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GEOLOGY OF THE KETTLEMAN HILLS OIL FIELD CALIFORNIA

STRATIGRAPHY, PALEONTOLOGY, AND STRUCTURE

BY

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CONTENTS

ILLUSTRATIONS

INSERTS

GEOLOGY OF THE KETTLEMAN HILLS OIL FIELD, CALIFORNIA
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By W. P. Woodring, Ralph Stewart, and R. W. Richards

ABSTRACT

The Kettleman Hills oil field came into prominence in 1928, when the completion of the discovery well indicated a rich supply of oil and gas in a region that had long been considered prospective oil territory. The Kettleman Hills, 30 miles long and 4 to 5 miles wide, consist of three northwestward-trending anticlines—North Dome, Middle Dome, and South Dome—which lie in echelon alinement along the west side of southern San Joaquin Valley. Although a part of the foothills of the Coast Ranges, they are separated from the mountains by the synclinal Kettleman Plain. South Dome is the northern part of the anticline that is overlapped by the alluvium of San Joaquin Valley. Ten miles southeast of South Dome, Lost Hills rise above the alluvium either as a part of the same anticline or as another one of the anticlines in a line extending southeastward from Anticline Ridge in the Diablo Range through the Kettleman Hills.

Stratigraphy and paleontology of exposed formations.—The exposed strata and those penetrated by wells have a thickness of about 14,000 feet and range in age from Pliocene and Pleistocene (?) to Eocene. Those exposed at the surface have a thickness of about 6,000 feet and are of Pliocene and Pleistocene (?) age. They represent in descending order the Tulare, San Joaquin, and Etchegoin formations. The Tulare formation has an exposed thickness of 1,700 to 3,500 feet. It is nonmarine and consists principally of sandstone and conglomerate and toward the base of fine-grained rocks in which fresh-water mollusks and fresh- and brackish-water diatoms are abundant. The San Joaquin formation has a thickness of 1,200 to 1,800 feet. It consists of silt and clay, in most of which marine fossils are apparently absent, alternating with silt, sandstone, and conglomerate, many strata of which contain marine fossils. Four marine faunal zones in the San Joaquin formation, the conglomerate at the base of the formation, and other less persistent lithologic and faunal units were mapped. The *Pecten* zone, a little above the middle of the formation, is the most widespread and most readily recognized. The San Joaquin formation is divided at the base of the *Pecten* zone into an upper and a lower part. The base of the San Joaquin formation is drawn at the base of the Cascajo conglomerate member. It is suggested that the Cascajo conglomerate is to be correlated with a conglomerate that lies unconformably on Miocene shale along the southwest border of San Joaquin Valley near McKittrick. The *Pecten* zone and Cascajo conglomerate correspond probably to marine zones recognized in the subsurface section of southern San Joaquin Valley and appear to represent the most extensive marine invasions during San Joaquin time. The exposed part of the Etchegoin formation has a thickness of about 700 feet in North Dome and an estimated exposed thickness of about 600 feet in Middle Dome. Apparently a considerably greater thickness, estimated as 1,800 feet, is represented in South Dome. With the exception of fresh-water beds near the top of the formation in North Dome, the Etchegoin consists of marine deposits, principally sandstone, conglomerate, and silt. Five faunal zones were mapped in the Etchegoin of North Dome. The structure contour lines showing the structure of the exposed formations are drawn on the *Littorina* zone, the highest of the five zones in North Dome, and its essential equivalent—the *Pseudocardium-Anadara* zone—in Middle and South Domes. One faunal zone and several generally discontinuous lithologic units in the Etchegoin formation were mapped in both Middle and South Domes, where fossils are relatively rare.

Volcanic debris is abundant in the exposed formations with the possible exception of the upper part of the Tulare formation. The material examined by M. N. Bramlette has the composition of augite andesite, hornblende andesite, and hypersthene andesite. A partial chemical analysis of a pumice tuff from the upper part of the San Joaquin formation indicates that it is dacitic. The Lassen Peak district at the south end of the Cascade Range in northern California and the region in the Coast Ranges north of San Francisco Bay appear to be the most likely source of this volcanic material. Most of the coarse-grained sandstones in the Etchegoin formation and in the basal part of the San Joaquin formation are characterized by a blue color due to a film of undetermined composition on the grains. According to Bramlette the film is probably a chloritic or clay mineral, and he suggests that there may be a relation between this mineral and tuffaceous material of the composition of hypersthene andesite, which appears to be characteristic of the blue sandstones.

Sand dollars (echinoids) of the genus *Dendraster* are perhaps the most abundant of the stratigraphically important fossils in the San Joaquin and Etchegoin formations. The *D. gibbsii* group, which is characterized by a markedly eccentric apical system, occurs in the Etchegoin and in the lower part of the San Joaquin; the *D. coalingaensis* group, which has a less eccentric apical system, is abundant in the upper part of the San Joaquin. The *D. coalingaensis* group also occurs in the lower part of the San Joaquin, and one member of the group is found in the upper *Pseudocardium* zone in the upper part of the Etchegoin. *Merriamaster*, treated as a subgenus of *Dendraster*, is characterized by inflated margins of the test, large spine bases, and open petals. Sand dollars assigned to *Merriamaster* were found only in the upper part of the San Joaquin formation.

The *Acila* zone fauna in the upper part of the San Joaquin formation lived probably in deeper water than any other fauna in the San Joaquin or Etchegoin formation. The upper *Mya* zone—the youngest of the marine zones in the San Joaquin—represents probably less saline water than the other marine zones. During the deposition of the *Pecten* zone of the San Joaquin formation the water was apparently warmer than during the deposition of the other zones and also was apparently warmer than the present coastal water north of Point Conception. Perhaps the inland San Joaquin Valley sea may have joined the open ocean south of Point Conception during the deposition of the *Pecten* zone and north of Point Conception at other times. Arnold and other writers considered certain species from the upper *Mya* zone and other beds indicative of cold water. It is more probable that these forms indicate estuarine conditions.

The Tulare formation is assigned to the upper Pliocene and Pleistocene (?), the San Joaquin formation to the upper Pliocene, and the Etchegoin formation to the middle Pliocene. Principally on the occurrence of *Merriamaster* the part of the San Diego formation exposed at Pacific Beach, near San Diego, is correlated with the San Joaquin formation. Strata in the eastern part of the Ventura Basin that have been correlated with the *Pecten* zone of the San Joaquin are considered older, more probably the equivalent of the Etchegoin.

Stratigraphy and paleontology of formations penetrated by wells and exposed nearby.—The unexposed part of the Etchegoin formation and the underlying Jacalitos formation are not differentiated in the subsurface section. The undifferentiated Etchegoin and Jacalitos have a thickness of 3,600 to 4,500 feet and consist chiefly of sandy shale, clay shale, and sand. The Jacalitos formation, which is assigned to the lower Pliocene, is underlain by the upper Miocene Reef Ridge shale—the caving shale or heaving shale of drillers. The Reef Ridge shale has an average thickness of 500 feet and is made up of shale, sandy shale, and tuffaceous sand. Foraminifera from the subsurface Reef Ridge shale and from the lower part of the formation at the foot of Reef Ridge, along the mountain front west of the Kettleman Hills, are referred by R. M. Kleinpell to his *Bolivina obliqua* zone. After passing through the Reef Ridge shale wells enter a hard siliceous shale representing a type of Miocene lithology characteristic of the Monterey shale of the Coast Ranges. This shale, which is called the brown shale by drillers and is here designated the McLure shale member of the Monterey shale, has an average thickness of 1,300 feet in North Dome and thickens southward to 2,500 feet in South Dome. Near the base of the McLure shale one to three beds of bentonite have been found in most wells. Bentonite of the same character also occurs near the base of the McLure at the outcrop on Reef Ridge. The bentonite is readily recognized in core and ditch samples and is used as a key bed. Foraminifera from the basal part of the McLure shale exposed on Reef Ridge are assigned by Kleinpell to a horizon in the lower part of the upper Miocene of current Coast Range chronology. This horizon is identified 3,500 to 4,000 feet below the top of the 7,000-foot section of Monterey shale on Chico Martinez Creek, along the front of the Coast Ranges 40 miles southeast of the Kettleman Hills.

The oil-bearing Temblor sandstone, which has a thickness of about 2,000 feet and is considered of lower and middle Miocene age, underlies the McLure shale. It consists of productive zones of sand and sandy shale and barren zones of shale, shaly sand, and sand. In North Dome the following productive and barren zones are recognized. The productive zones are numbered in consecutive order downward.

Driller's names used for subdivisions of Temblor sandstone in North Dome

First zone.	Fourth zone.
Upper variegated zone.	Lower variegated zone.
Second zone.	Fifth zone.
600-foot shale.	Felix siltstone.
Third zone.	Whepley shale.
800-foot shale.	Sixth zone.

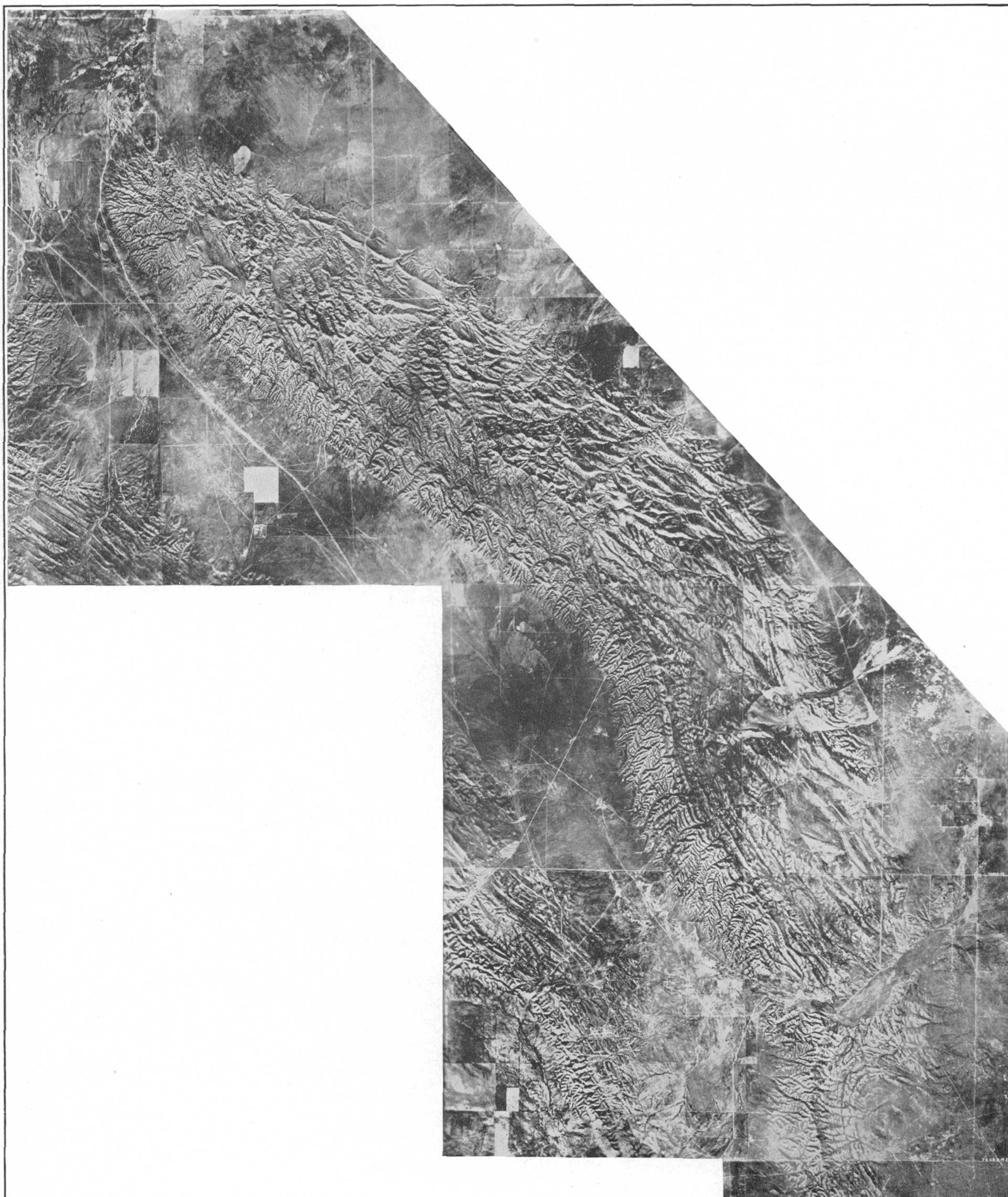
The lower part of the First zone is characterized by the abundance of serpentine and the green garnet uvarovite and is designated the serpentine zone by Bramlette. This zone and probably also the underlying upper variegated zone are the equivalent of the Big Blue serpentinous member at the top of the Temblor sandstone exposed on Anticline Ridge, northwest of the Kettleman Hills. On the basis of its Foraminifera the 600-foot shale is correlated by R. M. Kleinpell with the Gould shale, which represents his *Siphogenerina branneri* zone. The Gould shale is the lowest member of the 7,000-foot section of Monterey shale exposed on Chico Martinez Creek. According to this correlation and the correlation of the basal part of the McLure shale, the part of the Temblor sandstone in the Kettleman Hills subsurface section overlying the 600-foot shale is the equivalent of a considerable thickness of Monterey shale in the Chico Martinez Creek section, for it is improbable that there are discontinuities of any magnitude in either section. A thin mineral zone, designated by Bramlette the orthoclase-anhydrite zone, occurs at the top of the Fifth zone and apparently also in the lower part of the lower variegated zone. Most of the Fifth zone represents Bramlette's andesitic sand zone, characterized in the well material by the abundance of hornblende and by the presence of other ferromagnesian minerals.

Several wells in North Dome have been drilled through the Temblor sandstone into the Kreyenhagen shale, which has a thickness of 1,000 to 1,150 feet. The Kreyenhagen shale is a shale of Monterey type. At the outcrop it is of Eocene age or of Eocene and Oligocene age. As the age relations of the Kreyenhagen in the Kettleman Hills subsurface section are uncertain, it is designated Oligocene (?) and Eocene. Deep wells at the extreme north end of North Dome penetrated the Kreyenhagen shale and entered the McAdams sand, which may represent the middle Eocene Avenal sandstone of the Reef Ridge outcrop section.

Structure.—North Dome is much longer and 400 feet higher structurally than Middle Dome. South Dome is evidently part of an anticline that is wider than North and Middle Domes. As the structure of South Dome is interpreted, it is 800 feet higher structurally than North Dome. The southward extent of South Dome is uncertain owing to the overlap of alluvium, but South Dome may be the north end of the Lost Hills anticline structurally the highest part of which is about 10 miles south of South Dome.

Two sets of normal faults are recognized in North Dome: (1) strike faults that are about parallel to the strike of the strata, and (2) diagonal faults that in general trend slightly east of north at angles of about 60° to the strike of the strata. The faults of both sets have average dips of about 60°. The strike faults have displacements ranging from a few feet to about 300 feet. Most of the strike faults dip toward the axis of the anticline. Striae observed on a few strike-fault planes are almost invariably parallel to the dip of the fault planes. The axis of the middle part of the anticline lies in a complex fault trough limited by strike faults. The diagonal faults have displacements of less than 100 feet. Most of the diagonal faults on and near the plunging ends of the anticline dip in the direction of plunge. In the central part of the anticline, where the axis is essentially horizontal, eastward- and westward-dipping diagonal faults are about equally numerous. The trend and angle of inclination of striae were measured on many diagonal faults. With only a few exceptions the striae are oblique to the strike and dip of the fault planes, lie at angles of about 60° to the strike, and are inclined toward the axis of the anticline.

Middle Dome consists of three parts, the main part and a faulted minor dome at each plunging end. The axis of the anticline is bent sharply between the middle part and each of the minor domes. Most of the faults in Middle Dome are roughly radial or slightly diagonal. Strike faults were recognized only near the ends of the anticline close to the base of down-faulted wedges that point toward the concave sides of the bends in the axis. The strike faults dip toward the axis of the anticline. The radial and diagonal faults have the greatest displacement at the border of the down-faulted wedges or in wedges in the minor domes, the maximum displacement being generally about 150 feet. On the east limb most of the radial and diagonal faults in the central part of the anticline and in the area adjoining the minor dome at the north end dip westward; most of those on the west limb as far south as the minor dome at the south end dip eastward.



AIRPLANE PHOTOGRAPH MOSAIC OF KETTLEMAN HILLS.

From township mosaics by Fairchild Aerial Surveys.

RELIEF MAP OF CALIFORNIA.

In South Dome only minor diagonal or approximately radial faults were recognized. The axis of the anticline appears to rise southward as far as the south end of the hills.

The deformation of the Kettleman Hills is attributed to north-south compression applied to a northwestward-trending zone of weak strata in which echelon anticlines were formed. The upward squeezing of incompetent material lifted and folded the strata; the faulting is attributed to shearing that accompanied differential vertical stresses in competent strata overlying the rising incompetent material. The strike faults of the fault trough of North Dome formed after the strata had been lifted above the levels of direct influence of the north-south compression, but inasmuch as they dip toward the axis of the anticline there was evidently enough compression on the flanks to localize the movement on such faults. The diagonal faults appear to have been formed before the strata had been raised entirely above the levels of the effect of the north-south compression. The oblique striae of the diagonal faults appear to have been formed in a stage intermediate between the formation of the diagonal and the strike faults. Greater pressure on the flanks of Middle Dome than of North Dome may account for the absence of an axial fault trough in Middle Dome and for the general strike of the faults almost at right angles to the axis. On South Dome the dimensions of the incompetent material may have been such as to balance the horizontal and vertical stresses in the overlying competent rocks during the uplifting of the strata; under these conditions no axial fault trough would be formed.

Physiography.—The Kettleman Hills represent land forms carved from a deformed surface of low relief developed across folded strata of the Tulare (upper Pliocene and Pleistocene (?)) and older formations. The deformation of this surface is attributed to renewed arching along the axis of the Kettleman Hills anticline presumably during late Pleistocene time. A nearly flat surface at El Prado, near the north end of North Dome, truncates strata in the upper part of the San Joaquin formation. This surface has such low relief and covers such a large area that it evidently was formerly much more extensive than it now is and presumably covered the Kettleman Hills, but it has not been traced with certainty beyond its present limits. A surface truncating the lower part of the San Joaquin formation on La Palomera in southern North Dome may be a remnant of the surface at El Prado, but it seems to lie below the probable projection of that surface. Dissected surfaces on Las Alturas, in Middle Dome, and on Las Colinas, in South Dome, probably correspond to one or the other of the North Dome surfaces. The southward decrease in altitude from North Dome to South Dome may be explained by a southward tilt relative to the surrounding alluvium.

The lowest of the dissected erosion surfaces, representing a stage in the recent uplift of the hills, is the most conspicuous because of the older alluvium associated with it. La Vega, in northern North Dome, shows this surface and the accompanying older alluvium very well. Gravel lying above the floor of Avenal Gap, between Middle and South Domes, may have been deposited at about the same time as the older alluvium at La Vega and elsewhere.

INTRODUCTION

PREVIOUS WORK

The geology of the Coalinga district, which includes the Kettleman Hills, was first described by Watts [1] and F. M. Anderson.[2] Ralph Arnold and Robert Anderson mapped this district under the auspices of the Geological Survey, and the results of their work were published in final form in Bulletins 396[3] and 398.[4] The Kettleman Hills constitute only a small part of the Coalinga district—a relatively minor part so far as the preparation of Bulletin 398 was concerned. Only the youngest strata of the Coalinga district are exposed in the Kettleman Hills, but data on the remainder of the Tertiary section, described in Bulletin 398 and other publications, are essential in interpreting the subsurface section in the Kettleman Hills.

Unpublished studies in 1924–25 by R. D. Reed, W. D. Kleinpell, Chester Cassel, and D. D. Hughes, under the auspices of the Marland Oil Co., played an important part in guiding drilling operations that resulted in the discovery of an oil field in the Kettleman Hills. After the discovery well was completed in 1928 the Kettleman Hills were studied by many geologists, and many reports on the general geology of the area or on particular aspects of the geology have been published, the most comprehensive of which are those by Gester and Galloway [5] on the general geology and by Goudkoff [6] on the subsurface stratigraphy.

SCOPE OF REPORT

The Kettleman Hills embrace a considerable acreage of public lands. An estimate of the potentialities of the field showed that unrestricted development would not only result in a great waste of natural resources but would also be ruinous to the oil industry. This investigation of the geology of the Kettleman Hills was undertaken by the Geological Survey primarily to furnish data for the administration of the public lands with the view of cooperating with leaseholders and holders of private lands so as to conserve and utilize the resources to the greatest possible extent. This publication makes the results of the investigation available to anyone interested in the geology of the Kettleman Hills, including those having an interest in small holdings, for whom the expense of geologic work is prohibitive.

In addition to publishing material of immediate interest to oil operators in the Kettleman Hills, this report makes data available for investigations in oil geology in nearby regions. The Coalinga district has an unusually full succession of fossiliferous Pliocene deposits. In working out the stratigraphy and structure particular attention was given to the zonal paleontology of the part of this Pliocene section that crops out in the Kettleman Hills. The zonal distribution of the fossils is described, most of the species are illus-

[1] Watts, W. L., The gas and petroleum yielding formations of the central valley of California: California State Min. Bur. Bull. 3, pp. 53-68, 1894.

[2] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 155-248, pls. 12-35, 1905.

[3] Arnold, Ralph, Paleontology of the Coalinga district, Fresno and Kings Counties, Calif.: U. S. Geol. Survey Bull. 396, 173 pp., 30 pls., 1909 [1910].

[4] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, 354 pp., 52 pls., 9 figs., 1910.

[5] Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 1161-1193, 6 figs., 1933.

[6] Goudkoff, P. P., Subsurface stratigraphy of Kettleman Hills oil field, Calif.: Idem., vol. 18, pp. 435-475, 8 figs., 1934.

152190—41——2

trated, and the distribution and affinities of the stratigraphically important species are discussed. Many of the stratigraphically important fossils are recognized by field geologists, and the usefulness of fossils in field work in the Coast Ranges, where lithologic features are frequently unreliable, has long been realized. The results of this work on the paleontology of the Kettleman Hills may also be useful in interpreting the stratigraphy of subsurface sections in the San Joaquin Valley. The paleontology of the subsurface section in the Kettleman Hills is considered as far as practicable. The Foraminifera of the principal fossiliferous beds in the subsurface section, supplemented by material from the same horizons at nearby outcrop localities, are illustrated and discussed. The work on the mineralogy of the sandstones indicates that such investigations may yield fruitful results in working out the stratigraphic relations of the oil-bearing sands.

Details of the structure of the Kettleman Hills that are presented may not have a direct bearing on oil development but may be of interest to geologists in considering the geometric aspects of crustal deformation.

Of more general interest is the purpose of contributing data for the interpretation of the geologic history of the Coast Ranges. The paleontologic data on the outcrop section may be of some assistance in studying the stratigraphy of other Pliocene basins and in attempting to establish correlations. The discussion of stratigraphic classification and nomenclature, particularly with reference to the Miocene formations, may stimulate consideration of the principles underlying a subject that is especially troublesome in the Coast Ranges.

FIELD WORK

The field work that furnished the basis for this report was begun in 1930 and was continued at intervals until 1934. The anticlinal character of the Kettleman Hills is apparent to even the casual observer, but the many structural complications due to an intricate network of minor faults, at least in North Dome and Middle Dome, are much less obvious. Though it is improbable that these faults have any relation to the occurrence of oil, an attempt was made to map them, not only to represent the structure adequately but also because the stratigraphy could not be understood if they were neglected. Faunal zones were particularly useful in mapping. On the other hand, some lithologic units proved to be more persistent than had been expected. The two sets of features—fossils and lithology—served as checks on each other.

The mapping was done by W. P. Woodring and Ralph Stewart, assisted by J. C. Miller, G. F. Taylor, and C. L. Gazin. J. C. Miller mapped the *Amnicola* zones in the Tulare formation, the base of the Tulare formation, the upper *Mya* zone, and the oyster-bearing sandstones in the upper part of the San Joaquin formation. Ralph Stewart mapped the *Acila* zone, the *Trachycardium* and *Pecten* zones, and the interior of North Dome below the *Neverita* zone. W. P. Woodring mapped the *Neverita* zone, contributed data on minor units between the *Pecten* and *Neverita* zones and immediately below the *Neverita* zone, and mapped the interior of Middle and South Domes below the *Pecten* zone. G. F. Taylor measured sections in the Tulare formation and contributed other data. C. L. Gazin assisted in mapping the boundary between the upper and lower parts of the Etchegoin formation in Middle Dome. R. W. Richards gathered information on the subsurface stratigraphy and on the occurrence of oil, gas, and water.

The fossil zones and lithologic units were mapped by tracing along the strike. This procedure yielded more complete information for selected parts of the section than for intervening parts. Intervening parts of the section were examined at intervals, and it is improbable that important fossil zones or lithologic units have been completely overlooked. Not all the units that were recognized are shown on the geologic map and a great many more could be recognized, for the number of units mapped in an area like this depends principally on the length of time that can be devoted to field work.

The formations that are penetrated by wells are exposed at nearby localities. They were not studied at the outcrop localities as carefully as may be desirable. Information assembled by M. N. Bramlette in his study of the Monterey shale of the Coast Ranges, undertaken in collaboration with K. E. Lohman and R. M. Kleinpell, and the results of K. E. Lohman's work on the Temblor sandstone of Anticline Ridge are, however, available. Two sections of the Temblor sandstone measured on Reef Ridge by W. P. Woodring and the late H. R. Farnsworth before the Kettleman Hills project was started are included in this report. After the project was under way M. N. Bramlette investigated the mineralogy of the sandstones of the subsurface section, and in connection with this work W. P. Woodring and M. N. Bramlette made a brief examination of the upper part of the Temblor sandstone at localities on Reef Ridge and Anticline Ridge.

ADVANCE EDITION OF GEOLOGIC MAP

An advance edition of the geologic map, including the formation boundaries, structure contour lines showing the structure of the exposed formations, generalized stratigraphic sections, and structure sections was issued in July 1934 in order to make the data available prior to the completion and publication of the present report. The structure contours of the exposed formations and the structure sections are reproduced on plate 51. The generalized stratigraphic sections, somewhat modified, are shown on plates 3 and 51.

Since the advance edition was published the boundary between the San Joaquin and Etchegoin formations has been shifted about 100 feet higher in the

North Dome section. On the advance edition the boundary was drawn at the datum plane used for the contour lines. The datum plane is now designated the *Littorina* zone of the Etchegoin formation in North Dome and the *Pseudocardium-Anadara* zone of the Etchegoin formation in Middle and South Domes. The boundary between the San Joaquin and Etchegoin is now placed at the base of the Cascajo conglomerate member of the San Joaquin.

PRESENTATION OF DATA

The stratigraphy is described in the order in which the formations are penetrated, or would be penetrated, in drilling operations, beginning with the youngest formation.

The stratigraphy and paleontology of the exposed formations is described by W. P. Woodring and Ralph Stewart, each of whom deals with the strata and areas he has mapped. These two authors also discuss the "Environment suggested by fossils" (pp. 99–102) and "Age and correlation of exposed formations" (pp. 102–114). W. P. Woodring describes the stratigraphy and paleontology of the part of the section mapped by J. C. Miller and discusses the possible source of the volcanic material. He also describes the stratigraphy and paleontology of the formations penetrated by wells, with the exception of the matter dealing with the thickness and lithology of the subsurface formations, which was prepared by R. W. Richards. W. P. Woodring and Ralph Stewart describe the structure of the exposed formations, and Ralph Stewart discusses the origin of the structure and physiography. The discussion of the subsurface stratigraphy is based on development to the end of 1936 but includes, however, an outline of the deep formations penetrated by Kenda wells 4–18–J and 67–20–J, which were not completed until 1938.

Lists of fossils under the heading "Stratigraphy of exposed formations" show the geographic distribution of fossils collected from the different faunal zones and lithologic units. Only brief comments are made on the character of each fauna and on the fossils that may be particularly useful to stratigraphers. A discussion of the character of the faunas may be found under the heading "Environment suggested by fossils," and discussions of the stratigraphically important fossils are included under the heading "Paleontology of exposed formations." Not all the collections of fossils that were made are included in the fossil lists, as it seems unnecessary to duplicate records at nearby localities. On the other hand, some important occurrences are recorded in the lists on the basis of field determinations of fossils that were not collected. The fossil localities are plotted on the geologic map (pl. 3) and are described on pages 156–166. The report numbers for the localities were assigned before the collections were determined, so some of the collections are not in numerical stratigraphic sequence.

