about two dozen minerals from the basal Temblor, or lower 100 feet of the outcrops. This lower sand evidently corresponds to the lower member of the Temblor sandstone of this report, but the pebble conglomerate here used to divide the formation into two parts is within the andesitic sands, though it cannot be far above the base—perhaps as much as 50 feet in Garza Canyon.

The division of the Temblor sandstone into lower and upper members was made because it contains a mappable horizon, the fossiliferous pebble bed, separating the two members. There may be a more widespread recognizable horizon somewhat higher in the Temblor sandstone, but if so it is not so conspicuous and, therefore, not so readily mappable. The base of the lowest gritty sandstone containing "sand dollars" may be such a horizon. Very few fossils were found between the base of the upper member and the lowest sand dollar beds, so that on paleontologic evidence the oldest beds of the upper member might just as well be placed in the lower member. The fossiliferous pebble bed separating the two parts of the formation may represent a separate faunal zone, but it has been placed with the lower member. This bed is frequently exposed above somewhat cliff-forming sandstone and below more easily eroded silty sands. It is very thin; at places only a single layer of pebbles is present, but on the divide just west of Canoas Creek it is a foot thick and contains cobbles 3 inches long. South of Roundtop there appears to be two pebble beds about 50 feet apart. Faulting, however, causes the repetition of the pebble bed along the southeast side of Roundtop, and those on the southwest side are not typical and may be higher in the section. At the north end of McLure Valley there are two pebble beds about 40 feet apart. Farther east in Little Tar Canyon none were found. On the west side of Zapato Canyon a number of pebble layers are at approximately this horizon.

STRATIGRAPHIC RELATIONS

The Temblor sandstone rests upon the Kreyenhagen shale and is separated from it by a pebble layer and a surface of erosion. No marked difference in dip or strike has been noted between the two formations, but the Temblor overlaps both the Kreyenhagen and Avenal formations near Zapato Canyon. The surface of erosion apparently represents considerable geologic time—apparently all of

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[8] Anderson, F. M., op. cit., pp. 169-170, 171.

[9] Arnold, Ralph, and Anderson, Robert, op. cit., pl. 1, pp. 80, 83-84.

[10] Reed, R. D., Role of heavy minerals in the Coalinga Tertiary formations: Econ. Geology, vol. 19, pp. 731-732, 1924. Clark, B. L., Tectonics of the Valle Grande of California: Am. Assoc. Petroleum Geologists Bull., vol. 13, No. 3, p. 216, 1929. Gester, G. C., and Galloway, John, Geology of the Kettleman Hills oil fields, California: Am. Assoc. Petroleum Geologists Bull., vol. 17, No. 10, pp. 1167, 1178-1182, 1933.

[11] Reed, R. D., Geology of California, pp. 171, 172, Am. Assoc. Petroleum Geologists, Tulsa, 1933.

[12] Goudkoff, P. P., Subsurface stratigraphy of Kettleman Hills oil fields: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 4, p. 464, 1934.

[13] Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 12, p. 1567, 1934.

[14] Bramlette, M. N., op. cit., p. 1572.

[15] Bramlette, M. N., op. cit., p. 1564.

Oligocene time. The Leda zone[16] and the *Uvigerina cocoaensis zone*,[17] both of which appear to be included in the Tumey formation of Atwill,[18] found between the Temblor and Kreyenhagen north of Anticline Ridge, evidently record some of the time of this interval. Apparently about 1,000 feet of Kreyenhagen was removed from each end of Reef Ridge during this interval. The Temblor sandstone is overlapped by the McLure formation at the southeast end of Reef Ridge and is separated from it, where their dip and strike appear to be concordant, by a surface of erosion and a conglomerate. The contact is well exposed on the north side of Garza Creek, on the south side of Canoas Creek, and in Zapato Canyon (see pl. 16, *B*).

South of Roundtop, where the lower member rests upon an upper sandstone lens of the Kreyenhagen, the contact between the two formations has been affected by faulting. The base of the Temblor is there a layer of pebbly brown sandstone 1 foot thick, and the contact appears to coincide with the plane of a thrust fault that is practically parallel to the bedding. Apparently some 25 feet of upper Kreyenhagen shale has here been cut out by the overthrust. Cone-in-cone structure occurs in the fault zone, which is about 1 inch wide.

It has been suggested by Bramlette[19] that the highest Temblor beds in Big Tar Canyon (see pl. 16, *C*) are equivalent to the Big Blue serpentinous member, which is above the fossiliferous portion of the Temblor on Anticline Ridge, north of Coalinga, and that they are later than the uppermost beds in Canoas Creek. The presence of *Clementia* and *Miltha* in the upper beds at Big Tar Canyon also was cited as possibly indicating younger strata than those found elsewhere on Reef Ridge but possibly equivalent to *Clementia*-bearing sandstone just beneath the Big Blue member on Anticline Ridge. The *Clementia* beds in Big Tar Canyon are considered McLure, on the following evidence not available to Bramlette. *Clementia* and *Miltha* have since been found near Little Tar Spring (loc. 12). There the fauna is 40 feet below the shale part of the McLure, and the Temblor is only about 250 feet thick, less than half the thickness in Big Tar Canyon. In Big Tar Canyon this fauna is above a boulder conglomerate with serpentine boulders, which is considered the basal conglomerate of the McLure. The contact was not recognized near Little Tar Spring, where the exposures are not good, and some of the boulder conglomerates there may belong to a conglomerate facies of the Temblor not found in Big Tar Canyon and not recognized farther northwest .These conglomerates are thicker than those in Big Tar Canyon, and they take the place of the crest-forming Temblor ledge of Reef Ridge in this area. In Big Tar Canyon this ledge is about 250 feet below the basal conglomerate of the McLure. Although the conglomerates were not observed to truncate the ledge near Little Tar Spring, they overlie the ledge just west of the locality where it disappears, and they occupy the projected position of the ledge of the locality where it disappears. It seems more reasonable to identify the *Miltha* fauna and the conglomerates with the transgressing McLure than to introduce a transgressing member in the upper Temblor, which would here be, at least locally, conformable with the McLure. These conglomerates, however, may include thin and discontinuously deposited material older than the McLure. The beds of sand dollars just below the conglomerate of the base of the McLure on Canoas Creek are considered the highest Temblor beds exposed on Reef Ridge, and they are 500 feet above the probable equivalent of the crest-forming ledge of Big Tar Canyon.

Considering the unconformity at the base of the McLure at Little Tar Spring, where the Temblor, Kreyenhagen, and Avenal are overlapped, it seems reasonable to expect that the McLure overlaps strata not exposed on Reef Ridge. As suggested by Bramlette,[20] perhaps as much as 600 feet of oil-bearing Temblor sands of North Dome of the Kettleman Hills is missing from the outcrops on Reef Ridge. However, at least some of those oil-bearing sands may be lenses of basal McLure.

FOSSILS AND CORRELATION

GENERAL FEATURES.—The fossils found in the Temblor sandstone, particularly the guide fossil *Turritella ocoyana* (pl. 17, fig. 10), are the basis for the correlation of these strata with Temblor strata in the Temblor Range and in other parts of California. The general correlation was made by Anderson.[21] Arnold and Anderson[22] also made this correlation but used the name Vaqueros, which is the name of a formation in the Salinas Valley now considered slightly older than the Temblor. The publications by these authors contain lists of fossils from the Temblor on Reef Ridge.

The lower member of the Temblor sandstone on Reef Ridge lacks the fossiliferous ledges of the upper member, but fossils have been found in it in Big Tar Canyon south of Flattop (loc. 1), in Beltran Canyon (loc. 6), and in Zapato Canyon (loc. 9). The most abundant fossils are Anadara (pl. 17, fig. 7), which are found in layers with both valves preserved. *Lucinoma* preserving both valves occurs with it at some localities. *Turritella* has been found in this member in Garza Creek Canyon and *Bruclarkia* in Zapato and Beltran Canyons.

The most important fossils of the upper member are the small sand dollar *Astrodapsis? merriami* (pl. 11, fig. 2), *Turritella ocoyana* (pl. 17, fig. 10), *Vertipecten* cf. *V. nevadanus* (Conrad), and *Aequipecten andersoni* (pl. 17, figs. 1-3). The sand dollar is about the size of an ordinary button, and these strata have been called the button bed. The sand dollars are most abundant at the top of the Canoas Creek section, where some strata are formed solely of sand dollars, but they also occur lower, possibly within 50 feet of the base of the upper member. They are not abundant near the east and west ends of the Temblor outcrop where the McLure shale overlaps most of the Temblor sandstone. The *Turritella* is most abundant in the middle of the upper member, where beds 3 to 6 feet thick contain practically no other fossil, and the turritellas are very

[16] Jenkins, O. P., op. cit., p. 145.
[17] Goudkoff, P. P., op. cit., pp. 469-470.
[18] Atwill, E. R., Oligocene Tumey formation of California: Am. Assoc. Petroleum Geologists Bull., vol. 19, No. 8, pp. 1192-1204, 1935.
[19] Bramlette, M. N., op. cit., p. 1572. Also discussed in Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, California: U. S. Geol. Survey Prof. Paper 195, p. 142, 1940.
[20] Bramlette, M. N., op. cit., p. 1573.
[21] Anderson, F. M., op. cit., pp. 169, 171, 172. Lists of fossils from Tar springs (Big Tar Canyon), Sulphur Springs (Arroyo Pinoso), and Kreyenhagen Wells (Canoas Creek).
[22] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 80, 83, 87.

close together. In many places two beds are present 10 feet apart. The turritellas lie in many different positions in relation to the bedding; there seems to be no systematic orientation beyond the tendency for the long axis of the fossil to lie near the bedding planes. On the west side of Baby King Canyon the *Turritella* ledge is 6 feet thick and contains four *Turritella*-bearing layers, each 6 inches thick. In the western part, near Beltran Canyon, in Arroyo Pinoso, and in Zapato Canyon, *Turritella* is found with the borer *Zirphaea dentata* (Gabb).

The *Vertipecten* (pl. 17, fig. 4) was found in the lower member and particularly in the pebble conglomerate at the top of the member. This is a large pecten compared to the *Aequipecten andersoni* (pl. 17, figs. 1-3) that is abundant in the upper member of the formation.

The Temblor fauna from Reef Ridge is very different from the Eocene Avenal fauna. The genera *Anadara, Chione, Compsomyax, Dosinia, Kalayoldia* (subgenus), *Thracia, Austrotrophon, Bruclarkia, Nucella, Phos, Progabbia,* and *Tegula?* and the form "*Nassa arnoldi,*" although present in both the upper and lower members of the Temblor, were not found in the Avenal. *Aequipecten, Vertipecten,* and *Lucinoma* are likewise unknown in the Avenal, and *Turritella ocoyana* bears very little resemblance to the Avenal turritellas. On the other hand no Avenal forms (p. 90) were found in the Temblor. The Temblor fauna also differs from that of the Jacalitos formation, inasmuch as *Bruclarkia, Phos,* and *Progabbia* have not been found in the Jacalitos, and the sand dollar *Dendraster* of the Jacalitos has not been found in the Temblor. *Aequipecten* and *Turritella ocoyana* are also absent from the Jacalitos, but *Chione, Dosinia, Zirphaea,* and *Anadara* are known in the Jacalitos. Because of these last four forms the Temblor fauna resembles that of the Jacalitos more than it does that of the Avenal. Less abundant forms of the Temblor fauna, likewise show the same similarity.

A foraminiferal assemblage known as the *Nonion-Nonionella* fauna has been reported from the upper member of the Temblor of Big Tar Canyon, 400 feet below the top.[23]

VERTEBRATE FOSSILS. — Although no important vertebrate fossils were found, the following fragments are worth recording not only because they show that such fossils are present along Reef Ridge but also because some of the fragments may be useful when comparable elements of already described forms have been found. The identifications were made by Dr. Remington Kellogg of the National Museum.

On the top of Reef Ridge, just east of Beltran Canyon (Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30, 4,140 feet W., 1,130 feet N.), a cervical vertebra of a fur seal (otariid), large bivalves (mactroid and venerid), and a medium-size gastropod (*Bruclarkia*) were found in the upper member. On the south side of Roundtop the distal end of a left femur of a fur seal about the size of a living female fur seal was found in a pebble layer near the base of the upper member (loc. 10). A fragment of a lumbar vertebra of a porpoise was also found at this locality. The distal end of the shaft of a left humerus of a fur seal was found near locality 1 in the lower member, about 75 feet above the base. In the upper of the two pebble beds on Roundtop the anterior articular end of a left ulna of a whalebone whale (cetothere) was found in association with *Vertipecten;* it may be *Tiphyocetus temblorensis* Kellogg,[24] but comparable elements are not available. A fragment of a molar tooth of an extinct "sea cow" (*Desmostylus*)[25] was found on the surface near the Temblor-McLure contact on the west side of the first canyon east of Canoas Creek, below Dirty Spring, near locality 20. Fragments were also found by Bramlette [25a] northwest of Big Tar Canyon in basal McLure or uppermost Temblor sandstone and one fragment has been reported from the highest reef bed of the Temblor near the south end of Reef Ridge.[26] Abundant fragments of *Desmostylus* have been found in the Temblor north of Coalinga.

FAUNAL RELATIONS WITHIN THE TEMBLOR SANDSTONE

The Temblor sandstone contains two faunal zones (see list of Miocene fossils, table 2), a lower, or *Vertipecten* zone, practically corresponding to the lower member, and an upper, or *Aequipecten* zone, corresponding to the upper member. The faunas of these two zones are similar. Species of the following genera were found in both zones, and practically all were found at more than two localities:

Anadara	Thracia
Chione	Austrotrophon
Compsomyax	Bruclarkia
Dosinia	Cylichnina
Glycymeris	"Nassa" arnoldi
Kalayoldia	Neverita
Ostraea	Nucella
Saccella	Phos
Solen	Progabbia
Spisula	Tegula?
Tellina	

LOWER ZONE.—The type locality of the lower, or *Vertipecten*, zone is on the west side of Beltran Canyon at locality 6, where about 34 different forms have been collected. On the west side of Zapato Canyon at locality 9, an equally large fauna was collected, and a somewhat different fauna was found south of Roundtop at locality 1. The most conspicuous fossils in this zone are double-valved specimens of *Andara* and *Lucinoma,* found in thin layers in about the middle of the zone, and *Vertipecten,* particularly in thin pebble beds in the upper part of the zone. *Anadara* and *Lucinoma* are so abundant in this zone that either or both might equally well be used as the name for the zone. *Taras* is also abundant, but it is a smaller and less conspicuous fossil. *Anadara obispoana* was not recognized in the upper member but is abundant in the lower, but this species is not a very useful guide fossil because of its resemblance to *A. devincta,* which occurs in both zones. The forms of *A. obispoana* from Reef Ridge are less produced anteriorly and have fewer ribs (about 26 instead of about 30) than the forms of *A. devincta* from Reef Ridge.

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[23] Goudkoff, P. P., op. cit., pp. 464, 468.

[24] Kellogg, Remington, Pelagic mammals from the Temblor formation of the Kern River region, California: California Acad. Sci., 4th ser., vol. 19, No. 12, p. 337, fig. 88, 1931. Bone bed of Kern River, Shark-Tooth Hill.

[25] Vander Hoof, V. L., A study of the Miocene sirenian *Desmostylus:* California Univ., Dept. Geol. Sci., Bull., vol. 24, No. 8, pp. 169-262, 1937.

[25a] Bramlette, M. N., in Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., p. 124.

[26] Vander Hoof, V. L., op. cit., p. 199.

The following forms have been found in at least two localities in the lower zone but were not found in the upper zone:

Acila conradi	Crawfordina cf. C. weaveri
Anadara obispoana	"Drillia" temblorensis
Mytilus middendorffi	Oliva californica
Tellina oregonensis	Priscofusus? carlsoni
Acteon cf. A. boulderanus	Priscofusus lincolnensis
Calyptraea cf. C. mamillaris	Sinum cf. S. scopulosum

The absence of these forms from the upper member is probably a little more significant than the absence of the following, each of which was found at only one locality in the lower member:

Anomia? sp.	Calliostoma cf. C. pacificum
Atrina cf. A. alamedensis	Cancellaria cf. C. posunculensis
Macoma cf. M. copelandi	Fusinus empireënsis
Nucula cf. N. washingtonensis	Margarites? sp.
Spisula cf. S. catilliformis	?Niso antiselli
Tellina idae	Pseudotoma cf. P. keepi
Tivela cf. T. gabbi	Trophosycon nodiferum
Terebratalia sp.	Dentalium n. sp.
Acmaea sp.	

UPPER ZONE.—The upper, or *Aequipecten*, zone, known as the "button beds," includes particularly the uppermost part of the formation of Canoas Creek, where the "buttons" (the sand dollar *Astrodapsis? merriami*) are very abundant, some layers being composed entirely of them. The sand dollars are also found well down in the upper zone, almost to its base, but have not been found in the lower zone; consequently, they are a guide fossil for the upper zone, but they may also be present at the base of the overlying McLure shale in Little Tar Canyon where the contact of the formation is obscure. The small pecten *Aequipecten andersoni* is also very abundant in this zone, and the zone is named for it, although "button beds," or the "sand-dollar zone" is equally distinctive, and both are appropriate colloquial names for it. *Pseudocardium* (pl. 17, fig. 6) is another abundant bivalve. The type locality of the *Aequipecten* zone is on Canoas Creek and includes locality 21 and all the beds between the sand-dollar-bearing grit exposed where the road crosses the creek and the top of the formation (loc. 22). A number of fossiliferous beds are found in this interval, some of which may eventually prove to be sufficiently distinct and important to be named, but the interval has not been studied in detail and is not here divided. Conspicuous layers containing *Turritella* are present in the middle of the zone. In the western outcrops *Turritella* is associated with the borer *Zirphaea* in a bed a few feet thick that may be the westward extension of the *Turritella* bed, but the layers have not been definitely traced into one another.

Dosinia margaritana, Volsella cf. *V. inezana,* and *Zirphaea dentata* have been found in the upper zone but not in the lower.