The fossil lists are arranged systematically. An alphabetical arrangement, which was used by Arnold in his reports on the Coalinga district, has many advantages, but it has also disadvantages. The chief disadvantage is the separation of closely allied genera belonging to the same family. This disadvantage is even more marked now than at the time when Arnold prepared his lists, for former broadly conceived genera are now generally dismembered. As an extreme example, the Coalinga Pliocene Pectenidae, which were all listed by Arnold under *Pecten*, are listed in the present report under *Pecten*, *Aequipecten*, *Chlamys*, *Hinnites*, *Patinopecten*, and *Lyropecten*.

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Many members of the Geological Survey contributed directly to this report. M. N. Bramlette studied the mineralogy of sandstones in the subsurface section and in corresponding parts of the outcrop section on Reef Ridge and furnished notes on the mineralogy of rock specimens from the Kettleman Hills outcrop section. He also supplied stratigraphic sections of Miocene formations cropping out on Reef Ridge, Chico Martinez Creek, and Zemorra Creek. K. E. Lohman identified the diatoms, wrote the discussions of the diatom floras, and contributed stratigraphic sections of the Temblor formation on Carneros Creek and Anticline Ridge. R. M. Kleinpell, formerly of the Geological Survey, identified Foraminifera from core material and from outcrop localities on Reef Ridge, Zemorra Creek, and Chico Martinez Creek, prepared the discussion of the foraminiferal faunas, and made suggestions concerning the chronology and correlation of the subsurface formations. R. W. Brown identified the land plants. The porosity of samples of oil sand and the character of the bentonite in the McLure shale member were determined by P. G. Nutting. A sample of pumice tuff was examined by C. S. Ross and a partial chemical analysis of this tuff was made by R. C. Wells. Other members of the Geological Survey contributed through frequent discussions and by reviewing parts of the report. Special acknowledgment is due to A. A. Baker, James Gilluly, T. A. Hendricks, W. W. Rubey, and P. D. Trask. H. D. Miser, under whose direction this project was planned, enthusiastically supported and encouraged this protracted investigation. The writers are also under obligations to the members of the editorial staff and of the section of illustrations.

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LOCATION AND GEOGRAPHIC FEATURES

The Kettleman Hills lie close to the east foot of the Coast Ranges along the west border of southern San Joaquin Valley, about 175 miles northwest of Los Angeles and about the same distance southeast of San Francisco. (See pl. 2.) The greater part of the area is in Kings County, the northern part extends into Fresno County, and the southern part into Kern County. The Kettleman Hills constitute a northwestward-trending slightly arcuate range, convex eastward, that has a length of 30 miles and an average width of 4 or 5 miles. As shown in figures 1 and 15, this range forms the main part of the isolated outermost foothills of the Coast Ranges extending southeastward from the mountain front along the axis of the Coalinga anticline. The hills comprise three anticlines and the corresponding geographic divisions are called North Dome, Middle Dome, and South Dome. These anticlines lie in echelon alinement and are offset westward in the order named. (See pl. 1.) Eastward from the Kettleman Hills stretches the flat San Joaquin Valley for a distance of 60 miles to the foot of the Sierra Nevada. Tulare Lake, a body of shallow water of considerable extent representing the accumulation of flood waters from Kings River and other streams emerging from the Sierra Nevada, formerly lay east of the Kettleman Hills. Except during years of exceptionally heavy rainfall the lake is no longer in existence owing to increased utilization of the water in the Sierran streams and to reclamation by drainage. The former beach line is within a mile of the edge of the hills at the south end of North Dome. Between the Kettleman Hills and the foot of the Coast Ranges proper lies Kettleman Plain.

The names North Dome, Middle Dome, and South Dome that are in use for the three divisions of the Kettleman Hills are based on structural features but are applied to geographic divisions. The designation South Dome is inappropriate as regards structure. North Dome and Middle Dome are doubly plunging anticlines, whereas South Dome—or rather the part of South Dome that is visible—plunges northwestward and is overlapped at the south end of the hills by the alluvium of San Joaquin Valley. The geographic name "South Dome" has, however, come into general use. To some geologists accustomed to the usage of the term "dome" for essentially quaquaversal anticlines, the designation of elongate anticlines, such as North Dome and Middle Dome, as domes would also appear inappropriate. The three anticlines in the Kettleman Hills are part of a northwestward-trending line of folds extending from Anticline Ridge to Lost Hills, a distance of 70 miles.

South Dome and Middle Dome are separated by alluvium-floored Avenal Gap, which extends from the Kettleman Plain to the San Joaquin Valley. No feature of this kind separates North Dome and Middle Dome, but the change in the trend of the hills reflects the change in structure, and a southward decrease in ruggedness marks the boundary between them. (See pls. 56, 57.)

North Dome rises to a considerably greater altitude than Middle and South Domes and is more rugged. La Cima, the highest point in North Dome, has an altitude of 1,366 feet above sea level, and rises about 600 feet above the edge of the Kettleman Plain and about 900 feet above the border of the San Joaquin Valley.

Coalinga is 10 miles northwest of the north end of the Kettleman Hills. It is the center for the oil industry operating in the Coalinga fields and for the livestock and agricultural industries of the surrounding region. Avenal, founded after oil development began in the Kettleman Hills, is in the Kettleman Plain west of North Dome. Three public roads extend across the Kettleman Hills. A road along the crest of North Dome and one to the center of Middle Dome were constructed by oil companies. From these main roads many secondary roads and trails branch off, making almost all parts of the hills readily accessible.

Before the establishment of the oil industry a cattle ranch in Avenal Gap was the only permanent habitation in the Kettleman Hills. A sheep ranch at La Porteria, on the east side of Middle Dome, is occupied at intervals. South Dome, the southern part of Middle Dome, and adjoining parts of the Kettleman Plain and San Joaquin Valley are used for grazing cattle. During parts of the year sheep graze in Middle and North Domes. Oil camps have been built in North Dome, and several gasoline plants in North Dome and one in Middle Dome are handling wet gas.

The Coalinga oil fields are on the Coalinga anticline (Anticline Ridge) and on the monocline on the southwest limb of the adjoining Coalinga syncline. Southeast of the Kettleman Hills lie the Lost Hills, North Belridge, and Belridge fields, all of which are on low anticlinal hills or on the floor of San Joaquin Valley some distance from the mountains. Still farther southeast are the McKittrick and Elk Hills fields and the great area included in the Sunset-Midway field. These fields, or the structural features determining their location, are shown in figure 15.

The San Joaquin Valley and adjoining foothills are characterized by hot summers, mild winters, and low precipitation (almost all of which falls during the

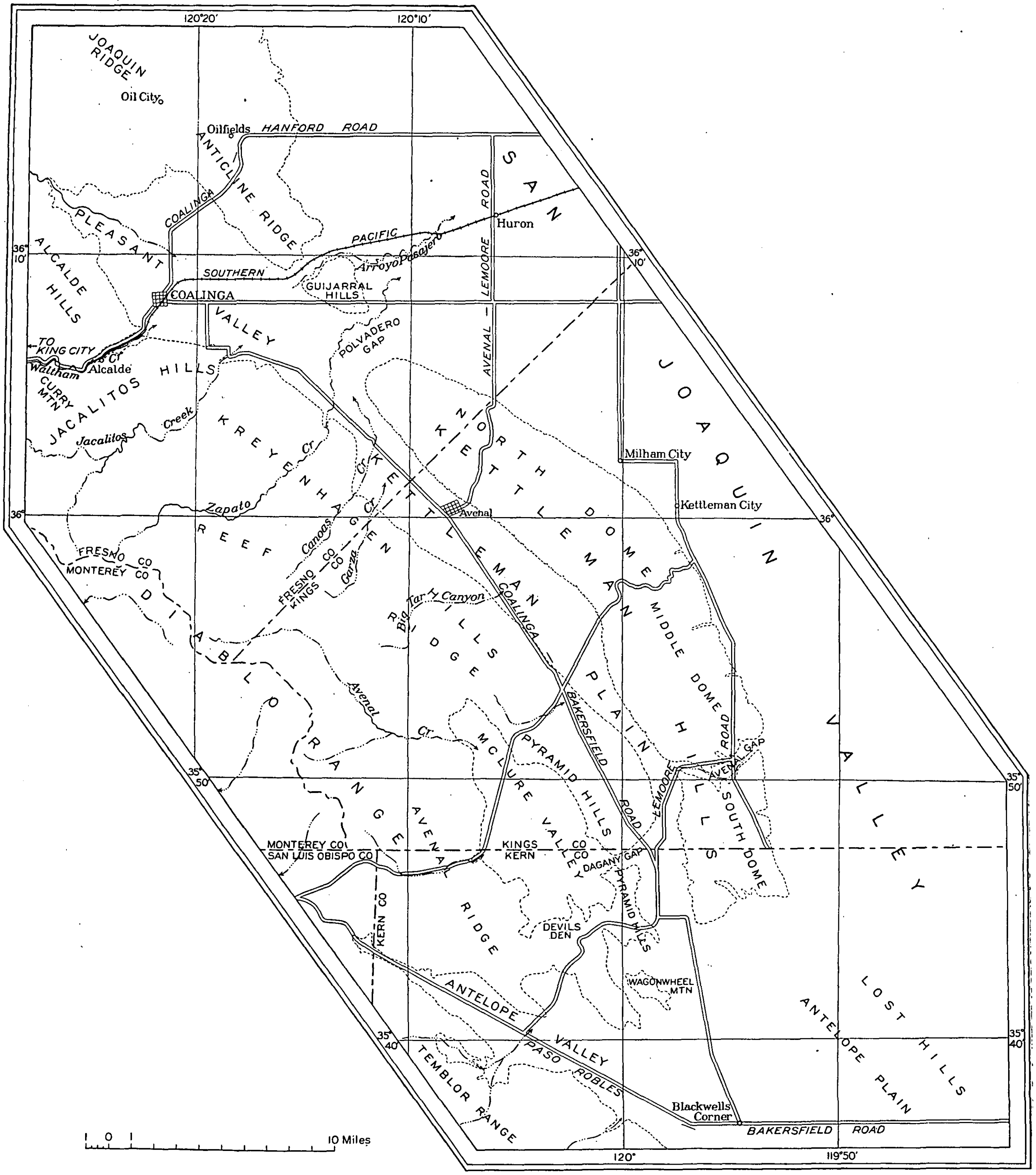


FIGURE 1.—Map showing location of Kettleman Hills with reference to other features in the Coalinga and other nearby areas. Dotted line represents edge of alluvium. Adapted from U. S. Geological Survey Bulletins 398 and 721.

winter)[7]—the hot desert climate of the modified Köppen classification used by Russell.[8] The mean annual rainfall decreases southward from 9.2 inches at Fresno to 5.6 inches at Bakersfield and 5.5 inches at Maricopa. (See Bakersfield and Maricopa on fig. 15. Fresno is on the east side of San Joaquin Valley 50 miles northeast of Coalinga.) During the 18-year period from 1912 to 1930 the mean annual rainfall at Coalinga was 6.5 inches, 90 percent of which fell between November 1 and April 30. The summers are virtually rainless. During the same 18-year period Coalinga had a mean annual temperature of 62.9°. During midsummer the temperature frequently rises above 100°, and the average maximum for July and August is a little over 100°. In winter the temperature at times drops below the freezing point, but temperatures below 20° are rare. The ground fogs that frequently blanket San Joaquin Valley after the winter rains begin extend at times as far west as the Kettleman Hills and rise above them.

The Kettleman Hills support no natural vegetation larger than sagebrush, and except along the deeper arroyos the growth of sagebrush is generally sparse. As in the San Joaquin Valley proper,[9] the vegetation is characterized by weedy annuals, among which brome grasses, alfileria (locally known as filaree), wild oats, and bur clover are abundant. During the winter rains these annuals mature rapidly and produce a green cover, which is luxuriant in years of exceptionally heavy rainfall. Showy flowering plants, particularly lupine, California poppy, and yellow composites, add color to the winter vegetation. After the rains cease these annuals dry up and remain as a dead cover the rest of the year. At the time the field work was in progress the sagebrush in deep sandy soil in Middle and South Domes was dead, probably the result of the period of low rainfall culminating in the year 1928–29, when only 2.1 inches was recorded at Coalinga. The 18-year record at Coalinga shows 3 years in which the annual rainfall was less than 3 inches. These years of exceptionally low rainfall were separated by 5-year periods of heavier rainfall. The difference in vegetation growing on sandy soil and on clayey soil is well shown in Middle Dome. Sagebrush (*Artemisia*) is virtually confined to sandy soil, which has also an open cover of relatively large annuals, among which rockcress (*Arabis*), fiddle-neck (*Phacelia*), tarweed (*Hemizonia*), and spikeweed (*Centromadia*) are conspicuous. Scattered dense clusters of low-growing peppergrass (*Lepidium*) are characteristic of clayey soil.

OUTLINE OF STRATIGRAPHY

A generalized stratigraphic section of North Dome, representing exposed formations and those penetrated by wells—a total thickness of about 14,000 feet—is shown on plate 51. Aside from differences in thickness, in details of lithology, and in depth of penetration of wells, this section is also representative of Middle and South Domes.

The exposed formations are of Pliocene, or of Pliocene and Pleistocene (?), age, disregarding alluvium deposited since the period of strong deformation. The youngest of these formations, the Tulare formation, consists of nonmarine deposits, principally poorly consolidated or unconsolidated sandstone and conglomerate. The lower part of the Tulare generally embraces thin-bedded sandstone, clay, limestone, and tuffaceous material. Underlying the upper Pliocene and Pleistocene (?) Tulare formation is the upper Pliocene San Joaquin formation. It consists of silt and clay, in which marine fossils are generally absent, alternating with beds of sandstone and conglomerate, many of which contain marine or nonmarine fossils. At least some of the deposits of the San Joaquin formation that lack marine fossils appear to be nonmarine. The Middle Pliocene Etchegoin formation, which underlies the San Joaquin, consists principally of marine deposits, but the upper part embraces beds containing fresh-water fossils. Sandstone, conglomerate, silt, and tuffaceous material are the prinicpal constituents of the Etchegoin formation. Apparently a considerably greater thickness of Etchegoin is exposed in South Dome than in North or Middle Domes, but the base of the formation is not exposed in the Kettleman Hills.

The formations penetrated by wells range in age from Pliocene to Eocene. The subsurface Etchegoin is not differentiated from the underlying lower Pliocene Jacalitos formation. Both formations consist of sandstone, sandy shale, and shale. Three Miocene formations are recognized. The youngest is the upper Miocene Reef Ridge shale—the caving shale of drillers. It consists of shale, silty shale, and tuffaceous sandstone. Underlying the Reef Ridge shale is the upper Miocene McLure shale member of the Monterey shale, a hard siliceous shale called the brown shale by drillers. The Temblor sandstone, of middle and lower Miocene age, underlies the McLure and embraces oil-bearing zones consisting principally of sand and barren zones made up chiefly of shale. The deepest wells drilled so far penetrate the underlying Kreyenhagen shale, which at the outcrop is of Eocene age, or embraces both Oligocene and Eocene deposits, and enter the McAdams sand, the probable equivalent of the middle Eocene Avenal sandstone, of the Reef Ridge outcrop section.

STRATIGRAPHY OF EXPOSED FORMATIONS

Generalized stratigraphic sections of the formations exposed in the three anticlines constituting the Kettleman Hills, omitting alluvium, are shown on plate 3. The total maximum thickness of the exposed formations is about 7,000 feet. The greatest thickness in any

[7] U. S. Dept. Agr., Weather Bur., Climatic summary of the United States, sec. 17, Central California, 63 pp., map, 1934.

[8] Russell, E. J., Dry climates of the United States: I, Climatic map: California Univ. Pub. Geography, vol. 5, pp. 1–41, 8 figs., map, 1931.

[9] Shantz, H. L., and Zon, Raphael, Natural vegetation: U. S. Dept. Agr., Atlas Am. Agr., pt. 1, sec. E, pp. 17–18, 1924.

area, however, does not exceed 6,000 feet, and over much of the region it is not more than 5,000 feet.

The names that are in use for the three exposed formations were proposed many years ago by Anderson[10] during the course of his pioneer work on the geology of the Coalinga district. The boundaries of these formations have been placed at different horizons, however, by different geologists, depending on individual preferences. This varying usage is a reflection of the absence of unequivocal discontinuities of major magnitude. There is no unconformity (angular discordance) in the entire section, nor is there evidence of disconformities (major discontinuities without angular discordance) of demonstrable major magnitude. The entire section is full of discontinuities; in fact, evidence of discontinuity is apparent at the base of almost any bed composed of material having a larger grain size than the underlying bed. These discontinuities are considered of minor magnitude, for it has not been demonstrated that a considerable thickness of strata was removed during their formation, nor that a considerable thickness of strata, represented elsewhere, was deposited during their formation. Minor discontinuities have been called diastems.[11] The discontinuities in the Kettleman Hills are considered of diastem rank.

Under these circumstances it is a matter of no great importance at what horizons the formation boundaries are drawn, so long as it is understood where they are placed and so long as a particular horizon is consistently used. It is naturally advantageous to choose horizons that can be recognized with reasonable certainty over as large an area as possible, as such horizons are likely to represent the greatest changes in geologic events. In the present report the base of the Tulare formation is drawn immediately above the youngest widespread marine deposits. This division places some brackish-water beds in the lower part of the Tulare formation which otherwise consists of deposits interpreted as lake and stream deposits. The boundary between the San Joaquin and Etchegoin formations is placed at the base of conglomerate or sandstone correlated on the basis of fossils with conglomerate that rests unconformably on Miocene shale farther south along the west side of San Joaquin Valley. Conglomerate has not been recognized at this horizon everywhere throughout the Kettleman Hills, but it is represented at many localities. This classification places most of the alternating marine and apparently nonmarine deposits in the San Joaquin formation, but leaves in the Etchegoin formation the earliest beds that contain fresh-water fossils. On the advance edition of the geologic map issued in 1934 the base of the San Joaquin formation was drawn at the base of the earliest bed containing fresh-water fossils. The faunal and lithologic features of this bed are recognizable, however, only in North Dome.

The clay and silt throughout the exposed section are hard rocks when fresh and dry. The rocks made up of coarser constituents present every gradation from loose sand and gravel to hard sandstone and conglomerate. Unconsolidated or imperfectly consolidated rocks are more abundant than firmly cemented rocks, and geologists accustomed to working with older rocks would use terms implying unconsolidation for most of the material. In the descriptions that follow there may be a tendency to favor the use of terms for consolidated rocks.

Pyroclastic material is abundant in the entire exposed section, with the possible exception of the coarse detrital deposits of the Tulare formation, which were not examined for this constituent. Some of this material consists of quite fresh water-laid tuff made up of unaltered glass. Beds of white clay, in which glass shards are still recognizable, represent probably altered tuff. Many of the sandstones are notably tuffaceous or contain notable quantities of material that represents probably an alteration product of volcanic glass.

PLEISTOCENE AND RECENT SERIES

YOUNGER ALLUVIUM AND EOLIAN DEPOSITS

The alluvium now being deposited along arroyos in the Kettleman Hills and in the adjoining plains, or recently deposited, is designated younger alluvium. The contact between this alluvium and the deformed strata is more evident along the west flank of North Dome and northern Middle Dome than elsewhere. The younger alluvium extends up flat-floored narrow arroyos for a distance of a mile or more from the edge of the surrounding plains, particularly on the west flank of North Dome. In the low-lying saddle between North and Middle Domes the alluvium extends up wide arroyos several miles from the edge of the San Joaquin Valley. Along Avenal Gap, in the saddle between Middle and South Domes, it forms a relatively wide band entirely across the hills.

The younger alluvium consists chiefly of silt and silty sand. At La Salida, on the east side of Middle Dome, half a mile west of the edge of the San Joaquin Valley, it has a thickness of about 25 feet. Its thickness in the plains surrounding the hills is not known. The younger alluvium is presumably mainly of Recent age. Its physiographic aspects are discussed under the heading "Physiography."

Areas of Recent eolian sand on the east flank of the North Dome-Middle Dome saddle, principally on the leeward (east) side of ridges composed chiefly of sand and sandstone, were mapped. Small areas of eolian deposits in North Dome, mostly derived from older

[10] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 178-182, 1905.

[11] Barrell, Joseph, Rhythms and the measurements of geologic time: Geol. Soc. America Bull., vol. 28, p. 794, 1917. Eaton, J. E., The bypassing and discontinuous deposition of sedimentary materials: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 728, 1929.

alluvium, are shown on the geologic map (pl. 3) by the same pattern as that used for older alluvium.

OLDER ALLUVIUM

Dissected alluvial deposits lying above the floors of present streams are designated older alluvium. The older alluvium is generally 25 to 150 feet above present stream beds. The largest areas mapped are on the east flank of North and Middle Domes mainly on the outcrop of the San Joaquin formation. Scattered patches, however, are found at higher altitudes on the outcrop of the Etchegoin formation. This older alluvium consists principally of silty sand. At many places it contains fossils derived from strata cropping out in the Kettleman Hills, notably *Pseudocardium* and sand dollars.

Gravel occurs at maximum altitudes of 100 to 150 feet above the floor along both flanks of Avenal Gap. Small patches of similar gravel farther south in central and eastern South Dome consist of volcanic rocks, brown sandstone, and red, green, and black chert. Conglomerates in deformed strata that crop out in the Kettleman Hills display similar constituents. The cobbles in the gravel, however, are generally larger than those observed in bedrock conglomerates. On Boulder Hill, where the largest area of gravel is exposed, some of the cobbles are 8 inches long. They decrease in size southward in South Dome.

Silty alluvium 10 to 25 feet above the floor of Avenal Gap is younger than the gravel.

The boundaries of the older alluvium are generally indefinite. The surface on which it rests, bevelling the deformed strata, was observed at only a few places. The older alluvium was deposited since the main erosion of the hills and is presumably of late Pleistocene age. The age, however, depends upon the uncertain dating of the upper part of the Tulare formation and the equally uncertain dating of the physiographic development of the hills. The origin of the older alluvium is discussed under the heading "Physiography."

PLEISTOCENE (?) AND PLIOCENE SERIES

TULARE FORMATION

The youngest folded strata in the Kettleman Hills constitute the Tulare formation. They were first noticed by Watts,[12] and the formation was named by F. M. Anderson.[13] No type locality was designated, but the Kettleman Hills have been regarded as the type region,[14] as the exposures there were the only ones described, and the name was derived from Tulare Lake, the shore of which at that time lay close to the east edge of North Dome. It is suggested that the section on La Ceja, on the east side of northern North Dome, which is probably the section examined by Watts and Anderson, be considered the type section, though here, owing to the overlap of alluvium, only the lower part of the formation is exposed.

The Tulare formation consists principally of sandstone, much of which is cross-bedded, silty, and pebbly, and conglomerate, apparently representing stream deposits. Most of this material is poorly consolidated or unconsolidated. At the base of the formation and also at higher horizons in the lower part are thin-bedded, fine-grained sediments—clay, silt, fine-grained sandstone, tuff, and limestone—that are interpreted as lake deposits. Pyroclastic material is abundant in the lower part of the formation. The upper part of the formation was not examined for this constituent. Less information was gathered concerning details of the stratigraphy and lithology of the Tulare formation, except for the basal part, than for the remainder of the exposed section, as the structural features of the anticlines are revealed by the underlying formations. In most of North and Middle Domes the Tulare can roughly be divided into two unequal parts. In these areas beds of conglomerate are generally numerous above a horizon 200 to 600 feet above the base of the formation and at most places are rare or absent below this horizon. At the north end of North Dome—the only place where the conglomerates were mapped—the base of the conglomeratic part represents a zone of interfingering beds. Moreover, on the west side of South Dome conglomerates are as abundant in the lower part of the formation as at higher horizons. It appears improbable that these conglomerates along the west side of South Dome represent an overlap of the upper part of the Tulare, for the marine beds immediately underlying the base of the Tulare elsewhere are recognized in part of this region, and other conglomerates underlie these marine beds at horizons where conglomerate is absent elsewhere.

The base of the Tulare formation is drawn just above the youngest widespread marine deposits constituting the upper *Mya* zone of the San Joaquin formation. In North Dome the upper *Mya* zone is overlain by a diatomaceous white silty clay that has been prospected for fuller's earth. This clay, therefore, is considered the basal bed of the Tulare formation. It varies considerably in thickness and in the proportion of detrital constituents. At places it is so diluted with detrital material that it is unrecognizable or it is replaced by other sediments. Where this bed consists principally of white clay it forms a light-co ored band and can readily be traced. Even though the clay could be traced only intermittently, the boundary on the map between the San Joaquin and Tulare formations was drawn at the top of the upper *Mya* zone, which was recognized more or less continuously throughout the

[12] Watts, W. L., The gas- and petroleum-yielding formations of the central valley of California: California State Min. Bur. Bull. 3, p. 55, fig. on p. 67, 1894.

[13] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 181–182, 1905.

[14] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, p. 143, 1910. 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, p. 101, 1915.

hills. This is an arbitrary division of sediments representing a change from a marine environment to an environment of lakes, swamps, and streams. No evidence of a major discontinuity was found at this horizon or at any other in this part of the section. The change in environment was probably due to deformation in the adjoining mountains that may represent an important event in the geologic history of the region, but it is not known whether this event corresponds to a chronologic division, such as the division between Pliocene and Pleistocene time. This horizon was chosen because it seems to represent the greatest environmental change and because the upper *Mya* zone could be traced with a reasonable degree of assurance. It has also the further cartographic advantage of showing by means of one line the boundary between the Tulare and San Joaquin formations and the outcrop of the upper *Mya* zone, which can be recognized in the field by its fossils. If the base of the conglomerates represented the same horizon throughout the hills, it would be advantageous to choose that horizon as the base of the Tulare. The conglomerates represent a change in erosional and depositional history, and the base of the Tulare along most of the mountain front may lie at a higher horizon than the white clay and other fine-grained rocks in the Kettleman Hills. The boundary between the Tulare and the San Joaquin has been placed at other horizons by other geologists: at the top of the white clay;[15] and also higher—at the base of the fossiliferous sandy and limy beds here designated the lower *Amnicola* zone.[16]

The conformable relation between the Tulare and San Joaquin formations in the Kettleman Hills is exceptional. Along the border of much of the Temblor Range and along the greater part of the Diablo Range the Tulare rests with discordance on Pliocene or older formations. These relations seem to indicate that the Kettleman Hills lie near the trough of the basin in which the late San Joaquin and Tulare sediments were laid down. The Tulare has been described as resting disconformably on the San Joaquin in the Kettleman Hills.[17] This interpretation appears to be based on assignment of *Amnicola*-bearing beds, which are at a lower horizon than the base of the lower *Amnicola* zone elsewhere, to the lower *Amnicola* zone. It seems to be doubtful, however, whether the presence of *Amnicola* and other fossils is sufficient evidence to determine the stratigraphic relations.

The overlap of recent alluvium covering San Joaquin Valley conceals a large part of the Tulare formation on the east side of the Kettleman Hills. The greatest exposed thickness on the east side is in southern North Dome, where the thickness is 1,700 feet. On the west side of the hills the exposed thickness increases from 1,700 feet in northern North Dome to 2,600 feet in southern North Dome, rises to a maximum of 3,500 feet in central Middle Dome, and decreases to 2,400 feet in South Dome. These figures are based on map computations that are not everywhere adequately controlled. The only fairly complete section that was measured in the field shows a thickness of 1,958 feet (see pp. 21–22) on the west side of southern North Dome, but this section does not include several hundred feet of poorly exposed beds near the edge of the hills. Though the overlap of alluvium makes estimates uncertain, the formation is probably thickest on the west side of central Middle Dome, where the greatest thickness is exposed, and thins northward, southward, and eastward.

STRATIGRAPHY AND LITHOLOGY

EAST FLANK OF NORTH DOME

The diatomaceous white silty clay mapped as the base of the Tulare formation is exposed almost continuously from the north end of North Dome southward to the south end of La Ceja. Farther south it was recognized at scattered localities, but in this region it is diluted with sand and at many places is not recognizable. The thickness of the clay and the percentage of detrital constituents vary from place to place (fig. 2). A prospect pit on the north line of sec. 35, T. 21 S., R. 17 E., near the Avenal-Lemoore road, exposes a thickness of 12 feet. In a nearby trenched section a thickness of 16 feet was measured. The clay exposed in the prospect pit is dirty white and is stained yellowish brown by small ferruginous concretions that lie along bedding planes. Thin laminae contain scattered sand grains. A layer half a foot from the top yielded a fragmentary leaf imprint and an impression of a fresh-water mussel. The clay is overlain along a sharp minutely irregular contact by rather dirty fine-grained sand that becomes cleaner upward. Narrow burrows filled with this sand extend down into the clay. A sample of the clay from this locality examined by M. N. Bramlette contains glass shards, indicating that it is an altered tuff. According to a preliminary examination by P. G. Nutting, this clay fails to qualify as a commercial bleaching clay, though when treated with acid its bleaching quality is superior to that of a clay in the upper part of the Etchegoin formation of Middle Dome, which has also been prospected.