Aequipecten, Turritella, and *Pseudocardium* are probably the most abundant mollusks in the *Aequipecten* zone, but a single specimen of *Turritella* was found in the lower zone (loc. 3). Although *Aequipecten* was not recognized in the lower zone, small incomplete specimens in that zone may be either *Aequipecten* or the young of *Vertipecten*.

The following forms were also found in the upper zone, but none were found at more than one locality:

?Gari edentula	Mitrella near M. tenuilineata
Lyropecten crassicardo	?Scaphander jugularis
Forreria n. sp.	

SIGNIFICANCE OF ZONES.—The differences between the *Vertipecten* and *Aequipecten* zones are evidently due to a change in facies. In general, the sandstones of the upper member of the Temblor sandstone are coarser and more irregularly bedded, a feature that might be due to more shallow water or to deposition in a more exposed position. The faunal differences also seem to be best explained by assuming shallower or more agitated water during the deposition of the upper zone. *Acila, Nucula, Yoldia,* and *Atrina,* and the abundance of gastropods may have been associated with deeper or less agitated water during the deposition of the sediments of the *Vertipecten* zone. In contrast, *Zirphaea,* abundant large *Turritella,* and the sand dollar, which may have lived only a few feet below low tide, suggest shallow or disturbed waters during the deposition of the sediments of the *Aequipecten* zone. Although the sand dollars may have been washed from their natural habitat into deeper water and killed in great numbers, there are so many of them, particularly in the upper part of the zone, that they probably were not washed very far. Consequently, it is possible, if not probable, that much of the deposition of the upper zone was at depths 50 fathoms or less below the low-tide level.

From locality 6 of the lower zone 19 gastropods and 15 bivalves are listed. This fauna contains *Acila, Nucula, Thracia,* and *Yoldia. Acila, Nucula,* and *Yoldia* have been dredged from stations in fine sand near the Farallon Islands.[27] Judging from this one example, locality 6 represents deposition in the open ocean but in fairly shallow water about 70 fathoms in depth. The fauna of the lower zone has more gastropods than bivalves, the ratio being 41 to 37; the upper actually shows more bivalves than gastropods, the ratio being 28 to 18.

The difference between the faunas may be due to shallowing of the water during the deposition of the later part of the formation. The fauna of the Temblor sandstone in general appears less varied than the fauna of the Avenal sandstone, it is comparable to that of the Jacalitos formation, and possibly it is a little less varied in composition than that of the Etchegoin formation and not so varied as the marine faunas of the San Joaquin formation.[28] These less varied faunas seem appropriately associated with the shallower, more restricted seas that presumably accompanied the deposition of the later Tertiary formations. The progressive restriction must have been interrupted many times and reversed by marine planation.

COMPARISON WITH OTHER FAUNAS

The Temblor fauna from Reef Ridge should be compared with at least five faunas in California:

[27] Packard, E. L., Molluscan fauna from San Francisco Bay: California Univ. Zoology Bull. 14, No. 2, pp. 246, 249, 1918. Dredging No. 5788, at 68 fathoms, included 9 bivalves, 11 gastropods, and 2 scaphopods.

[28] Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, California: U. S. Geol. Survey Prof. Paper 195, 1940 [1941].

the Temblor fauna of the Coalinga anticline, the Temblor Mountains, and the Kern River; the Vaqueros fauna; the fauna transitional between the Vaqueros and Temblor; the San Ramon fauna near the Berkeley Hills; and the Santa Margarita fauna of the Coalinga anticline.

The lower, or *Vertipecten*, zone has not been recognized on the Coalinga anticline, but the unfossiliferous oil sand at the base of the Temblor sandstone there[29] corresponds to the lower Temblor member of Reef Ridge, although the correspondence may be in stratigraphic position only.

Three faunal zones were recognized by Arnold and Anderson[30] in the Temblor sandstone on the Coalinga anticline: a lower *Ostraea titan* zone; a middle zone with *Aequipecten, Anadara,* and *Astrodapsis? merriami;* and an upper zone with a number of forms, such as *Apolymetis, Bruclarkia santacruzana, Cancellaria vetusta,* and *Conus* that have not been found along Reef Ridge. In addition to the forms listed, the collection from the upper zone, which is now in the National Museum, also contains *Terebra, Ficus,* and fragments of a large *Astrodapsis,* which likewise have not been found along Reef Ridge. Possibly all three of these zones are equivalent to part, at least, of the upper, or *Aequipecten,* zone of the Temblor on Reef Ridge, but they have not been recognized as such on Reef Ridge.

The fauna of the Santa Margarita sandstone,[31] which overlies the Temblor of the Coalinga anticline, lacks many forms present in the Temblor of Reef Ridge, such as species of *Bruclarkia, Phos,* and *Progabbia, Turritella ocoyana,* and *Aequipecten andersoni,* and it contains *Aequipecten raymondi,* which has not been recognized on Reef Ridge. The Santa Margarita sandstone overlies the Big Blue serpentinous member of the Temblor sandstone on the Coalinga anticline, and strata equivalent to the Big Blue member are present in a well in Canoas Creek (p. 109) above the exposed beds of the Temblor sandstone of Reef Ridge. The Santa Margarita of the Coalinga anticline is, therefore, younger than the Temblor of Reef Ridge.

The molluscan fauna of the type Temblor sandstone of the Temblor Mountains has not been described in detail, and no comparison with the zones of Reef Ridge can be made. In fact, most references to Temblor Mollusca are not to those of the type locality but to the well-preserved fauna in the "Ocoya Creek series" on Kern River, on the opposite side of the San Joaquin Valley. That fauna, which has been called the "Barker's Ranch fauna," is well known, and a new list of its species has been published by Loel and Corey[32] in their important description of the Vaqueros sandstone. Most of the Reef Ridge Temblor species are closely related to, if not identical with, species in the Temblor sandstone on Kern River, but the poor preservation of many of the specimens from Reef Ridge does not permit many unqualified identifications. The presence of *Turritella ocoyana, Aequipecten andersoni Phos dumbleanus, "Nassa" arnoldi, "Drillia" temblorensis,* and *Bruclarkia barkeriana* would seem to justify a direct correlation of the upper, or *Aequipecten,* zone with the Temblor sandstone on Kern River. The small size of the fauna on Reef Ridge, however, and the preponderance of bivalves over gastropods, the ratio being 28 to 18, is not typical of Temblor faunas. Presumably further search will result in the finding of fauna of larger size from Reef Ridge and probably also increase the relative number of gastropods, but the upper zone may be somewhat younger than the Temblor on Kern River and may represent shallower water conditions.

The lower, or *Vertipecten*, zone has a few more gastropods than bivalves. This ratio is more like that of the Temblor fauna on Kern River, 75 to 56,[33] and contrasts with the typical Vaqueros sandstone, from which three times as many bivalves as gastropods have been listed.[34] Such an abundance of bivalves is unusual, but from many places in the Vaqueros about twice as many bivalves as gastropods have been listed.[35] The similarity of the molluscan ratio suggests that the facies of the Temblor sandstone on Kern River is similar to that of the lower zone of Reef Ridge, and this is further indicated by the presence of the bivalves *Acila, Nucula, Thracia, Yoldia,* and *Kalayoldia,* not one of which was listed from the Vaqueros formation.[36] These bivalves probably indicate deposition in an open sea (p. 100), and their presence conforms to the prevailing generalization that the Temblor strata were deposited in more open seas than the typical Vaqueros strata. The more open sea and probably deeper water conditions represented by the Temblor sandstone may be thought of as a probable stage in passing from the shallow-water Vaqueros sandstone to the deeper-water shales of the Monterey formation. This is suggested also in the La Panza region, where 49 bivalves and 26 gastropods were reported from the Vaqueros sandstone and 85 bivalves and 71 gastropods from the Temblor sandstone.[37] The transition from shallow water to deeper water is not indicated along Reef Ridge, however, where the gastropod fauna comes first, and in addition the overlying McLure shales are unconformable upon the Temblor sandstone. The upper fauna of the Temblor sandstone on Reef Ridge lacks characteristic Vaqueros fossils and would not be confused with a typical Vaqueros fauna containing *Turritella inezana, Lyropecten magnolia, Anomia,* and *Rapana. Lyropecten magnolia* and *Anomia vaquerosensis* have been reported[38] from San Emigdeo in a bivalve fauna considered to be Vaqueros, and *Anomia* and *Turritella inezana* were reported from the bivalve fauna of the Vaqueros-Temblor transition of La Panza,[39] but the absence of these forms from a gastropod fauna may not be significant. Similarly, the presence of Temblor forms in the Reef Ridge gastropod fauna may not be significant, but they may be conveniently used as the basis for associating this fauna with the Temblor, regardless of the geologic significance of the association. All the

29 Arnold, Ralph, and Anderson, Robert, op. cit., p. 81.
30 Arnold, Ralph, and Anderson, Robert, op. cit., p. 87.
31 Nomland, J. O., Fauna of the Santa Margarita beds in the North Coalinga region of California: California Univ., Dept. Geol. Sci., Bull. 10, No. 18, pp. 300, 301, 1917.
32 Loel, Wayne, and Corey, W. H., The Vaqueros formation, lower Miocene of California; I, Paleontology: California Univ., Dept. Geol. Sci., Bull., vol. 22, No. 3, pp. 167-174, 1932.
33 Loel, Wayne, and Corey, W. H., op. cit., pp. 167-174.
34 Loel, Wayne, and Corey, W. H., op. cit., pp. 117-120. Lists from Vaqueros Creek.
35 Loel, Wayne, and Corey, W. H., op. cit., pp. 126-132. The ratios for the 10 localities are 53:29, 56:25, 33:17, 56:29, 42:25, 50:19, 42:16, 50:26, 54:18, and 26:5.
36 Loel, Wayne, and Corey, W. H., op. cit., pp. 126-130.
37 Loel, Wayne, and Corey, W. H., op. cit., pp. 108-111, 167-174.
38 Loel, Wayne, and Corey, W. H., op. cit., p. 95.
39 Loel, Wayne, and Corey, W. H., op. cit., pp. 107-111.

species in the lower zone are similar to or identical with species from the Temblor sandstone of Kern River, except some of the few discussed below.

Tellina oregonensis, described from Astoria, Oreg., is said to be common in the Briones and San Ramon formations[40] but was not reported from the Vaqueros sandstone by Loel and Corey.

Nucella packi was described from the San Ramon sandstone[41] but has not been reported from the Vaqueros sandstone. All the specimens from the Temblor sandstone of Reef Ridge, except one from locality 2 and a fragment from locality 7, are much worn. They appear to be a little more slender (pl. 17, fig. 11) than the figured type of this specimen and are here named variety *talea.*

Tellina idae is a living species not listed from the Vaqueros sandstone, nor is *T. tenuilineata* Clark,[42] probably a closely related species from the San Ramon sandstone. The radial sculpture on Kern River specimens (loc. 6623, Nat. Mus.) is very delicate.

Tegula? malibuensis is a Vaqueros species.[43] The Reef Ridge specimens are not sufficiently well preserved to permit an unqualified identification.

Crawfordina weaveri, Acteon boulderanus, and *Nucula washingtonensis* are from the Astoria shale in Chehalis Valley, Wash.,[44] which is correlated with the Temblor sandstone of California. The *Acteon* and *Nucula* were also reported from the Temblor sandstone of Kern River.

Priscofusus lincolnensis and *P.? carlsoni* were described from Miocene strata north of Yaquina Bay, Oreg.,[45] and *Fusinus empireënsis* from the Empire formation, probably Pliocene, of Oregon.[46]

Lyropecten estrellanus and *L. crassicardo* were not found in the Vaqueros by Loel and Corey.[47]

Macoma copelandi and *Dosinia margaritana* are from the Temblor sandstone of La Panza,[48] and *D. margaritana* also occurs at Kern River.[49]

The specimens referred to as *Tivela* cf. *T. diabloensis* may be a new species. They are poorly preserved but seem to be nearer *T. diabloensis*[50] of the San Pablo group than *T. inezana* of the Vaqueros sandstone.[51] The genus is evidently absent from localities on Kern River.

Volsella inezana, from the *Aequipecten* zone, is a Vaqueros species[52] and was not reported by Loel and Corey from the Temblor sandstone. It may be related to *Mytilus? arnoldi* Clark[53] of the Kirker and San Ramon formations.

Mytilus middendorffi is from probable Miocene strata of Alaska and apparently has not, heretofore, been recognized in this country.[54]

Xenohelix clarki is a spiral cast, probably the filling of the burrow of some animal. It was described from the Monterey group in Pine Canyon, Contra Costa County, where it is associated with marine fossils.[55] Their age is approximately equivalent to that of the Temblor fauna. In the vicinity of Garza Creek it was found in both zones. It is interesting that both occurrences of this fossil in California should be of approximately the same geologic age.

The absence of sand dollars from the *Vertipecten* zone is due to ecologic conditions, the lower zone probably representing greater depth of water than the upper zone. The sand dollars or "buttons" of the "button bed" seem to be immature *Astrodapsis.* The species was described as an *Astrodapsis,* long referred to as *Scutella* and recently placed under *Echinarachnius.*[56] *Echinarachnius* is the living northern sand dollar, also known as *Phelsumia,* which seems to be closely related to *Astrodapsis;* in fact, the characteristic features that separate these two genera have not yet been worked out. Raised petals are more common in *Astrodapsis* than *Phelsumia,* but the character is apparently not of specific importance in *Phelsumia* and is known in *Dendraster.* The ambulacral furrows appear to be the same in *Astrodapsis* and *Phelsumia.* The interambulacral plates near the mouth are different, but the variation in this character is such that the difference, if it proves to be fairly constant, would be rather of subgeneric rank, thus making *Phelsumia* a subgenus of *Astrodapsis.* As it is difficult to classify the small "buttons," they seem better left where they were described. The species was not recognized in the Vaqueros sandstone nor on Kern River, but is listed from other Temblor localities.[57]

Scutella? andersoni has also been placed under *Echinarachnius.*[58] This species may be a thin form of *A.? merriami,* but connecting links are not known. It is probably immature, and until the ambulacral furrows, at least, are known the generic determination is doubtful. It may actually be a *Scutella.* The species has been reported from both the Vaqueros and the Temblor sandstones, including the localities on Kern River.[59]

The San Ramon sandstone, as reported from Walnut Creek, has a fauna with a predominance of bivalves, the ratio being 44 bivalves to 25 gastro-

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[40] Etherington, T. J., Stratigraphy and fauna of the Astoria Miocene of southwest Washington: California Univ., Dept. Geol. Sci., Bull. 20, No. 5, p. 84, 1931.

[41] Clark, B. L., The San Lorenzo series of middle California: California Univ., Dept. Geol. Sci., Bull., vol. 11, No. 2, p. 177, pl. 19, figs. 2, 13, 1918 (listed as *Thais*).

[42] Clark, B. L., op. cit., p. 153, pl. 10, figs. 1, 3, 5.

[43] Loel, Wayne, and Corey, W. H., op. cit., p. 272, pl. 64, figs. 1a, 1b (figured as *Tegula* (*Chlorostoma*).

[44] Etherington, T. J., Stratigraphy and fauna of the Astoria Miocene of southwest Washington: California Univ., Dept. Geol. Sci., Bull., vol. 20, No. 5, p. 108, pl. 14, figs. 1, 3, 17 (figured as *Cancellaria* (*Crawfordina*); p. 113; pl. 14, fig. 9; p. 64, pl. 1, figs. 10-12, 1931.

[45] Anderson, F. M., and Martin, B., Neocene record in the Temblor basin, California, and Neocene deposits of the San Juan district, San Luis Obispo County: California Acad. Sci. Proc., 4th ser., vol. 4, pp. 88-89, pl. 6, fig. 8, pl. 5, figs. 2a, 2b, 1914 (figured as *Turis*). Packard, E. L., and Kellogg, Remington, A new cetothere from the Miocene Astoria formation of Newport, Oreg.: Carnegie Inst. Washington Pub. 447, p. 16, 1934.

[46] Anderson and Martin, op. cit., p. 84, pl. 5, fig. 7. Howe, Henry, Faunal and stratigraphic relationships of the Empire formation, Coos Bay, Oregon: California Univ., Dept. Geol. Sci., Bull., vol. 14, No. 3, p. 91, 1922.

[47] Loel, Wayne, and Corey, W. H., op. cit., p. 145.

[48] Wiedey, L. W., Notes on the Vaqueros and Temblor formations of the California Miocene with descriptions of new species: San Diego Soc. Nat. Hist. Trans., vol. 5, p. 149, pl. 19, fig. 2, p. 145, pl. 18, figs. 1-3, 1928. Loel, Wayne and Corey, W. H., op. cit., p. 216, pl. 38, 39.

[49] U.S.N.M. locality 6627, a bivalve fauna, probably Temblor. "12 miles N. 30° E. of Bakersfield, in center W. ½ sec. 36, T. 27 S., R. 28, E.; in small arroyo tributary to Adobe Canyon from west, about one mile above its mouth. In first arroyo upstream from 1070-foot hill. Middle part of lower Miocene."—R. W. Pack and A. T. Schwennesen, 1911.

[50] Clark, B. L., Fauna of the San Pablo Group of middle California: California Univ., Dept. Geol. Sci., Bull., vol. 8, No. 22, p. 462, pls. 54, 55, 1915.

[51] Loel, Wayne and Corey, W. H., op. cit., p. 219, pl. 40, figs. 7-9.

[52] Loel, Wayne, and Corey, W. H., op. cit., p. 206, pl. 33, figs. 7-9 (figured as *Modiolus*).

[53] Clark, B. L., The San Lorenzo series of middle California: California Univ., Dept. Geol. Sci., Bull., vol. 11, No. 2, p. 135, pl. 12, fig. 1, 1918.

[54] Grant, U. S. IV, and Gale, H. S., Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. Hist. Mem., vol. 1, p. 247, 1931.

[55] Mansfield, W. C., Some peculiar spiral fossil forms from California and Mexico: U. S. Nat. Mus. Proc., vol. 77, No. 13, p. 1, pl. 1, fig. 1, 1930. Dryden, Lincoln, *Xenohelix* in the Maryland Miocene; Nat. Acad. Sci. Proc., vol. 19, No. 1, pp. 139-143, 1933.