The beds between the white clay and the lower *Amnicola* zone consist principally of sand and clay, which are generally poorly exposed. West of the fault running through the gap traversed by the road in the northeastern part of sec. 28, T. 21 S., R. 17 E., a fresh tuff overlies the white clay (fig. 2, column 2). The tuff, which has a maximum thickness of 15 inches, and an overlying limy sandstone, 3 to 6 feet thick, contain

[15] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 144.

[16] Reed, R. D., Geology of California, fig. 52 (op. p. 254), Tulsa, Am. Assoc. Petroleum Geologists, 1933. Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 1172–1173, fig. 3 (p. 1169), 1933. Barbat, W. F., and Galloway, John, San Joaquin clay, California: Idem., vol. 18, pp. 480, 481, 1934.

[17] Gester, G. C., and Galloway, John, op. cit. Barbat, W. F., and Galloway, John, op. cit.

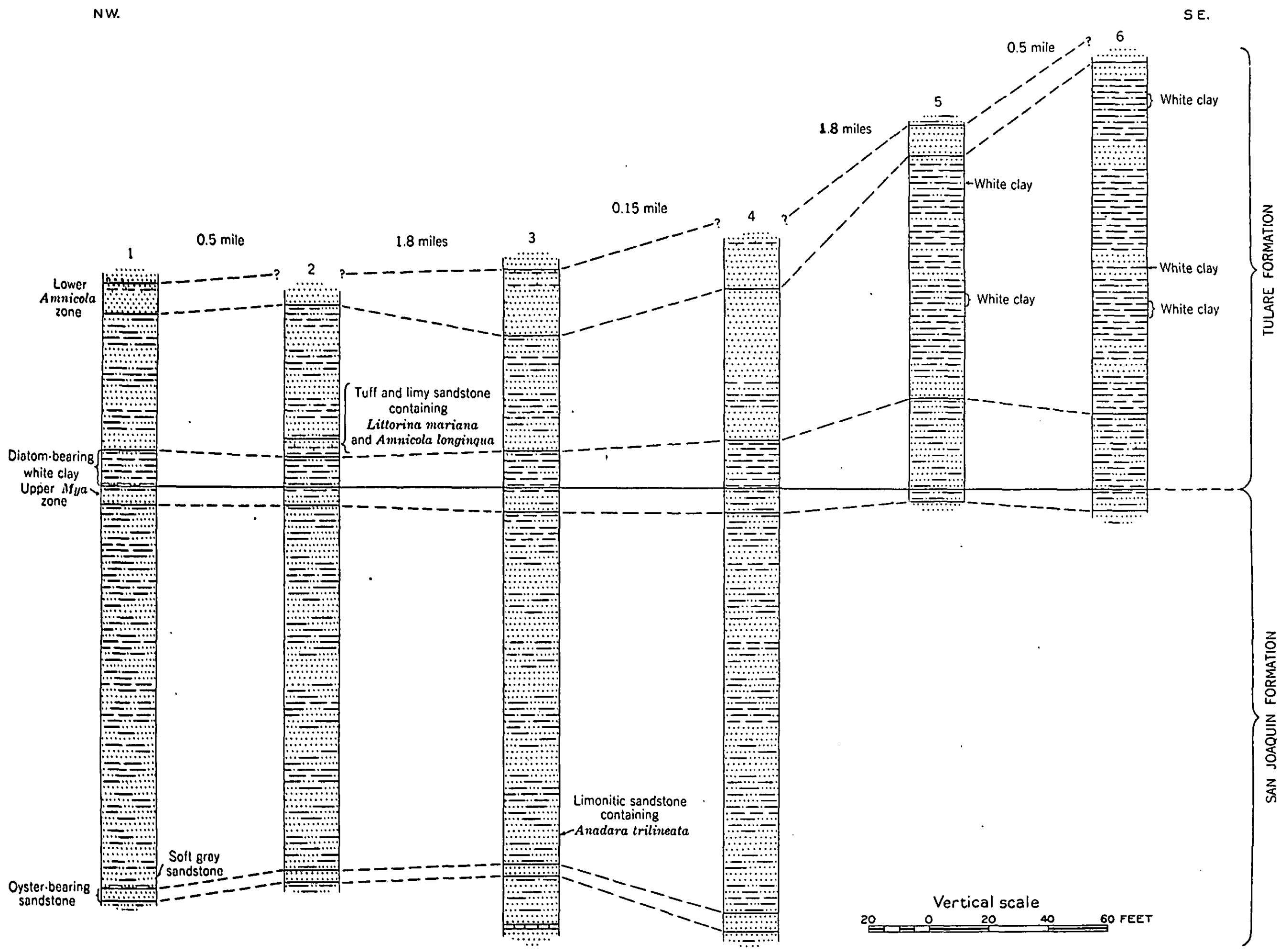


FIGURE 2.—Sections of lower part of Tulare formation and upper part of San Joaquin formation on east flank of northern North Dome. Figures between columns represent distances between sections.

1. Half a mile southeast of Arroyo Vadosa, sec. 28, T. 21 S., R. 17 E.
2. Spur west of road, northeastern part of sec. 28, T. 21 S., R. 17 E. (locality 3).
3. La Ceja, a quarter of a mile southeast of Avenal-Lemoore road, sec. 35, T. 21 S., R. 17 E. (localities 5, 6, 7, 29, 51).
4. La Ceja, 750 feet southeast of preceding section.
5. Near Arroyo Torcido, 350 feet along strike southeast of north line of sec. 6, T. 22 S., R. 18 E.
6. Near Arroyo Torcido, northern part of sec. 6, T. 22 S., R. 18 E., 2,500 feet along strike southeast of preceding section.

Littorina and *Amnicola* (locality 3).[18] Both beds also contain molds, representing probably fresh-water mussels. These beds extend northwestward along the strike for a distance of about 150 feet and lens out. According to Bramlette, the tuff consists principally of glass, which has an index of refraction of about 1.50 and contains much biotite, some andesine, and a little augite and hornblende.

Beds that apparently underlie the lower *Amnicola* zone are well exposed on the east side of Arroyo Largo. At that locality a ledge-making *Amnicola*-bearing sandstone, which forms the crest of the ridge to the southeast where it was mapped as the base of the lower *Amnicola* zone, is the highest bed exposed. Cross-bedded and evenly bedded sand, sandstone, silty sandstone, and limy sandstone, representing a thickness of about 50 feet, underlie the ledge-making bed. A ferruginous brown sandstone, which is 30 feet below the ledge-making sandstone and is crowded with *Amnicola*, is particularly prominent. Weathered outcrops of *Amnicola*-bearing sandstone are found farther southeast between Arroyo Largo and the Avenal-Lemoore road at a horizon between the white clay and the ledge-making sandstone. The presence of *Amnicola*-bearing beds so low in the section may point to an erosional disconformity at the base of the lower *Amnicola* zone, but it seems probable that these fossiliferous beds are the lateral equivalent of beds elsewhere barren of fossils.

The following section of the lower part of the Tulare formation was measured by trenching on La Ceja a quarter of a mile northwest of Arroyo Bifido (fig. 2, column 4):

[18] The fossil localities are plotted on the geologic map, plate 3, and are described on pages 150-166.

Section of basal part of Tulare formation on La Ceja, a quarter of a mile northwest of Arroyo Bifido, sec. 35, T. 21 S., R. 17 E.

[Measured by G. F. Taylor]

	Feet
Tulare formation:	
Hard brown ferruginous sandstone, many *Amnicola*, taken as base of lower *Amnicola* zone, but may correspond to unit 5c of section on page 17.	
Medium-grained gray sand	10
Fine-grained, concretionary gray sandstone	3
Fine-grained gray sand	2
Fine-grained, concretionary gray sandstone	2
Fine-grained gray sand	10
Dirty white silty clay	1
Fine-grained gray sand, stained yellowish brown	4
Grayish-brown clay	7
Fine-grained gray sand	1
Grayish-brown silty clay	1
Fine-grained gray sand	10
Dirty white silty and sandy clay	16
Thickness of Tulare formation below base of lower *Amnicola* zone	67
San Joaquin formation, upper *Mya* zone:	
Silt, clay, and silty clay:	
Grayish-brown silty clay, probably representing upper part of upper *Mya* zone that elsewhere contains small oysters	4
Grayish-brown silt and clay, sandy toward base; contains *Calyptraea, Ostrea, Saxidomus, Mya.*	

Two sections measured farther southeast near Arroyo Torcido at localities 2,500 feet apart along the strike are as follows (fig. 2, columns 5, 6):

Section of basal part of Tulare formation near Arroyo Torcido, 350 feet along strike southeast of north line of sec. 6, T. 22 S., R. 18 E.

[Measured by G. F. Taylor]

	Feet
Tulare formation:	
Grayish-brown mudstone.	
Lower *Amnicola* zone:	
Brownish-gray to gray sandstone, many *Amnicola*	3
Hard brown ferruginous sandstone, *Amnicola* and mussels	2
Brown ferruginous sand, few *Amnicola*	1½
Hard brown ferruginous sandstone, *Amnicola, Sphaerium,* and mussels	3
Beds below lower *Amnicola* zone:	
Gray sand	2
Grayish-brown clay	6
Dirty white silty clay	2
Clay and silty clay:	
Grayish-brown silty clay	2
Grayish-brown clay	9
Yellowish-brown sand	2
Grayish-brown clay	9
Yellowish-brown sand	1
Grayish-brown clay	7
Yellowish-brown sand	1
Clay and silty clay:	
Gray silty clay	1
Grayish-brown clay	5
Dirty white silty clay, stained yellow	4

Section of basal part of Tulare formation near Arroyo Torcido, 350 feet along strike southeast of north line of sec. 6, T. 22 S., R. 18 E.—Continued.

	Feet
Tulare formation—Continued.	
Beds below lower *Amnicola* zone—Continued.	
Clay and silty clay:	
Light-gray clay grading downward into underlying clay	2
Grayish-brown clay	12
Grayish-brown silty clay	1
Grayish-brown clay	3
Grayish-brown sandy clay	6
Yellowish-brown sand	6
Silty and sandy clay and silty sand:	
Dirty white silty and sandy clay	1
Gray silty sand	3
Dirty white sandy clay	2
Gray silty sand	24
Thickness of Tulare formation below lower *Amnicola* zone	111
San Joaquin formation, upper *Mya* zone:	
Grayish-brown silty clay representing upper part of upper *Mya* zone; contains oysters.	

Section of lower part of Tulare formation near Arroyo Torcido, northern part of sec. 6, T. 22 S., R. 18 E., 2,500 feet along strike southeast of locality of preceding section

[Measured by G. F. Taylor]

	Feet
Tulare formation:	
Gypsiferous hard brown sandstone, *Amnicola* and mussels (base of lower *Amnicola* zone)	1⅔
Yellowish-brown sand	4
Clay:	
Grayish-brown clay	7
Dirty white clay	3
Gypsiferous grayish-brown clay	13
Gypsiferous yellowish-brown sand	8
Gypsiferous grayish-brown clay	27
Gypsiferous yellowish-brown sand	3
Dirty white clay, stained yellow	2
Gray to grayish-brown sand	2
Clay:	
Gypsiferous grayish-brown clay	8
Dirty white clay	5
Grayish-brown clay	10
Gypsiferous gray sand	1
Grayish-brown clay	4
Gray sand	3
Grayish-brown clay	14
Dirty white sandy clay	25
Thickness of Tulare formation below base of lower *Amnicola* zone	139
San Joaquin formation, upper *Mya* zone:	
Grayish-brown clay	3
Grayish-brown sandy clay, contains oysters	4

On Arroyo Estrecho, at the south end of North Dome, an *Amnicola*-bearing sandstone lies about 30 feet above the base of the formation, but in that area the base of the lower *Amnicola* zone is not clearly defined (see section, p. 18).

The lower *Amnicola* zone embraces beds in which fresh-water fossils are abundant, particularly small snails of the genus *Amnicola*. One or more hard ferruginous or limy sandstones, which are oolitic on the east side of Middle Dome, also serve to identify the zone at many places. These hard sandstones stand in marked contrast to the sand and soft sandstone that make up the bulk of the lower part of the Tulare. In the absence of good exposures the lowest of the hard sandstones was mapped as the base of the zone. On the east side of northern North Dome the base of the lower *Amnicola* zone is 50 to 150 feet above the base of the formation, and the thickness of beds embraced in the zone, as determined by the lower and upper limits of abundant fossils, ranges from 10 to 25 feet (fig. 2). Farther south the zone is thicker and the base is generally about 150 feet above the base of the formation, but at some localities fossiliferous beds occur at a horizon about 50 feet above the base. The varying position of the base and top may be due to thickening and thinning of the lower part of the formation, to the lensing of fossiliferous beds, to a combination of these changes, or to an erosional discontinuity. In view of the uncertainty that the base and top represent the same horizons in different regions, the observed relations are probably the result of changes in thickness and of lensing. The base of this zone is considered by some geologists as the base of the Tulare formation, but its doubtful stratigraphic quality and the uncertainty of its recognition in parts of the hills make it an unsatisfactory horizon at which to place a major stratigraphic division.

The following section of the lower *Amnicola* zone, embracing a thickness of about 10 feet, was measured half a mile southeast of Arroyo Vadosa (fig. 2, column 1):

Section of lower Amnicola zone in lower part of Tulare formation half a mile southeast of Arroyo Vadosa, northeastern part of sec. 28, T. 21 S., R. 17 E.

	Ft.	in.
Coarse sandstone forming crest of ridge farther west, includes lenses of conglomerate	1	3
Lower *Amnicola* zone:		
Ferruginous limy sandstone, molds of mussels	3	
Ferruginous sand	2	3
Speckled grayish-olive sand and polished spherules of brown iron oxide; 4- to 5-inch layer near top contains paired mussels	1	11
Ferruginous sand	1	1
Ferruginous poorly cemented sand; contains *Amnicola*	1	8
Thickness of lower *Amnicola* zone	9	11

The most readily accessible exposures of the lower *Amnicola* zone are on La Ceja, southeast of the Avenal-Lemoore road, in the strata suggested as the type section of the Tulare formation. The following section was measured on La Ceja (fig. 2, column 3):

Section of basal part of Tulare formation on La Ceja, a quarter of a mile southeast of Avenal-Lemoore road, sec. 35, T. 21 S., R. 17 E.

	Ft.	in.
Lower *Amnicola* zone:		
11. *Amnicola*-bearing limestone		7
10. Ferruginous concretionary dirty sand	2	3
9. Limestone and marl:		
c. Hard ledge-making limestone, molds of mussels and *Sphaerium*		7–9
b. Soft marl		7
a. Impure limestone, molds of mussels and *Sphaerium*		12
8. Ferruginous concretionary dirty sand		11
7. Sand:		
e. *Hydrobia*-bearing sand		7–9
d. Speckled grayish-olive sand, many polished spherules of brown iron oxide of about same size as sand grains; 3-inch layer at top contains mussels; collection of fossils (locality 7) represents units 7d and 7e		7
c. Ferruginous dirty sand; ferruginous concretions at top	1	1
b. *Amnicola*-bearing sand	1	7
a. Ferruginous sand	2	3
6. Unexposed; probably same material as unit 7a	2	
5. Sand:		
d. Poorly cemented brown sand, few *Amnicola*	1	11
c. Hard brown sandstone, *Amnicola* concentrated at base and scattered throughout		1½–2
b. Poorly cemented brown sand; ½-inch mudstone layer at top containing many *Amnicola*		1½–3
a. Cross-bedded brown sandstone, scattered *Amnicola*		1–2
4. Sand:		
b. *Amnicola*-bearing sand; lower 21 inches crowded with *Amnicola;* 8 inches below top layer of ferruginous concretions contains at top "bulbous fish growths" (see p. 97)	2	6
a. Brown dirty sand, molds of mussels; 3 inches above base layer of ferruginous concretions contains at top "bulbous fish growths" and *Amnicola* (locality 6)		8
3. Ferruginous dirty sand, many *Amnicola*	1	11
Maximum thickness of lower *Amnicola* zone	21	11
Beds below lower *Amnicola* zone:		
2. Unexposed, except few inches of gray sand immediately overlying unit 1	37	6
1. Dirty white silty clay containing fresh-water diatoms (locality 5)	12	
Thickness of Tulare formation below lower *Amnicola* zone	49	6

Unit 7d of this section and also unit 3 of the preceding section, measured near Arroyo Vadosa, are made up of about equal amounts of sand grains and polished spherules of brown iron oxide. The spherules have the same size range as the sand grains—from a little less than half a millimeter to a little more than a millimeter. Though they are dark brown, they give the sand a speckled olive-green color. These spherules are apparently an oolitic form of iron oxide. The lower *Amnicola* zone throughout the hills contains more iron oxide than other parts of the formation. Unit 8 of the section on La Ceja has lavender blotches attributed to manganese oxide. The iron and manganese oxides are interpreted as representing bog deposits that accumulated in swamps on the edge of the lake in which these fine-grained sediments were laid down. In addition to the fresh-water snails and mussels, "bulbous fish growths" (described on p. 97) are conspicuous fossils in certain beds at this and other localities.

Along part of the east flank of North Dome—near Arroyo Torcido, and southward from Arroyo Doblegado—*Amnicola*-bearing sandstones are at two horizons separated by 50 to 150 feet of beds apparently barren of fossils. The beds at the lower horizon, 50 to 150 feet above the base of the formation, correspond to those just described. Those at the upper horizon are less persistent. Both sets of fossiliferous sandstones are referred to the lower *Amnicola* zone. On Arroyo Estrecho, where the following section was measured, *Amnicola*-bearing sandstones are scattered through the lower 300 feet of the formation, and a division into two horizons is not apparent. A 10-inch bed of white clay, partly altered to siliceous shale, is conspicuous in this section.

Section of lower part of Tulare formation on Arroyo Estrecho, NE¼ sec. 6, T. 23 S., R. 19 E.

[Measured by G. F. Taylor]

	Ft.	in.
Tulare formation:		
Sandstone and sand:		
Hard grayish-brown sandstone, many *Amnicola* (top of lower *Amnicola* zone)		8
Grayish-brown sand		11
Hard grayish-brown sandstone, uppermost 6 inches contains *Amnicola*	1	10
Grayish to yellowish-brown sand, *Amnicola* in some layers	30±	
Hard grayish-brown sandstone		2
Yellowish-brown sand, *Amnicola*	1	3
Hard grayish-brown sandstone		6
Yellowish-brown cross-bedded sand, *Amnicola*	3	4
Hard yellowish-brown standstone, *Amnicola*		6
Yellowish-brown cross-bedded sandstone, *Amnicola*	15±	
White clay partly altered to siliceous shale		10
Yellowish-brown cross-bedded sand, *Amnicola*	15±	
Hard grayish-brown sandstone		3
Poorly exposed yellowish-brown sand, hard grayish-brown sandstone, and brown clay; some beds contain *Amnicola*	200±	
Hard grayish-brown sandstone, *Amnicola*		5
Poorly exposed yellowish-brown sand and clay	30±	
Thickness of Tulare formation measured	300±	
San Joaquin formation, upper *Mya* zone.		

The uppermost *Amnicola*-bearing bed on the ridge between Arroyo Robador and Arroyo Pino may correspond to the upper *Amnicola* zone recognized in Middle Dome and on the west side of southern North Dome.

Most of the conglomeratic upper part of the Tulare formation is overlapped by alluvium on the east side of North Dome. In the area between Arroyo Vadosa and Arroyo Largo the lowest thick zone of conglomerate, 375 feet above the base of the Tulare, forms a low ridge or disconnected low hills. The conglomerate is composed principally of cobbles of brown sandstone that have a maximum length of about 6 inches. Heavy conglomerates, like those just described, form a discontinuous ridge between Arroyo Bifido and Arroyo Torcido, but at this locality they are 500 to 625 feet above the base of the formation. Several hundred feet of cross-bedded channeled coarse-grained sandstone underlying the conglomerates is well exposed on Arroyo Torcido. Farther southeast on Arroyo Hondo no heavy conglomerates were observed in the exposed part of the formation. On Arroyo Doblegado the Tulare above the lower *Amnicola* zone is made up almost entirely of massive or thinly bedded, cross-bedded, or evenly bedded sandstone, much of which is channeled. Small pebbles and chips of white siliceous shale are common in some beds. *Amnicola* and *Sphaerium* were observed on Arroyo Degollado in a sandstone about 600 feet above the base of the formation, and an *Amnicola*-bearing sandstone at about the same horizon, or higher, is exposed on Arroyo Estrecho. At the south end of North Dome, east of La Lomica, is a conglomerate ridge 575 feet above the base of the formation. The material, which consists of pebbles less than half an inch long and a few cobbles as much as 6 inches long, represents lava, granitic and basic intrusives, chert, and sandstone. In this region about 1,200 feet above the base of the formation is a thicker zone of conglomerates. Small oysters, *Littorina*, and a fresh-water snail, identified in the field as *Amnicola* but possibly representing *Fluminicola*, occur together in sandstone that includes also lenses of conglomerate at the top of this zone (locality 13).

EAST FLANK OF MIDDLE DOME

The white clay at the base of the Tulare was not recognized south of the north end of Middle Dome. The base of the lower *Amnicola* zone along the east flank of Middle Dome is 100 to 150 feet above the base of the formation. The zone has a maximum thickness of at least 120 feet and embraces several conspicuous beds of fossiliferous sandstone and limestone, some of the latter oolitic. The following section, which probably represents virtually the full thickness of the zone, though the base is not exposed, was measured at La Salida, where Arroyo Culebrino is deeply entrenched.

PLATE 4

FIGURES 1, 2. *Valvata virens platyceps* Pilsbry. Paratypes. Locality 19, upper *Amnicola* zone.
1. Height 3.8 mm., width 3.6 mm. U. S. Nat. Mus. 495198.
2. Height 2 mm., width 2.1 mm. U. S. Nat. Mus. 495199.

3. *Valvata humeralis californica* Pilsbry. Height 2.5 mm., width 3.7 mm. Locality 20, lower *Amnicola* zone. U. S. Nat. Mus. 495200.

4–6. *Littorina mariana* Arnold. Locality 3, below lower *Amnicola* zone.
4. Height (incomplete) 10 mm., width 6.6 mm. U. S. Nat. Mus. 495201.
5. Height (incomplete) 13 mm., width 11 mm. U. S. Nat. Mus. 495202.
6. Height (incomplete) 10.3 mm., width 9.1 mm. U. S. Nat. Mus. 495203.

7–9. *Fluminicola* cf. *F. spiralis* Pilsbry. Locality 4732, lower *Amnicola* zone.
7. Height 3.7 mm., width 2.6 mm. U. S. Nat. Mus. 495204.
8. Height 3.1 mm., width 2.4 mm. U. S. Nat. Mus. 495205.
9. Height 2.8 mm., width 1.9 mm. U. S. Nat. Mus. 495206.

10, 11. *Fluminicola* cf. *F. spiralis* Pilsbry. Locality 19, upper *Amnicola* zone.
10. Height 4.5 mm., width 3.1 mm. U. S. Nat. Mus. 495207.
11. Height 3.1 mm., width 2.6 mm. U. S. Nat. Mus. 495208.

12. *Fluminicola* cf. *F. yatesiana* (Cooper). Length 3.1 mm., width 2.2 mm. Locality 8, lower *Amnicola* zone. U. S. Nat. Mus. 495209

13–16. *Pyrgulopsis vincta* Pilsbry. Locality 20, lower *Amnicola* zone.
13. Height 3.7 mm., width 2.2 mm. U. S. Nat. Mus. 495210.
14. Height 3.8 mm., width 2.2 mm. U. S. Nat. Mus. 495211.
15. Height about 3.0 mm., width 1.8 mm. U. S. Nat. Mus. 495212. (Specimen broken after drawing was made.)
16. Height 4 mm., width 2 mm. U. S. Nat. Mus. 495213.

17, 18. *Calipyrgula carinifera* Pilsbry. Paratypes. Locality 7, lower *Amnicola* zone.
17. Height 3 mm., width 1.3 mm. U. S. Nat. Mus. 495215.
18. Height 3.4 mm., width (incomplete) 1.3 mm. U. S. Nat. Mus. 495216.

19. *Calipyrgula ellipsostoma* Pilsbry. Height (incomplete) 2.9 mm., width 1.2 mm. Locality 10, lower *Amnicola* zone. U. S. Nat. Mus. 495217.

20, 21. *Calipyrgula stewartiana* Pilsbry. Topotypes. Locality 14, lower *Amnicola* zone.
20. Height 2.5 mm., width 1.4 mm. U. S. Nat. Mus. 495219.
21. Height 3.1 mm., width 1.7 mm. U. S. Nat. Mus. 495220.

22. *Littoridina woodringi* Pilsbry. Paratype. Height 3 mm., width 1.7 mm. Locality 19, upper *Amnicola* zone. U. S. Nat. Mus. 495222.

23–27. *Amnicola longinqua* Gould. Lower *Amnicola* zone.
23. Height 4 mm., width 2.4 mm. Locality 20. U. S. Nat. Mus. 495223.
24. Height 3.9 mm., width 2.7 mm. Locality 20. U. S. Nat. Mus. 495224.
25. Height 4 mm., width 2.4 mm. Locality 20. U. S. Nat. Mus. 495225.
26. Height 3.9 mm., width 2.3 mm. Locality 18. U. S. Nat. Mus. 495226.
27. Height 3.3 mm., width 2 mm. Locality 18. U. S. Nat. Mus. 495227.

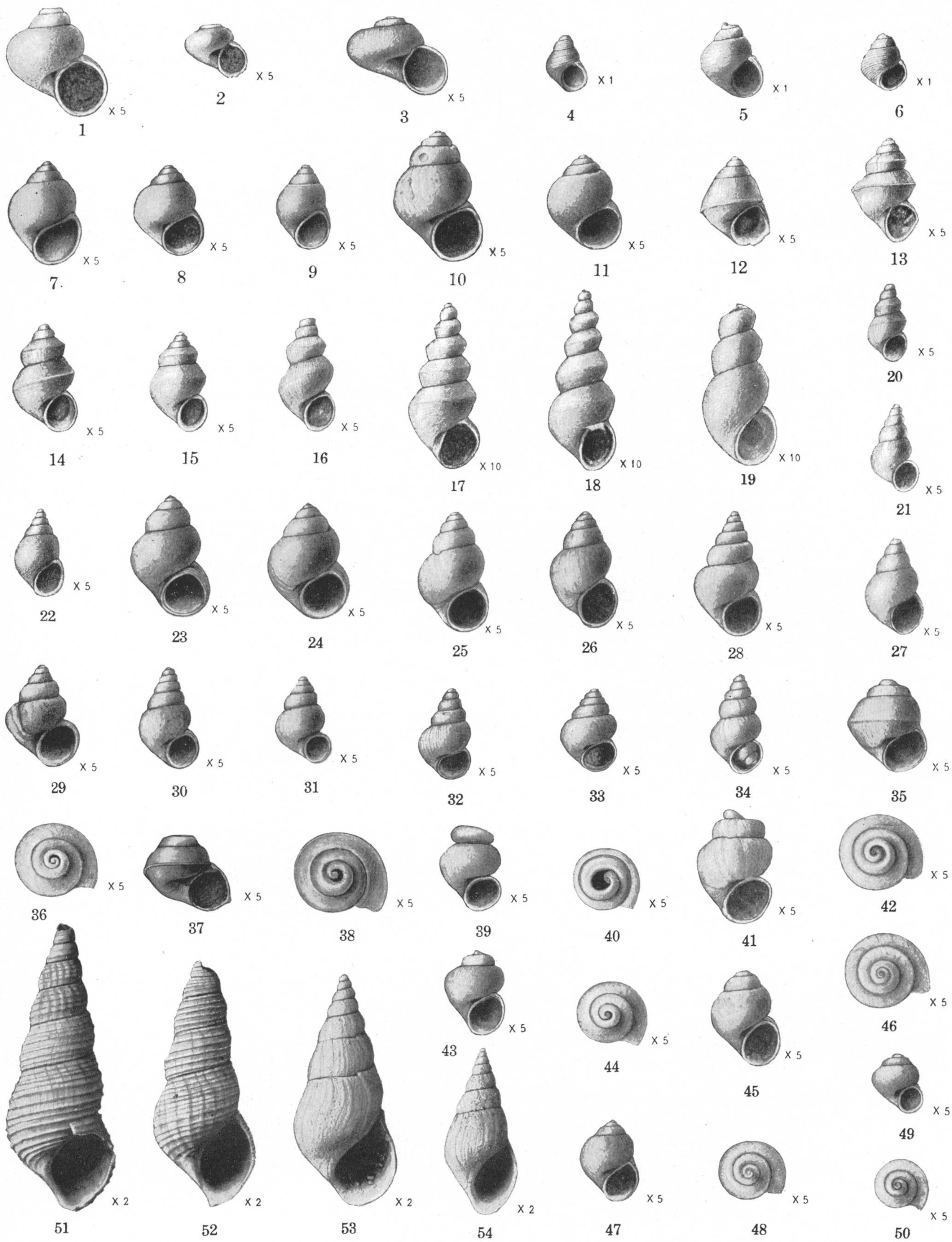
28–34. *Hydrobia andersoni* (Arnold). Lower *Amnicola* zone.
28. Holotype. Height 4.2 mm., width 2.4 mm. Locality 4732. U. S. Nat. Mus. 165505.
29. Topotype. Height 3.3 mm., width 2.3 mm. Locality 4732. U. S. Nat. Mus. 495228.
30. Topotype. Height 3.4 mm., width 2.2 mm. Locality 4732. U. S. Nat. Mus. 495229.
31. Topotype. Height 3 mm., width 1.8 mm. Locality 4732. U. S. Nat. Mus. 495230.
32. Height 3 mm., width 1.9 mm. Locality 7. U. S. Nat. Mus. 495231.
33. Height 2.9 mm., width 1.9 mm. Locality 7. U. S. Nat. Mus. 495232.
34. Height 3.5 mm., width 1.8 mm. Locality 7. U. S. Nat. Mus. 495233.