[56] Grant, U. S., IV, and Hertlein, L. G., The west American Cenozoic Echinoidea: California Univ., Los Angeles, Pub., Math.-Phys. Sci., vol. 2, p. 60, fig. 7 (copy of original figs.), 1938. Arnold, Ralph, Paleontology of the Coalinga District, Fresno and Kings Counties, California: U. S. Geol. Survey Bull. 396, pl. 6, fig. 4, 1909. Record from Garza Creek. Arnold, Ralph, and Anderson, Robert op. cit., pl. 28, fig. 4.

[57] Loel, Wayne, and Corey, W. H., op. cit., p. 141, 167 (listed as *Scutella*).

[58] Grant, U. S., IV, and Hertlein, L. G., op. cit., p. 57, pl. 21, figs. 11, 12.

[59] Loel, Wayne, and Corey, W. H., op. cit., pp. 167, 177, pl. 4, figs. 1, 2.

pods, but like the lower zone of the Temblor sandstone on Reef Ridge it lacks sand dollars.[60] This fauna, known as the *Agasoma gravidum* fauna, has long been associated with the Vaqueros and Temblor molluscan faunas, and this association is apparently also indicated by the Foraminifera.[61] The San Ramon is said to underlie a Temblor molluscan fauna, and the predominance of bivalves suggests the Vaqueros. This bivalve fauna, however, is not that of the typical Vaqueros; in fact the fauna as listed contains *Acila, Nucula, Thracia,* and *Yoldia,* bivalves which are known in dominantly gastropod faunas from the Kern River Temblor and from the lower (*Vertipecten*) zone on Reef Ridge but are not known in the Vaqueros sandstone. The reason for the small number of gastropods in the San Ramon fauna is not evident, though possibly the fauna lived in shallow water protected from wave action. The bivalves cited above seem to indicate a more open sea and possibly deeper water than is indicated by those of the typical Vaqueros fauna—an environment similar to that in which the Temblor fauna lived. This may account for the similarity between the San Ramon and Temblor faunas. The possibility of a Temblor facies appearing in the Vaqueros sandstone has often been mentioned, but, unfortunately, in the most important study of the Vaqueros fauna published to date there is only an indirect reference to the San Ramon fauna.[62] Possibly the absence of such San Ramon gastropods as *Bruclarkia gravida* Gabb and *Ancilla fishii* Gabb from the Vaqueros sandstone is due to the general absence of gastropod faunas from that formation.

McLURE SHALE MEMBER OF MONTEREY SHALE AND REEF RIDGE SHALE

The shales of Miocene age along Reef Ridge have, in the past, been referred to the Monterey[63] and mapped as doubtful Santa Margarita[64] and later differentiated into the McLure shale below and the Reef Ridge shale above.[65] The McLure and Reef Ridge shales are not mapped separately in this report.

McLURE SHALE MEMBER OF MONTEREY SHALE

The McLure shale member of the Monterey is a hard, platy, typically resistant, siliceous shale, about 1,000 feet thick. It was named for its occurrence in McLure Valley.[66] The type locality is on Avenal Creek, in the Tent Hills, along the west line of sec. 6, T. 24 S., R. 17 E., just south of the southern boundary of the area shown on the geologic map (pl. 9).

The McLure shale crops out on the north side of Reef Ridge and forms the main ridge in Little Tar Canyon, for here the ridge-forming Temblor sandstone is overlapped by the McLure. Outcrops of the middle part of the McLure shale are often barren of soil and form a row of light-gray, bare knobs along the north face of Reef Ridge and northwest beyond Reef Ridge. A section was measured by Bramlette[66a] northwest of Big Tar Canyon. Southwest of Reef Ridge the McLure shale forms the Chalk Buttes and the Tent Hills.

The McLure shale is brittle, platy, and siliceous in its typical outcrops. The shale may weather to a light color but is ordinarily dark. Some portions, particularly the lower and upper parts, are not so indurated and probably contain more sand. It was assigned by Arnold and Anderson[67] to the lower part of their Santa Margarita (?) and described by them as a lower, harder, more siliceous, and more thinly laminated, purple and white shale. The upper, softer, more argillaceous brown shale is the Reef Ridge shale of later usage. The base of the McLure at some outcrops consists of coarse sand and conglomerate, which are particularly conspicuous on the south side of Canoas Creek, Zapato Canyon, Garza Canyon, Big Tar Canyon, and at the southeast end of Reef Ridge. At the last three localities the conglomerate is fossiliferous. On Canoas Creek at the base of the McLure is a conglomerate of cobbles 1 foot thick, and 10 feet higher in the section is a 6-inch layer of sticky, fragmentary, light-gray bentonite[68] similar to that used as a datum plane in the Kettleman Hills well sections. Serpentine pebbles[69] and Franciscan pebbles[70] have been recognized in the conglomerate. In Big Tar Canyon the conglomerate is 30 feet thick. Mineralogic analyses of the lowest sand of the McLure in Canoas Creek and Big Tar Canyon differ from those of the Temblor.[71]

Along Reef Ridge the McLure shale seems to be roughly parallel with the underlying Temblor sandstone, but at Canoas Creek, Zapato Canyon, and Garza Canyon the basal sandstone and conglomerate are separated from the Temblor by an erosion surface. Near the south end of the Reef Ridge area, at the north end of Little Tar Canyon (loc. 12 and to the northwest), boulder conglomerates just beneath the shale are included in the McLure. They are absent east of Little Tar Spring, where only a thin, pebbly sand forms the base of the McLure where it rests upon the overturned Cretaceous. The association of the boulder conglomerate with the McLure shale member is discussed under the stratigraphic relations of the Temblor (p. 98). In Zapato Canyon (see pl. 16, *B*) typical McLure shale overlies a 40-foot sandstone having a pebble bed at the top and another at the base. The basal conglomerate contains pebbles 3 inches long. Two feet below this lower pebble bed fragments of *Turritella, Pecten, Dosinia,* and *Glycimeris* were found. The base of the 40-foot sandstone was considered the base of the McLure, and the fossils were considered Temblor. In a prospect well drilled at a point about half a mile across the strike from the base of the McLure in Canoas Creek the McLure and the Temblor are separated by about 21 feet of green and red clay and silt with some sand and pebbles and conglomerate at the base (see p. 109). The clay has many slickensides, and the bed is evidently the equivalent

[60] Clark, B. L., op. cit., p. 80, 1918. Loc. 1131, check list, p. 82, said to be beneath the Temblor horizon.
[61] Kleinpell, R. M., Miocene stratigraphy of California: Am. Assoc. Petroleum Geologists, Tulsa, p. 163, 1938, "Lower Zemorrian". The correlation of the Vaqueros and Temblor strata with the Oligocene of Europe is at variance with the molluscan and vertebrate fossil evidence and does not appear to be unequivocally indicated even by the Foraminifera.
[62] Loel, Wayne, and Corey, W. H., op. cit., p. 156.
[63] Anderson, F. M., op. cit., p. 171.
[64] Arnold, Ralph, and Anderson, Robert, op. cit., p. 93, pl. 1.
[65] Gester, G. C., and Galloway, John, op. cit., pp. 1167, 1174, 1178. Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., pp. 119-129.
[66] Henny, Gerard, McLure shale of the Coalinga region, Fresno and Kings Counties, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, No. 4, pp. 404, 408, 1930.
[66a] Bramlette, M. N., in Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., p. 124.
[67] Arnold, Ralph, and Anderson, Robert, op. cit., p. 92.
[68] Bramlette, M. N., op. cit., p. 1564.
[69] Bramlette, M. N., op. cit., p. 1572.
[70] Gester, G. C., and Galloway, John, op. cit., p. 1177.
[71] Bramlette, M. N., op. cit., p. 1564, 1569, as uppermost Temblor.

of the Big Blue[72] serpentinous member that lies at the top of the Temblor on Anticline Ridge. No outcrops of the Big Blue were found in Reef Ridge, but some trace of it is suggested by the mineral content of the basal conglomerate of the McLure in Big Tar Canyon.[73] The well on Canoas Creek indicates a thickness of the Temblor sandstone comparable to that at the outcrop but at least a hundred feet greater than that of an intervening well (p. 109). Possibly the difference is due to pre-McLure erosion. The McLure-Reef Ridge shale contact is evidently gradational (see below).

The McLure shale was correlated with the Monterey by Anderson[74] but later considered probably Santa Margarita in age by Arnold and Anderson.[75] Because it was found in Waltham Valley northwest of Reef Ridge to rest unconformably upon strata correlated with the Santa Margarita, it was considered later than Santa Margarita and given the new name McLure.[76] Its relation to typical Santa Margarita is in doubt.[77] The McLure and Reef Ridge shales correspond stratigraphically to the Monterey shale, but they evidently do not include all the type Monterey.[78]

Foraminifera related to those of the *Gyroidina obesa* zone at Chico-Martinez Creek have been reported from horizons near the base of the McLure.[79] Basal beds of the McLure shale along Reef Ridge, according to Goudoff, are the stratigraphic equivalent of the *Pulvinulinella gyroidinaformis* zone, which he considered to be the stratigraphic equivalent of the *Bulimina uvigerinaformis* and *Baggina californica* zones, forming the basal part of the upper Miocene of California and falling within the lower Mohnian stage of Kleinpell.[80] A few Foraminifera from the basal McLure figured by Kleinpell[81] are identified with the *Bulimina uvigerinaformis* zone.

The molluscan fauna of the basal sand and conglomerate of the McLure resembles that of the Santa Margarita (?) north of Coalinga in having large oysters, pectens, mussels, and barnacles. This fauna is abundant in Garza Canyon. Farther southeast the bivalve fauna of *Clementia, Miltha, Here, Dosinia,* and *Panope* (loc. 12, a, b) is present in this conglomerate. North of Coalinga a somewhat similar fauna has been reported from the top of the Temblor sandstone.[83] The presence of *Clementia* in both these faunas has already been pointed out.[84] The Temblor fauna north of Coalinga, however, lacks *Miltha.* A similar fauna also occurs south of Reef Ridge in the Devils Den district, where *Miltha* and *Clementia* were reported in sandstone with *Turritella ocoyana.*[85] *Turritella* was not found with the *Miltha* fauna along Reef Ridge. Presumably, the *Miltha* fauna of Reef Ridge is later than the top zone of the Temblor on the Coalinga anticline, north of Coalinga, and, judging from the absence of *Turritella ocoyana,* is also later than the fauna of the Devils Den district at locality 4861. Its stratigraphic position and the presence of a fauna on Garza Creek that appears to be a local equivalent seem to justify correlation with the Santa Margarita (?) north of Coalinga.

REEF RIDGE SHALE

The upper part of the Miocene shales of Reef Ridge has been named the Reef Ridge shale.[86] It has not been mapped separately from the McLure in the area covered by this report. Recently, the name Reef Ridge along Reef Ridge was restricted by Siegfus[87] to a gray shale about 300 feet thick. Its contacts with the underlying McLure shale and the overlying Jacalitos formation were described as gradational, and it is said to be absent from the type locality of the McLure. Unfortunately, no type section has been selected for the Reef Ridge shale. It has been suggested that the Reef Ridge shale might be a bentonitic shale;[88] it has been called a blue clay[89] and a gray, soft, silty shale.[90] The top of the undifferentiated McLure and Reef Ridge shales shown on plate 9 is based on the change in topography accompanying the lithologic change from finer sediments to the coarser ridge-forming sands and silts of the overlying Jacalitos formation.

A small foraminiferal fauna from the Reef Ridge shale in Big Tar Canyon has been described and correlated with the upper part of the upper Miocene, *Bolivina obliqua* zone (Delmontian stage), by Kleinpell.[91] A small fauna of mollusks and Foraminifera and pyritized diatoms has been recorded from the Reef Ridge shale in well cores from the Kettleman Hills and Belridge.[92] Above the siliceous shale (restricted McLure) in Garza Creek a generic assemblage similar to that of the "caving blue shale" (Reef Ridge shale) of the Kettleman Hills wells has been reported.[92a]

PLIOCENE SERIES

The Pliocene strata were not remapped for this report; most of the data and mapping shown are from the earlier report by Arnold and Anderson.

JACALITOS FORMATION

The Jacalitos formation consists of sandstones, conglomerates, and some silts, together about 3,700 feet thick, that form a wide band of low strike ridges north of Reef Ridge. The formation is also present in the Avenal syncline south of Chalk Butte. The formation was named and described by

72 Arnold, Ralph, and Anderson, Robert, op. cit., pp. 76, 89. Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga: U. S. Geol. Survey Bull. 603, pp. 83, 84, 1915.
73 Bramlette, M. N., op. cit., pp. 1569, 1572.
74 Anderson, F. M., op. cit., p. 171.
75 Arnold, Ralph, and Anderson, Robert, op. cit., p. 93.
76 Henny, Girard, op. cit., p. 403-410.
77 Barbat, W. F., and Johnson, F. L., Stratigraphy and Foraminifera of the Reef Ridge shale, upper Miocene, California: Jour. Paleontology, vol. 8, pp. 6, 7, 1934.
78 Kleinpell, R. M., op. cit., correlation chart.
79 Goudkoff, P. P., op. cit., p. 463.
80 Cushman, J. A., and Goudkoff, P. P., A new species of *Pulvinulinella* form the Miocene of California: Cushman Lab. Foram. Research Contr., vol. 14, pt. 1, p. 1, March 1938. Kleinpell, R. M., Miocene stratigraphy of California: Am. Assoc. Petroleum Geologists, Tulsa, p. 165, 1938.
81 Kleinpell, R. M., in Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., p. 128, pl. 50, figs. 1-12.
83 Arnold, Ralph, and Anderson, Robert, op. cit., pp. 85, 87, locality 4631.
84 Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 12, p. 1572, 1934. Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., p. 142, 13 species listed. The *Turritella ocoyana* probably came from the underlying Temblor.
85 Arnold, Ralph, and Anderson, Robert, op. cit., p. 86, loc. 4861.
86 Barbat, W. F., and Johnson, F. L., op. cit., pp. 3-17; abs. in Pan-Am. Geologist, vol. 59, p. 239, 1933. Gester, G. O., and Galloway, John, op. cit., pp. 1167, 1174-1176.
87 Siegfus, S. S., Stratigraphic features of the Reef Ridge shale in southern California: Am. Assoc. Petroleum Geologists Bull., vol. 23, No. 1, pp. 24-44, 1939.
88 Bramlette, M. N., op. cit., p. 1570. As caving shale.
89 Gester, G. C., and Galloway, John, op. cit., p. 1175.
90 Siegfus, S. S., op. cit., p. 30.
91 Kleinpell, R. M., Miocene stratigraphy of California: Am. Assoc. Petroleum Geologists, Tulsa, p. 165, 1938. Also quoted in Siegfus, S. S., Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 38-40, 1939, and in Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, California: U. S. Geol. Survey Prof. Paper 195, p. 121, 1940 [1941]. Eleven species listed.
92 Barbat, W. F., and Johnson, F. L., op. cit., pp. 8, 10, pl. 1.
92a Goudkoff, P. P., op. cit., p. 453.

Arnold and Anderson,[93] who included in their discussion a section on Jacalitos Creek, the type locality, and sections between Zapato and Canoas Creeks, along Canoas Creek, and 3½ miles east of Big Tar Canyon. The sands have been described by Bramlette[94] as follows:

The Pliocene andesitic sands of the Jacalitos formation contain an abundance of fresh zoned andesine, more or less altered volcanic glass, and ferromagnesian minerals. In the lower part the ferromagnesian mineral is largely hornblende, but in the upper half augite becomes increasingly abundant. A large part of this sand is pyroclastic though admixed with much ordinary clastic sand. Most of the original vitric or glassy tuff has been altered to minute zeolitic crystals that appear to be clinoptilolite.

A 20-foot bed of bentonitic clay is exposed on Jacalitos Creek just above a prominent fossiliferous sandstone that probably represents the *Pecten estrellanus* zone. It has been traced to the vicinity of Willow Spring on Canoas Creek and may be a continuation of the white brittle shale described by Arnold and Anderson[95] from the Jacalitos Hills. South of Little Tar Creek a similar shale is present. The formation appears to be conformable with the underlying Reef Ridge shale and the overlying Etchegoin formation. Some of the sandstones are fossiliferous, and three fossil zones were recognized by Arnold and Anderson.[96] The fauna was considered of upper Miocene age by them but is now generally regarded as lower Pliocene.[97]

ETCHEGOIN AND SAN JOAQUIN FORMATIONS

These two formations were not differentiated by Arnold and Anderson, and the strata of both were described as Etchegoin. In their section measured between Zapato and Canoas Creeks,[98] the Etchegoin is represented by beds labeled *n*, *o*, *p*, *q*, and *r*, including the upper *Mulinia* zone (now called upper *Pseudocardium* zone) near the top and the *Glycymeris* zone near the base. Sections on Canoas Creek and 3½ miles southeast of Big Tar Canyon were also described by them.[99] The Etchegoin formation as now restricted is about 1,000 feet thick and consists of conglomeratic blue sands, greenish-gray sands, sandy silts, and some clay. The sands of the Etchegoin and San Joaquin formations have been described by Bramlette[1] as follows:

The andesitic sands of the Etchegoin formation are also in considerable part pyroclastic admixed with ordinary clastic material and contain the same andesitic phenocryst minerals and altered vitric material as the Jacalitos. However, there is also a large amount of hypersthene, and all the beds that are called "blue sands" contain abundant hypersthene. The heavy mineral content of these Pliocene sands is unusually high, commonly forming 20 percent or more of the total.

According to Bramlette,[2] the color of the blue sands is due to a thin film of a soft mineral encrusting the sand grains. The mineral is evidently secondary, of chloritic type, and its formation seems to be related in some manner to the presence of hypersthene.