35–38. *Brannerillus physispira* Hannibal. Lower *Amnicola* zone.
35, 36. Height 3.2 mm., width 2.8 mm. Locality 8. U. S. Nat. Mus. 495234.
37, 38. Height 2.7 mm., width 3.1 mm. Locality K14 (U. S. G. S. 13380). U. S. Nat. Mus. 495235.

39–50. *Brannerillus involutus* Pilsbry. Lower *Amnicola* zone.
39, 40. Height 3 mm., width 2.2 mm. Locality 21. U. S. Nat. Mus. 495236.
41, 42. Height 4 mm., width 2.8 mm. Locality 21. U. S. Nat. Mus. 495237.
43, 44. Height 3 mm., width 2.2 mm. Locality 21. U. S. Nat. Mus. 495238.
45, 46. Height 3.3 mm., width 2.6 mm. Locality 21. U. S. Nat. Mus. 495239.
47, 48. Height 2.7 mm., width 2.2 mm. Locality 21. U. S. Nat. Mus. 495240.
49, 50. Height 1.9 mm., width 1.7 mm. Locality K14 (U. S. G. S. 13380). U. S. Nat. Mus. 495241.

51, 52. *Goniobasis kettlemanensis woodringi* Pilsbry. Locality 17, lower *Amnicola* zone.
51. Height (incomplete) 27.5 mm., width (incomplete) 10.5 mm. U. S. Nat. Mus. 495245.
52. Height (incomplete) 23.8 mm., width (incomplete) 9.9 mm. U. S. Nat. Mus. 495246.

53, 54. *Goniobasis arnoldiana* Pilsbry. Locality 27, below lower *Amnicola* zone.
53. Height (virtually complete) 22.4 mm., width 10 mm. U. S. Nat. Mus. 495247.
54. Height 16.1 mm., width 7.6 mm. U. S. Nat. Mus. 495248.



FOSSILS FROM TULARE FORMATION.

PLATE 5

FIGURES 1–3. *Brannerillus involutus* Pilsbry. Apparently sinistral, actually ultradextral, form. Locality 21, lower *Amnicola* zone.
1. Height 2 mm., width 2.3 mm. U. S. Nat. Mus. 495242.
2, 3. Height 1.7 mm., width 2.8 mm. U. S. Nat. Mus. 495243.

4–6. *Carinifex sanctaeclarae marshalli* Arnold. Height 2.6 mm., width 4.2 mm. Locality 19, upper *Amnicola* zone. U. S. Nat. Mus. 495249.

7–9. *Menetus centervillensis* (Tryon). Specimen glossed with thin oolitic coat. Height 1.3 mm., width 2.8 mm. Locality 18, lower *Amnicola* zone. U. S. Nat. Mus. 495250.

10–15. *Menetus vanvlecki* (Arnold). Topotypes. Locality 7, lower *Amnicola* zone.
10–12. Height 1.7 mm., width 3.6 mm. U. S. Nat. Mus. 495251.
13–15. Height 2 mm., width 4.9 mm. U. S. Nat. Mus. 495252.

16, 17. *Physa wattsi* Arnold. Height 10 mm., width 8 mm. Locality 19, upper *Amnicola* zone. U. S. Nat. Mus. 495253.

18, 19. *Physa humerosa* Gould. Height 6.5 mm., width 4.3 mm. Locality 27, below lower *Amnicola* zone. U. S. Nat. Mus. 495254.

20. *Parapholyx* cf. *P. effusa* (Lea). Height 3.4 mm., width 4 mm. Locality 21, lower *Amnicola* zone. U. S. Nat. Mus. 495255.

21–24. *Sphaerium kettlemanensis* Arnold. Topotypes. Locality 7, lower *Amnicola* zone.
21, 22. Length 7.7 mm., height 6.5 mm., thickness 1.9 mm. U. S. Nat. Mus. 495256.
23, 24. Length 7.4 mm., height 6.6 mm., thickness 1.7 mm. U. S. Nat. Mus. 495257.

25–28. *Sphaerium* n. sp.? Locality 17, lower *Amnicola* zone.
25, 26. Length 7.2 mm., height 6.5 mm., thickness 2.2 mm. U. S. Nat. Mus. 495258.
27, 28. Length 7 mm., height 6.2 mm., thickness 2.5 mm. U. S. Nat. Mus. 495259.

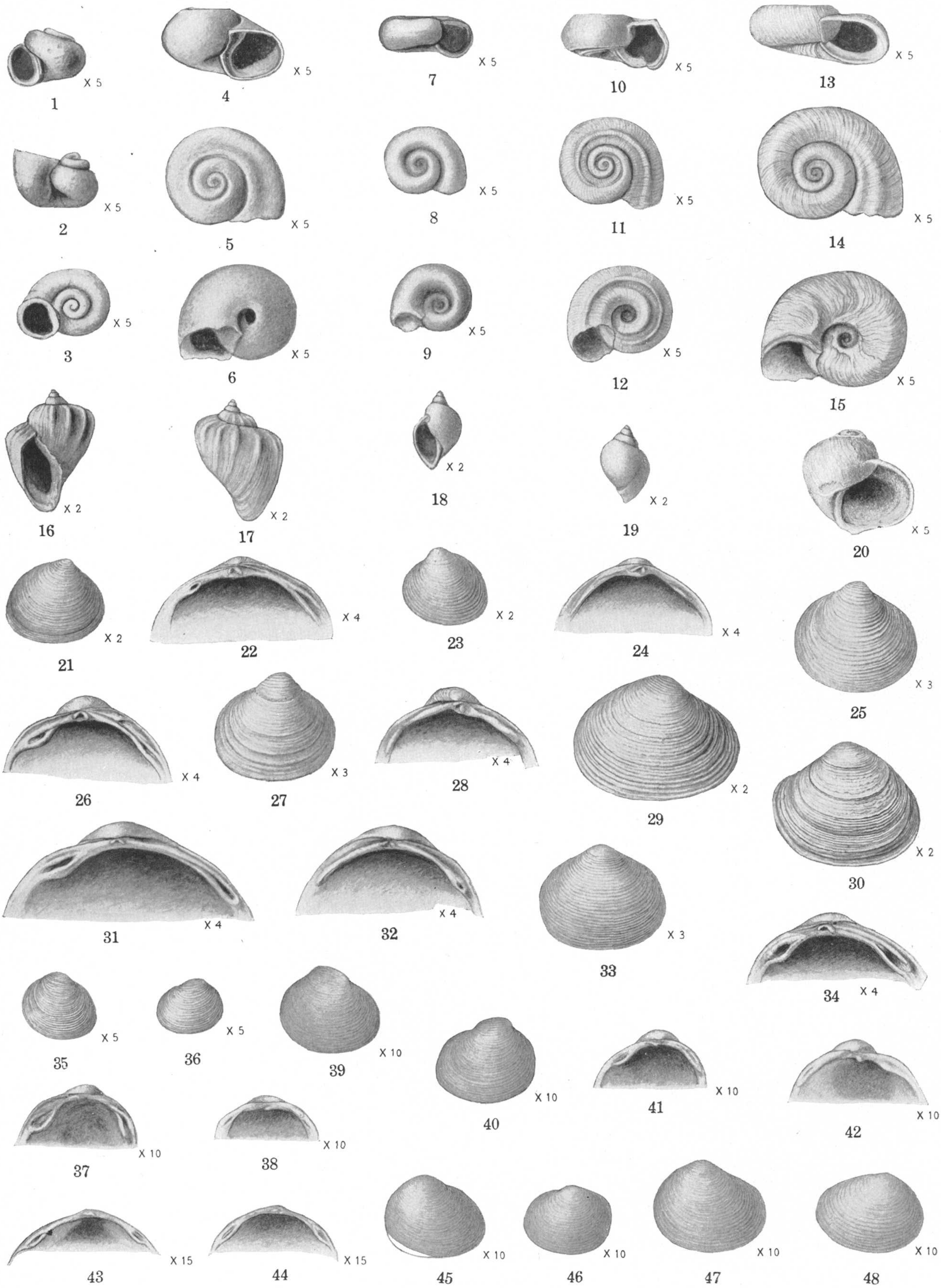
29–34. *Sphaerium cooperi* Arnold.
29. Length 13.9 mm., height 10.5 mm., thickness 4 mm. Locality 26, below lower *Amnicola* zone. U. S. Nat. Mus. 495260.
30. Length 12.6 mm., height 10.5 mm., thickness 3.8 mm. Locality 27, below lower *Amnicola* zone. U. S. Nat. Mus. 495261.
31. Length 12.6 mm., height 10.1 mm., thickness 3.5 mm. Locality 27, below upper *Amnicola* zone. U. S. Nat. Mus. 495262.
32. Length 10.8 mm., height 8.6 mm., thickness 3.2 mm. Locality 27, below upper *Amnicola* zone. U. S. Nat. Mus. 495263.
33, 34. Length 6.9 mm., height 5.6 mm., thickness 2 mm. Locality 21, lower *Amnicola* zone. U. S. Nat Mus. 495264.

35–38. *Pisidium compressum praecompressum* Pilsbry. Locality 10, lower *Amnicola* zone.
35. Length 2.3 mm., height 2.1 mm., thickness 0.6 mm. U. S. Nat. Mus. 495265.
36. Length 1.8 mm., height 1.6 mm., thickness 0.6 mm. U. S. Nat. Mus. 495266.
37. Length 1.8 mm., height 1.7 mm., thickness 0.6 mm. U. S. Nat. Mus. 495267.
38. Length 1.4 mm., height 1.3 mm., thickness 0.5 mm. U. S. Nat. Mus. 495268.

39–42. *Pisidium* sp. Locality 20, lower *Amnicola* zone.
39. Length 1.6 mm., height 1.3 mm., thickness 0.5 mm. U. S. Nat. Mus. 495269.
40. Length 1.6 mm., height 1.3 mm., thickness 0.5 mm. U. S. Nat. Mus. 495270.
41. Length 1.7 mm., height 1.5 mm., thickness 0.5 mm. U. S. Nat. Mus. 495271.
42. Length 1.9 mm., height 1.7 mm., thickness 0.7 mm. U. S. Nat. Mus. 495272.

43–46. *Pisidium* cf. *P. insigne* Gabb. Locality 8, lower *Amnicola* zone.
43. Length 1.3 mm., height 1 mm., thickness 0.4 mm. U. S. Nat. Mus. 495273.
44. Length 1.5 mm., height 1.1 mm., thickness 0.4 mm. U. S. Nat. Mus. 495274.
45. Length 1.6 mm., height 1.3 mm., thickness 0.5 mm. U. S. Nat. Mus. 495275.
46. Length 1.4 mm., height 1.2 mm., thickness 0.4 mm. U. S. Nat. Mus. 495276.

47, 48. *Pisidium* cf. *P. abortivum exiguum* Sterki. Locality 21, lower *Amnicola* zone.
47. Length 1.8 mm., height 1.4 mm., thickness 0.6 mm. U. S Nat. Mus. 495277.
48. Length 1.7 mm., height 1.3 mm., thickness 0.5 mm. U. S. Nat. Mus. 495278.



FOSSILS FROM TULARE FORMATION.

PLATE 6

[Figures natural size]

FIGURES 1–3. *Anodonta kettlemanensis* Arnold. Lower *Amnicola* zone.

1, 2. Short form. Length 64 mm., height 42 mm., thickness 13 mm. Locality 10. U. S. Nat. Mus. 495279.

3. Elongate, strongly inflated form. Length 72.8 mm., height 42.8 mm., thickness of both valves 30 mm. Locality 8. U. S. Nat. Mus. 495280.

4–9. *Gonidea coalingensis* Arnold.

4. Strongly inflated, high-beaked form. Length 68 mm., height 35.5 mm., thickness 14 mm. Locality 27, below lower *Amnicola* zone. U. S. Nat. Mus. 495281.

5, 6. Length 65.5 mm., height 29.2 mm., thickness 8.4 mm. Locality 10, lower *Amnicola* zone. U. S. Nat. Mus. 495282.

7, 8. Length 69.2 mm., height 31 mm., thickness 8 mm. Locality 10, lower *Amnicola* zone. U. S. Nat. Mus. 495283.

9. High-beaked large form. Length 88.7 mm., height 42.7 mm., thickness 12 mm. Locality 20, lower *Amnicola* zone. U. S. Nat. Mus. 495284.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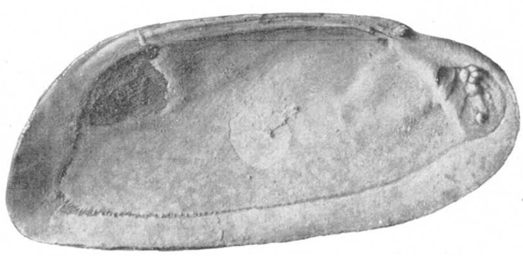
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FOSSILS FROM TULARE FORMATION.

PLATE 7

FIGURE 1. *Surirella utahensis* Grunow. Length 0.030 mm., width 0.024 mm. Locality 11, white clay at base of formation. U. S. G. S. diatom catalog No. 1520–4.

2. *Stephanodiscus carconensis* Grunow. Diameter 0.040 mm. Locality 5, white clay at base of formation. U. S. G. S. diatom catalog No. 1602–5.

3. *Epithemia zebra* (Ehrenberg) Kützing var. *saxonica* (Kützing) Grunow. Length 0.058 mm., width 0.010 mm. Locality 11, white clay at base of formation. U. S. G. S. diatom catalog No. 1520–3.

4. *Rhopalodia gibba* (Ehrenberg) Müller. Length 0.083 mm., width 0.022 mm. Locality 16, lower *Amnicola* zone. U. S. G. S. diatom catalog No. 1512–1.

5. *Hyalodiscus schmidtii* Frenguelli. Diameter 0.039 mm. Locality 11, white clay at base of formation. U. S. G. S. diatom catalog No. 1518–1.

6. *Eunotia robusta* Ralfs var. *tetraodon* (Ehrenberg) Ralfs. Length 0.034 mm., width 0.011 mm. Locality 5, white clay at base of formation. U. S. G. S. diatom catalog No. 1602–7.

7. *Melosira granulata* var. *curvata* Grunow. Diameter 0.009 mm. Locality 5, white clay at base of formation. U. S. G. S. diatom catalog No. 1602–3.

8. *Melosira granulata* (Ehrenberg) Ralfs. Length (two frustules) 0.047 mm., diameter 0.013 mm. Locality 5, white clay at base of formation. U. S. G. S. diatom catalog No. 1602–2.

9. *Melosira ambigua* (Grunow) Müller. Length (two frustules and two valves) 0.069 mm., diameter 0.016 mm. Locality 5, white clay at base of formation. U. S. G. S. diatom catalog No. 1602–4.

10. *Diploneis smithii* (Brebisson) Cleve. Length 0.060 mm., width 0.033 mm. Locality 11, white clay at base of formation. U. S. G. S. diatom catalog No. 1518–2.

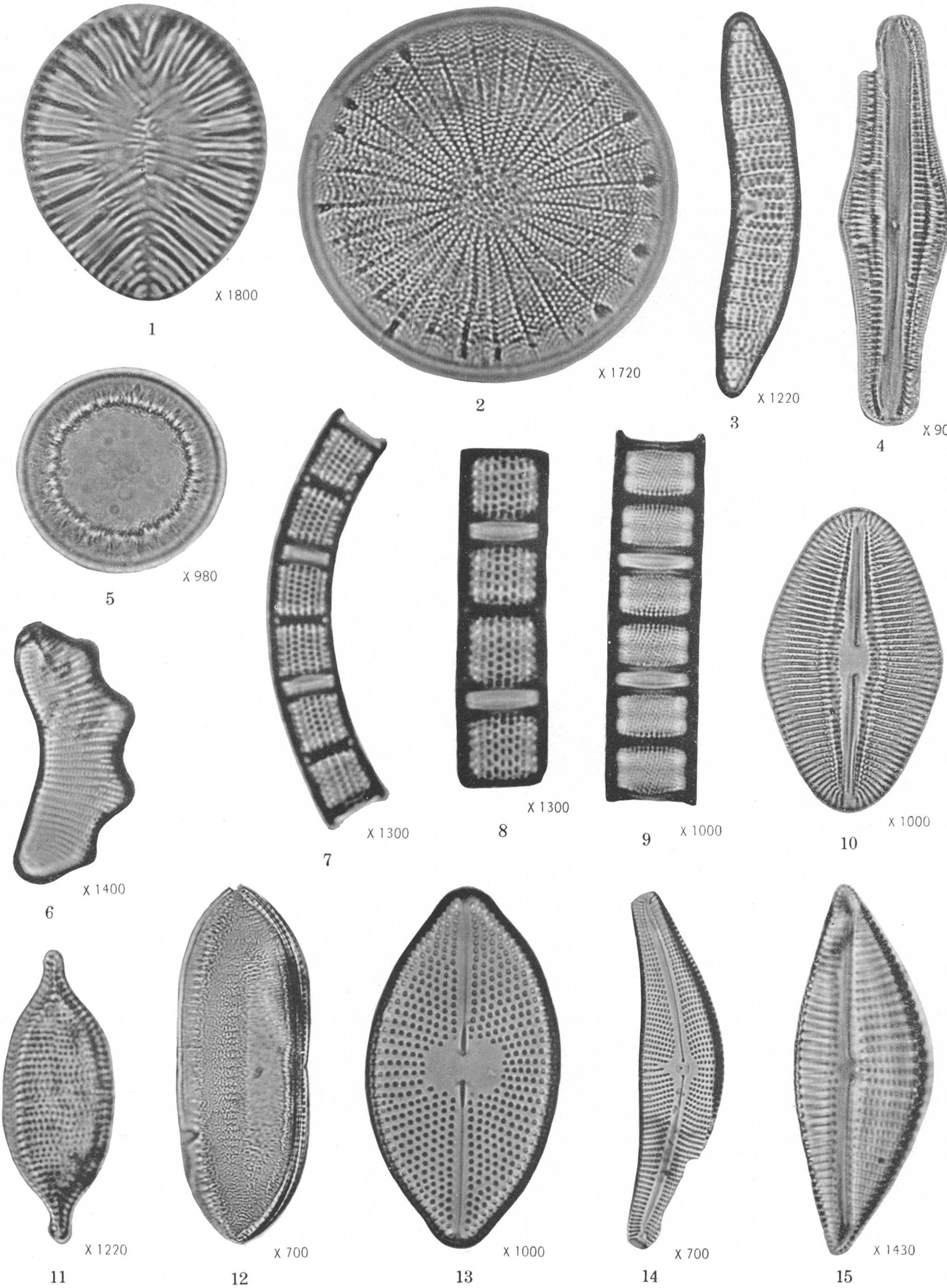
11. *Nitzschia etchegoinia* Hanna and Grant. Length 0.096 mm., width 0.034 mm. Locality 11, white clay at base of formation. U. S. G. S. diatom catalog No. 1520–5.

12. *Nitzschia punctata* (W. Smith) Grunow. Length 0.045 mm., width 0.017 mm. Locality 5, white clay at base of formation. U. S. G. S. diatom catalog No. 1602–11.

13. *Navicula marina* Ralfs. Length 0.066 mm., width 0.035 mm. Locality 11, white clay at base of formation. U. S. G. S. diatom catalog No. 1519–1.

14. *Cymbella mexicana* (Ehrenberg) Cleve. Length 0.095 mm., width 0.023 mm. Locality 11, white clay at base of formation. U. S. G. S. diatom catalog No. 1520–2.

15. *Cymbella prostrata* (Berkeley) Cleve. Length 0.048 mm., width 0.017 mm. Locality 5, white clay at base of formation. U. S. G. S. diatom catalog No. 1602–9.



DIATOMS FROM TULARE FORMATION.

Section of lower Amnicola zone of Tulare formation at La Salida on east side of northern Middle Dome, sec. 17, T. 23 S., R. 19 E.

	Ft.	in.
8. Thin-bedded gray iron-stained fine-grained sandstone and silt; top not exposed	11	9+
Lower *Amnicola* zone:		
7. Cross-bedded gray sand containing scattered mussels. Several discontinuous, hard and flaggy ferruginous layers. Ferruginous nodules arranged along other layers. Much of the sand contains small flat pebbles of white siliceous shale. Black chert pebbles as much as 3½ inches long form a thin bed 33 inches below top. The sand between this layer of pebbles and top of bed contains scattered *Amnicola*	30	2
6. Tuff and sandy tuff:		
b. Thin-bedded sandy tuff, fine sandstone, and silt. The silt contains brackish-water diatoms (locality 16)	8	
a. Fresh tuff, consisting of glass with an index of refraction of about 1.51	4	
5. Grayish-olive silt and fine-grained sandstone, poorly exposed except at intervals in bottom of arroyo	12	2
4. Sand:		
b. Ferruginous sand; some layers have ferruginous cement; *Amnicola* and mussels scattered throughout. At base a 2-inch layer of cross-bedded sand containing *Amnicola* is overlain by a 1-inch layer containing many mussels. At the base of a 6-inch layer lying 2 feet below top are mussels and "bulbous fish growths"	9	
a. Cross-bedded gray sand, surface iron-stained. Includes four discontinuous hard layers. A thin layer 35 inches below top contains broken mussels	11	9
3. Thin-bedded, fine-grained gray sand with mud partings. Includes three discontinuous layers of hard, ferruginous flaggy sandstone 1 foot or less thick. Many layers contain small pebbles and an occasional 2- or 3-inch pebble of white siliceous shale	25	
2. Limestone and sand:		
e. *Amnicola*- and mussel-bearing sand. Mussels most abundant at base, middle, and top	2	6
d. Limestone, made up of *Amnicola* and calcareous oolites; contains few mussels		8
c. Ferruginous, oolitic sand; many calcareous oolites, scattered *Amnicola*, and a few *Calipyrgula*, ostracodes and otoliths (locality 15)	1	
b. Limestone, made up of *Amnicola* and calcareous oolites; few mussels. Resembles unit 2d. Between algal heads it rests on unit 1b. May be absent above thick algal heads		0–3½
a. Discontinuous layer of flat heads of calcareous algae that have a mammillary upper surface. Penetrates cracks in unit 1b		0–2

Section of lower Amnicola zone of Tulare formation at La Salida on east side of northern Middle Dome, sec. 17, T. 23 S., R. 19 E.—Continued.

	Ft.	in.
Lower *Amnicola* zone—Continued.		
1. Sand and sandstone:		
b. Imperfectly cemented cross-bedded, brecciated brown sandstone. May represent part of underlying sandstone brecciated by storm waves		2–7
a. Cross-bedded gray sand, containing oolites and scattered *Amnicola*, *Calipyrgula*, *Valvata*, *Pyrgulopsis*, and *Pisidium* (locality 14) alternating with discontinuous layers of imperfectly cemented brownish-gray sandstone as much as 2 feet thick. Base not exposed	13+	
Thickness of measured section	130±	

The tuff in unit 6a of the preceding section is fresher than volcanic material observed elsewhere in the Tulare formation. The oolites in unit 2 consist of thin layers of calcareous material enveloping sand grains of varying size and bits of clay. On many of the sand grains the calcareous material is thin and is partly worn off. Oolitic limestone or limy sandstone extends southward along the north half of Middle Dome. Near the west line of sec. 21, T. 23 S., R. 19 E., two beds of oolitic sandstone, each of which has a thickness of about a foot, are separated by 10 feet of fine-grained rocks.

Fossils strewn along soil-covered outcrops reveal the presence of the lower *Amnicola* zone at places in the low hills on the east side of the saddle between Middle Dome and South Dome.

A higher *Amnicola* zone, designated the upper *Amnicola* zone, was mapped at localities on the east side of Middle Dome. It is 350 feet above the base of the formation and consists of one or two soft fossiliferous sandstones. The southernmost locality may represent a different horizon, as it is apparently 275 feet above the base of the formation.

At La Salida the base of the stratigraphically lowest conglomerate represents a horizon 750 feet above the top of the lower *Amnicola* zone. This conglomerate is a lens in coarse-grained sandstone and consists principally of flat pebbles of siliceous shale that have a maximum length of 5 inches. *Carinifex* shells occur at the top of an overlying layer of smaller pebbles in this exposure. Farther down the arroyo a miniature box canyon is cut in conglomerate and massive sandstone.

WEST FLANK OF NORTH DOME

The white clay at the base of the Tulare formation forms conspicuous exposures around the north end of North Dome and southward on the west flank, but toward the south end of the anticline it is less prominent, owing apparently to a greater admixture of brown clay. The white clay has been prospected on Arroyo del Camino, where it consists in ascending order of 4 feet of white clay, 8 feet of grayish-brown clay, and 14 inches of white clay. Near the north line of sec. 30, T. 21 S., R. 17 E., the upper part of the clay consists of hard siliceous shale that resembles the Monterey (Miocene) type of siliceous shale.

The lower *Amnicola* zone was recognized along virtually the entire west side of North Dome. Near the north end of the anticline the base of the zone is 30 feet above the top of the white clay, or 45 feet above the base of the formation. Farther south it is 100 to 200 feet above the base. An *Amnicola*-bearing sandstone less than 50 feet above the base of the formation near the south end of the anticline is considered to represent a horizon below the lower *Amnicola* zone, as on the east flank. Between Arroyo Corto and La Cañada Simada a 2-foot fine-grained fresh tuff lies in the lower *Amnicola* zone about 50 feet above its base. The index of refraction of the glass constituting this tuff, as determined by M. N. Bramlette, is about 1.50. At places, for example locality 22, the tuff contains *Amnicola*. Southward from Arroyo Somero hard *Amnicola*-bearing sandstones exposed at two horizons in the lower *Amnicola* zone, as on part of the east flank, are separated by 85 to 150 feet of poorly exposed, apparently barren beds. At many places where there are no actual exposures the soil formed from these beds is marked by a brown ferruginous crust. On both sides of the main western branch of Arroyo Conchoso a 4-foot white sandy clay crops out about 100 feet above a hard brown limy sandstone in the upper part of the lower *Amnicola* zone. The following section of beds below the lower *Amnicola* zone was measured on Arroyo Conchoso.

Section of basal part of Tulare formation on Arroyo Conchoso, sec. 30, T. 22 S., R. 18 E.

[Measured by G. F. Taylor]

	Ft.	in.
Tulare formation:		
Hard brown ferruginous sandstone, *Amnicola* and mussels; base of lower *Amnicola* zone.		
Unexposed	60	
Dark brown clay and silt, poorly exposed	80	
Clay:		
Yellowish-white clay	1	
Dark-brown clay	8	
Light-grayish-yellow clay	2	
Dark-grayish-brown clay		10
Grayish-brown clay, stained yellowish; upper part sandy	2	3
Thickness of Tulare formation below lower *Amnicola* zone	154	1
San Joaquin formation, upper *Mya* zone:		
Dark gray clay; contains oysters.		

The following section of the lower part of the Tulare formation was measured on Arroyo Delgado.

Section of basal part of Tulare formation on Arroyo Delgado, sec. 33, T. 22 S., R. 18 E.