The San Joaquin formation is about 2,000 feet thick. The lithology is similar to that of the Etchegoin, but in general the sediments are less coarse and there is probably more clay; it was, in fact, originally named the San Joaquin clays by Anderson[3] and has been called the San Joaquin clay by Barbat and Galloway,[4] who have described it from the Kettleman Hills, the Coalinga region in general, and its subsurface occurrences in the southern San Joaquin Valley. It is represented by beds *b* to *m* in Arnold and Anderson's section[5] in the Kreyenhagen Hills between Zapato and Canoas Creek, and it probably constitutes most of the Etchegoin strata above the "upper *Mulinia* zone" in their sections on Canoas Creek and east of Big Tar Canyon.[6] On Canoas Creek the base of the San Joaquin formation was recognized as a coarse, cross-bedded conglomeratic blue sandstone overlying a bed of *Mya* shells, which is in turn about 30 feet above *Pseudocardium*-bearing silts with *Dendraster* cf. *D. macer*. About 45 feet lower still are found *Pseudocardium* and *Dendraster gibbsii*. The sequence resembles the upper *Pseudocardium* zone, *Littorina* zone, and Cascajo conglomerate member of the Kettleman Hills. The Cascajo conglomerate member has been taken as the base of the San Joaquin formation[7] in the Kettleman Hills,[8] and conglomeratic blue sandstones that seem to represent a stratigraphic zone have been shown as the base of the San Joaquin in the Kreyenhagen Hills in the area covered by this report (pl. 9). Both the Etchegoin and San Joaquin formations are considered to be of Pliocene age.[9]

TULARE FORMATION

Conglomerates, sands, and silts above the San Joaquin formation are known as the Tulare formation. They are evidently nonmarine and about 3,000 feet thick. They have been described by Arnold and Anderson[10] from their type locality, the Kettleman Hills, and briefly from the Kreyenhagen Hills. In the area considered in this report they form the main, and highest, parts of the Kreyenhagen Hills, being more resistant to erosion than the underlying San Joaquin formation. The Tulare formation appears to be conformable upon the San Joaquin formation. About 3 miles north of the area described in this report, on Zapato Creek, an unconformity was mapped and described by Arnold and Anderson[11] as being at the base of the Tulare. It is now thought that this unconformity is between older alluvium and the San Joaquin formation instead of at the base of the Tulare. The formation was considered Pliocene and lower Pleistocene in age by Arnold and Anderson,[12] and is now regarded as of upper Pliocene and probable lower Pleistocene age.[13]

[93] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 98-105.
[94] Bramlette, M. N., op. cit., p. 1570.
[95] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California: U. S. Geol. Survey Bull. 398, p. 105, 1910.
[96] Arnold, Ralph, and Anderson, Robert, op. cit., p. 100, fig. 4, p. 111.
[97] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geol. Sci., Bull., vol. 10, No. 14, pp. 191-254, 1917. Correlation of these strata is also considered in the report on the Kettleman Hills, U. S. Geol. Survey Prof. Paper 195, p. 103, 1940 [1941].
[98] Arnold, Ralph, and Anderson, Robert, op. cit., p. 101, fig. 4.
[99] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 118-120.
[1] Bramlette, M. N., op. cit., p. 1571.
[2] Bramlette, M. N., op. cit., p. 1574.
[3] Anderson, F. M., op. cit., p. 181.
[4] Barbat, W. F., and Galloway, John, San Joaquin clay, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 4, pp. 476-499, 1934. p. 483, Kreyenhagen Hills.
[5] Arnold, Ralph, and Anderson, Robert, op. cit., p. 101, fig. 4.
[6] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 119,120.
[7] Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., pp. 49-53.
[8] Nomland, J. O., op. cit., p. 225.
[9] Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., p. 103.
[10] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 143-149.
[11] Arnold, Ralph, and Anderson, Robert, op. cit., p. 149, pl. 1.
[12] Arnold, Ralph, and Anderson, Robert, op. cit., p. 154.
[13] Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., pp. 103-104.

QUATERNARY SYSTEM

The upper part of the Tulare formation in the Kreyenhagen Hills along the flank of Reef Ridge is probably of Pleistocene age, but it was not studied during the present investigation. As conglomerates are present near the base of the Tulare in the Kreyenhagen Hills,[14] it may be that the equivalents of the lower Tulare of the North Dome of the Kettleman Hills are missing in the Kreyenhagen Hills. Conglomerates, however, occur in the lower part of the Tulare of Middle Dome,[15] and those of the Kreyenhagen Hills may correspond to those of Middle Dome instead of to the much higher conglomerates of North Dome. An unconformity indicated at the base of the Tulare north of Zapato Creek seems to be between older alluvial gravels and the San Joaquin formation rather than at the base of the Tulare.[16]

Alluvium.—Some older alluvium consisting of boulders, gravel, and sand is mapped along the drainage lines that cross the Kreyenhagen Hills. These deposits all appear to be very thin, probably less than 15 feet thick. Boulders of the Avenal and Temblor sandstones are recognized in the alluvium by their fossils. This alluvium is not all of the same age, because it occurs on terraces at different altitudes. These terraces are mostly 25 to 150 feet above the stream channels, but the alluvium at the west end of Oak Flat is 300 feet above Beltran Creek. The best preserved terraces are along the west side of Zapato Creek,[17] just north of the area mapped.

The alluvium of the Kettleman Plain resembles the Tulare formation so much that the actual contact of the two is obscure. Possibly another reason for this obscurity is the fact that the contact between the Tulare and the alluvium is on northward-facing slopes where the soil is thick. On the east side of Kettleman Plain, where the alluvial contact lies on southward-facing slopes with little soil, the contact is more evident. The alluvium consists of sand, silt, and gravel of unknown thickness, possibly as much as 500 feet, as shown on the cross-section *B-B*, plate 9. Alluvium also occurs along many of the stream beds, in the southern part of the area examined, in McLure Valley, Hay Flat, and Avenal Canyon.

STRUCTURE

MAJOR FEATURES AND AGE OF FOLDING

The most conspicuous structural features of the Reef Ridge area include the southeastward-plunging Reef Ridge anticline, the Avenal syncline on the southwest, and the Kettleman Plain syncline. To the northeast beyond the area is the Kettleman Hills anticline. On the northeast flank of the Reef Ridge anticline are Reef Ridge and the Kreyenhagen Hills, and on the southwest flank are Black Mountain and the Chalk Buttes. In much of the area the core or crest of the anticline reveals vertical Cretaceous strata, but in the northwest part of the area it is marked by a narrow discontinuous band of faulted metamorphic rocks of Jurassic or older age.

The Cretaceous core narrows to a width of less than a mile to the southeast in McLure Valley and disappears beneath Miocene strata (McLure shale) 2 miles south of the region shown on the map. The Avenal syncline is overturned to the northeast in Avenal Creek near the Turtle Hole. It presumably extends farther northwest and joins the Dark Hole syncline of Black Mountain, but the structure is locally concealed by landslides of Franciscan debris and has not been traced through. The two synclines have been interpreted by some geologists[18] as continuous and by others[19] as separated by a fault. The faults between the metamorphic rocks and the Cretaceous rocks of the northeast flank of the Reef Ridge anticline are thought to dip to the southwest, because the Cretaceous strata are overturned to the northeast. The faults may continue southeastward beyond the separate outcrop of metamorphic rocks in Bullpen Canyon to Little Tar Canyon, as suggested by Arnold and Anderson,[20] who named this zone of faulting the Castle Mountain fault zone,[21] but the faults have not been traced across the Reef Ridge quadrangle.

On the northeast flank of the Reef Ridge anticline the strike of the ridge and the constituent strata is about 15° more westerly between Roundtop and Big Tar Peak; northward across the strike the strata do not flatten so rapidly away from the ridge, a 70° dip being measured near the top of the Jacalitos. Northwest of Roundtop the Miocene beds dip about 45°, and the steeper dips are limited to the early Tertiary and Cretaceous strata. The absence of steep dips in the Jacalitos formation northwest of Roundtop is evidently associated with the proximity of the Jacalitos anticline,[22] whose southern end lies at the north end of the Kreyenhagen Hills. South of Big Tar Canyon there are a few lower dips, but in the main they are steep like those in the Roundtop-Big Tar Peak area. At Little Tar Spring the McLure is vertical, but the dip decreases southward along the strike, and along the Cottonwood Pass road, just south of the area mapped, it is 30°.

The last major deformation of the rocks of Reef Ridge took place during Quaternary time. The folding evidently started earlier than Tulare time, probably at the beginning of the San Joaquin deposition (Pliocene), for it was definitely in progress near the end of San Joaquin time. The evidence for this beginning of folding has been found on the west flanks of Middle and South Domes of the Kettleman Hills. There fragments of probable McLure shale are abundant in conglomerates in the upper part of the San Joaquin.[23] During and since this deformation the area has been subjected to erosion. The area apparently was at first eroded to a terrain with much less relief than that of the present one and was then evidently lifted. The rounded Cretaceous upland and Roundtop are remnants of the older surface. The present drainage is now carving a new and lower terrain, which includes stream terraces,

[14] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 148-149.
[15] Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit., p. 22.
[16] Arnold, Ralph, and Anderson, Robert, op. cit., p. 149.
[17] Arnold, Ralph, and Anderson, Robert, op. cit., p. 155, pl. 4, fig. A.

[18] Reed, R. D., and Hollister, J. S., Structural evolution of southern California: Am. Association Petroleum Geologists Tulsa, pp. 54, 55, 1936. Castle Mountain-McLure Valley syncline.
[19] Clark, B. L., Tectonics of the Mt. Diablo and Coalinga areas, middle Coast Ranges of California: Geol. Soc. America Bull., vol. 46, pl. 89, p. 1066, 1935.
[20] Arnold, Ralph, and Anderson, Robert, op. cit., p. 167.
[21] Clark, B. L., Tectonics of the Valle Grande of California: Am. Assoc. Petroleum Geologists Bull., vol. 13, No. 3, p. 221 footnote, 1929. Reed, R. D., and Hollister, J. S., op. cit., pp. 55, 57, and 67.
[22] Arnold, Ralph, and Anderson, Robert, op. cit., pl. 1, geologic map.
[23] Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, California: U. S. Geol. Survey Prof. Paper 195, p. 37, 1940 [1941].

alluvial deposits, and landslides. Oak Flat and the top of the Kreyenhagen Hills (altitude 1,449 ft.) may be remnants of a surface later than that preserved on the upland but earlier than most of the stream terraces.

MINOR FAULTS

Some minor faults were noted along Reef Ridge, particularly in the Temblor sandstone, whose extensive exposure permits their easy recognition. The longest of these is a northward-trending, apparently vertical fault, 1½ miles long, located south of Flattop, where the Temblor and the conglomerates in the Panoche formation appear to be offset about 500 feet southward on the east side of the fault. Presumably, the fault is due to horizontal displacement. The fault plane was not seen, however, and the only drag effects noted were in the Temblor sandstone on the west side, where the strata curve to the north as if the displacement of this side had been southward. If the west side did move southward, then the direction of the apparent stratigraphic displacement could be accounted for by nearly vertical movement of perhaps 3,000 feet. It seems more likely, however, that the northward curving of the strata on the west side of the fault is due to recent movement caused by the landslide that conceals the north end of the fault. It thus appears that the fault is a flaw with southward movement on the east side. This fault may correspond to the local change in strike of the McLure shale on the opposite flank of the anticline, for both enlarge the core of the anticline northwestward.

On the west side of Flattop is another steep fault, about 1,000 feet long, striking northeast with a southwest displacement on the northwest side of the fault. The movement offsets the strata 50 feet normal to the bedding. The fault plane as measured at one place strikes N. 45° E. and dips 65° NW. The more general dip is probably steeper, and the general strike is N. 35° E. Some minor faults, striking north and having the east side displaced southward, are present about one mile north of Flattop in the Jacalitos formation. One of these minor faults (sec. 8, T. 23 S., R. 17 E.) is vertical, has horizontal striae, and shows a stratigraphic displacement of 10 feet. Two nearby fault planes have dips of 60° and 75° to the west, but the stratigraphic displacement is south on the east side, and the faults, therefore, are apparently thrusts. If, however, all the displacement has been parallel to the fault-plane striae, which are inclined less than the strata, the faults are normal with a greater horizontal than a vertical component.

On the west side of Roundtop and just west of a landslide, three beds of the lower member of the Temblor sandstone are broken by thrust faults. They are strike faults and have a greater dip than the strata but in the same direction. Two of the faults have a stratigraphic displacement of 5 feet; the other apparently has greater displacement. The faults are associated with an abrupt change in strike of the strata. The strata within the faulted ground strike 55° NW., parallel to the ridge, and dip 60° NE., but east of the faults the lower member of the Temblor sandstone strikes at right angles to the ridge and has vertical and overturned dips for a distance of about 500 feet, where the normal sequence seems present. One of the overturned dips is 45° E.

The uppermost Temblor strata exposed on the north side of Roundtop are faulted and slightly overturned, but apparently there is no important change in their strike.

On the east side of Roundtop the top of the lower member of the Temblor, a pebble bed with *Patinopecten*, 160 feet above the base of the lower member, is duplicated by a strike thrust fault. The stratigraphic displacement is at least 55 feet. The strata dip about 50° NE. The fault plane dips 57° NE. and exhibits striae that are inclined to the east at an angle of 15° with the line of the dip. The strike of the fault seems to change to the north so that the fault apparently cuts across the strata and probably passes around the north side of Roundtop to connect with the thrust on the west side. Possibly the dip of the fault changes to the southwest on the north side of Roundtop. Farther east, on the south side of the ridge, and about 2,000 feet from Roundtop, small complicated faults are exposed at an altitude of about 2,250 feet. Here one steep southwestward-dipping fault appears to flatten out up the dip and then increase until vertical, if not actually to a steep northeast dip; although this fault may have originated as two intersecting faults, it now appears as one sinuous plane. Although the details of the structure on Roundtop have not been worked out, it is evidently a small faulted fold, which probably dies out rapidly down the dip. A larger, much better example of a fold of this type is exposed on Monocline Ridge north of Arroyo Hondo, in sec. 6, T. 17 S., R. 14 E.[24] Local changes in the dip of the strata are associated with the faulting on both Flattop and Roundtop.

On the east slope of Reef Ridge a strike fault is exposed in the McLure shale on the 1,475-foot knoll near the center of the SW¼ sec. 22, T. 23 S., R. 17 E., near Little Tar Canyon. The strike is N. 65° W., and the dip is less than that of the strata but in the same direction. The dip of the fault plane near its west end is 45° NE., but as the fault is followed down the ridge the dip of both the fault plane and the strata increases to almost vertical. The hanging wall has apparently moved upward so that this is a thrust fault. The pitch of minor folds in the hanging wall is very steep, suggesting some westward displacement of the hanging wall. Extensive strike faulting may have occurred in the Kreyenhagen shale, but none was recognized. A minor strike fault between the Kreyenhagen shale and Temblor sandstone is exposed south of Roundtop (see p. 94), and small faults and slickensides are exposed in the Kreyenhagen on Tar Peak (see p. 94).

On Reef Ridge, west of Beltran Creek, near locality 6, the Kreyenhagen shale and the lower member of the Temblor sandstone are displaced about 35 feet stratigraphically along a fault dipping west 70° to 83° and striking 10° to 20° west of north. On Reef Ridge, just west of Arroyo Pinoso, the lower member of the Temblor is displaced 40 feet along a northward-striking fault. A dip of 63° to the west and a strike of N. 10° E. seem to represent the general attitude of the fault plane. The strata dip

[24] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of San Joaquin Valley north of Coalinga: U. S. Geol. Survey Bull. 603, pl. 1, 1915.

80°, and striae on the fault plane are 30° north of the direction of the dip on the fault plane. The stratigraphic displacement on these two faults appears to indicate a thrust, as the west side is up and is the hanging wall; but, if the total displacement was parallel to the observed oblique striae, the west side of the faults has moved obliquely downward, and the faults are normal.

In McLure valley the Avenal sandstone appears to be offset at four localities, but no fault planes were found. In Little Tar Canyon, however, the Avenal has apparently overridden the Kreyenhagen shale to the northeast along a strike fault that dips to the southwest; the strata are overturned and dip more steeply than the supposed fault but in the same direction. This fault may be a subsidiary of a pre-McLure fault between the Avenal sandstone and the Panoche formation indicated questionably on the map (pl. 9).

A major fault is shown by Arnold and Anderson[25] as passing through the upper end of Little Tar Canyon and as forming the eastern end of the Castle Mountain fault. The presence of a small outcrop of McLure shale in the NE¼ sec. 28, T. 23 S., R. 17 E.[26] seems to indicate some local post-McLure faulting along or near the contact between the Avenal and the Panoche. The McLure evidently lies there in a narrow graben. A little farther northwest, in the NE¼ sec. 19, coarse conglomerate of the Panoche formation, containing large boulders of volcanic rocks, locally strikes N. 75° E. and dips 65° SE. and is presumably faulted, inasmuch as the general strike is northwest.

Between Zapato Canyon and Arroyo Pinoso the Avenal sandstone is locally overturned, and faulting probably accompanies some of the abrupt changes in direction of dip (see pl. 16, *A*). The details of the structure have not been worked out, but movement appears to be along steep northward-trending faults, possibly flaws. The faulting appears to be absent from the overlying Temblor sandstone and may, therefore, be pre-Temblor. Some of the faulting, however, as well as some of the overturning, may be due to landslides of Cretaceous strata. If faults are actually present they are evidently local.

ECONOMIC GEOLOGY

Some road material is quarried by the State Highway Department from the McLure shale in Big Tar Canyon. Gravel has been quarried from the Cretaceous conglomerates along the road just west of Big Tar Canyon, and numerous pits have been dug in the Cretaceous shales farther west, evidently for driller's mud. The bentonitic clays of the Kreyenhagen shale may have some value. The oil seeps along Reef Ridge (pl. 9) in Canoas, Garza, Baby King, and Big Tar Canyons, McLure Valley, and Little Tar Canyon led to early exploration of this region for petroleum, which resulted in a very small output of oil in Canoas, Big Tar, and possibly Little Tar Canyons. The early exploration for oil in this region prior to 1908 was described by Arnold and Anderson,[27] and the region was referred to by them as the Kreyenhagen field. Their account is briefly summarized in the two following paragraphs:

Two wells were drilled in the Kreyenhagen shale in Canoas Creek, and one of them was said to have yielded 15 barrels a day at the start, but the yield soon fell to 5 or 6 barrels of light-green oil of 37°-38° B. It was drilled to a depth of 650 feet, ending in 10 feet of oil sand. A well drilled on Garza Creek, beginning in the Kreyenhagen shale, reached a depth of 1,100 feet and was said to have obtained a good showing of 20° B. amber-colored oil. A well drilled to a depth of over 1,000 feet in Baby King Canyon, beginning near the top of the Kreyenhagen, was yielding water with occasional blebs of black heavy oil and some gas when visited by Arnold and Anderson in 1907. Two wells were drilled to a depth of about 1,000 feet in the Kreyenhagen shale of Big Tar Canyon and found some traces of oil. All these wells were south of Reef Ridge.

Four wells were drilled north of Reef Ridge. One of these on Canoas Creek started in the McLure shale and was drilled 720 feet before it encountered oil sands. The reported production was 5 to 6 barrels of black 18° B. oil. A well in Garza Creek, evidently started near the base of the McLure, was drilled almost 1,000 feet; heavy oil was reported at a depth of 240 feet. Oil was also reported at an unknown depth from a well on Baby King Creek in the SE¼ NE¼ sec. 12, T. 23 S., R. 16 E. Apparently this well started in the Jacalitos formation. Data are lacking on a well started in 1908 in the NW¼ sec. 14, T. 23 S., R. 17 E. It evidently started in the upper part of the San Joaquin formation south of Big Tar Creek.

In recent years three prospect wells were drilled near the western end of the area on Canoas Creek and three near the eastern end near Little Tar Canyon (see pl. 9 for location of wells), and, although some of them found shows of oil, none of the wells produced oil in commercial quantity.

In 1930 the Richfield Oil Co. of California drilled a prospect well, the Shrock No. 1, on Canoas Creek, in the NW¼ sec. 33, T. 22 S., R. 16 E. (323 feet east of west line and 1,608 feet south of north line). This company has generously supplied the information here given. The well started near the top of the McLure shale where it dips about 45° to the northeast. The well was drilled to a depth of 3,434 feet, and many shows of oil were reported from the Temblor, Kreyenhagen, and Avenal. A wedge of Kreyenhagen shale, about 140 feet thick, appears to have been faulted in between the Avenal sandstone and the Panoche formation. The top of a sand-dollar bed of the Temblor sandstone was reached at a depth of 822 feet, which is 21 feet below a 2-foot bed of "white alkali," possibly a bed of bentonite. The first brown shale, containing fish scales, reported at a depth of 1,651 feet, is thought to be the top of the Kreyenhagen shale. The Temblor sandstone would thus be about 580 feet thick, if the hole were straight, and the 45° dip of the strata maintains below the surface. The next 120 feet was reported as mostly fine sand, but, if 30 feet of unrecovered material in this interval were shale, this 120 feet (calculated thickness 85 feet) could

[25] Arnold, Ralph, and Anderson, Robert, op. cit., p. 167, pl. 1.

[26] Clark, B. L., Age of primary faulting in the Coast Ranges of California: Jour. Geology, vol. 40, No. 5, p. 395, 1932; Tectonics of the Mount Diablo and Coalinga areas, middle Coast Ranges of California: Geol. Soc. America Bull., vol. 46, No. 7, pp. 1066, 1067, 1935. Reed, R. D., and Hollister, J. S., Structural evolution of Southern California: Am. Assoc. Petroleum Geologists, Tulsa, p. 69, 1936.

[27] Arnold, Ralph, and Anderson, Robert, op. cit., pp. 227-232.

be a sandy phase in the upper part of the Kreyenhagen. Typical Kreyenhagen shale (calculated thickness 680 feet) evidently extended from 1,770 feet down to a fine-grained, gray sandstone reported at 2,702 feet. This sandstone may be the top of the Avenal sandstone, for just above it beds were reported that may represent the green clay at the base of the exposed Kreyenhagen. The beds encountered in this zone are 23 feet (16½ feet thick) of sandy brown shale probably glauconitic above 12 feet (8½ feet thick) of pyritiferous, brownish-green, greasy shale.

Fine-grained, oil-stained sandstone reported from 2,702 to 3,077 feet is fairly uniform and contains some shaly streaks. In addition, it contains 4 feet of conglomerate at 2,823 feet, 6 inches of conglomerate at 2,871 feet, and 8 feet of coarse sandstone containing pebbles in its basal part below 2,927 feet. Below 2,956 feet there are 20 feet of shaly sand separated by 1 foot of brown shale with foraminifers and diatom casts. From 2,978 to 2,994 feet there is granitic sand, and below this are 3 inches of brown shale, and next 18 feet of gray sandstone. From 3,021 to 3,077 feet there is a sandstone that has carbonaceous material and shaly streaks. The sandstones from 2,702 to 3,077 feet, about 265 feet thick, may be the upper part of the Avenal sandstone, but, if this is Avenal, it is surprising that no molluscan fossils were reported. An alternative interpretation is that the sandstone is the sandy phase of the lower part of the Kreyenhagen; if this is true, the Kreyenhagen is at least 945 feet thick and possibly more than 1,030 feet thick.

Below this sandstone brown shale was cored from 3,077 to 3,272 feet, a distance of 195 feet (thickness about 140 feet). The contact between the two is evidently a fault, for the shale is shattered and distorted. Below the shale to the bottom, at 3,434 feet, the well penetrated 162 feet of gray sand and gray and blue and carbonaceous shales belonging presumably to the Panoche formation (Cretaceous). In this interval streaks of micaceous sand were reported below 3,300 feet, but apparently most of the sand is not so micaceous as the sandstone of the Panoche at the outcrop. Apparently the 140 feet of brown shale above the Panoche formation is Kreyenhagen and has been faulted between the Avenal and the Panoche in such a manner as to take the place of the lower part of the Avenal.

In the Schrock No. 1 well oil was reported at depths of 720 feet in vertical fractures in the McLure shale. Below 752 feet about 13 feet of soft sand, poorly saturated with heavy oil, was penetrated, and then 7 feet of sandy shale with oil in the bedding planes. In the Temblor sandstone shows of oil were reported as follows: oil sand in the upper part down to 1,070 feet; oil stains at 1,550 feet; 4 feet of soft, fine sand well saturated with light oil at 1,680 feet; fossiliferous sand saturated with oil for 1 foot at 1,700 feet; and oil stains at 1,715 feet. In the Kreyenhagen a "fair cut" was reported at depths of 1,972, 2,006, 2,008, and 2,009 feet, in laminated brown shale and fine sandstone; oil in fractures in badly broken brown shale at 2,516 feet; and 1½ feet of green sand with light oil at about 2,605 feet. Many oil stains were reported in the underlying Avenal (?) sandstone, but none were reported in the lowermost 100 feet. Some of the operator's data on this well have been published.[28]

The Taft Well Drilling Co. drilled a prospect well in 1935, the Kreyenhagen No. 2, on Canoas Creek, about 1 mile east of the Schrock No. 1 well, near the east ¼ corner of sec. 33, T. 22 S., R. 16 E. (990 feet north and 990 feet west of east ¼ corner). This company has supplied the information here given, including the descriptions of the cores, which were examined by the author with S. S. Siegfus. The well was started in the lower part of the Jacalitos formation, where the strata dip 40° to the northeast, and was drilled to a depth of 5,005 feet, penetrating the Reef Ridge and McLure shales, the Temblor sandstone (including the Big Blue equivalent), the Kreyenhagen shale, and part of the Avenal sandstone. Bentonite near the base of the McLure was found at a depth of 2,319 feet. A 5½-foot bed of conglomerate, 19 feet lower in the well, forms the base of the McLure; it is composed of chert pebbles as much as 2 inches in diameter in a light greenish-gray matrix. Below the conglomerate is 21 feet (calculated thickness) of slickensided colored clays, sands, and oil-stained conglomerate with angular pebbles at the base, corresponding to the Big Blue serpentinous member of the Temblor sandstone of the Coalinga anticline. The top of the "button beds" (Aequipecten zone) beneath the equivalent of the Big Blue is at 2,388 feet. These beds consist of a fossiliferous (oyster fragments and *Solen*), pebbly, gray sand with some oil stains. *Turritella* and *Pecten andersoni* (*Aequipecten*) were reported from oil-stained gray sand just below 2,409 feet, and fragments of sand dollars from gray sand at 2,450 feet, just above a layer of dark gray slightly calcareous foraminiferal (*Valvulineria?* and *Eponides?*) shale with fish remains and pyritized diatoms. The first definite "button bed" was reported at 2,473 feet, and the sand dollars were irregularly abundant in oil-stained sands to a depth of 2,519 feet, below which there was 10 feet of shaly sands with some oil in cracks. A *Turritella* bed was reported at 2,886 feet. The lowest sand dollars were with *Aequipecten andersoni* in gray calcareous sandstone at 3,218 feet (about 230 feet stratigraphically above the base of the Temblor). Badly preserved foraminifers, *Cibicides* predominating, were reported for 7 feet in shaly sand below 3,278 feet. Layers containing *Anadara* were reported in fine-grained sandstone with spots of dark clayey material and black bitumen at 3,413 to 3,415 feet, in clayey sand at 3,421 feet, and in sandy siltstone with some *Ledas* and fish remains at 3,430 feet. This is just above a layer of chert, shale, sandstone, and quartzite pebbles, which may correspond to the top of the lower member of the Temblor, as mapped at the surface. About 80 feet stratigraphically lower, below a sequence of sands and siltstones, is the top of the Kreyenhagen shale at 3,545 feet. The contact between the Temblor and the underlying shale is clearly indicated by the occurrence in the basal Temblor of shale fragments, apparently derived from the subjacent shale. The Kreyenhagen shale is hard, dark brown, well bedded, siliceous, and fossiliferous, and contains pyritized fish remains, *Propeamusium*, sponge spicules, and Foraminifera including *Nodosaria*, *Frondicularia*,

[28] Summary of operations, California oil fields, vol. 16, No. 1, p. 196, 1930.

Gyroidina, Eponides, Dentalina, and *Lenticulina?* Glauconitic sand layers containing no fossils are present from depths of 3,952 to 3,968 feet and 3,980 to 3,998 feet. Fish remains, radiolarians, diatom imprints, poorly preserved foraminifers, and *Propeamusium* occur in fractured shale at depths of 4,597 to 4,615 feet. A pebble bed of rounded black chert and gray shale pebbles in a bluish-gray sandy matrix found at 4,868 feet may represent the base of the Kreyenhagen shale. Below it to the bottom of the hole (5,005 feet) were fine-grained sandstones, some with pebbles and some slightly glauconitic, which may be the top of the Avenal sandstone. Above the pebble bed is a shear zone of crushed and slickensided gray shale that contains fragments of hard sandstone. Foraminiferal green clay also occurs not far above the pebble bed, but its exact position is not certain; it is evidently the green clay member at the base of the Kreyenhagen and is the chief basis for considering the underlying sandstone to be the Avenal. Strong odors of gasoline and light oil were reported from this sandstone.

The Temblor sandstone is about 800 feet thick in the Kreyenhagen No. 2 well. This is possibly 100 feet less than the thickness at the outcrop but at least 100 feet more than in the intervening Shrock well. The Kreyenhagen shale is about 950 feet thick, which is about the thickness at the outcrop, but the thickness in the Shrock well appears to be about 200 feet less.

The third prospect well on Canoas Creek was drilled in 1939 by the M.C.A. Drilling Co., 3,500 feet west of the Taft well, in the northwest corner of sec. 33, T. 22 S., R. 16 E. The well is 358 feet south of the north line of the section and 771 feet east of the west line and has an altitude of 1,362 feet. It started near the base of the Jacalitos where it dips about 40° to the northeast. The well, which was drilled to a depth of 2,003 feet, cored oil-stained sands in the basal McLure shale and upper Temblor sandstone. The bentonite near the base of the McLure was cored at a depth of 1,470 feet and the top of the "button beds" at 1,565 feet. The intervening 95 feet of oil-stained sands with shell fragments may include the Big Blue member of the Temblor, but the characteristic lithology of the Big Blue found in the Taft well was not reported. Possibly much of this sand belongs to the basal McLure, although boulders suggesting the basal conglomerate were reported at a depth of 1,510 feet. Irregular patches of oil-stained sands were cored at depths of about 1,650 and 1,725 feet.

Near the southeast end of Reef Ridge three prospect wells have been drilled to the Temblor sandstone. The first was drilled half a mile east of the ridge, the second 800 feet east of the ridge, and the third on top of the ridge just east of the tar springs in Little Tar Canyon.

The first well, known as the Knudsen & Schmidt Co.'s Avenal No. 1, is located about 500 feet southwest of the center of sec. 36, T. 23 S., R. 17 E., at an altitude of 816 feet. It was started near the base of the Jacalitos in strata dipping about 75° NE. A columnar section of strata penetrated by this well was published by Goudkoff,[29] who referred to it as the well at the southeast end of Reef Ridge. Below the Temblor sandstone he identified 890 feet of shale including two fossil zones, the *Leda* and *Uvigerina cocoaensis,* as his upper Kreyenhagen. These two zones have, however, not been definitely recognized on the surface along Reef Ridge. Apparently no oil was found in the well.

The other two wells are the Avenal Nos. 1 and 2 of the Associated Oil Co. Information about these wells was generously supplied by the company, and part of the cores were examined by the writer. The Avenal No. 1 well, drilled in 1936, is just east of Reef Ridge, 1,750 feet south and 100 feet west of the northeast corner of sec. 35, T. 23 S., R. 17 E. The altitude of the well is 963 feet, and its depth is 3,110 feet. The well started in the McLure shale, and it is reported to have obtained showings of heavy oil at a depth of 210 to 230 feet in that shale. The top of the Temblor sandstone was reached at about 2,840 feet and included about 18 feet (core length) of oil sand with beds of hard calcareous reefs containing *Ostrea* and *Aequipecten andersoni.* Fragmentary cores between depths of 2,880 and 2,965 feet contained some oil sand and also shale and fossil fragments. From 2,965 feet to the bottom of the hole, 3,110 feet, fossiliferous Temblor sand was reported.

The Avenal No. 2 well was drilled in 1937 on top of Reef Ridge, 1,535 feet south and 990 feet west of the northeast corner sec. 35, T. 23 S., R. 17 E., at an altitude of 1,207 feet. The depth of the well is 3,088 feet. It was started in McLure shale which dips about 80° northeast. The first cores, which were obtained at a depth of 687 feet, were sand. Oil-stained sands were encountered at a depth of 707 feet. Brown oil-stained sand, oil sand, free oil, tar, and gilsonite were reported from depths between 707 and 2,763 feet. *Aequipecten andersoni* was reported at a depth of 937 feet and from numerous cores to a depth of 2,882 feet—the greatest depth at which fossils were reported, except some fragments, possibly *Aequipecten,* near the bottom at a depth of 3,057 feet.

All the cores from the Avenal No. 2 well appear to have been obtained from the Temblor sandstone. Samples of shale from depths of 628 to 658 feet above the cores of Temblor sandstone contained radiolaria and types of Foraminifera found in the Kreyenhagen. In this well, the McLure, dipping 80° to the northeast, appears to rest with angular unconformity on the overturned Kreyenhagen and Temblor, which dip steeply to the southwest. Such relations, which are indicated by the surface geology, would permit, as already mentioned, the penetration of the McLure, Kreyenhagen, and Temblor in the order named.

The three wells just described are east of the Little Tar Springs where early attempts, possibly as early as the 1860's, were made to obtain oil. A square wooden casing is still preserved at the spring and is said to reach a depth of at least 100 feet.

Renewed efforts to obtain oil in commercial quantities from the Avenal sands by shallow wells have been made since 1932 in Baby King and Garza Creek

[29] Goudkoff, P. P., Subsurface stratigraphy of Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, No. 4, fig. 7, pp. 448, 436, 463-465; fig. 8, p. 474, 1934. The columns in fig. 7 are said to represent "true thicknesses" (p. 438), but this evidently means penetration "thickness" of this well, for the thickness of the beds indicated, 7,000 feet, is practically the depth of the hole (6,854 feet). Summary of operations, California oil fields, vol. 21, No. 4, p. 77, 1936. The top of the Temblor is shown at a depth of 4,200 feet.

Canyons, secs. 10, 11, T. 23 S., R. 16 E.,[30] but they have not been successful.

The possibility of obtaining some productive wells along Reef Ridge has not been completely exhausted. The steep dips of the strata, 42° to vertical and even overturned, have probably discouraged many operators, but the most unfavorable factor seems to be the apparent absence of a trap where the oil would accumulate and be retained in commercial quantity. Oil is escaping from Reef Ridge and presumably has been escaping since the Pleistocene epoch, when the rocks of the region were last folded and erosion reduced the region approximately to its present altitude. The more or less impervious McLure shale overlaps the underlying Tertiary strata and rests upon the Cretaceous, but any oil beneath the McLure may have moved northwestward to the highest area of the rocks beneath the overlap. Any such area would have stood above the present crest of Reef Ridge.

The present oil seeps may be due to local accumulations in lenticular bodies that have since been exposed by erosion. Any porous sandstone that thins out upward toward the surface, if overlain by an impervious layer of shale, would form a trap for oil. Such stratigraphic traps may be preserved under Reef Ridge, but they would be difficult to locate.

If the upper half of the Miocene oil-bearing strata of the North Dome of the Kettleman Hills oil field is missing from the Reef Ridge section (p. 98) it is presumably overlapped somewhere between North Dome and Reef Ridge. Naturally the closer this overlap is to Reef Ridge the more likely it is that it has trapped commercial quantities of oil. Search for this possible overlap could be carried out by drilling further exploratory wells to a little below the base of the McLure. The wells in Canoas Creek and at the south end of Reef Ridge may be regarded as such exploratory wells.