[Measured by G. F. Taylor]

	Ft.	in.
Alternating sandstone and silty clay.		
Lower *Amnicola* zone:		
Cross-bedded yellowish-gray sandstone, *Amnicola*	4	10
Hard dark yellow limy sandstone, few *Amnicola*		5
Moderately coarse yellowish-gray sandstone, many small clay pellets	2	
Brownish-gray iron-stained sandy clay and silt		4
Fine-grained cross-bedded yellowish-gray sandstone, scattered *Amnicola*	1	
Dark-gray to brownish-gray sandy clay and silt, many *Amnicola* and mussels	1	4
Beds below lower *Amnicola* zone:		
Fine-grained cross-bedded light-yellow sandstone	2	4
Grayish-brown sandy clay and silt	1	2
Alternating sandstone and clay, poorly exposed; some beds contain few *Amnicola* and mussels	50±	
White clay at base of Tulare formation; thickness uncertain.		
Thickness of measured section	63±	

This section shows *Amnicola*-bearing beds lower than a horizon considered the base of the lower *Amnicola* zone. On branches of the first main arroyo north of Arroyo Raso *Amnicola* and other fossils were collected less than 50 feet above the base of the Tulare (localities 26, 27). In the section measured on the first arroyo south of Arroyo Raso (see pp. 21–22) fossiliferous beds referred to the lower horizon in the lower *Amnicola* zone are 135 feet above the base of the formation and the upper horizon is 85 feet higher. A higher *Amnicola*-bearing sandstone, 330 feet above the base of the formation, is at essentially the same horizon as the upper *Amnicola* zone of the east side of Middle Dome, which also appears to be represented at a few localities from Arroyo Somero southward to Arroyo Raso. At the head of the first main arroyo south of the Paso Robles-Hanford road grayish-brown sandstone that contains *Amnicola* and mussels and represents the lowest observed fossiliferous beds in the lower *Amnicola* zone is 100 feet above the base of the Tulare.

At the north end of North Dome the upper part of the Tulare consists of many discontinuous beds of conglomerate, some of which are imperfectly cemented, interbedded with sandstone, much of which is poorly consolidated. The lowest beds of conglomerate are 200 to 275 feet above the base of the formation, not far above the lower *Amnicola* zone. Where the strike of the beds bends southward along the west side of the anticline the base of the main conglomerate zone is 425 to 500 feet above the base of the formation. On the first arroyo north of La Cañada Simada scattered beds of conglomerate begin at a horizon 200 feet above the base of the formation and extend up through the section. In this area the pebbles and cobbles are smaller than in the conglomerates farther south. Brown sandstone is the most abundant rock in the conglomerate, though granitic rocks, red chert, and lavas were noted. On Arroyo Somero and also on the first arroyo south of Arroyo Mellado conglomerate is absent, except thin lenses of small pebbles. A coarse, pebbly, massive brown sandstone near the edge of the hills on Arroyo Chico, 1,800 feet above the base of the formation, contains small oysters.

The following section, in which the lithologic description is generalized, was measured on the first main arroyo south of Arroyo Raso, three-quarters of a mile northwest of the Paso Robles-Hanford road. This section does not include an estimated thickness of 700 feet of poorly exposed beds near the edge of the hills.

Section of Tulare formation on arroyo three-quarters of a mile northwest of Paso Robles-Hanford road

[Measured by G. F. Taylor]

	Feet
Conglomerate, contains oyster fragments	½
Grayish-brown slightly cross-bedded sandstone; contains oyster fragments	25
Conglomerate; contains fragments of mussels	½
Grayish-brown sandstone with mudstone partings	10
Conglomerate; contains oyster fragments	1
Grayish-brown sandstone; contains small oysters	16
Hard conglomerate; contains small oysters	½
Grayish-brown sandstone; contains small oysters	45
Grayish-brown muddy sandstone	6
Grayish-brown sandstone; contains small oysters	42
Hard conglomerate; contains small oysters	1
Grayish-brown sandstone; contains small oysters	9
Conglomerate; contains small oysters	1
Grayish-brown sandstone	12
Hard conglomerate; many pebbles of siliceous shale; contains small oysters	1
Grayish-brown sandstone; contains small oysters	4
Conglomerate made up of large cobbles; contains small oysters	1
Grayish-brown sandstone including occasional conglomerate lenses and oysters; upper 125 feet poorly exposed	145
Poorly sorted coarse-grained, pebbly gray sandstone; contains small oysters	1½
Grayish-brown pebbly sandstone, poorly exposed	109
Poorly sorted pebbly gray sandstone	1½
Coarse-grained grayish-brown sandstone	9
Hard conglomerate	½
Grayish-brown sandstone including conglomerate lenses	142
Grayish-brown silt	37
Grayish-brown sandstone including conglomerate lenses	72
Grayish-brown silt	12
Grayish-brown sandstone including conglomerate lenses	21
Hard cross-bedded grayish-brown sandstone	1
Cross-bedded soft light-grayish-brown sandstone	3
Poorly bedded muddy grayish-brown sandstone	28
Conglomerate; siliceous shale pebbles abundant	3
Cross-bedded yellowish-gray sandstone	3
Poorly bedded silty grayish-brown sandstone	4
Cross-bedded yellowish-gray sandstone	6
Poorly bedded muddy grayish-brown sandstone	3
Cross-bedded yellowish-gray sandstone	15
Yellowish-gray silt	33
Grayish-brown sandstone	11

Section of Tulare formation on arroyo three-quarters of a mile northwest of Paso Robles-Hanford road—Continued

	Feet
Hard cross-bedded grayish-brown sandstone	1
Poorly exposed grayish-brown sandstone including thin conglomerate lenses and thin beds of silt	120
Hard coarse-grained gray sandstone	1
Conglomerate	1
Grayish-brown sandstone including few conglomerate lenses	45
Conglomerate consisting almost entirely of siliceous shale and chert pebbles	2
Silt	3
Silty grayish-brown sandstone including few conglomerate lenses	85
Poorly sorted rudely bedded coarse sand and pebbles	6
Coarse-grained grayish-brown sandstone including conglomerate lenses	18
Conglomerate	3
Grayish-brown sandstone	21
Poorly sorted rudely stratified coarse sand and pebbles; pebbles composed principally of siliceous shale	6
Coarse-grained grayish-brown sandstone including many conglomerate lenses	90
Hard grayish-brown sandstone	1
Cross-bedded yellowish-gray sandstone; contains many small pebbles and chips of siliceous shale about ⅛ inch long	3
Coarse-grained cross-bedded pebbly sandstone including conglomerate lenses	61
Conglomerate; well-rounded chert cobbles abundant	½
Coarse-grained cross-bedded yellowish-gray sandstone	1
Conglomerate	½
Cross-bedded dark-gray sandstone	2
Hard conglomerate made up of pebbles to large cobbles	10
Coarse-grained yellowish-gray pebbly sandstone including many conglomerate lenses	72
Hard grayish-brown pebbly sandstone	3
Conglomerate; siliceous shale pebbles abundant	15
Coarse-grained yellowish-gray sandstone including many conglomerate lenses	65
Hard conglomerate	3
Coarse-grained yellowish-gray sandstone including few conglomerate lenses	45
Hard conglomerate	4
Coarse-grained poorly bedded yellowish-brown sandstone	78
Hard grayish-brown sandstone	3
Massive gray sandstone	21
Hard gray sandstone; contains many *Amnicola*, *Goniobasis*, *Sphaerium*, and other fossils (locality 28); represents upper *Amnicola* zone	2
Massive yellowish-gray sandstone	40
Hard gray sandstone	2
Massive yellowish-gray sandstone	30
Conglomerate	1
Hard gray sandstone	1
Yellowish-gray sandstone	34
Yellowish-gray sandstone; contains *Amnicola* and mussels. This bed and underlying bed assigned to upper horizon in lower *Amnicola* zone	½
Yellowish-gray sandstone; contains *Amnicola*	3
Hard gray sandstone	½
Massive yellowish-gray sandstone	15
Hard gray sandstone	½
Massive yellowish-gray sandstone	15
Gray sandstone; small pebbles of siliceous shale abundant	15
Well-bedded gray sandstone	10
Hard gray sandstone	½

Section of Tulare formation on arroyo three-quarters of a mile northwest of Paso Robles-Hanford road—Continued

	Feet
Massive gray sandstone	25
Hard grayish-brown sandstone; contains many *Amnicola* and mussels at base. Assigned to lower horizon in lower *Amnicola* zone	6
Poorly exposed sandstone and clay	10
White clay	1
Poorly exposed sandstone and clay; soil has ferruginous crust and "bulbous fish growths." Base of lower *Amnicola* zone in this interval. Underlain by upper *Mya* zone of San Joaquin formation	120
Thickness of measured section	1, 958

In this section the base of the conglomerate zone is 434 feet above the base of the formation, though there is a 1-foot conglomerate bed 177 feet lower. Small oysters were observed in a sandstone 1,636 feet above the base of the formation and upward to the top of the measured section through a thickness of 322 feet of sandstone and conglomerate.

WEST FLANK OF MIDDLE DOME

The exposed part of the Tulare formation is about 3,500 feet thick on the west flank of Middle Dome and is thicker in this region than elsewhere in the Kettleman Hills. Fossiliferous beds representing the lower *Amnicola* zone were mapped for only short distances at the north and south ends of the anticline. Fossils identifying the zone could doubtless be found elsewhere on soil-covered slopes. At several places beds of dirty white sandy clay, representing probably altered tuff, are exposed about 250 feet above the base of the formation and also closer to the base. A few small oysters and one specimen of *Littorina* were found in pebbly sandstone in the upper part of the Tulare near the edge of the hills on Arroyo Menudo and the first arroyo to the north.

WEST FLANK OF SOUTH DOME

The location of the contact between the Tulare and San Joaquin formations is doubtful along the greater part of the west flank of South Dome. The lower *Amnicola* zone was not found in this region, and the upper *Mya* zone was identified by its fossils only at the north end of the anticline and near the south end of the Kettleman Hills. Two loose specimens of *Olivella* were picked up at localities corresponding to an estimated stratigraphic position within 50 feet of the base of the Tulare. This genus is not known to occur in the upper *Mya* zone nor at any other horizon in the San Joaquin formation above the *Pecten* zone. It is quite certain that these specimens are not Tulare fossils. They may represent detrital constituents weathered out of a conglomerate in the Tulare, though they are not badly worn, or they may have been dropped by Indians.[19]

Conglomerates—or rather gravels, for most of the material is unconsolidated—are abundant throughout the Tulare formation on the west flank of South Dome, even at the base of the formation. In many of these beds the pebbles consist almost entirely of flat, crudely elliptical pieces of white siliceous shale, derived presumably from the McLure shale member of the Monterey shale exposed on Reef Ridge and in the Pyramid Hills and probably also from the Kreyenhagen shale of Reef Ridge. Although these beds are rarely exposed in the low rolling hills on the west side of South Dome, the pieces of siliceous shale cover the ground along their strike. These gravels also contain cobbles and poorly rounded pieces of buff limestone, which, like limestone concretions in the McLure shale of Reef Ridge, contain diatoms. Other rocks are represented in the gravels, such as fossiliferous Temblor sandstone, containing *Aequipecten andersoni*, and hard brown sandstone like that in concretions in Eocene and Cretaceous formations back of Reef Ridge. One of the Temblor boulders in gravel about 20 feet above the base of the Tulare measured 18 by 13 inches.

FOSSILS

At many places fossils, consisting principally of fresh-water snails, mussels, and diatoms, are abundant in the lower part of the Tulare formation, particularly in the beds assigned to the lower and upper *Amnicola* zones. The fossils aside from diatoms are listed on page 23, and the diatoms are listed on pages 24–25. The fresh-water mollusks, representing the largest known Pliocene fresh-water fauna on the Pacific coast, have recently been described by Pilsbry.[20] They are illustrated on plates 4 to 6.

Shells were collected from beds regarded as underlying the lower *Amnicola* zone at three localities. At locality 3, near the north end of North Dome, a sandy tuff overlying the white clay at the base of the formation contains *Littorina mariana* (pl. 4, figs. 4–6) and a small form of *Amnicola longinqua*—an association of a fresh-water genus with a marine genus that tolerates water of low salinity. The *Littorina* is represented by 23 specimens, some of which are well-preserved and have color markings. The condition of the material and the absence of other marine fossils suggest that these shells are not detrital, and their presence points to a temporary connection with the sea at the time when the tuff was laid down. The other two collections are from adjoining localities on the west side of southern North Dome (localities 26, 27). *Goniobasis arnoldiana* (pl. 4, figs. 53, 54) was found only at these localities but was collected by Arnold and Anderson at their locality 4732 [*Goniobasis "nigrina?"*], which represents the lower *Amnicola* zone near locality 21. The *Amnicola*

[19] For the extensive use of *Olivella* by California Indians see Kroeber, A. L., Handbook of the Indians of California: Bur. Am. Ethnology Bull. 78, p. 826, 1925.

[20] Pilsbry, H. A., Mollusks of the fresh-water Pliocene beds of the Kettleman Hills and neighboring oil fields, Calif.: Acad. Nat. Sci. Philadelphia Proc., vol. 86, pp. 541-570, pls. 18-23, 2 figs., 1935.

Fossils from Tulare formation

[Identifications by W. P. Woodring unless otherwise stated. F, fragments; P, paired valves]

Species	Localities																									
	Below lower *Amnicola* zone				Lower *Amnicola* zone																	Upper *Amnicola* zone			Above upper *Amnicola* zone	
	East flank of North Dome		West flank of North Dome		East flank of North Dome						East flank of Middle Dome				West flank of North Dome							East flank of Middle Dome		West flank of North Dome	East flank of North Dome	
	3	4	26	27	2	6	7	K14[1]	8	10	14	15	17	18	4732[2]	20	21	22	23	24	25	12	19	28	9	13
Gastropods:																										
Littorina mariana Arnold (pl. 4, figs. 4–6)	X																									X
Valvata virens platyceps Pilsbry (pl. 4, figs. 1, 2)					X																X		X			
Valvata humeralis californica Pilsbry (pl. 4, fig. 3)											X			X		X	X									
Fluminicola cf. *F. spiralis* Pilsbry (pl. 4, figs. 7–11)					X					X					X	X	X				X		X			
Fluminicola cf. *F. yatesiana* (Cooper) (pl. 4, fig. 12)									X																	
Pyrgulopsis vincta Pilsbry (pl. 4, figs. 13–16)											?					X										
Calipyrgula carinifera Pilsbry (pl. 4, figs. 17, 18)							X								X	?				X						
Calipyrgula ellipsostoma Pilsbry (pl. 4, fig. 19)										X																
Calipyrgula stewartiana Pilsbry (pl. 4, figs. 20, 21)			?	?							X	?														
Littoridina woodringi Pilsbry (pl. 4, fig. 22)																					X		X			
Amnicola longinqua Gould (pl. 4, figs. 23–27)	X		X	X		X		X		X	X	X	X	X	X	X	X	?				X		X		
Hydrobia andersoni (Arnold) (pl. 4, figs. 28–34)					X		X	X							X											
Hydrobia birkhauseri Pilsbry					X			X																		
Brannerillus physispira Hannibal (pl. 4, figs. 35–38)					X			X	X												X					
Brannerillus involutus Pilsbry (pl. 4, figs. 39–50; pl. 5, figs. 1–3)					X		X	X		X					X	X	X			X						
Goniobasis kettlemanensis woodringi Pilsbry (pl. 4, figs. 51, 52)					X								X								X	X		X		
Goniobasis arnoldiana Pilsbry (pl. 4, figs. 53, 54)			X	X											X											
Carinifex sanctaeclarae marshalli Arnold (pl. 5, figs. 4–6)										X			X		X		X				X	X	X	X		
Parapholyx cf. *P. effusa* (Lea) (pl. 5, fig. 20)																	X									
Menetus centervillensis (Tryon), (pl. 5, figs. 7–9)														X												
Menetus vanvlecki (Arnold), (pl. 5, figs. 10–15)					X		X			X					X					X						
Physa wattsi Arnold (pl. 5, figs. 16, 17)							X			X					X						X	X	X	X		
Physa humerosa Gould (pl. 5, figs. 18, 19)				X										X	X	X	X									
Pelecypods:																										
Ostrea cf. *O. vespertina sequens* Arnold (small form, probably dwarfs)																										X
Anodonta kettlemanensis Arnold (pl. 6, figs. 1–3)							X		P	X				?F	X	X				F	F		?F			
Gonidea coalingensis Arnold (pl. 6, figs. 4–9)				X	X		P		P	P					X	X				?F	?F		?F			
Sphaerium kettlemanensis Arnold (pl. 5, figs. 21–24)					X		P		X	X					X	P				X	X	X				
Sphaerium n. sp.? (pl. 5, figs. 25–28)													X										X	X		
Sphaerium cooperi Arnold (pl. 5, figs. 29–34)			P	X									X		X		X									
Pisidium compressum praecompressum Pilsbry (pl. 5, figs. 35–38)							X			X				X	X	P	X					X				
Pisidium sp. (pl. 5, figs. 39–42)																X										
Pisidium cf. *P. insigne* Gabb (pl. 5, figs. 43–46)									X		?															
Pisidium cf. *P. abortivum exiguum* Sterki (pl. 5, figs. 47, 48)																	P									
Ostracodes (identifications by R. S. Bassler):																										
Cytherella sp.		X										X														
Cytherelloidea sp.																		X								
Undetermined otoliths							X				X	X		X	X		X	X			X					
Undetermined fish remains:																										
"Bulbous growths"						X													X							
Plates																			X							
Spines																		X	X				X			
Vertebrae											X							X	X							
Mammal (identification by C. L. Gazin):																										
Horse tooth (*Plesippus?*; float)																									X	

[1] K14. East flank of North Dome, Arroyo Torcido, 2,400 feet east and 900 feet south of northwest corner of sec. 6, T. 22 S., R. 18 E. Base of Tulare formation. Max Birkhauser, collector. Mr. Birkhauser donated material from this locality and Dr. E. F. Davis kindly furnished the locality data, which have been entered in the records of the Geological Survey as Tertiary invertebrate locality 13380.

[2] 4732. About 2 miles from northwest end of Kettleman Hills, on south side of main ridge 1½ miles northwest of 1,245-foot hill, SW¼NE¼ sec. 30, T. 21 S., R. 17 E. Fresh-water zone at base of Tulare formation. R. Arnold and R. Anderson, collectors, August 1907. Most of the material from this locality apparently was not examined in the preparation of U. S. Geological Survey Bulletins 396 and 398.

Diatoms from Tulare formation

[Identifications by K. E. Lohman. R, rare; F, few; C, common; A, abundant]

Species	Localities			
	White clay at base of formation			Lower *Amnicola* zone
	East flank of North Dome			East flank of Middle Dome
	1	5	11	16
Melosira sulcata (Ehrenberg) Kützing			F	
Melosira sol (Ehrenberg) Kützing			R	
Melosira undulata (Ehrenberg) Kützing var. *normanii* Arnott			R	
Melosira solida Eulenstein		F		
Melosira distans Kützing var. *lirata* (Ehrenberg) Bethge		F		
Melosira granulata (Ehrenberg) Ralfs (pl. 7, fig. 8)		C	A	F
Melosira granulata var. *curvata* Grunow (pl. 7, fig. 7)		F		R
Melosira granulata var. *australiensis* Grunow		R		
Melosira granulata var. *muzzanensis* (Meister) Bethge			F	
Melosira ambigua (Grunow) Müller (pl. 7, fig. 9)		C		
Melosira crenulata Kützing var. *semilaevis* Grunow		F	F	
Podosira stelliger (Bailey) Mann			R	
Hyalodiscus schmidtii Frenguelli (pl. 7, fig. 5)			A	
Stephanopyxis turris (Greville and Arnott) Ralfs var. *cylindrus* Grunow				R
Thalassiosira decipiens (Grunow) Joergensen			F	
Cyclotella meneghiniana Kützing		F	C	
Cyclotella compta (Ehrenberg) Kützing var. *pliocaenica* Krasske			R	
Cyclotella iris Brun and Heribaud		F		
Cyclotella pygmaea Pantocsek		R		
Stephanodiscus dubius (Fricke) Hustedt		F		
Stephanodiscus astraea (Ehrenberg) Grunow		F		
Stephanodiscus carconensis Grunow (pl. 7, fig. 2)		C		
Stephanodiscus carconensis var. *pusilla* Grunow		C		F
Coscinodiscus excentricus Ehrenberg			R	
Coscinodiscus kützingii Schmidt		R		
Actinoptychus undulatus Ehrenberg			R	
Xanthiopyxis ovalis Lohman			R	
Triceratium uncinatum Schmidt			F	
Biddulphia cf. *B. pulchella* Gray			R	
Terpsonoe americana (Bailey) Ralfs			F	
Tetracyclus lacustris Ralfs		F	R	
Tetracyclus japonicus (Petit) Hustedt		R		
Grammatophora cf. *G. maxima* Grunow			F	
Meridion circulare Agardh		R		
Fragilaria construens (Ehrenberg) Grunow		R		
Fragilaria construens var. *subsalina* Hustedt		R		
Fragilaria construens var. *venter* (Ehrenberg) Grunow		R		
Fragilaria harrissonii W. Smith			R	
Fragilaria harrissonii var. *dubia* Grunow		R		
Synedra ulna (Nitzsch) Ehrenberg			R	
Synedra ulna var. *amphirhynchus* (Ehrenberg) Grunow		R		
Eunotia robusta Ralfs var. *tetraodon* (Ehrenberg) Ralfs (pl. 7, fig. 6)		F		
Eunotia praerupta Ehrenberg		F	R	
Eunotia tenella (Grunow) Hustedt		F		
Eunotia pectinalis (Kützing) Rabenhorst		R		
Eunotia pectinalis var. *minor* (Kützing) Grunow		R		
Eunotia pectinalis var. *undulata* (Ralfs) Rabenhorst		R		
Eunotia pectinalis var. *ventralis* (Ehrenberg) Hustedt			R	
Eunotia lunaris (Ehrenberg) Grunow		R		
Eunotia cf. *E. gracilis* (Ehrenberg) Rabenhorst			R	
Eunotia formica Ehrenberg		R		
Eunotia cf. *E. didyma* Grunow var. *curta* Hustedt		R		
Eunotia trigibba Hustedt		F		
Eunotia serpentina Ehrenberg		F		
Cocconeis placentula Ehrenberg		F	F	
Cocconeis placentula var. *lineata* (Ehrenberg) Cleve		R	R	
Cocconeis scutellum Ehrenberg var. *minutissima* Grunow				F
Cocconeis sp. (indeterminable)	C			
Rhoicosphenia curvata (Kützing) Grunow		F		
Mastogloia elliptica Agardh				F
Gyrosigma attenuatum (Kützing) Rabenhorst		F		
Gyrosigma kützingii (Grunow) Cleve		R		
Caloneis formosa (Gregory) Cleve var. *rostrata* Frenguelli		R		
Caloneis silicula (Ehrenberg) Cleve var. *kjellmaniana* (Grunow) Cleve		R		
Caloneis trinodis (Lewis) Meister		R		
Diploneis elliptica (Kützing) Cleve		F		
Diploneis advena (Schmidt) Cleve				R
Diploneis smithii (Brebisson) Cleve (pl. 7, fig. 10)		F	A	
Stauroneis phoenicenteron Ehrenberg			R	

Diatoms from Tulare formation—Continued

[Identifications by K. E. Lohman. R, rare; F, few; C, common; A, abundant]

Species	Localities			
	White clay at base of formation			Lower *Amnicola* zone
	East flank of North Dome			East flank of Middle Dome
	1	5	11	16
Stauroneis cf. *S. anceps* Ehrenberg var. *gracilis* Ehrenberg			R	
Stauroneis parvula Grunow		R		
Navicula cf. *N. cuspidata* Kützing		F		
Navicula cuspidata var. *heribaudi* M. Peragallo			R	
Navicula pupula Kützing var. *capitata* Hustedt		R		
Navicula pupula var. *rostrata* Hustedt			R	
Navicula radiosa Kützing		F	R	
Navicula radiosa var. *tenella* Brebisson		F		
Navicula pennata Schmidt var. *kinkerii* Pantocsek				R
Navicula peregrina (Ehrenberg) Kützing var		F		
Navicula gastrum Ehrenberg		F		
Navicula exigua (Gregory) O. Müller		R		
Navicula cf. *N. subtilissima* Cleve		R		
Navicula tuscula Ehrenberg		R		
Navicula amphibola Cleve		R		
Navicula marina Ralfs (pl. 7, fig. 13)			C	
Pinnularia borealis Ehrenberg		R		
Pinnularia major (Kützing) Cleve		F	R	
Pinnularia cf. *P. major* var. *subacuta* (Ehrenberg) Cleve				R
Pinnularia dactylus Ehrenberg		F		
Pinnularia cf. *P. viridis* (Nitzsch) Ehrenberg			R	
Pinnularia fasciata (Lagerstedt) Hustedt		R		
Amphora ovalis Kützing				R
Amphora ovalis var. *libyca* (Ehrenberg) Cleve		F		
Amphora affinis Kützing			F	
Cymbella cuspidata Kützing				R
Cymbella prostrata (Berkeley) Cleve (pl. 7, fig. 15)		R		
Cymbella ventricosa Kützing	C		F	R
Cymbella cymbiformis (Kützing) Brebisson		R		
Cymbella parva (W. Smith) Van Heurck	C	R		
Cymbella cistula (Hemprich) Kirchner		R	R	
Cymbella lanceolata (Ehrenberg) Kirchner			R	
Cymbella mexicana (Ehrenberg) Cleve (pl. 7, fig. 14)		F	F	
Gomphonema acuminatum Ehrenberg var. *turris* Ehrenberg		R		
Gomphonema augur Ehrenberg var. *gauteri* Van Heurck		R		
Gomphonema intricatum Kützing		R		
Gomphonema constrictum Ehrenberg		F		
Gomphonema scapha M. Schmidt		R		
Gomphoneis mamilla (Ehrenberg) Cleve		F		
Gomphoneis herculeana (Ehrenberg) Cleve		R	R	
Gomphoneis cf. *G. herculeana* var. *robusta* Grunow		R		
Gomphoneis elegans (Grunow) Cleve		R	R	
Epithemia argus (Ehrenberg) Kützing		F		
Epithemia zebra (Ehrenberg) Kützing				F
Epithemia zebra var. *saxonica* (Kützing) Grunow (pl. 7, fig. 3)		R	F	A
Epithemia zebra var. *porcellus* (Kützing) Grunow		F	R	
Epithemia turgida (Ehrenberg) Kützing	C	F	F	
Epithemia turgida var. *granulata* (Ehrenberg) Grunow	F			
Epithemia turgida var. *westermanni* (Ehrenberg) Grunow		F	F	
Epithemia sorex Kützing		R		
Rhopalodia gibba (Ehrenberg) Müller (pl. 7, fig. 4)		F		C
Rhopalodia gibba var. *ventricosa* (Ehrenberg) Grunow	F	F		C
Rhopalodia gibberula (Ehrenberg) Müller		F		
Hantzschia amphioxys (Ehrenberg) Grunow		F	F	
Nitzschia tryblionella Hantzsch var. *maxima* Grunow			F	
Nitzschia tryblionella var. *victoriae* Grunow		R		
Nitzschia etchegoinia Hanna and Grant (pl. 7, fig. 12)			C	
Nitzschia punctata (W. Smith) Grunow (pl. 7, fig. 11)		F		
Nitzschia granulata Grunow		R	C	F
Nitzschia cf. *N. denticula* Grunow		R		
Nitzschia scalaris (Ehrenberg) W. Smith			R	
Cymatopleura sp		R		
Surirella striatula Turpin			F	
Surirella utahensis Grunow (pl. 7, fig. 1)			F	
Campylodiscus echeneis Ehrenberg			F	
Campylodiscus clypeus Ehrenberg			R	

in these two collections is a slender form of *A. longinqua* that has slightly inflated whorls, also found in the lower *Amnicola* zone. The thick-shelled strongly inflated high-beaked form of *Gonidea coalingensis* (pl. 6, fig. 4) represented at locality 27 was not found at other horizons.

Most of the Tulare fossils are from the lower *Amnicola* zone, characterized by the abundance of Amnicolidae (*Fluminicola, Pyrgulopsis, Calipyrgula, Littoridina, Amnicola, Hydrobia,* and *Brannerillus*).

The fossils in the upper *Amnicola* zone, from which collections were made at only three localities, also occur in the lower *Amnicola* zone. *Pyrgulopsis, Calipyrgula, Hydrobia,* and *Brannerillus*, however, were not found in the upper zone, so far as these few collections go, whereas *Valvata, Fluminicola,* and *Littoridina* are more abundant in the upper zone, though represented at only one locality. The apparent differences between the two zones are probably due to habitat control or to insufficient collecting.