These wells indicate that the Big Blue serpentinous member of the Temblor sandstone is there overlapped by the McLure shale. However, oil is escaping from the basal McLure, as well as from the upper part of the Temblor sandstone at the outcrop in Canoas Creek, so that the basal McLure at that locality does not appear to be a good seal for possible oil in the Big Blue member.

Apparently the Temblor overlaps a great deal of shale near Little Tar Canyon and eastward, for the *Leda* and *Uvigerina cocoaensis* zones (upper Kreyenhagen of Goudkoff) are reported from the Knudsen and Schmidt well but not from Reef Ridge (see p. 110). Perhaps the oil in the Temblor at Little Tar Spring is connected with that overlap. As the *Leda* and *Uvigerina cocoaensis* zones are also reported from wells on North Dome, they are evidently overlapped all along Reef Ridge somewhere between Reef Ridge and North Dome. Possibly this overlap might be located by exploratory wells, but the Temblor sandstone, unless thoroughly cemented, would not be expected to seal the oil at such an overlap, and the oil would presumably rise up the dip to the outcrops of the Temblor along Reef Ridge. There is, however, also the possibility of oil-bearing lenses within the overlapped strata.

[30] Summary of operations, California oil fields, vol. 17, No. 4, p. 91, 1932; vol. 18, No. 2, p. 136, 1932; vol. 19, No. 2, p. 78, 1933; vol. 20, No. 4, p. 83, 1935; vol. 21, No. 1, p. 199, 1935.

Lower Eocene, Paleocene, and some Upper Cretaceous strata are missing along Reef Ridge and may be overlapped in this area. The Avenal sandstone, the oldest Eocene formation, if cemented might form a cap for oil beneath it, or there might be oil-bearing lenses within the overlapped strata, but direct evidence as to the existence and location of such possibilities is not available.

FOSSIL LOCALITIES

The fossil localities are described in the following list. The number in the first column is the locality number used on plate 9 of this report; the number in the second column is the Geological Survey locality number. The figures following the land-net data represent distances within the section from its boundaries to the fossil locality.

Fossil localities

No. on plate 9.	Geological Survey No.	Locality data
		TEMBLOR SANDSTONE, LOWER MEMBER
1	14384	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 17; 1,900 feet north, 2,870 feet east; south of Flat Top; 100 feet stratigraphically above the top of the Kreyenhagen shale.
2	14385	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 10; 250 feet west, 1,150 feet south.
2a	14385a	10 feet above locality 14385.
3	14386	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 3; 1,800 feet east, 1,200 feet north; 180 feet above the top of the Kreyenhagen shale, 7 feet above a conspicuous blue sandstone 18 inches thick; doubtful *Priscofusus lincolnensis* is 8 feet below the blue sandstone, where it occurs with *Patinopecten*, *Lucinoma*, and *Anadara*.
4	14387	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 4; 430 feet south, 2,380 feet west; Dirty Spring; lower of two layers of *Anadara* about 6 feet apart.
5	14388	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 32; 600 feet west, 2,000 feet north; west side of Canoas Creek; 40 feet below pebble bed with *Patinopecten*.
6	14389	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 1,900 feet north, 6,900 feet west; about 25 feet above the top of the Kreyenhagen shale and 50 feet below 6-inch fossil pebble layer (top of lower Temblor); bivalves most abundant.
7	14390	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 25; 450 feet west, 2,050 feet north; first arroyo west of Beltran; from upper three layers of *Anadara* just beneath 12-foot silt.
8	14391	Kreyenhagen Hills quadrangle, T. 22 S., R. 15 E., sec. 22; 3,400 feet south, 200 feet west; divide between first and second canyons west of Arroyo Pinoso.
9	14392	Kreyenhagen Hills quadrangle, T. 22 S., R. 15 E., sec. 21; 1,700 feet west, 900 feet south; west side of Zapato Canyon; main concretionary layer.
9a	14392a	4 feet above locality 14392.
10	14393	Reef Ridge quadrangle, T. 22 S., R. 16 E., sec. 12; pebble beds with *Patinopecten* on southeast and southwest sides of Roundtop; there are evidently two layers about 50 feet apart near top of lower Temblor.
11	14394	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 23; 800 feet north, 1,900 feet east; pebble bed on divide just west of Arroyo Pinoso.
11a	14394a	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 4,080 feet west, 1,150 feet north; Beltran Creek; vertebrate.

Fossil localities—Continued

No. on plate 9.	Geological Survey No.	Locality data
		TEMBLOR SANDSTONE, UPPER MEMBER
12	14395	*See* below under McLure shale.
13	14396	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 12; southeast side of Roundtop, 50 feet from the top.
14	14397	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 12; 1,800 feet north, 1,700 feet east; two beds 6 feet apart and just above silt with *Aequipecten.*
15	14398	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 12; near locality 14397; *Turritella* beds overturned on the north slope of Roundtop.
16	14399	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 11; 1,100 feet east, 1,000 feet south; road into Garza Canyon; *Turritella* layers.
17	14400	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 11; road into Baby King Canyon; just below lowest sand-dollar or button beds.
18	14401	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 10; 800 feet south, 20 feet west; bivalve layer at crest of Reef Ridge just south of the road.
19	14402	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 3; 1,580 feet west, 1,050 feet north; in Garza Creek on north bank about 50 feet above creek bed.
20	14403	Reef Ridge quadrangle, T. 22 S., R. 16 E., sec. 33; 480 feet north, 1,740 feet west; near top of Temblor below Dirty Spring.
21	14404	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 33; 20 feet east, 2,220 feet north; measured section in road cut into Canoas Canyon, about the middle of the Temblor sandstone; fossils in three 6-inch lenses with worn barnacle fragments near the base; first lens, 6 feet above base of gray sandstone, has barnacle fragments, small *Volsella*, some with both valves and some also lying just above first lens, a large mactroid, *Aequipecten*, venerid, and gastropods; second lens, 4 feet higher, has small shell fragments; and third lens 15 feet higher, near the top, has *Nuculana, Yoldia, Lucinoma, Nassa?*, and *Neverita.*
21a	14404a	25 feet below locality 14404.
22	14405	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 33; 600 feet east, 2,500 feet south; uppermost button or sand-dollar bed east of road on north side of Canoas Creek.
23	14406	Dark Hole quadrangle, T. 23 S., R. 15 E., sec. 25; 1,520 feet east, 800 feet south; top of Temblor sandstone on west side of first canyon east of Arroyo Pinoso.
24	14407	About 300 feet north of locality 14389; sand layer with *Dosinia* about halfway between grit with barnacle fragments and *Turritella* bed.
25	14408	On ridge about 500 feet east of locality 14389; *Volsella* just below *Dosinia* layer, *Zirphaea* and *Turritella* 35 feet above it.
26	14409	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 23; 700 feet north, 1,600 feet west; in Arroyo Pinoso.
27	14410	Kreyenhagen Hills quadrangle, T. 22 S., R. 15 E., sec. 21; 2,350 feet west, 530 feet south; west side of Zapato Canyon about 300 feet above the creek.
28	14411	Kreyenhagen Hills quadrangle, T. 22 S., R. 15 E., sec. 21; 1,450 feet west, 700 feet south; top of Temblor sandstone in left bank of Zapato Creek.
28a	14412	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 2,050 feet south, 6,080 feet west; second small arroyo west of Beltran Creek.
		MCLURE SHALE
12	14395	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 26; 550 feet north, 2,130 feet east; lenticular sand layers in basal sand 40 and 50 feet below the main body of the shale.

Fossil localities—Continued

No. on plate 9.	Geological Survey No.	Locality data
		MCLURE SHALE—Continued
12a	14395a	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 18; 500 feet west, 250 feet south; basal conglomerate, east side of Big Tar Canyon.
12b	14395b	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 7; 2,620 feet east, 180 feet north; basal conglomerate.
12c	14395c	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 2; 50 feet east, 700 feet north; conglomerate in Garza Canyon.
		AVENAL SANDSTONE AND KREYENHAGEN SHALE
------	4617	On southwest flank of Reef Ridge, north of McLure Valley, 2¼ miles south-southeast of El Cerrito well, in sec. 27, T. 23 S., R. 17 E. Lower member.[31]
------	14437	See 63c.
------	14438	See 62a.
29	14447	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 670 feet south, 2,580 feet west; Kreyenhagen shale.
30	14448	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 480 feet south, 2,320 feet east; Kreyenhagen formation.
30a	14448a	50 feet above the forks of gully above loc. 30; Kreyenhagen shale, possibly green clay member.
31	14449	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 380 feet south, 1,600 feet east; green clay member, just below 6-inch green sand and 30 feet above Avenal ledge.
31a	14449a	380 feet northeast of locality 14449; green clay member of Kreyenhagen shale.
31b	14449b	15 feet above green clay member.
33	14450a	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 120 feet south, 1,120 feet east; Kreyenhagen shale.
34	14451	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 26; 110 feet east, 410 feet north; Kreyenhagen shale about 60 feet above the top of of the Avenal.
35	14452	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 27; 1,220 feet north, 1,870 feet west; green clay member, possibly 60 feet thick.
35a	14452a	Same strata in bottom of canyon at locality 14452.
36	14453	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 27; 1,320 feet north, 2,690 feet west; green clay member, just above Avenal sandstone.
36a	14453a	Same locality; green clay about 60 feet above Avenal sandstone.
36c	14453c	Near locality 14453a; green clay about 100 feet above Avenal sandstone.
36d	14453d	170 feet northwest of locality 14453; green clay member.
39	14456	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 27; 40 feet east, 1,600 feet south; green clay member.
39a	14456a	200 feet east of locality 14456; upper part of zone represented by locality 14456.
39b	14456b	200 feet east of locality 14456; lower part of zone represented by locality 14456.
39d	14456d	About 30 feet above zone represented by locality 14456; green clay member.
39e	14456e	500 feet southeast of locality 14456; green clay member?
40	14457	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 28; 800 feet south, 700 feet west; green clay member.
40a	14457a	About 50 feet above locality 14457 and 150 feet north and a little west of locality 14457; Kreyenhagen shale?
40b	14457b	About 25 feet below locality 14457; Avenal sandstone.

[31] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, p. 71.

Fossil localities—Continued

No. on plate 9.	Geological Survey No.	Locality data
		AVENAL SANDSTONE AND KREYENHAGEN SHALE—Continued
41	14458	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 40 feet north, 1,880 feet west; green clay member.
41a	14458a	80 feet southeast of locality 14458; green sand in green clay member.
42	14459	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 2,430 feet west, 500 feet north; green clay member of the Kreyenhagen shale or just below the top of the Avenal sandstone.
42a	14459a	100 feet north of locality 14459; green clay member.
42b	14459b	350 feet east of locality 14459; Kreyenhagen shale.
42D	----------	300 feet north of locality 14459; green clay member.
43	14460	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 2,420 feet east, 1,120 feet north; green clay member.
44	14461	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 2,040 feet east, 1,700 feet north; green clay member?
45	14462	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 1,760 feet east, 2,000 feet north; green clay member?
45a	14462a	About 100 feet east of locality 14462 and possibly a little lower; green clay member.
46	14463	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 900 feet east, 2,780 feet north; green clay member.
46a	14463a	About 800 feet southeast of locality 14463; green clay member.
47	14464	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 20; 820 feet south, 600 feet west; Kreyenhagen shale.
47a	14464a	300 feet west, 50 feet south of locality 14464; green clay member.
48	14465	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 20; 90 feet south, 1,320 feet west; green clay member.
49	14466	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 13; 1,080 feet south, 2,880 feet east; green clay member.
50	14466a	About 50 feet below locality 14466; green clay member.
51	14467	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 11; 1,300 feet west, 1,200 feet north; green clay member of Kreyenhagen shale or upper part of Avenal sandstone.
52	14468	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 11; 1,400 feet north, 1,600 feet west; green clay member.
53	14469	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 11; 2,000 feet east, 2,250 feet north; green clay member.
55	14471	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 4; 900 feet north, on the east line; green clay member.
56	14472	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 4; 1,600 feet west, 1,750 feet north; green clay member.
57	14473	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 32; 600 feet west, 850 feet north; green clay member?, about 100 feet downstream from top of Avenal, but there may be sliding.
58	14474	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 1,070 feet north, 5,460 feet west; Kreyenhagen shale.
59	14475	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 25; 20 feet east, 1,690 feet south; green clay member.
59a	14475a	15 feet above locality 14475; green clay member.
61	14477	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 23; 550 feet north, 3,480 feet west; green clay member.
62	14478	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 28; 300 feet south, 1,430 feet west; Avenal sandstone.
		AVENAL SANDSTONE AND KREYENHAGEN SHALE—Continued
62a	14438	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 28; 100 feet south, 1,430 feet west; green clay member.
63	14479	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 1,630 feet west, 1,400 feet south; Little Tar Spring; Avenal sandstone.
63a	14479a	A few feet above or below locality 14479; attitude of strata obscure.
63b	14479b	Sandstone below locality 14479; Avenal sandstone.
63c	14437	150 feet north of locality 14479; green clay member; collectors, S. S. Siegfus and Ralph Stewart.
64	14480	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 1,700 feet north, 1,690 feet east; Avenal sandstone.
64a	14480a	Just above locality 14480; Avenal sandstone.
64b	14480b	100 feet northwest along strike from locality 14480; Avenal sandstone.
64c	14480c	400 feet northwest along strike from locality 14480; Avenal sandstone.
64d	14480d	900 feet southeast of locality 14480; just below upper bed of Avenal sandstone.
65	14481	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 800 feet south, 2,920 feet east; Avenal sandstone.
66	14482	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 400 feet south, 2,100 feet east; Avenal sandstone.
66a	14482a	Same layer on next ridge east of locality 14482; Avenal sandstone.
66b	14482b	Just below top of next ridge west of locality 14482; Avenal sandstone.
67	14483	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 600 feet south, 1,670 feet east; Avenal sandstone.
67a	14483a	Lower ledge in canyon 700 feet west of locality 14483; Avenal sandstone.
68	14484	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 27; 350 feet west, 400 feet north; Avenal sandstone.
68a	14484a	15 feet below locality 14484; Avenal sandstone.
68b	14484b	Kettleman Plain quadrangle T. 23 S., R. 17 E., sec. 27; 1,100 feet west, 700 feet north; Avenal sandstone.
68c	14484c	600 feet northwest of locality 14484b; below *Turritella* bed, Avenal sandstone.
68d	14484d	5 feet above *Turritella* bed of locality 14484c; Avenal sandstone.
68e	14484e	800 feet northwest of locality 14484b; Avenal sandstone.
69	14485	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 27; 3,150 feet west, 1,490 feet north; Avenal sandstone.
70	14486	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 27; 650 feet east, 2,400 feet south; Avenal sandstone.
71	14487	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 27; 200 feet east, 2,000 feet south; Avenal sandstone.
71a	14487a	Float near locality 14487; Avenal sandstone.
72	14488	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 28; 680 feet south, 1,200 feet west; Avenal sandstone.
72a	14488a	300 feet southeast of locality 14488; about same horizon but not in place; Avenal sandstone.
73	14489	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 28; 1,430 feet west, 340 feet south; Avenal sandstone.
73S	----------	See 63c.
74	14490	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 2,200 feet west, 280 feet north; Avenal sandstone.
75	14491	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 1,320 feet east, 1,800 feet north; Avenal sandstone.

Fossil localities—Continued

No. on plate 9.	Geological Survey No.	Locality data
		AVENAL SANDSTONE AND KREYENHAGEN SHALE Continued
76	14492	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 21; 120 feet east, 980 feet south; Avenal sandstone.
76a	14492a	150 feet north of locality 14492; Avenal sandstone.
77	14493	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 20; 100 feet south, 1,320 feet west; top of Avenal sandstone.
78	14494	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 17; 2,700 feet east, 250 feet north; Avenal sandstone.
78a	14494a	170 feet stratigraphically above locality 14494, near top of Avenal sandstone.
78b	14494b	Basal conglomerate 70 feet below locality 14494; Avenal sandstone.
79	14495	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 17; 2,020 feet east, 400 feet north; just southeast of Big Tar Canyon; lower part of formation near type locality; Avenal sandstone.
79a	14495a	Near top of lower part of section exposed at locality 14495; Avenal sandstone.
80	14496	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 17; 1,500 feet north, 220 feet east; basal conglomerate, Avenal sandstone.
81	14497	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 13; 1,410 feet south, 2,370 feet west; basal conglomerate, Avenal sandstone.
81a	14497a	About 80 feet above zone represented by locality 14497; Avenal sandstone.
81b	14497b	About 100 feet above zone represented by locality 14497; Avenal sandstone.
82	14498	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 11; 700 feet north, 1,720 feet west; 36 feet above Cretaceous-Avenal contact; Avenal sandstone.
83	14499	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 11; 2,150 feet east, 1,600 feet north; Avenal sandstone.
83a	14499a	In canyon 600 feet northwest of locality 14499; Avenal sandstone.
84	14500	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 10; 2,500 feet east, 1,030 feet south; Avenal sandstone.
84a	14500a	5 feet above zone represented by locality 14500; Avenal sandstone.
84b	14500b	About 300 feet east of locality 14500; higher stratigraphically; Avenal sandstone.
84c	14500c	25 feet stratigraphically below zone represented by locality 14500; Avenal sandstone.
85	14501	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 4; 800 feet north, 1,450 feet west; Avenal sandstone.
86	14502	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 4; 2,200 feet north, 2,700 feet west; Avenal sandstone.
87	14503	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 32; 800 feet west, 450 feet north; in small tributary just east of main Canoas Canyon; 270 feet above base, in black pebble bed; Avenal sandstone.
87a	14503a	On trail on west side of Canoas Canyon; 230 feet above lowest ledge; Avenal sandstone.