Amnicola-bearing beds at horizons above the upper *Amnicola* zone were seen at several places, but the only shells collected are from a locality on the east side of southern North Dome, where *Littorina mariana*, a small oyster referred to *Ostrea* cf. *O. vespertina sequens*, and molds of part of the body whorl of a small snail occur in sandstone about 1,200 feet above the base of the formation (locality 13). The small snail was identified in the field as *Amnicola;* the material collected is indeterminable but more probably represents *Fluminicola*. Small oysters were seen also on the west side of North Dome and on the west side of Middle Dome. At the latter locality, which was recorded by Arnold and Anderson,[21] they are accompanied by *Littorina*. The possible significance of these fossils is discussed under the heading "Environment suggested by fossils."

Diatoms were collected from the white clay at the base of the Tulare along the east side of North Dome and from the lower *Amnicola* zone at La Salida, on the east side of Middle Dome. This material was examined by K. E. Lohman, of the Geological Survey, who identified the species listed on pages 24–25. Some of the characteristic species are shown on plate 7. According to Lohman, the flora from locality 5, which yielded the largest number of species, represents fresh or slightly brackish water. Most of the species from locality 11 also represent fresh and brackish water, but the considerable number of marine species suggests deposition near tide level. The flora from locality 16 indicates brackish water.

PLIOCENE SERIES

CLASSIFICATION AND NOMENCLATURE

There is no general agreement in the classification and nomenclature of the Pliocene strata underlying the Tulare formation. F. M. Anderson[22] originally divided them into two units, the San Joaquin clays and the Etchegoin sands, but he also used the name Etchegoin in a group sense (Etchegoin beds) for both. Arnold and Anderson[23] divided this part of the section into two formations: Etchegoin formation and Jacalitos formation, the latter embracing part of the original Coalinga beds of F. M. Anderson. This division was based essentially on the overlap of Pliocene beds onto Cretaceous rocks in the White Creek syncline, in the Diablo Range northwest of Coalinga, and an attempt was made to draw the boundary between the two formations at a horizon corresponding to the base of the overlapping beds.[24] This overlap doubtless represents an important event in the geologic history of the region, but it is not yet known how successful the attempt was to use it as a basis for stratigraphic classification in more complete sections. In the work undertaken by Arnold and Anderson no attempt could be made to trace individual beds or thin zones throughout the Jacalitos Hills and Kreyenhagen Hills. The boundary on their map between Etchegoin and Jacalitos consequently was based on paleontologic data supplemented by the prevalence of blue sandstone in the Etchegoin formation and its absence in the Jacalitos formation throughout most of the area. This classification has the disadvantages of subdividing an essentially similar lithologic sequence on paleontologic grounds. Notable differences between Jacalitos and Etchegoin fossils are apparent, and detailed mapping may reveal lithologic features that could be used in mapping the beds containing these different faunas and perhaps in recognizing smaller divisions. However that may be, the current practice of the Geological Survey in the separation of Etchegoin and Jacalitos is left unchanged, as the Jacalitos formation is not exposed in the Kettleman Hills.

Mapping in the Kettleman Hills and work in the Kreyenhagen Hills show the desirability of recognizing as a separate unit the upper part of the Etchegoin formation of Arnold and Anderson. As this unit corresponds to F. M. Anderson's San Joaquin clay, that name has recently been revived.[25] As there is general agreement concerning the desirability of recognizing this unit and only minor differences of opinion concerning its limits, the name in the form San Joaquin formation is here adopted. There is no uniformity, however, in the nomenclature for the remainder of the Pliocene section. Nomland,[26] Barbat and Galloway,[27]

[21] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, pp. 147, 150, 1910.

[22] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci., 3d ser., vol. 2, pp. 178–181, 1905.

[23] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 75–79, 96–140.

[24] Idem, pp. 98, 114.

[25] Barbat, W. F., and Galloway, John, San Joaquin clay, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 476–499, 2 figs., 1934. See also Gester, G. C., and Galloway, John, Geology of the Kettleman Hills oil field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 1171–1173, 1933.

[26] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geology, Bull., vol. 10, pp. 195–197, 1917.

[27] Op. cit.

and Gester and Galloway [28] extended the name Etchegoin to embrace the Jacalitos formation—that is, they adopted F. M. Anderson's revised nomenclature,[29] with the exception that Etchegoin was not used in a group sense. Reed [30] raised Etchegoin to group rank and extended the name Jacalitos to include Arnold and Anderson's Etchegoin minus the San Joaquin. As the usage of the same name for a group and a formation within the group is confusing, the simplest solution so far as the Kettleman Hills are concerned would be to raise Etchegoin to group rank and to propose a new name for the formation underlying the San Joaquin. This action would result in the virtual elimination of the well-known name Etchegoin in this region, and even if the new unit were adopted by other geologists its base would have to be found elsewhere. In view of the conflicting opinions and the undesirable features of other schemes, a compromise involving the restriction of the name Etchegoin to Arnold and Anderson's Etchegoin minus the San Joaquin is adopted—a solution independently reached by Goudkoff.[31] This restriction is unfortunate inasmuch as Etchegoin has been widely used in the broader sense, but it has the advantage of retaining both Etchegoin and Jacalitos as formation names. The different classifications proposed and the one here adopted are diagrammatically shown below.

[28] Op. cit.

[29] Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 28-31, 1908.

[30] Reed, R. D., Geology of California, pp. 235-236, Tulsa, Am. Assoc. Petroleum Geologists, 1933.

[31] Goudkoff, P. P., Subsurface stratigraphy of Kettleman Hills oil field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 438-439, 1934.

Classification and nomenclature of Pliocene formations underlying Tulare formation in Coalinga district

F. M. Anderson, 1905, 1908		Arnold and R. Anderson, 1910	Reed, 1933		Gester and Galloway, 1933; Barbat and Galloway, 1934	Goudkoff, 1934	This report
Etchegoin beds.	San Joaquin clays.	Etchegoin formation.	Etchegoin group.¹	San Joaquin clay.	San Joaquin clay.	San Joaquin clay.	San Joaquin formation.
	Etchegoin sands.			Jacalitos formation.	Etchegoin sand.	Etchegoin formation.	Etchegoin formation.
		Jacalitos formation.				Jacalitos formation.	Jacalitos formation.

¹ The Reef Ridge shale, which seems to be Miocene, was also included in the Etchegoin group.

SAN JOAQUIN FORMATION

The name San Joaquin formation is adopted for the greater part of the apparently nonmarine and marine strata underlying the nonmarine Tulare formation. No type locality was designated in the original description of the San Joaquin clays, but the Kettleman Hills were mentioned, and the section in sec. 23, T. 22 S., R. 18 E., on the east side of North Dome has been recently suggested as the type section.[32] The section exposed along Arroyo Hondo on the east side of North Dome may be a more satisfactory standard section.

The preponderance of fine-grained rocks—fine-grained silty sandstone, silt, and clay—is the most apparent lithologic feature of the San Joaquin formation. Weathered outcrops give the impression that clay is the principal constituent, but fresh exposures show that much of the material is silt and silty sandstone and that a large part of the clay is silty. Some of these fine-grained rocks appear to be nonmarine; at least marine fossils have not been found in many of them, and the remains of land plants and fresh-water shells have been found in some. Beds of sand or sandstone and of gravel or conglomerate are interbedded with the fine-grained rocks. Many of these coarse-grained beds contain marine fossils, and a few contain nonmarine fossils. Thin lenses of limestone occur at several horizons in the upper half of the formation. Fresh tuff is rare in the San Joaquin formation, but volcanic material, or material regarded as an alteration product of volcanic glass, makes up a considerable part of some beds. On account of the lack of a prevailing type of lithology the original name San Joaquin clays is changed to San Joaquin formation.

Many of the marine beds have characteristic suites of fossils, apparently representing different animal communities, that can be recognized in the field. The zonal nomenclature introduced by Arnold and Anderson for some of these marine beds is adopted in an expanded and modified form. The largest marine faunas are generally found in sand, sandstone, and conglomerate. Such beds are distinctive not only on account of their fossils but also on account of their lithology, for they lie between rocks that are for the most part fine-grained. As most of them show more or less change in lithology along the strike and as their recognition depends principally on the fossils, a zonal nomenclature appears preferable to member names. The only member name proposed is the one for the conglomerate and sandstone at the base of the formation—the Cascajo conglomerate member.

[32] Barbat, W. F., and Galloway, John, op. cit., pp. 478-480.

The base of the San Joaquin formation is drawn at the base of the Cascajo conglomerate member. As interpreted in this report, this member is recognized in the three anticlines of the Kettleman Hills. It is probably the equivalent of the conglomerate that rests unconformably on Miocene shale near McKittrick, farther south on the west border of the San Joaquin Valley. On the advance edition of the geologic map of the Kettleman Hills, issued in 1934, the base of the San Joaquin formation was placed at the base of the *Littorina* zone, which is now assigned to the Etchegoin formation. In North Dome the *Littorina* zone is about 100 feet below the Cascajo member. The *Littorina* zone embraces a layer of oolite and the earliest fresh-water fossils. The oolite is the most reliable stratigraphic datum plane in North Dome, but no oolite or fresh-water fossils have been found at this horizon in Middle Dome or South Dome. The base of the Cascajo conglomerate is considered a more satisfactory horizon for a major stratigraphic division, as it is believed to be recognizable over a larger area and is apparently the equivalent of conglomerate that elsewhere marks a transgression following deformation in the adjoining Coast Ranges.

Barbat and Galloway[33] placed the boundary between the San Joaquin and Etchegoin formations at the base of a lenticular bluish-gray sandstone that rests on the upper *Mulinia* zone (designated the upper *Pseudocardium* zone in the present report). The equivalent of the upper *Pseudocardium* zone of North Dome has not been certainly recognized, however, in Middle and South Domes. Evidence indicating discontinuity is apparent at the base of the sandstone that at places lies on the upper *Pseudocardium* zone, as at the base of other sandstones and conglomerates.

The San Joaquin formation is thickest on the west flank of southern North Dome and northern Middle Dome and thins eastward across the hills. The approximate thickness of the principal faunal and lithologic units and of the entire formation is shown in the following table.

[33] Barbat, W. F., and Galloway, John, op. cit., pp. 480 (table), 482.

Approximate thickness, in feet, of San Joaquin formation

	Stratigraphic unit	West flank of Kettleman Hills			East flank of Kettleman Hills		
		North Dome	Middle Dome	South Dome	North Dome	Middle Dome	South Dome
Upper part.	Upper *Mya* zone.	10	10	10	10	10	10
	Strata between upper *Mya* zone and *Acila* zone.	375			350		
	Acila zone.	30	[1] 625	[1] 500	30	[1] 500	[1] 425
	Strata between *Acila* zone and *Pecten* zone.	200			200		
	Pecten zone.	50	50	50	50	50	50
Lower part.	Strata between *Pecten* zone and *Neverita* zone.	700	625	575	550	450	425
	Neverita zone.	50	50	[2] 20	50	50	[2] 20
	Strata between *Neverita* zone and Cascajo conglomerate member.	250	425	250	200	200	200
	Cascajo conglomerate member.	50	50	50	50	50	50
	Total approximate thickness.	1, 700	1, 800	1, 500	1, 500	1, 300	1, 200

[1] The *Acila* zone is not represented in Middle Dome and South Dome.
[2] The identification of the *Neverita* zone in South Dome is uncertain.

The generalized stratigraphic sections on plate 3 represent graphically the character of the San Joaquin formation in the three anticlines. These sections show the stratigraphic position and map symbol of the mapped faunal and lithologic units, including minor units not shown in the preceding table. The mapped lines represent the base of the units, but some of the units are so thin that the width of the line exceeds the width of outcrop of the unit.

The *Pecten* zone is the most distinctive and most widespread faunal unit in the San Joaquin formation. In order to show the base of the *Pecten* zone more clearly, the formation is divided into a lower part and an upper part at the base of this zone, and the two parts are shown by a separate pattern on the geologic map (pl. 3). This subdivision also corresponds to a major faunal subdivision based on the sand dollars or echinoids. On the greater part of the east flank of Middle Dome, where the *Pecten* zone is not well developed, the division is made at the base of the *Trachycardium* zone, which might be considered the upper part of the *Pecten* zone.

UPPER *MYA* ZONE

STRATIGRAPHY AND LITHOLOGY

The upper *Mya* zone, first briefly described by Arnold,[34] constitutes the uppermost part of the San Joaquin formation. It has an observed thickness of 6 to 7 feet. A fossiliferous sand, in which *Mya* generally is the most abundant fossil, is the most conspicuous

[34] Arnold, Ralph, Paleontology of the Coalinga district, Fresno and Kings Counties, Calif.: U. S. Geol. Survey Bull. 396, p. 42, 1909 [1910].

part of the zone. At places the sand is overlain by silty clay that is nonfossiliferous or contains small oysters regarded as dwarfs. The silty clay was observed only in fresh exposures and may not be widespread. A thin limestone that underlies the sand at some localities is included in the zone. In the absence of exposures the upper *Mya* zone was mapped by following the narrow band of fossils and the narrow band of thin sandy soil.

Arnold and Anderson [35] defined the upper *Mya* zone as embracing a thickness of 300 to 400 feet of sand and clay in the Kreyenhagen Hills and a thickness of 200 to 300 feet in the Kettleman Hills. As both areas were mentioned and no type region was designated, it is suggested that Las Alturas, on the west side of nothern Middle Dome, be considered the type region of the upper *Mya* zone as here restricted. The term upper *Mya* zone is restricted to the uppermost part of the original zone. Geologists working in this region have informally made this restriction in view of the absence of *Mya* in other parts of the original upper *Mya* zone, at least in the Kettleman Hills. The upper *Mya* zone as here defined is separated from the next underlying *Mya*-bearing zone by beds whose minimum thickness is 875 feet. The lower *Mya* zone of Arnold [36] probably corresponds to the *Littorina* zone of the Etchegoin formation. So many *Mya*-bearing beds have been recognized, however, in the lower part of the San Joaquin and in the upper part of the Etchegoin that the term lower *Mya* zone is inappropriate. Nevertheless, the retention of the name upper *Mya* zone for the zone at the top of the San Joaquin is appropriate, as it is the highest *Mya* zone.

East flank of Kettleman Hills.—The upper *Mya* zone is exposed at intervals on the east flank of North Dome and was recognized at other places by its fossils. The following section was measured in an arroyo 500 feet west of Arroyo Bifido. At this locality the fossils are poorly preserved.

Section of upper Mya zone of San Joaquin formation in arroyo 500 feet west of Arroyo Bifido, sec. 35, T. 21 S., R. 17 E.

	Ft.	in.
Tulare formation:		
Dirty white silty clay.		
San Joaquin formation, upper *Mya* zone:		
Olive-gray silty clay, fragments of dwarf oysters and barnacles		5
Fossiliferous sand:		
Fine-grained dirty sand containing many molds of *Mya;* upper surface minutely irregular and iron-strained	3	
Muddy sand; many *Mytilus*		3
Fine-grained sand; many molds of *Mya*		4–5
Fine-grained dirty iron-stained sand containing mudstone pellets at base; molds of clams (base of upper *Mya* zone). Underlain by olive-gray silty clay	2	
Thickness of upper *Mya* zone	6	1

[35] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 119, 121, 1910.
[36] Idem, pp. 121, 123. See also Bull. 396, p. 42.

The following section is exposed on Arroyo Robador:

Section of upper Mya zone of San Joaquin formation on Arroyo Robador, sec. 25, T. 22 S., R. 19 E.

	Ft.	in.
Tulare formation:		
Dirty white clay containing brackish-water diatoms (locality 11).		
San Joaquin formation, upper *Mya* zone:		
Broken dwarf oysters in matrix of olive-green silty clay. Contact with overlying bed sharply defined and marked by gypsiferous layer	6	
Shells and shell fragments in matrix of clean gray sand. Most abundant shells represent *Mya*, mostly single valves lying in various attitudes. In upper half of bed small and medium-sized single-valved *Anadara*, *Calyptraea*, and a few small fragments of *Mytilus*. Grades downward into nonfossiliferous gray sand	1	7
Thickness of upper *Mya* zone	7	7

On a tributary of Arroyo Estrecho near the north end of Los Viejos, at the south end of North Dome, the exposed part of the zone, representing a thickness of 2½ feet, consists of a mass of shells and shell fragments in a matrix of clean gray sand (locality 35).

Along the east side of Middle Dome and of the saddle between Middle and South Domes the zone was traced by following the narrow band of fossils, the most abundant of which are fragments of *Mya* and *Macoma*.

West flank of Kettleman Hills.—On Arroyo Conchoso and farther south a hard, dirty, white, sandy, limestone 3 to 8 inches thick immediately underlies the fossiliferous sand and is included in the upper *Mya* zone. At places the limestone contains molds of *Mya*. The following section was measured on Arroyo Conchoso, where the clay containing dwarf oysters makes up the bulk of the zone.

Section of upper Mya zone of San Joaquin formation on Arroyo Conchoso, sec. 30, T. 22 S., R. 18 E.

[Measured by G. F. Taylor]

	Ft.	in.
Tulare formation:		
Grayish-brown clay, stained yellowish, upper part sandy (see section, p. 20).		
San Joaquin formation, upper *Mya* zone:		
Dark gray clay; many dwarf oysters	6	
Yellowish-gray sand	1	
Limestone containing molds of *Mya*		3
Thickness of upper *Mya* zone	7	3

The limestone underlying the fossiliferous sand crops out at places along the west side of Middle Dome. It is generally less than a foot thick but has a maximum thickness of 2 feet. In this region the limestone contains indeterminable molds of broken shells. The overlying sand is very fossiliferous in northern Middle Dome and is exposed at many localities along the crest and west slope of Las Alturas (localities 38–43).

At the north end of South Dome *Littorina* is particularly abundant in the upper *Mya* zone (localities 44, 45). A few float fossils, principally dwarf oysters, were observed on the soil-covered eastern slope of Las Colinas. Farther south no indication of the zone was found, with the exception of float dwarf oysters in the northeastern part of sec. 9, T. 25 S., R. 19 E. (locality 46).

FOSSILS

The fossils collected from the upper *Mya* zone are listed in the following table, and the abundant and characteristic species are shown on plates 8 and 9.

Fossils from upper Mya zone of San Joaquin formation

[Identifications by W. P. Woodring unless otherwise stated. F, Fragments; P, paired valves]

Species	Localities																	
	East flank of Kettleman Hills								West flank of Kettleman Hills									
	North Dome								North Dome	Middle Dome						South Dome		
	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
Byrozoön (identification by R. S. Bassler):																		
Electra monostachys Busk	X																	
Gastropods:																		
Littorina mariana Arnold (pl. 8, figs. 1-6)							F				X	X	X	X	X	X	X	
Goniobasis cf. *G. kettlemanensis* Arnold												F						
Calyptraea cf. *C. inornata* (Gabb)		X		X			X					X			X			
Calyptraea cf. *C. filosa* (Gabb) (pl. 8, fig. 7)												X						
Nucella etchegoinensis (Arnold)												F	X					
Pelecypods:																		
Anadara trilineata (Conrad) of Arnold		X	X				F					X			X			
Mytilus cf. *M. edulis* Linné (pl. 8, fig. 8)							X					X						
Ostrea vespertina sequens Arnold (pl. 8, figs. 10-14)	X				X				X	X	X		X		X			
Ostrea cf. *O. vespertina sequens* Arnold (probably dwarfs of preceding form)																		X
Macoma affinis Nomland (pl. 9, figs. 1-3)							P					X	P		P			
Saxidomus nuttalli latus Stewart, n. var. (pl. 8, fig 15)		X	X	X								P	?		?			
Transennella cf. *T. tantilla* (Gould)		X					P											
Mya cf. *M. dickersoni* Clark (pl. 9, figs. 4-9)		X	X	X			P				?F	X	P	P	F			
Solen perrini Clark (pl. 8, fig. 9)							X	P				X	X	?F	X			
Barnacles:																		
Balanus hesperius Pilsbry, var.		X					X											
Mammal (identification by C. L. Gazin): Horse-tooth fragment						X												

The fauna of the upper *Mya* zone embraces only a few species. It consists of marine forms, but the most abundant species represent genera that thrive in brackish water (*Littorina*, *Ostrea*, *Macoma*, *Mya*). Fragmentary remains of a fresh-water snail (*Goniobasis*) and of a horse tooth may have weathered out of the Tulare formation. Burrowing pelecypods (*Macoma*, *Saxidomus*, *Mya*, *Solen*) and attached pelecypods (*Mytilus*, *Ostrea*) are the most widespread fossils. *Calyptraea* is the only widespread gastropod, but *Littorina* is abundant on the west side of northern South Dome.

The species in the upper *Mya* zone were found at other horizons in the Kettleman Hills. *Mytilus* cf. *M. edulis* is more common in the upper *Mya* zone than at other horizons and was not observed in beds more than 200 feet below the upper *Mya* zone. The association of *Mya* cf. *M. dickersoni*, *Ostrea lurida sequens*, *Macoma affinis*, *Saxidomus nuttalli latus*, and *Calyptraea* cf. *C. inornata*, and the absence of species associated with these at other horizons are characteristic of the upper *Mya* zone. Strata in Arnold's upper *Mya* zone in the Kreyenhagen Hills have the same faunal association. These beds may represent the chronologic equivalent of the upper *Mya* zone of the Kettleman Hills, or they may represent the same environmental conditions at an earlier or later date. It is improbable that the *Mya* zone underlying the Tulare formation north of Anticline Ridge is the equivalent of the upper *Mya* zone in the Kettleman Hills, for *Glycymeris* is recorded in this *Mya* zone north of Anticline Ridge, and *Pseudocardium* occurs immediately below it.[37]

STRATA BETWEEN UPPER *MYA* ZONE AND *ACILA* ZONE

STRATIGRAPHY AND LITHOLOGY

In North Dome the strata between the upper *Mya* and the *Acila* zones embrace a thickness of 350 to 375 feet. These beds consist principally of sand, silty sand, and silty clay. A few thin beds of hard sandstone and hard limestone are conspicuous. The *Acila* zone was not recognized in Middle Dome and South Dome. The strata in these two anticlines corresponding to those between the upper *Mya* and *Acila* zones in North Dome are similar to North Dome strata in general features. On the west side of Middle Dome and South Dome, however, they include a considerable thickness of conglomerate.

Near the north end of North Dome sand dollars were found in silty sand about 115 feet below the upper *Mya* zone on both flanks of the anticline (localities 49, 50). This is the highest horizon at which sand dollars were observed in the Kettleman Hills. A soft gray tuffaceous sandstone about 30 feet above the sand-dollar-bearing sand at locality 49 was examined by M. N. Bramlette, who found that it contains some fresh glass, abundant hypersthene and andesine, and some augite and hornblende.

[37] Nomland, J. O., Relation of the invertebrate to the vertebrate faunal zones of the Jacalitos and Etchegoin formations in the north Coalinga region, Calif.: California Univ., Dept. Geology, Bull., vol. 9, pp. 83, 85 (table), 1916.

In northern North Dome a hard ferruginous sandstone 2 to 5 feet thick and containing small oysters lies 120 to 150 feet below the upper *Mya* zone. (See fig. 2.) It is the only hard sandstone in this part of the section. The sandstone and oysters are iron-stained, and field geologists have designated the sandstone the "brown oyster zone." As shown on plate 3, oyster-bearing sandstones were observed in this part of the section at scattered localities on both flanks of North Dome and Middle Dome. They are evidently at different horizons in different areas. On the west flank of northern Middle Dome, near the crest of Las Alturas, the sandstones are thicker and more numerous than elsewhere. The lowest sandstone in this region is about 175 feet below the upper *Mya* zone. The following section was measured in a ravine on the east slope of Las Alturas.

Section of oyster-bearing sandstones in upper part of San Joaquin formation on slope of Las Alturas, 2,000 feet southeast of El Bulto, sec. 14, T. 23 S., R. 18 E.

	Feet
Ledge-forming ferruginous sandstone; contains fewer oysters than underlying sandstone and a few small pebbles	2½
Unexposed, except 2 feet of thin-bedded siltstone at top	50
Main ledge-forming sandstone is a mass of small oysters in a matrix of coarse-grained ferruginous sandstone and a few pebbles less than half an inch long, which consist principally of red and black chert and some siliceous shale. Sandstone somewhat cross-bedded, grades downward into cross-bedded barren sandstone (locality 54)	20

Another section measured on a spur 400 feet north of the ravine in which the preceding section was measured is as follows:

Section of oyster-bearing sandstones in upper part of San Joaquin formation on spur 400 feet north of preceding section

	Feet
Ledge-forming ferruginous sandstone containing small oysters. Apparently corresponds to upper part of main ledge-forming sandstone of preceding section	4½
Unexposed apparently soft sandstone	12½
Ledge-forming ferruginous sandstone containing small oysters. Probably corresponds to basal part of main ledge-forming sandstone of preceding section	2½
Unexposed, except a layer of hard ferruginous sandstone at middle. Probably mostly soft sandstone	7½
Soft gray sandstone containing sand-filled borings. A layer of coarse-grained and darker sandstone at top contains a few small oysters and a few small pebbles. A hard ferruginous layer lies 3 feet above base. Only parts of intervening soft sandstone are exposed. Underlain by thin bed of buff limestone	10

A thin bed of buff limestone, apparently corresponding to the limestone underlying the lowest unit of the preceding section, is exposed at intervals along most of the west flank of Middle Dome.

Oyster-bearing sandstone was not found on the plunging crest of northern North Dome. In this area a 6-inch buff limestone crops out on the flanks 25 feet below the projected stratigraphic position of the oyster-bearing sandstone. This limestone corresponds stratigraphically to a thin limestone exposed at places on La Ceja (fig. 2, column 3). Small sand dollars were collected from a soft sandstone 60 feet below the oyster-bearing sandstone on the east flank of northern North Dome (locality 56).

FOSSILS

Fossils collected from strata between the upper *Mya* and the *Acila* zones are listed in the following table. The oysters and sand dollars are illustrated on plate 10.

Fossils from strata in upper part of San Joaquin formation between upper Mya zone and Acila zone

[Identifications by W. P. Woodring unless otherwise stated. F, Fragments]

Species	Localities									
	East flank of Kettleman Hills					West flank of Kettleman Hills				
	North Dome				Middle Dome	North Dome		Middle Dome		
	49	51	52	56	48	47	50	53	54	55
Echinoids (identifications by Ralph Stewart):										
Dendraster coalingaensis Twitchell, small variety with slightly raised petals and deep ambulacral furrows (pl. 10, figs. 6–9)	X		?F				X		?F	
Dendraster coalingaensis Twitchell, small variety with flat petals (pl. 10, figs. 10–12)				X						
Bryozoön (identification by R. S. Bassler): *Membranipora* sp			X							
Pelecypods:										
Anadara trilineata (Conrad) of Arnold						X				
Mytilus cf. *M. edulis* Linné										F
Ostrea vespertina sequens Arnold (pl. 10, figs. 1–5)		X	X						X	X
Ostrea cf. *O. vespertina sequens* Arnold (probably dwarfs of preceding form)					X		X	X		
Solen perrini Clark?										F
Barnacle: Unidentified fragments of small barnacle									X	

The small oysters in the oyster-bearing sandstones are the most abundant fossils in this part of the section. They are smaller and are generally more elongate and less strongly plicate than the oysters in the sand of the upper *Mya* zone. The small variety of *Dendraster coalingaensis* that has slightly raised petals is also found in the *Acila* zone. The smaller variety that has flat petals occurs also in the *Neverita* zone and in the Cascajo conglomerate member.

ACILA ZONE

STRATIGRAPHY AND LITHOLOGY

The *Acila* zone is about halfway between the top of the San Joaquin formation and the *Pecten* zone, 300 to 400 feet below the top of the San Joaquin and 200 to 300 feet above the *Pecten* zone. It consists of fossiliferous brownish or greenish muddy sand or silt interbedded with clay. The sand and clay appear to vary in thickness and in stratigraphic position relative to each other. The observed thickness of strata assigned to the zone is about 30 feet. Outcrops of the zone are inconspicuous, and the zone generally is recognizable only by the presence of fossils on weathered or soil-covered outcrops. With few exceptions the solid lines showing the outcrop of the zone on the geologic map (pl. 3) indicate the presence of *Acila* zone fossils at the surface.

An artificial cut along the Avenal-Lemoore road on the west flank of North Dome is selected as the type locality of the *Acila* zone. (See section, pp. 32–33.) *Anadara* is more abundant in the zone than *Acila*. The zone is called the *Acila* zone, however, as *Acila* was not found in the San Joaquin formation below this zone and is known from only two localities above it, whereas *Anadara* is found at many horizons in the San Joaquin.

The *Acila* zone is known in North Dome but was not recognized in Middle Dome or South Dome. This lateral change occurs roughly in the saddle between North and Middle Domes and is comparable to the lateral change in the *Pecten* zone in about the same area.