Fossil localities—Continued

No. on plate 9.	Geological Survey No.	Locality data
		AVENAL SANDSTONE AND KREYENHAGEN SHALE Continued
87b	14503b	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 31; 700 feet west, 1,650 feet south; Reese Canyon; near top of Avenal sandstone.
87c	14503c	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 31; 1,750 feet west, 1,120 feet south; west fork of Reese Canyon; 200 feet above the Avenal conglomerate; Avenal sandstone.
88	14504	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 580 feet north, 5,500 feet west; Avenal sandstone.
89	14505	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 26; 250 feet west, 1,550 feet south; top of Avenal sandstone.
		PANOCHE FORMATION
90	14527	Kettleman Plain quadrangle, T. 23 S., R. 17 E., sec. 35; 220 feet west, 2,400 feet south; Little Tar Canyon; collectors R. D. Reed, W. D. Kleinpell, D. D. Hughes, and Ralph Stewart.
91	14528	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 20; 780 feet west, 1,250 feet north; boulder in conglomerate.
92	14529	Reef Ridge quadrangle, T. 23 S., R. 17 E., sec. 20; 1,470 feet south, 2,680 feet east; boulder in conglomerate.
93	14530	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 13; 1,820 feet east, 2,600 feet south.
94	14531	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 13; 1,720 feet east, 2,230 feet south.
95	14532	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 31; 830 feet south, 4,620 feet west; boulder in conglomerate.
96	14533	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 25; 1,120 feet east, 2,080 feet north; boulder in conglomerate.
97	14534	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 26; 1,020 feet west, 2,100 feet south.
98	14535	550 feet west of locality 14534; boulder that probably rolled down hillside.
		KREYENHAGEN SHALE
99	14559	Reef Ridge quadrangle, T. 23 S., R. 16 E., sec. 12; 800 feet east, 600 feet north; southwest of Roundtop.
100	14560	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 32; 1,450 feet north, 1,050 feet west; Canoas Canyon.
101	14561	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 3,450 feet west, on south line.
102	14562	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 1,390 feet north, 5,500 feet west.
103	14563	Dark Hole quadrangle, T. 22 S., R. 16 E., sec. 30; 1,800 feet north, 7,420 feet west.
104	14564	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 25; 2,000 feet north, 2,000 feet west.
105	14565	Dark Hole quadrangle, T. 22 S., R. 15 E., sec. 25; 140 feet east, 1,500 feet south.

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PLATES 11, 12, 15-17

Plates 9, 10, 13, 14 are in pocket

PLATE 11

[Figures natural size unless otherwise designated]

FIGURE 1. *Agaronia mathewsonii* (Gabb), × 3. Height (incomplete) 13 mm., diameter 4.5 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498702.

2. *Amaurellina lajollaensis* Stewart, × 3. Small, slightly crushed specimen. Height 8.2 mm., diameter 6.5 mm. Eocene. Avenal sandstone, locality 87 (14503). U. S. Nat. Mus. 498703.

3. *Amaurellina* (*Euspirocrommium*?) *clarki* Stewart. Height 25.8 mm., diameter 20 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498704.

4. *Architectonica* (*Stellaxis*) *cognata* Gabb, × 3. Small specimen. Height about 3.5 mm., diameter 11 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498705.

5. *Calyptraea diegoana* (Conrad), × 2. Height about 7 mm., diameter 19.3 mm. Eocene. Avenal sandstone, locality 78 (14494). U. S. Nat. Mus. 498706.

6. *Conus hornii umpquaensis* "Hendon" Turner, × 3. Height 9.3 mm., diameter 5.5 mm. Eocene. Avenal sandstone, locality 81a (14497a). U. S. Nat. Mus. 498707.

7. *Corbula complicata* Hanna, × 3. Right valve. Length 13 mm., height 7.7 mm., thickness about 3 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498708.

8. *Corbula complicata* Hanna, × 3. Left valve. Length 11.5 mm., height 7.6 mm., thickness about 4.5 mm. Eocene. Avenal sandstone, locality 87 (14503). U. S. Nat. Mus. 498709.

9. *Corbula parilis* Gabb, × 3. Right valve. Length 9 mm., height 6.2 mm., thickness 3 mm. Eocene. Avenal sandstone, locality 78 (14494). U. S. Nat. Mus. 498710.

10. *Corbula parilis* Gabb, × 3. Left valve. Length 9 mm., height 5 mm., thickness of both valves 6 mm. Eocene. Avenal sandstone, locality 78 (14494). U. S. Nat. Mus. 498711.

11. *Cylichnina tantilla* (Anderson and Hanna), × 3. Height 10 mm., diameter 4.2 mm. Eocene. Avenal sandstone, locality 81a (14497a). U. S. Nat. Mus. 498712.

12. *Ectinochilus macilentus* (White), × 5. Varices shown on early whorls. Length 4.9 mm., diameter of longest whorl 2.4 mm. Eocene. Avenal sandstone, locality 84 (14500). U. S. Nat. Mus. 498713.

13. *Ectinochilus macilentus* (White), × 3. Smooth protoconch and early whorls. Height 8.9 mm., diameter 4.4 mm. Eocene. Avenal sandstone, locality 76 (14492). U. S. Nat. Mus. 498714.

14. *Ectinochilus macilentus* (White), × 2. Height 11.4 mm., diameter 5 mm. Eocene. Avenal sandstone, locality 76 (14492). U. S. Nat. Mus. 498715.

15. *Ectinochilus macilentus* (White). Incomplete specimen showing part of posterior canal. Height 25.8 mm., diameter 8 mm. Eocene. Avenal sandstone, locality 84 (14500). U. S. Nat. Mus. 498716.

16. *Euspira nuciformis* (Gabb), × 2. Height 16 mm., diameter 17.3 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498717.

17. *Ficopsis crescentensis* Weaver and Palmer, × 2. Height 20.8 mm., diameter 8.5 mm. Eocene. Avenal sandstone, locality 78 (14494). U. S. Nat. Mus. 498718.

18. *Globularia* (*Eocernina*) *hannibali* (Dickerson). Height 43.6 mm., diameter 40.6 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498719.

19. *Nemocardium linteum* (Conrad), × 2. Height 24.3 mm., length 21 mm., thickness 10 mm., slightly crushed. Eocene. Av nal sandstone, locality 67 (14483). U. S. Nat. Mus. 498720.

20. *Plagiocardium* (*Schedocardia*) *brewerii* (Gabb), × 2. Height 11.5 mm., length 11 mm., thickness of one valve 4 mm. Eocene. Avenal sandstone, locality 76 (14492). U. S. Nat. Mus. 498721.

21. *Spiroglyphus*? *tejonensis* Arnold, × 2. Diameter normal to axis 10.3 mm., diameter of last whorl parallel to axis 2.9 mm. Eocene. Avenal sandstone, locality 81b (14497b). U. S. Nat. Mus. 498722.

22. *Leiorhinus*? *reedi* Stewart, n. sp., × 3. The collar and the spiral rib just below are crenulated with fine arcuate growth lines. The inner lip is smooth; the outer lip is crenulated internally and has a shallow anterior notch but lacks a distinct posterior notch. Height 13.8 mm., diameter 6.5 mm. Eocene. Avenal sandstone, locality 66a (14482a). U. S. Nat. Mus. 498723. Type.

23. *Spisula merriami* Packard, × 2. Left valve. Height 13 mm., length 16.4 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498724.

24. *Turritella buwaldana* Dickerson, × 2. Height 15.7 mm., diameter 6 mm. Eocene. Avenal sandstone, locality 79 (14495). U. S. Nat. Mus. 498725.

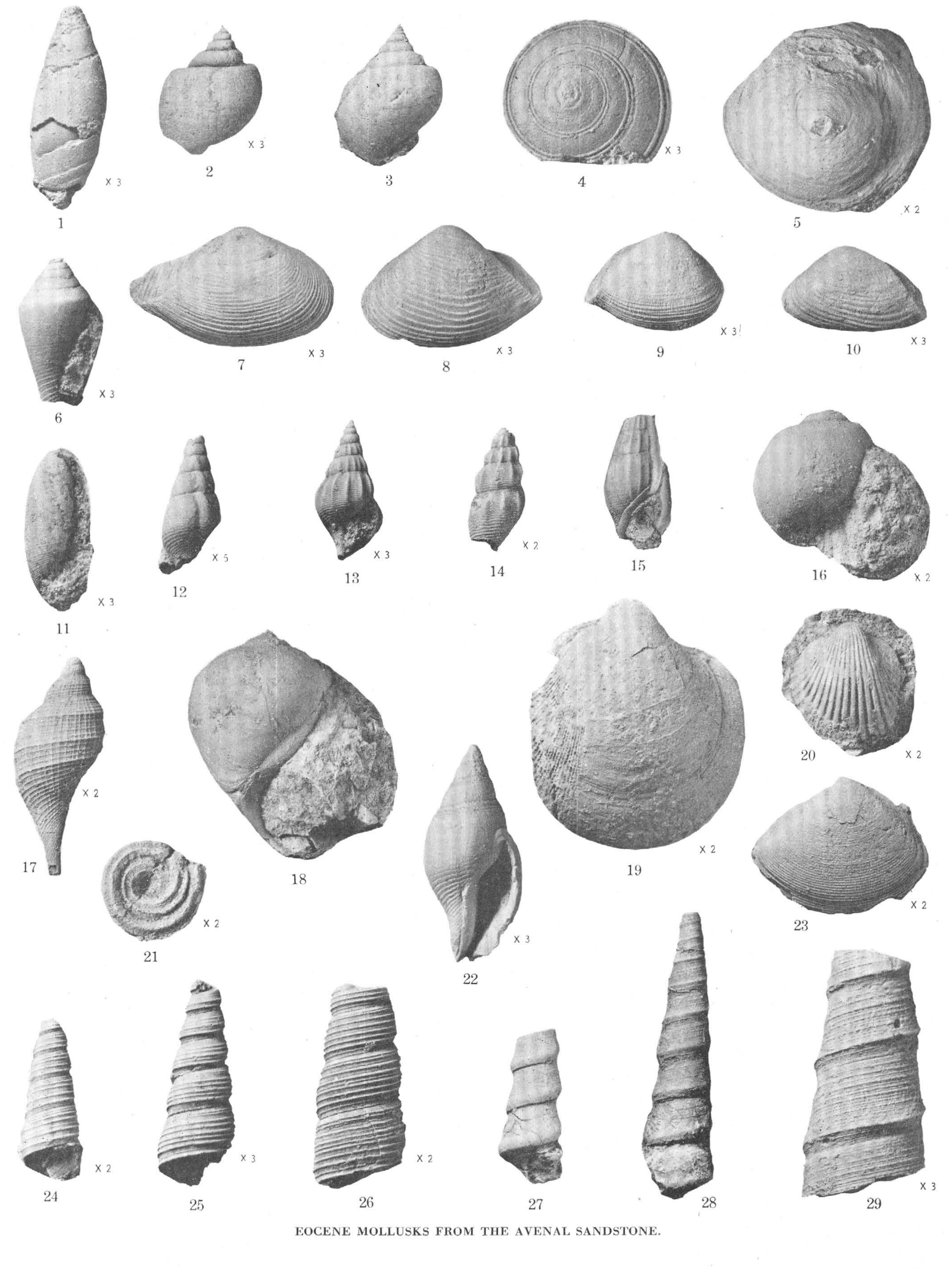
25. *Turritella uvasana* Conrad, × 3. Height 13 mm., diameter 5 mm. Eocene. Avenal sandstone, locality 78 (14494). U. S. Nat. Mus. 498726.

26. *Turritella uvasana* Conrad, × 2. Height 19 mm., diameter 9 mm. Eocene. Avenal sandstone, locality 78 (14494). U. S. Nat. Mus. 498727.

27. *Turritella lawsoni* Dickerson. Height 29.3 mm., diameter 12.5 mm. Eocene. Avenal sandstone, locality 66 (14482). U. S. Nat. Mus. 498728.

28. *Turritella lawsoni* Dickerson. Height 53.3 mm., diameter 13.4 mm. Eocene. Avenal sandstone, locality 66b (14482b). U. S. Nat. Mus. 498729.

29. *Turritella lawsoni* Dickerson, × 3. Height 15.5 mm., diameter 8 mm. Eocene. Avenal sandstone, locality 66 (14482). U. S. Nat. Mus. 498730.



EOCENE MOLLUSKS FROM THE AVENAL SANDSTONE.

PLATE 12

FIGURE 1. *Scutella*? cf. *S.*? *andersoni* Twitchell, × 2. Length 27.4 mm., width 25.9 mm., thickness 5.5 mm. Miocene. Temblor sandstone, locality 20 (14403). U. S. Nat. Mus. 498731.

2. *Astrodapsis*? *merriami* Anderson, × 3. Length 20.5 mm., width 20 mm., thickness about 4 mm. Miocene. Temblor sandstone, locality 22 (14405). U. S. Nat. Mus. 498732.

3. *Glycymeris sagittata* (Gabb), × 2. Height 24 mm., length 27 mm., thickness of one valve about 10 mm. Eocene. Avenal sandstone, locality 81a (14497a). U. S. Nat. Mus. 498733.

4. *Glycymeris perrini* Dickerson, × 4. Length 8.3 mm., height 7.5 mm., thickness of one valve 2.5 mm. Eocene. Avenal sandstone, locality 66 (14482). U. S. Nat. Mus. 498734.

5. *Pitar* (*Calpitaria*) *uvasanus coquillensis* Turner, × 2. Right valve. Length 18.5 mm., height 15 mm., thickness of right valve about 3.5 mm. Eocene. Avenal sandstone, locality 78 (14494). U. S. Nat. Mus. 498735.

6. *Pitar*? *joaquinensis* Vokes, × 3. Left valve. Length 13.7 mm., height 11.3 mm., thickness 4 mm. Eocene. Avenal sandstone, locality 81a (14497a). U. S. Nat. Mus. 498736.

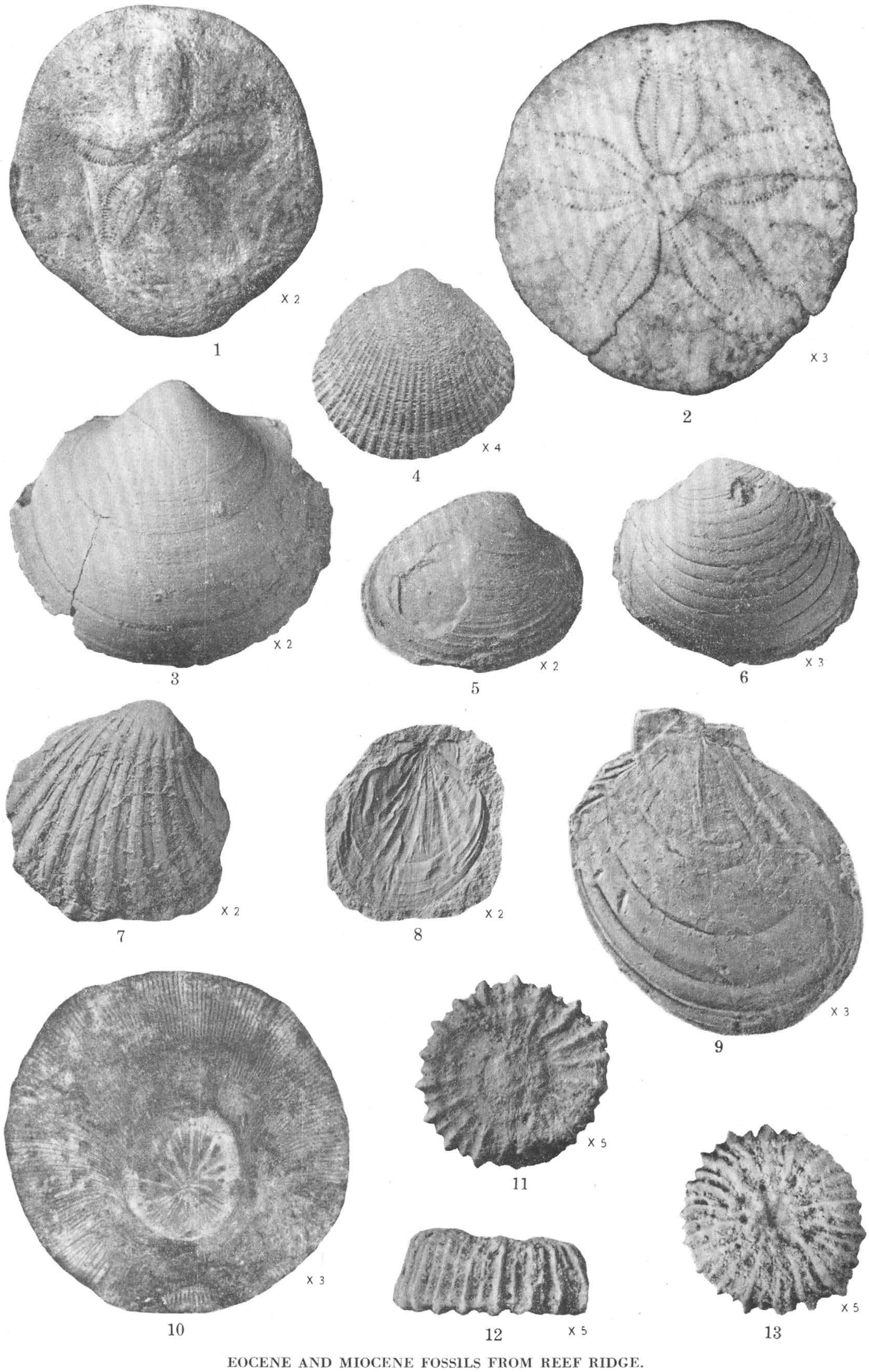
7. *Venericardia* cf. *V. sandiegoensis* (M. Hanna), × 2. Right valve. Length 18.5 mm., height 16.9 mm., thickness 6 mm. Eocene. Avenal sandstone, locality 76 (14492). U. S. Nat. Mus. 498737.

8. *Propeamussium interradiatum* (Gabb), × 2. External view of crushed left valve showing concentric sculpture. Length 12.5 mm., height 14 mm. Eocene. Kreyenhagen shale, locality 103 (14563). U. S. Nat. Mus. 498738.