East flank of North Dome.—The following section was measured in a pit excavated for drilling mud near Arroyo Hondo.

Section of strata in upper part of San Joaquin formation, including Acila zone, in mud pit near Arroyo Hondo, SW¼ sec. 5, T. 22 S., R. 18 E. (locality 58)

	Feet
Strata overlying *Acila* zone:	
Thinly laminated clay and sand streaked gray and blue. Four to five feet above base are 1-inch sandstone layers, the base of each layer marking a discontinuity. Contact at base abrupt. Top not exposed	20+
Acila zone:	
Brownish-gray sand with yellowish-brown lenticles less than 1 inch thick. Large *Anadara* and a few scattered pebbles in lower 18 inches. Clay partings near top and a few *Anadara* near top in a 3-inch sand layer separated from underlying clay parting by discontinuity. Discontinuity at base; contact abrupt; fragments of clay above contact; 1-inch sand-filled boreholes in underlying clay	14
Blue clay, excavated for drilling mud. Contact at base not observed	12±
Muddy sand containing some pebbles, *Acila*, small *Anadara*, *Calyptraea*, and other fossils (locality 58). Contact at base abrupt (?)	2
Strata below *Acila* zone:	
Greenish-gray, iron-stained, fine-grained sandstone, irregular clay partings; contains sand dollars. (The sand dollars are listed with the *Acila* zone fossils.) Contact at base abrupt and irregular, sand-filled boreholes in underlying silt. The numerous holes obscure the contact, but it represents a discontinuity	9
Laminated bluish-green-gray and brown silt; 2-inch limy lens 3 feet below top; base not exposed	12+

The southernmost locality of the *Acila-Anadara* association is on a low ridge on the west side of Los Viejos, about 1½ miles south of Arroyo Estrecho. A bed containing *Anadara*, exposed just south of Arroyo Culebrino, is in the approximate stratigraphic position of the *Acila* zone and is correlated with it. Farther south the zone or its equivalents were not recognized.

West flank of North Dome.—The section below was measured at the type locality of the *Acila* zone on the Avenal-Lemoore road.

Section of strata in upper part of San Joaquin formation, including Acila zone, in cut on Avenal-Lemoore road, sec. 10, T. 22 S., R. 17 E.

	Ft.	in.
Strata overlying *Acila* zone:		
9. Poorly exposed gray sand. Contact at base abrupt. Top not exposed	6+	
8. More or less laminated gray clay. Contact at base abrupt	3½	
Acila zone:		
7. Greenish-gray muddy sand. One fragment of *Anadara* observed. Chert pebbles as much as half an inch long near top. Contact at base apparently abrupt; unworn fragments of clay in basal part	11	
6. Laminated sandy clay. Contact at base abrupt, obscured by gypsum crystals	14	
5. Grayish-green muddy sand. Contact at base abrupt; sand-filled boreholes in underlying clay:		
c. Abundant and somewhat scattered *Acila* and small *Anadara*; few *Calyptraea*	3	9
b. Nonfossiliferous	1	
a. Large *Anadara*		3

Section of strata in upper part of San Joaquin formation, including Acila zone, in cut on Avenal-Lemoore road, sec. 10, T. 22 S., R. 17 E.—Continued

Strata underlying *Acila* zone:	*Ft.*	*in.*
4. Laminated blue clay, weathering light gray, and some lenses of sand		6
3. Gray sand similar to unit 2, but containing more clay layers	15	
2. Irregularly bedded, fine-grained gray sand containing small clay pellets. Contact at base abrupt; sand-filled borings in underlying mud	17	
1. Irregularly bedded light-gray sand; iron concretions and thin mud layers near and at top. Base not exposed. (Probably corresponds to sand containing sand dollars in other sections.)	12+	

In this section a layer containing large *Anadara* underlies a layer containing small *Anadara* and *Acila*, and the layers are not separated by a discontinuity, whereas in the section measured on the east flank of the anticline the stratigraphic relations are reversed and the layers are separated by a discontinuity.

The *Acila-Anadara* association was found on a knoll on the steep east slope of Las Alturas, just east of El Paso, the southernmost locality at which the *Acila* zone was recognized on the west flank of the Kettleman Hills. It is quite possible that the zone may extend farther southward, for its stratigraphic position would place it on the steep eastern slope of Las Alturas, where exposures are rare. In La Zanja, farther south on the west flank of Middle Dome, conglomerates and an occasional limestone layer occur in this part of the section, and it is reasonably certain that the *Acila* zone is not present as a fossil zone.

FOSSILS

Fossils from the *Acila* zone are listed in the following table, and some of the species are illustrated on plates 11, 39, 41, 45, and 46.

Fossils from Acila zone of San Joaquin formation and underlying sand

[Identifications by Ralph Stewart. F, fragments; P, paired valves; S, small specimens; W, worn specimens]

Species	Localities													
	North Dome													
	East flank								West flank					
	57	57a	58	59	60	61	62	63	64a	64	65	66	67	68
Echinoids:														
Dendraster coalingaensis Twitchell					cf.									
Dendraster coalingaensis Twitchell, small variety with slightly raised petals and deep ambulacral furrows (pl. 45, figs. 3, 4)					[1] X							cf.		
Dendraster (Merriamaster) arnoldi Twitchell [2] (pl. 39, fig. 5; pl. 41, fig. 3; pl. 46, fig. 9, cf.).	X		X	X	X						X			
Gastropods:														
Turcica caffea brevis Stewart, n. var. (pl. 11, figs. 1, 6)					X			X				X		X
Calliostoma coalingense Arnold (pl. 11, figs. 2, 3)	X	X	cf.				X	X				X		X
Calliostoma kerri Arnold		X	X											X
Bittium sp					X									
Calyptraea cf. *C. inornata* (Gabb) (pl. 11, fig. 7)	X		X				X		X	X		X	X	X
Calyptraea cf. *C. filosa* (Gabb)			X				X							
Crepidula sp			X											
Crepidula princeps Conrad		W												
Neverita cf. *N. reclusiana* (Deshayes)									X			X		
Lunatia cf. *L. lewisii* (Gould)				X										
"*Nassa*" cf. "*N.*" *waldorfensis* Arnold (pl. 39, fig. 4)							X							
"*Nassa*" cf. "*N.*" *coalingensis* Arnold			X											
Siphonalia cf. *S. humerosa* (Gabb) (pl. 11, fig. 9)				X										
Mitrella cf. *M. gausapata* (Gould) (pl. 11, fig. 5)						X								
"*Pleurotoma*" cf. "*P.*" *coalingensis* Arnold (pl. 11, fig. 4)			X											
Pelecypods:														
Acila castrensis (Hinds) (pl. 11, figs. 11–17)	X		X		X		X		X		X	X	X	
Anadara trilineata (Conrad) of Arnold (pl. 11, figs. 10, 19–24)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mytilus coalingensis Arnold					P					F	X	F		F
Pecten coalingaensis Arnold [3]					X									
Chlamys cf. *C. islandicus* (Müller)					F							F	F	F
Ostrea sp				X								S		S
Macoma sp			?											
Semele cf. *S. rubropicta* Dall (pl. 11, fig. 18)			X											
Schizothaerus cf. *S. nuttallii* (Conrad) (pl. 11, fig. 25)										X				
Saxidomus sp					P									
Compsomyax cf. *C. subdiaphana* (Carpenter) (pl. 11, fig. 8)			X											
Cryptomya cf. *C. quadrata* Arnold (pl. 39, fig. 2)					X									X
Solen sp			F											
Panope cf. *P. generosa* Gould			P											
Zirfaea gabbi (Tryon) var												F		
Barnacle: *Balanus* sp					X									
Fish: Shark teeth					X		X							

[1] About 300 feet southeast of locality 60, from a 2-foot gray sand just above the layer of silt containing *Acila* and evidently part of the *Acila* zone.
[2] From sand a few feet below *Acila* zone.
[3] Probably weathered out of older alluvium.

Anadara and *Acila* are the most abundant fossils, and the association of these two genera is a characteristic feature of this zone. A specimen of *Acila* was found on the steep western slope of La Ceja, on the west side of Arroyo Largo. This specimen may have come from the upper *Mya* zone or more probably from strata about 25 feet lower, in which a medium-sized *Anadara* was found on the east side of Arroyo Largo. A more satisfactory occurrence of *Acila* above the *Acila* zone was found by Dr. Max Birkhauser. This locality is farther southeast on the east flank of North Dome on the south branch of Arroyo Torcido (NW¼SW¼NE¼ sec. 6, T.

22 S., R. 18 E.), where *Acila* and *Anadara* occur in fine-grained sand or sandy silt about 30 feet below the upper *Mya* zone. Aside from these two localities, *Acila* was not found in the San Joaquin formation outside the *Acila* zone.

Calyptraea is the only abundant gastropod. The other fossils are rare. The fragments of *Chlamys* are the highest stratigraphically and therefore the last of the Pectinidae yet found in the Kettleman Hills.

Most of the sand dollars included in the list of *Acila* zone fossils occur in sand a few feet below the *Acila* zone. (See section, p. 32.) In the sand underlying the *Acila* zone is the highest horizon at which *Merriamaster* was found (pl. 39, fig. 5; pl. 41, fig. 3; pl. 46, fig. 9). The variety of *Dendraster coalingaensis* with slightly raised petals (pl. 45, figs. 3, 4) that occurs in the *Acila* zone itself also was found in strata about 250 feet higher stratigraphically.

STRATA BETWEEN *ACILA* ZONE AND *PECTEN* ZONE

In North Dome the strata between the *Acila* and the *Pecten* zones are about 200 feet thick. They consist chiefly of muddy silt and sand. In Middle and South Domes, where the *Acila* zone was not recognized, beds of conglomerate occur in the corresponding part of the section. These beds of conglomerate are more numerous on the west flank of the Kettleman Hills than on the east.

On the east flank of North and Middle Domes and on the west flank of North Dome are marine fossils in sand at a horizon generally 125 to 150 feet above the base of the *Pecten* zone, about halfway between the *Acila* zone and the *Pecten* zone. The faunal zone is designated the *Trachycardium* zone. On account of the similarity of its fauna to that of the *Pecten* zone it is described with the *Pecten* zone.

A conspicuous white fresh pumice tuff crops out on the north bank of Arroyo Doblegado, 100 feet west of the east line of sec. 16, T. 22 S., R. 18 E., at a horizon about 125 feet above the base of the *Pecten* zone. The tuff is in the form of a lens that has a maximum thickness of 10 feet. It overlies cross-bedded bluish-gray sandstone, the uppermost part of which has pellets and stringers of tuff, and is overlain by a 2-foot layer of cross-bedded tuff and bluish-gray sandstone in thin stringers. The tuff consists of lumps of pumiceous glass that have a diameter of 2 to 5 millimeters. The index of refraction of the glass, as determined by M. N. Bramlette, is 1.50. A partial chemical analysis is given below.

Partial chemical analysis of pumice tuff from upper part of San Joaquin formation

[R. C. Wells, analyst]

	Percent
SiO_2	64.2
CaO	1.9
K_2O	2.4
Na_2O	3.0

C. S. Ross comments on the analysis as follows:

> The analysis shows that in the norm the plagioclase feldspar would be sodic, near oligoclase in composition, and would exceed the potash feldspar orthoclase. There would also be a considerable proportion of normative quartz. A rock of this composition would be a dacite, a type of rock that commonly forms pumice tuff.

It is not known whether similar tuff occurs elsewhere at the same horizon.

On the west flank of southern Middle Dome worn fragments of *Aequipecten*, *Pseudocardium?*, *Trachycardium?*, *Mya*, and horse-tooth fragments were found in conglomerate at locality 136. On an assumption of an average dip of 20° this conglomerate is about 400 feet above the horizon regarded as the base of the *Pecten* zone in this region and about 250 feet below the upper *Mya* zone, or about in the stratigraphic position of the *Acila* zone. Elsewhere *Pseudocardium* occurs at much lower horizons; and *Aequipecten* and *Trachycardium* were not observed above the *Trachycardium* zone. The worn condition of these fossils leaves little doubt that they were transported into the gravel as fossils or as dead shells. According to available information, it seems more likely that they were derived as fossils from earlier strata than that they are worn fragments of shells that lived in this region when the gravel was deposited. If they were transported as fossils, they were presumably derived from strata cropping out west of the Kettleman Hills.

PECTEN ZONE AND *TRACHYCARDIUM* ZONE

STRATIGRAPHY AND LITHOLOGY

The *Pecten* zone is about 200 feet below the *Acila* zone and from 425 to 625 feet below the upper *Mya* zone. As typically developed it consists of sand and silty sand that has an average thickness of about 50 feet and includes fossiliferous layers. Locally the zone is as much as 175 feet thick, but it is not fossiliferous throughout such thickness. The base of the sand is generally pebbly. In general the sand in the upper part of the zone is silty and locally contains many sand dollars. A thin limestone layer is present at the base of the zone at some localities, particularly on the west flank of Middle and South Domes. On the west flank of Middle Dome thick beds of conglomerate occur in the zone. Conglomerate is less abundant on the east flank of Middle Dome. On the east flank of South Dome the zone consists of silty sediments. The character and thickness of the zone at localities on the east flank of North Dome and on the west flank of Middle and South Domes are shown on plate 12.

The *Pecten* zone contains a peculiar and therefore easily recognized marine fauna. On the basis of its fossils this zone is correlated with Arnold's typical *Pecten coalingaensis* zone of the Kreyenhagen Hills,[38]

[38] Arnold, Ralph, op. cit. (Bull. 396), p. 42. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 119, 137.

PLATE 8

[Figures natural size]

FIGURES 1–6. *Littorina mariana* Arnold.

1. Height (incomplete) 22.7 mm., width 17.8 mm. Locality 41. U. S. Nat. Mus. 495285.
2. Height 14.3 mm., width 10.7 mm. Locality 44. U. S. Nat. Mus. 495286.
3. Height (incomplete) 19.8 mm., width 13 mm. Locality 44. U. S. Nat. Mus. 495287.
4. Height 15.5 mm., width 10.6 mm. Locality 44. U. S. Nat. Mus. 495288.
5. Height (almost incomplete) 13.5 mm., width 9.5 mm. Locality 44. U. S. Nat. Mus. 495289.
6. Height 19.3 mm., width 12 mm. Locality 44. U. S. Nat. Mus. 495290.

7. *Calyptraea* cf. *C. filosa* (Gabb). Height 9.8 mm., greatest diameter 17 mm. Locality 40. U. S. Nat. Mus. 495291.

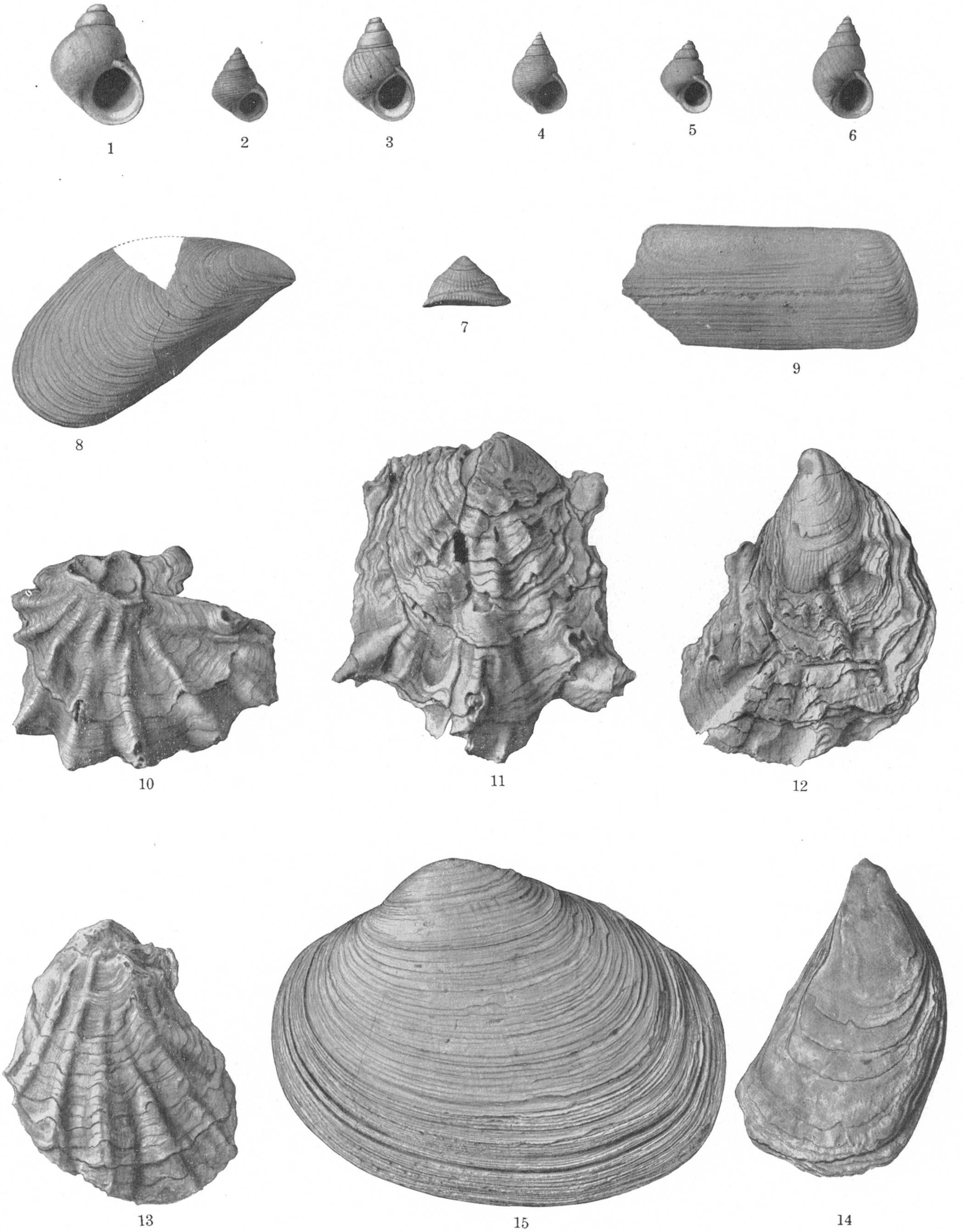
8. *Mytilus* cf. *M. edulis* Linné. Greatest length 54.2 mm., width 26.8 mm., thickness 8.2 mm. Locality 40. U. S. Nat. Mus. 495293.

9. *Solen perrini* Clark. Length (incomplete) 53.8 mm., height 22.5 mm., thickness 8.1 mm. Locality 40. U. S. Nat. Mus. 495294.

10–14. *Ostrea vespertina sequens* Arnold.

10. Left valve. Length 51.5 mm., height 42 mm., thickness about 12 mm. Locality 33. U. S. Nat. Mus. 495295.
11. Left valve. Length 58 mm., height 63.8 mm., thickness about 14.5 mm. Locality 33. U. S. Nat. Mus. 495296.
12. Right valve. Length 47.5 mm., height 59.5 mm., thickness about 5 mm. Locality 33. U. S. Nat. Mus. 495297.
13. Left valve. Length 40.5 mm., height 54.5 mm., thickness about 15 mm. Locality 37. U. S. Nat. Mus. 495298.
14. Right valve. Length 36 mm., height 59.5 mm., thickness about 6 mm. Locality 37. U. S. Nat. Mus. 495299.

15. *Saxidomus nuttalli latus* Stewart, n. var. Length 85.5 mm., height 62 mm., thickness 21 mm. Locality 31. U. S. Nat. Mus. 495300.



FOSSILS FROM UPPER *MYA* ZONE OF SAN JOAQUIN FORMATION.

PLATE 9

[Figures natural size]

FIGURES 1–3. *Macoma affinis* Nomland. Locality 41.

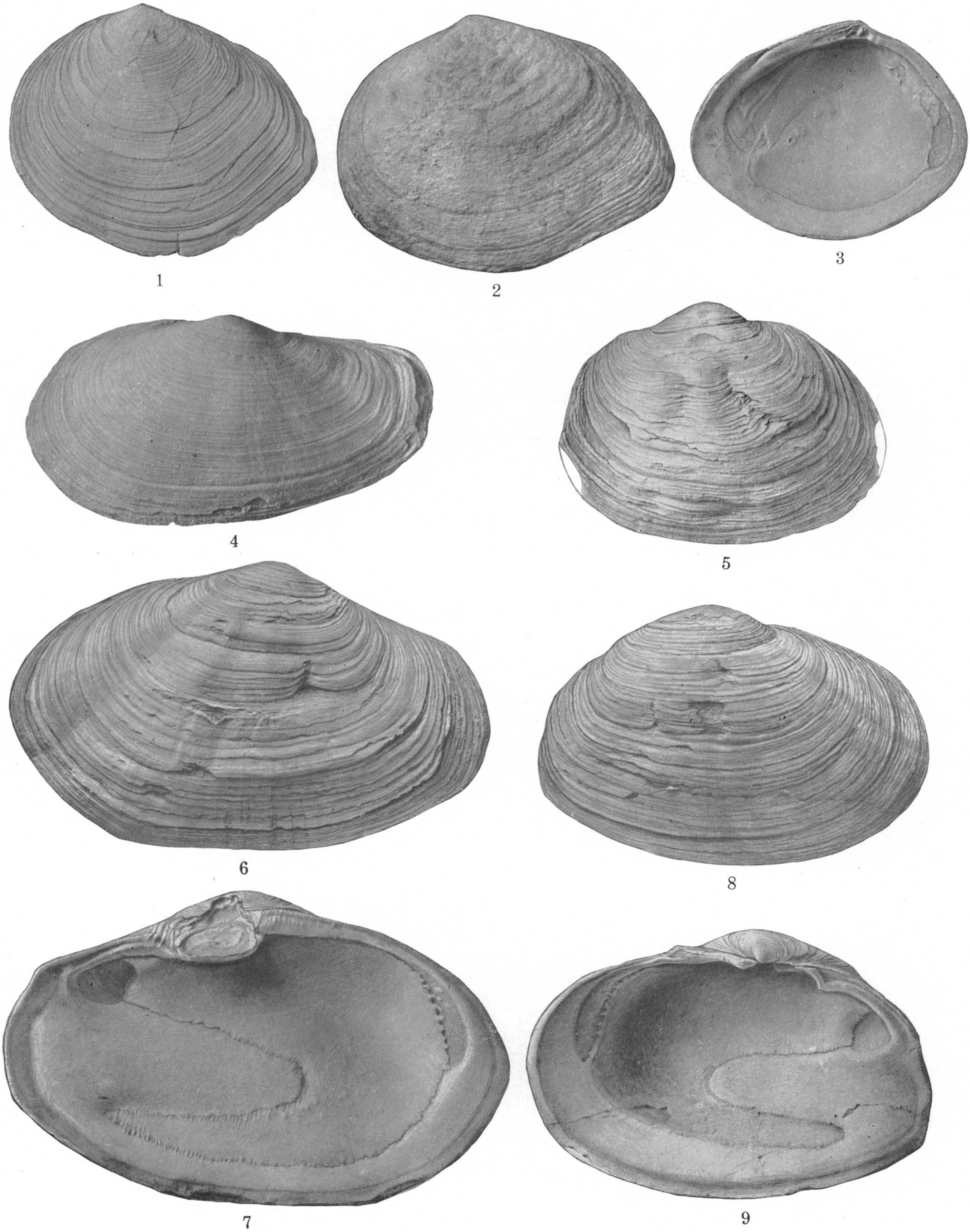
1. Length 56 mm., height 44 mm., thickness of both valves 17.5 mm. U. S. Nat. Mus. 495301.
2. Length 62.5 mm., height 48 mm., thickness of both valves 20.5 mm. U. S. Nat. Mus. 495302.
3. Length 50 mm., height 40 mm., thickness 9.5 mm. U. S. Nat. Mus. 495303.

4–9. *Mya* cf. *M. dickersoni* Clark.

4. Length 78 mm., height 40.5 mm., thickness (not including chondrophore) 12.8 mm. Locality 42. U. S. Nat. Mus. 495305.
5. Length (virtually complete) 62.2 mm., height 46.2 mm., thickness 19 mm. Locality 30. U. S. Nat. Mus. 495306.

6, 7. Length 95.5 mm., height 58.5 mm., thickness (not including chondrophore) 20.5 mm. Locality 31. U. S. Nat. Mus. 495304.

8, 9. Length 74.5 mm., height 49 mm., thickness 20 mm. Locality 31. U. S. Nat. Mus. 495307.



FOSSILS FROM UPPER *MYA* ZONE OF SAN JOAQUIN FORMATION.

PLATE 10

[Figures natural size unless otherwise designated]

FIGURES 1–5. *Ostrea vespertina sequens* Arnold.

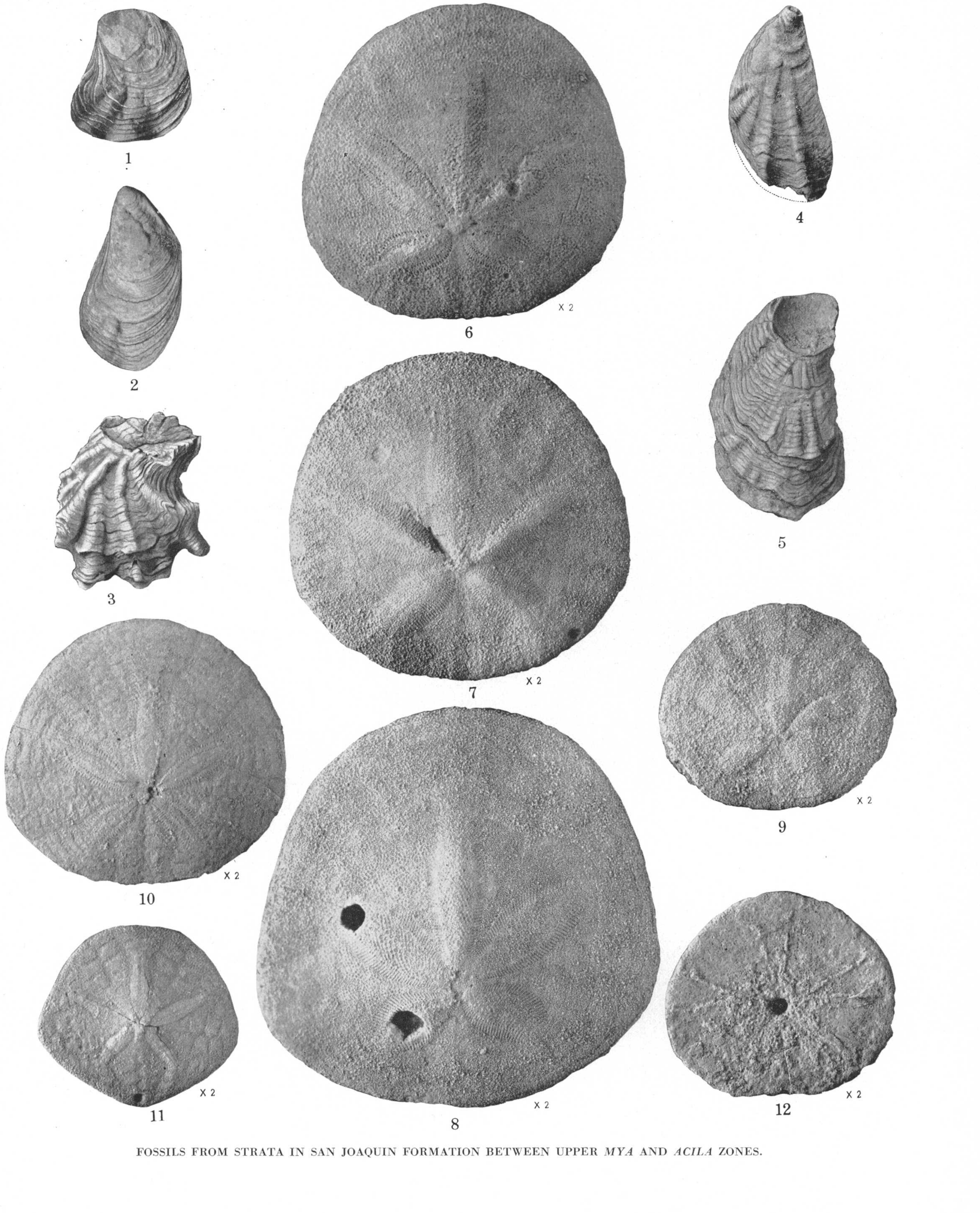
1. Right valve. Length 24 mm., height 27.5 mm., thickness about 4.5 mm. Locality 52. U. S. Nat. Mus. 495307a.
2. Right valve. Length 20.5 mm., height 37.5 mm., thickness about 2.5 mm. Locality 52. U. S. Nat. Mus. 495308.
3. Left valve. Length 32 mm., height 34.5 mm., thickness about 9 mm. Locality 52. U. S. Nat. Mus. 495309.
4. Left valve. Length 22 mm., height 40 mm., thickness about 5 mm. Locality 52. U. S. Nat. Mus. 495310.
5. Left valve. Length 28 mm., height 43.5 mm., thickness about 14 mm. Locality 55. U. S. Nat. Mus. 495311.