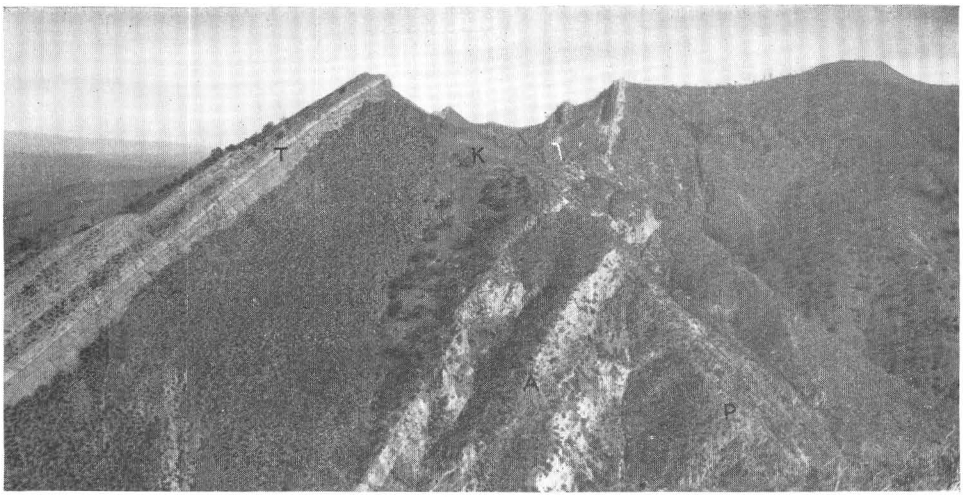
9. *Propeamussium interradiatum* (Gabb), × 3. Crushed right valve showing radial sculpture and impressions of internal radial ribs on the posterior (left side). Length 16.5 mm., height 18.5 mm. Eocene. Kreyenhagen shale, locality 104 (14564). U. S. Nat. Mus. 498739.

10. *Antilloseris*? *vaughani* Wells, × 3. Basal view showing polished surface of base. Diameter of calice 20 mm., height of corallum 7 mm., diameter of corallum at plane 7 mm. below calice 7 mm. Eocene. Avenal sandstone, locality 66 (14482). U. S. Nat. Mus. 498697. Type.

11–13. *Discotrochus californicus* Wells, × 5. 11, Basal view; 12, lateral view; 13, calice. Diameter of corallum at base 6 mm., height of corallum 2.5 mm. Eocene. Avenal sandstone, locality 66 (14482). U. S. Nat. Mus. 498698. Type.

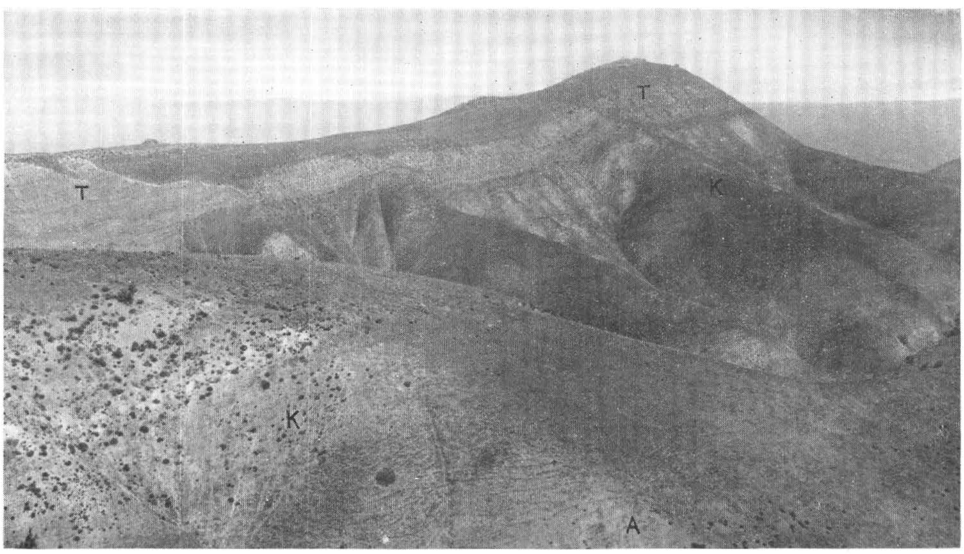


EOCENE AND MIOCENE FOSSILS FROM REEF RIDGE.



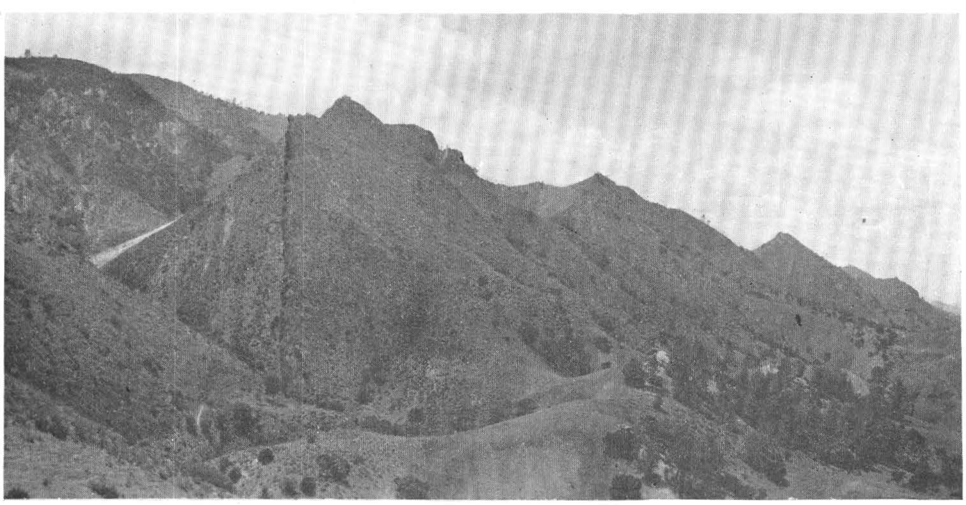
A. REEF RIDGE LOOKING EASTWARD ACROSS ARROYO PINOSO.

Massive Avenal sandstone (A) in center and stratified Temblor sandstone (T) on the left. The Temblor sandstone forms the ridge and is separated from the Avenal by about 200 feet of poorly exposed Kreyenhagen shale (K). Panoche conglomerates and shales (P) on the right.



B. REEF RIDGE LOOKING EASTWARD FROM GARZA PEAK.

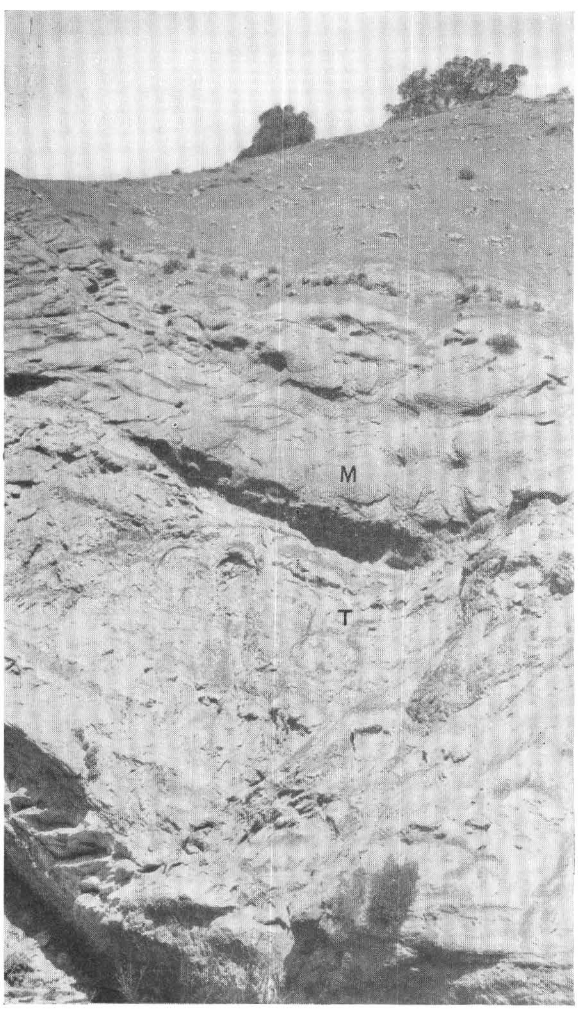
Temblor sandstone (T), Kreyenhagen shale (K) above the green clay member (not exposed), and the Avenal (A).



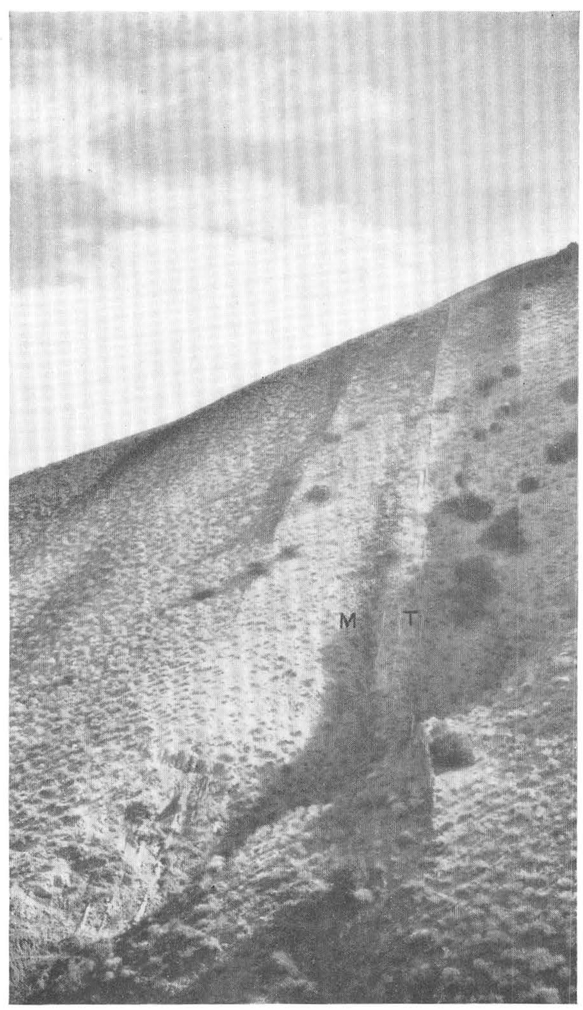
C. REEF RIDGE LOOKING WESTWARD ACROSS BELTRAN CANYON, WITH DIP SLOPES TO THE RIGHT, AT THE BASE OF WHICH IS EXPOSURE OF THE McLURE SHALE—LIGHT GRAY IN PHOTOGRAPH.

A. REEF RIDGE LOOKING EASTWARD FROM THE SECOND RIDGE EAST OF ZAPATO CANYON

Massive white Avenal sandstone (A) in the left foreground overlain by Temblor sandstone (T). Overturned sands and shales of the Panoche formation (P) on the right.



B. CONTACT OF McLURE (M) AND TEMBLOR (T) IN ZAPATO CANYON.



C. CONTACT OF McLURE AND TEMBLOR, BIG TAR CANYON.

Shows fossiliferous ledges at the top of the Temblor (T) apparently truncated by the basal sandstone and conglomerate of the McLure (M).

PLATE 17

[Figures natural size unless otherwise designated]

FIGURE 1. *Aequipecten andersoni* (Arnold), × 3. Right valve. Height 21.5 mm., length 20.8 mm., thickness of single valve 3.5 mm. Miocene. Temblor sandstone, U.S.G.S. locality 6066, north of Kern River, about 11 miles northeast of Bakersfield; about ¼ mile downstream from bridge 1 mile below the mouth of the granite canyon of the Kern River; 30 feet above the stream in low bluff. Collector, Robert Anderson, 1910. U. S. Nat. Mus. 498740.

2. *Aequipecten andersoni* (Arnold), × 2. Right valve. Height 24.5 mm., length (incomplete) 24 mm. Miocene. Temblor sandstone, 135 feet below the top in the first small arroyo west of Big Tar Canyon. U. S. Nat. Mus. 498741.

3. *Aequipecten andersoni* (Arnold), × 2. Left valve. Height 27.5 mm., length 29 mm., thickness of one valve 6 mm. Miocene. Temblor sandstone, U.S.G.S. 6890, about 12 miles east and a little north of Bakersfield on the north side of Kern River 1 mile northeast of the Barker Ranch house. U. S. Nat. Mus. 166577.

4. *Vertipecten* cf. *V. propatulus* (Conrad). Incomplete right valve. Height 72 mm., length 72 mm. Miocene. Lower part of Temblor sandstone, locality 10 (14393). U. S. Nat. Mus. 498742.

5. *Miltha sanctaecrucis* Arnold. Incomplete right valve. Height 51 mm., length 55.7 mm., thickness of sixth valve about 10 mm. Miocene. Temblor sandstone, U.S.G.S. 6622, north bank of Kern River about 10 miles northeast of Bakersfield; float from bluffs above the irrigation ditch about 1¼ miles northeast of the Rio Bravo Ranch and ¾ mile below the bridge ¾ mile below the mouth of the canyon. Collectors, R. W. Pack and J. D. Northrop, 1911. U. S. Nat. Mus. 498743.

6. *Pseudocardium densatum minor* (Arnold). Left valve. Height 36.5 mm., length 43 mm., thickness of both valves 28.5 mm. Miocene. Temblor sandstone, float in Garza Canyon, originally from 185 feet or 140 feet above the ledges of *Turritella*. U. S. Nat. Mus. 498744.

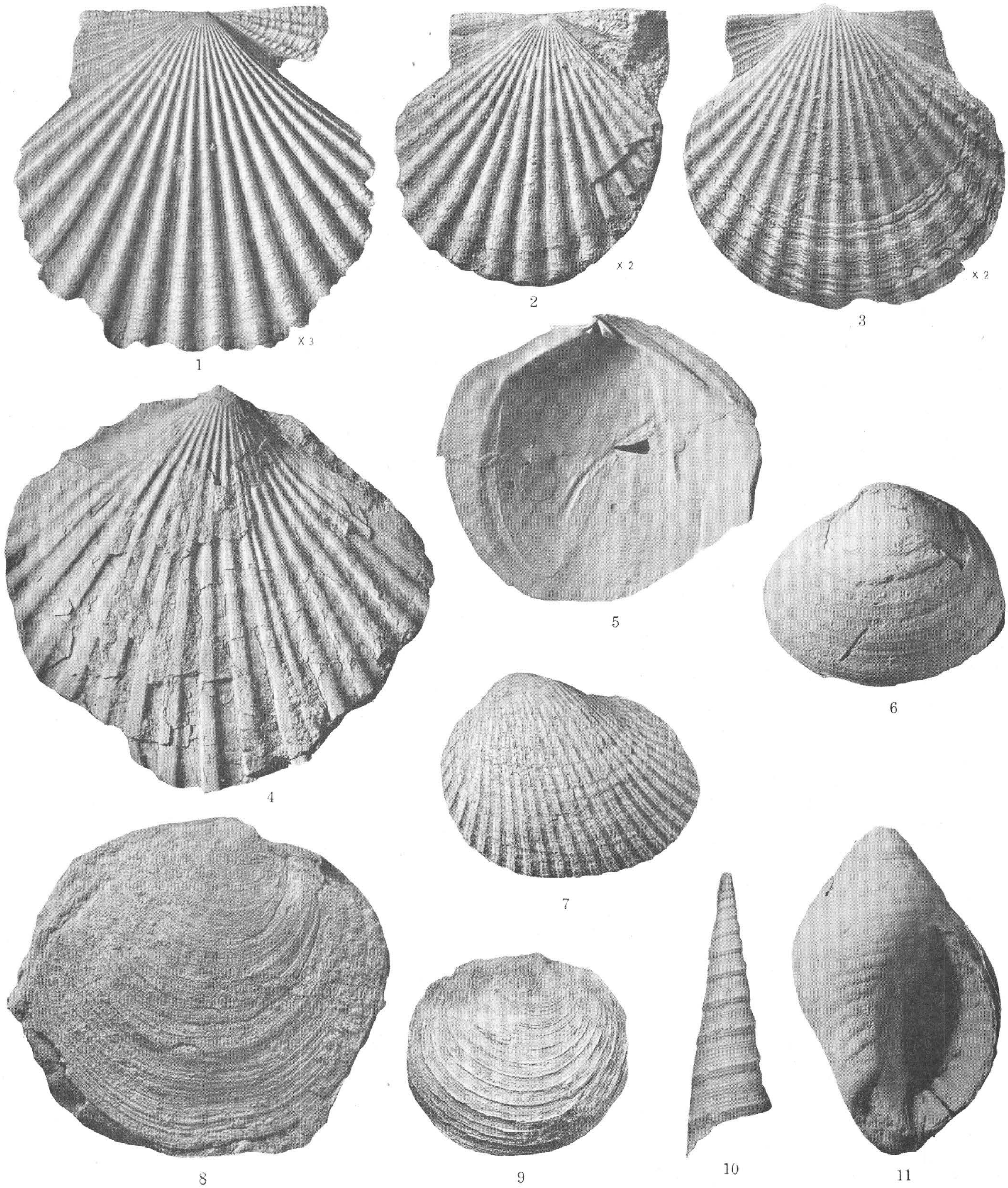
7. *Anadara devincta* (Conrad). Left valve. Height 38 mm., length 47 mm., thickness of both valves 33.3 mm. Miocene. Temblor sandstone, locality 9 (14392a). U. S. Nat. Mus. 498745.

8. *Miltha sanctaecrucis* Arnold. Right valve. Height 59 mm., length 63.5 mm. Miocene. McLure shale, locality 12b (14395b). U. S. Nat. Mus. 498746.

9. *Lucinoma acutilineata* (Conrad). Right valve. Height 37 mm., length 40 mm., thickness of both valves 15.5 mm. Miocene. Temblor sandstone, locality 9 (14392). U. S. Nat. Mus. 498747.

10. *Turritella ocoyana* Conrad. Height above fracture 44 mm., diameter above fracture 14.4 mm. Miocene. Temblor sandstone, locality 19 (14402). U. S. Nat. Mus. 498748.

11. *Nucella packi* (Clark) var. *talea* Stewart n. var. × 2. Height 29.8 mm., diameter 19 mm. Miocene. Temblor sandstone, locality 7 (14390). U. S. Nat. Mus. 498749. Type. This variety is more slender than the typical form.



MIOCENE MOLLUSKS FROM THE TEMBLOR AND McLURE.