6–9. *Dendraster coalingaensis* Twitchell, small var. with slightly raised petals, and deep ambulacral furrows.

6. Length 31.6 mm., width 33 mm., height 7 mm. Locality 50. U. S. Nat. Mus. 495312.
7. Length 33.2 mm., width 34.8 mm., height 7.8 mm. Locality 50. U. S. Nat. Mus. 495313.
8. Length 39.7 mm., width 40.8 mm., height 7.7 mm. Locality 50. U. S. Nat. Mus. 495314.
9. Length 20.7 mm., width 24 mm., height 4 mm. Locality 49. U. S. Nat. Mus. 495315.

10–12. *Dendraster coalingaensis* Twitchell, small var. with flat petals. Locality 56.

10. Form with marginal periproct. Length 26.4 mm., width 28.5 mm., height 4 mm. U. S. Nat. Mus. 495316.
11. Form with supramarginal periproct. Length 18.3 mm., width 19.9 mm., height 3.4 mm. U. S. Nat. Mus. 495316a.
12. Form with periproct at margin of oral surface. Length 20.5 mm., width 23.8 mm., height 3.3 mm. U. S. Nat. Mus. 495317.



FOSSILS FROM STRATA IN SAN JOAQUIN FORMATION BETWEEN UPPER *MYA* AND *ACILA* ZONES.

PLATE 11

[Figures natural size unless otherwise designated]

FIGURE 1. *Turcica caffea brevis* Stewart, n. var. Height (incomplete) 20.5 mm., width (incomplete) 18 mm. Locality 68. U. S. Nat. Mus. 495709.

2, 3. *Calliostoma coalingense* Arnold. Height 11.5 mm., width 15.6 mm. Locality 57. U. S. Nat. Mus. 495710.

4. "*Pleurotoma*" cf. "*P.*" *coalingensis* Arnold. Height (incomplete) 10.2 mm., width (incomplete) 4.6 mm. Locality 58. U. S. Nat. Mus. 495711.

5. *Mitrella* cf. *M. gausapata* (Gould). Height (incomplete) 8.3 mm., width 4.1 mm. Locality 62. U. S. Nat. Mus. 495712.

6. *Turcica caffea brevis* Stewart, n. var. Holotype. Height (incomplete) 24.1 mm., width 21.2 mm. Locality 58. U. S. Nat. Mus. 495713.

7. *Calyptraea* cf. *C. inornata* (Gabb). Height 25 mm., greatest diameter 26 mm. Locality 58. U. S. Nat. Mus. 495714.

8. *Compsomyax* cf. *C. subdiaphana* (Carpenter). Length (incomplete) 33 mm., height 30 mm. Locality 58. U. S. Nat. Mus. 495715.

9. *Siphonalia* cf. *S. humerosa* (Gabb). Height (incomplete) 58 mm., width (incomplete) 34 mm. Locality 59. U. S. Nat. Mus. 495716.

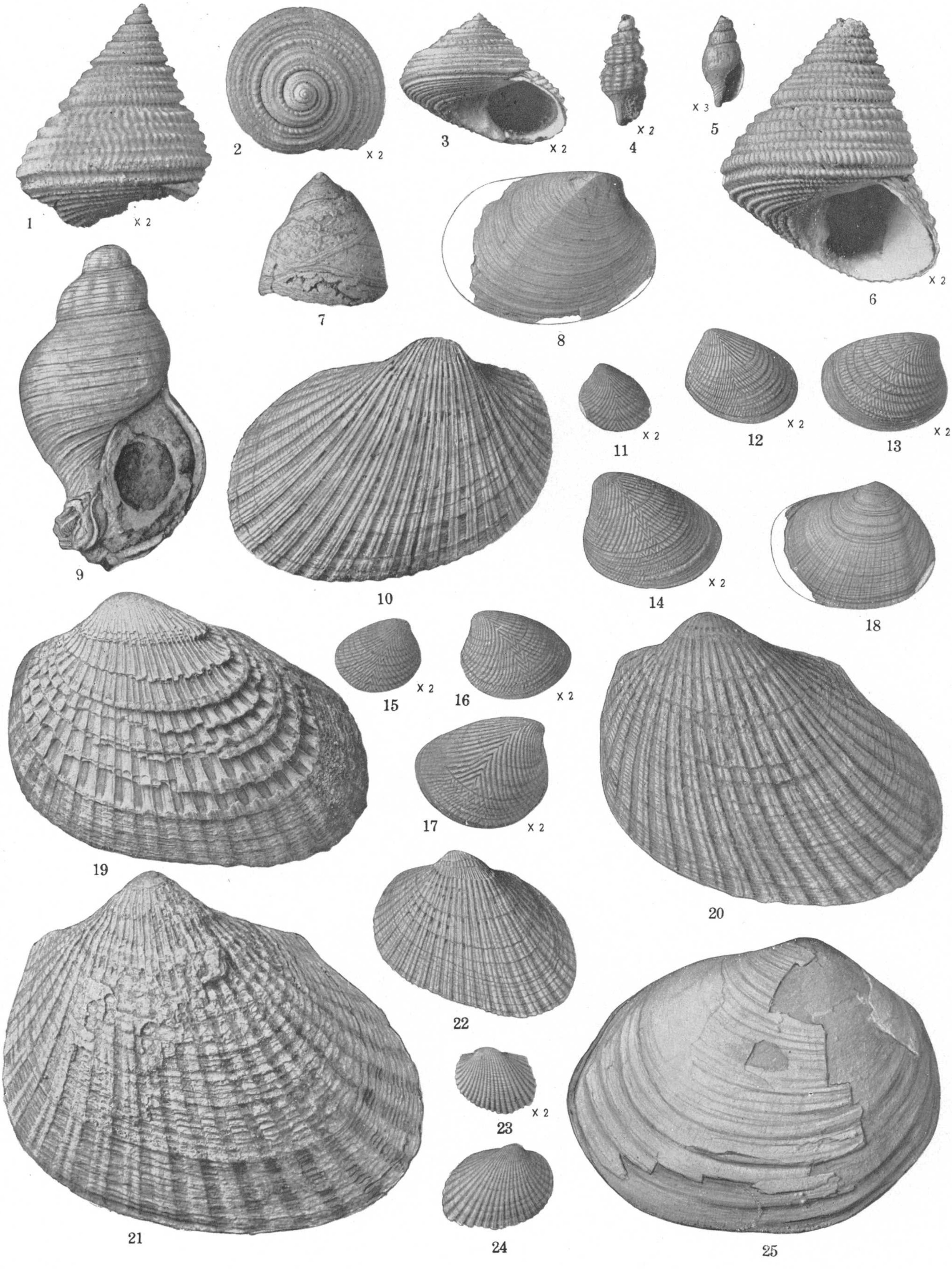
10. *Anadara trilineata* (Conrad) of Arnold. Length 61.5 mm., height (almost complete) 46.5 mm., thickness 18 mm. Locality 57. U. S. Nat. Mus. 495717.

11–17. *Acila castrensis* (Hinds). Locality 60. U. S. Nat. Mus. 495718.
- 11. Length (incomplete) 6.5 mm., width 5.6 mm., thickness 2 mm.
- 12. Length 10.6 mm., height 8.3 mm., thickness 3.3 mm.
- 13. Length 11.9 mm., height 9.3 mm., thickness 3.4 mm.
- 14. Length 13.1 mm., height 11 mm., thickness 4.3 mm.
- 15. Length 8.4 mm., height 6.7 mm., thickness 2.3 mm.
- 16. Length 10.3 mm., height 8.4 mm., thickness 2.6 mm.
- 17. Length 12 mm., height 10.4 mm., thickness 3.6 mm.

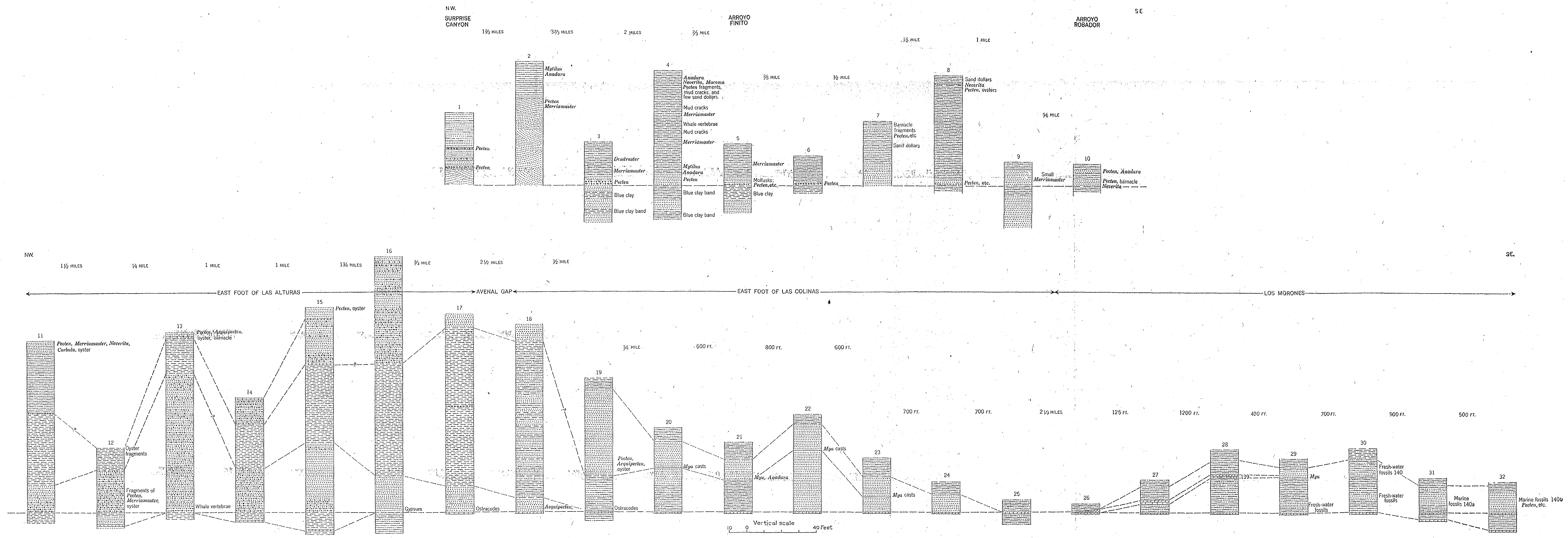
18. *Semele* cf. *S. rubropicta* Dall. Incomplete specimen. Length 29 mm., height 24 mm., thickness 6.5 mm. Locality 58. U. S. Nat. Mus. 495719.

19–24. *Anadara trilineata* (Conrad) of Arnold.
- 19. Length 69 mm., height 55 mm., thickness 20 mm. Locality 57. U. S. Nat. Mus. 495720.
- 20. Length 65 mm., height 56 mm., thickness of both valves 37.5 mm. Locality 57. U. S. Nat. Mus. 495721.
- 21. Length 79.5 mm., height 70 mm., thickness 25 mm. Locality 57. U. S. Nat. Mus. 495722.
- 22. Length 39 mm., height 31 mm., thickness 10 mm. Locality 58. U. S. Nat. Mus. 495723.
- 23. Length 7.5 mm., height 6.3 mm., thickness of both valves 4.4 mm. Locality 62. U. S. Nat. Mus. 495724.
- 24. Length 20.5 mm., height 16 mm., thickness 5 mm. Locality 62. U. S. Nat. Mus. 495725.

25. *Schizothaerus* cf. *S. nuttallii* (Conrad). Length 61 mm., height 48.5 mm., thickness of both valves (not completely closed) 31 mm. Locality 64. U. S. Nat. Mus. 495726.



FOSSILS FROM *ACILA* ZONE OF SAN JOAQUIN FORMATION.



SECTIONS OF *PECTEN* ZONE OF SAN JOAQUIN FORMATION.

EAST FLANK OF NORTH DOME

1. Locality 72, sec. 29, T. 21 S., R. 17 E., east fork of Surprise Arroyo.
2. North center of SW¼ sec. 27, T. 21 S., R. 17 E., west fork of Arroyo Largo.
3. Locality 81, center of sec. 6, T. 22 S., R. 18 E., east fork of Arroyo Torcido.
4. Locality 87, sec. 9, T. 22 S., R. 18 E., divide between Arroyo Pequeño and Arroyo Finito.
5. Locality 91, NE¼ sec. 16, T. 22 S., R. 18 E., Arroyo Finito.
6. East center of NE¼ sec. 16, T. 22 S., R. 18 E., Arroyo Doblegado.
7. Locality 92, SW¼ sec. 15, T. 22 S., R. 18 E., Arroyo Degollado.
8. Locality 93, SE¼ sec. 15, T. 22 S., R. 18 E., Arroyo Degollado.
9. Near locality 96; mud pit in SW¼ sec. 23, T. 22 S., R. 18 E.
10. Locality 97, NW¼ sec. 25, T. 22 S., R. 18 E., Arroyo Robador.

WEST FLANK OF MIDDLE AND SOUTH DOMES

11. Near center of sec. 11, T. 23 S., R. 18 E., 761-foot hill southeast of El Mirador.
12. Near south line of sec. 14, T. 23 S., R. 18 E., north of La Morra.
13. NE¼ sec. 23, T. 23 S., R. 18 E., 700 feet north of locality 130a.
14. Near center of NW¼ sec. 25, T. 23 S., R. 18 E., on knoll at north end of El Caballete.
15. Near center of NE¼ sec. 36, T. 23 S., R. 18 E., El Caballete south of La Brecha.
16. SE¼ sec. 6, T. 24 S., R. 19 E., 1,870 feet north and 680 feet west of southeast corner, near south end of El Caballete.
17. Locality 135, NW¼ sec. 8, T. 24 S., R. 19 E., south end of El Caballete.
18. Locality 138, near west line of sec. 21, T. 24 S., R. 19 E., west of El Rincon.
19. NE¼ sec. 29, T. 24 S., R. 19 E., 1,600 feet south and 800 feet west of northeast corner.
20. SE¼ sec. 29, T. 24 S., R. 19 E., 400 feet north and 800 feet west of southeast corner.
21. Near northeast corner of sec. 32, T. 24 S., R. 19 E.
22. NE¼ sec. 32, T. 24 S., R. 19 E., 800 feet south of preceding locality.
23. East center of NE¼ sec. 32, T. 24 S., R. 19 E., 1,500 feet south and 400 feet west of northeast corner.
24. NE¼ sec. 32, T. 24 S., R. 19 E., 2,200 feet south and 250 feet west of northeast corner.
25. First ridge southwest of east quarter corner of sec. 32, T. 24 S., R. 19 E., 2¼ miles south of Badger Hill.
26. Sec. 10, T. 25 S., R. 19 E., 125 feet north of 503-foot hill, Los Morones.
27. Sec. 10, T. 25 S., R. 19 E., 503-foot hill, Los Morones.
28. Sec. 10, T. 25 S., R. 19 E., 640 feet north of locality 139, Los Morones.
29. Sec. 10, T. 25 S., R. 19 E., 330 feet east of locality 139, Los Morones.
30. Sec. 10, T. 25 S., R. 19 E., 200 feet north of locality 140, Los Morones.
31. Locality 140a, sec. 15, T. 25 S., R. 19 E., Los Morones.
32. Locality 140b, sec. 15, T. 25 S., R. 19 E., south end of Los Morones.

PLATE 13

Figures natural size unless otherwise designated]

FIGURES 1, 2. *Pecten coalingensis* Arnold.

1. Length 42 mm., height 38 mm., thickness 13 mm. Locality 79. U. S. Nat. Mus. 495727.
2. Length 20 mm., height 18.6 mm., thickness 2 mm. Locality 91. U. S. Nat. Mus. 495728.

3, 4. *Aequipecten circularis impostor* (Hanna). Locality 101.

3. Length 16.6 mm., height 17.7 mm., thickness 3.7 mm. U. S. Nat. Mus. 495729.
4. Length 16.4 mm., height 17.2 mm., thickness 3.5 mm. U. S. Nat. Mus. 495730.

5. *Chlamys etchegoini* (Anderson). Length 33.6 mm., height 40.5 mm., thickness 8 mm. Locality 71. U. S. Nat. Mus. 495731.

6–9. *Aequipecten circularis impostor* (Hanna). Locality 101.

6. Length 43.6 mm., height 41.5 mm., thickness 9 mm. U. S. Nat. Mus. 495732.
7. Length 31 mm., height 31.5 mm., thickness 6.4 mm. U. S. Nat. Mus. 495733.
8. Length 26.5 mm., height 27 mm., thickness 5 mm. U. S. Nat. Mus. 495734.
9. Length 46.5 mm., height 42.6 mm., thickness 11 mm. U. S. Nat. Mus. 495735.

10–13. *Venerupis grata tarda* Stewart, n. var. Locality 111.

10. Length 10.3 mm., height 9.3 mm., thickness 3.7 mm. U. S. Nat. Mus. 495736.
11. Length 12 mm., height 12 mm., thickness 4.5 mm. U. S. Nat. Mus. 495737.
12, 13. Holotype. Length 14.6 mm., height 14.6 mm., thickness 6 mm. U. S. Nat. Mus. 495738.

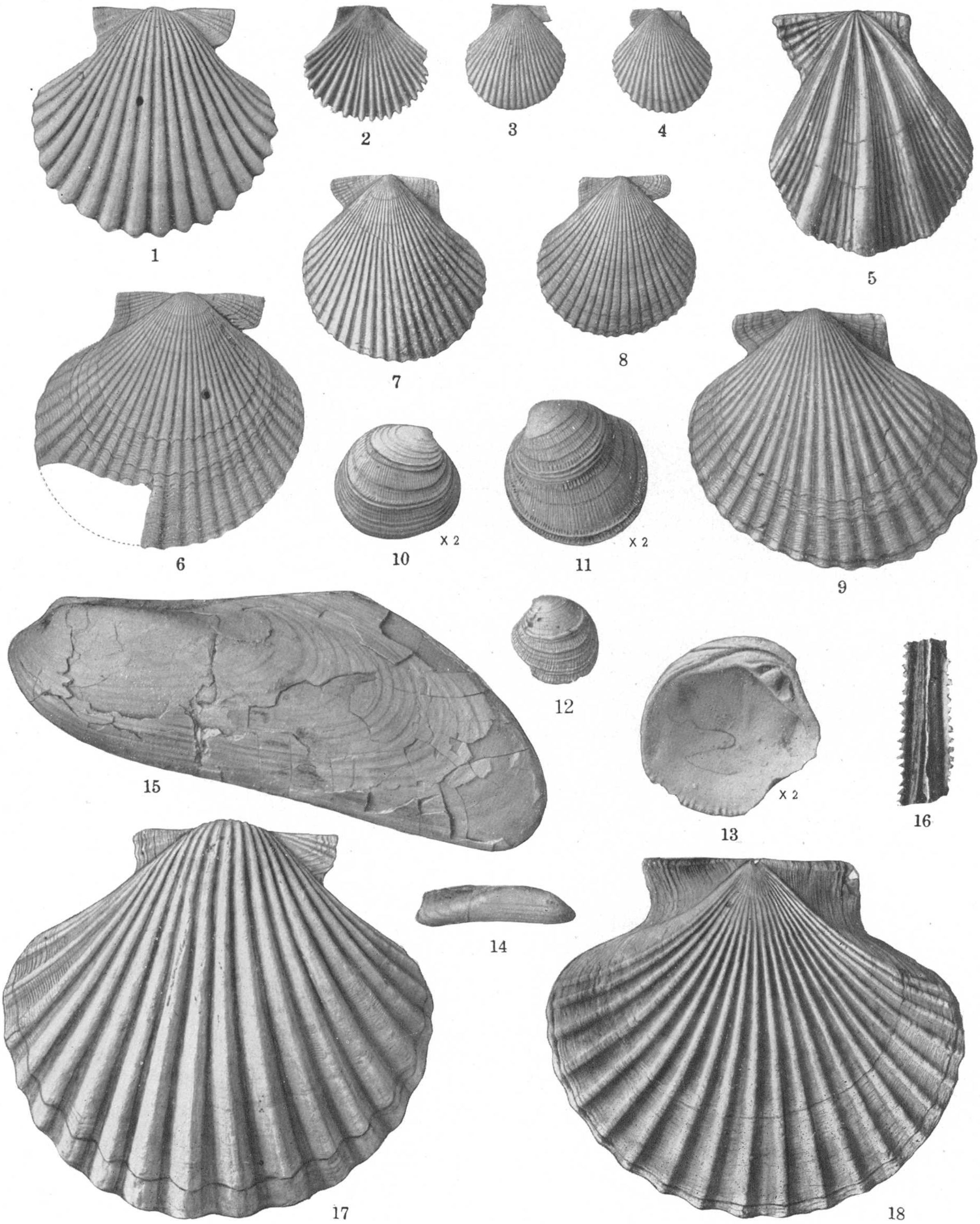
14. *Botula ?* sp. Length (incomplete) 24.6 mm., height 6 mm., thickness of both valves 6 mm. Locality 82. U. S. Nat. Mus. 495739.

15. *Volsella* cf. *V. recta* (Conrad). Length 88 mm., width 36.4 mm., thickness of both valves 25 mm. Locality 75. U. S. Nat. Mus. 495740.

16. Caudal spine of sting ray. Length (incomplete) 27.5 mm., width 9 mm. Locality 86. U. S. Nat. Mus. 495741.

17, 18. *Pecten coalingensis* Arnold.

17. Length 73.9 mm., height 68.5 mm., thickness about 21 mm. Locality 82. U. S. Nat. Mus. 495742.
18. Length 69.4 mm., height 60 mm., thickness about 5 mm. Locality 75a. U. S. Nat. Mus. 495743.



FOSSILS FROM *PECTEN* ZONE OF SAN JOAQUIN FORMATION.

PLATE 14

[Figures natural size]

FIGURES 1–4. *Chama pellucida* Broderip.

1. Length of both valves 73 mm. Locality 87. U. S. Nat. Mus. 495744.
2. Length 36.5 mm., height 42 mm., thickness of both valves 30 mm. Locality 119. U. S. Nat. Mus. 495745.
3. Length 47 mm., height 39 mm., thickness 15 mm. Locality 102. U. S. Nat. Mus. 495746.
4. Length 34 mm., height 31 mm., thickness 10 mm. Locality 91. U. S. Nat. Mus. 495747.

5. *Macoma* cf. *M. nasuta* (Conrad). Length 50 mm., height 45 mm., thickness of both valves 14.5 mm. Locality 75. U. S. Nat. Mus. 495748.

6. *Pholadidea ovoidea* (Gould), short var. Length (practically complete) 35 mm., height 26.7 mm., thickness of both valves about 26 mm. Locality 119. U. S. Nat. Mus. 495749.

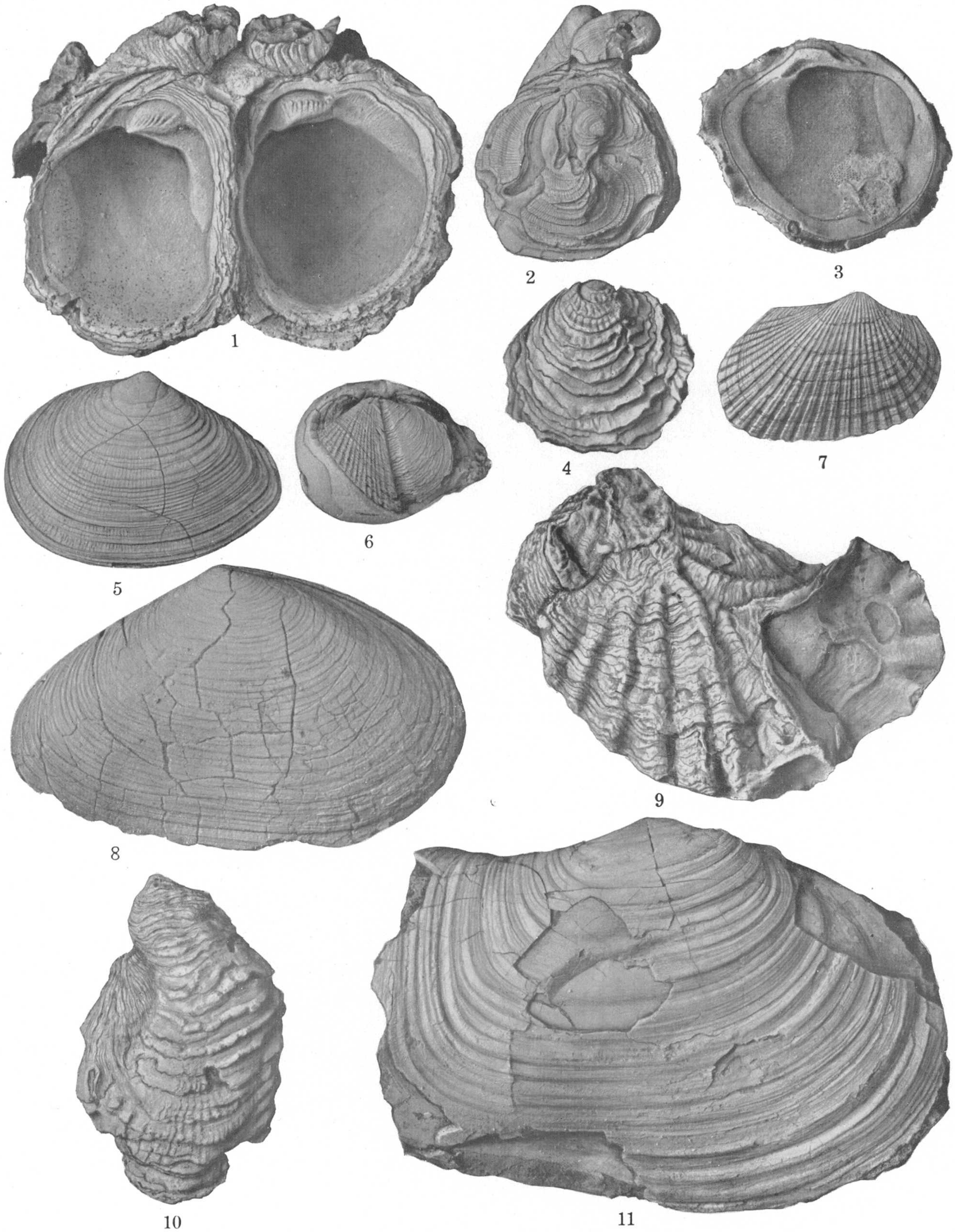
7. *Anadara trilineata* (Conrad) of Arnold, elongate flat var. Length 41.3 mm., height 26.6 mm., thickness of both valves 18 mm. Locality 75. U. S. Nat. Mus. 495750.

8. *Tellina ?* cf. *T. ? oldroydi* Wiedey. Length 84.4 mm., height 53 mm., thickness of both valves 23.8 mm. Locality 75. U. S. Nat. Mus. 495751.

9. *Ostrea vespertina* Conrad. Length 66.5 mm., height 55 mm., thickness about 18 mm. Locality 130. U. S. Nat. Mus. 495752.

10. *Chama pellucida* Broderip. Length 36 mm., height 58.5 mm., thickness 19 mm. Locality 87. U. S. Nat. Mus. 495753.

11. *Panope* cf. *P. generosa* Gould. Length (almost complete) 103 mm., height 70 mm., thickness of both valves 45 mm. Locality 87. U. S. Nat. Mus. 495754.



FOSSILS FROM *PECTEN* ZONE OF SAN JOAQUIN FORMATION.

PLATE 15

[Figures natural size unless otherwise designated]

FIGURES 1, 7. *Cancellaria rapa* Nomland. Height (almost complete) 73 mm., width (almost complete) 38 mm. Locality 75. U. S. Nat. Mus. 495755.

2. *Jaton* cf. *J. festivus* (Hinds). Height (incomplete) 29.5 mm., width (incomplete) 18.5 mm. Locality 87. U. S. Nat. Mus. 495756.

3. *"Nassa" coalingensis* Arnold. Height 33 mm., width 16 mm. Locality 94. U. S. Nat. Mus. 495757.

4. *Progabbia* sp. Height (incomplete) 30.5 mm., width 17 mm. Locality 82. U. S. Nat. Mus. 495758.

5, 6. *Goniobasis kettlemanensis* Arnold.
 5. Height (incomplete) 27.5 mm., width (almost complete) 11 mm. Locality 98. U. S. Nat. Mus. 495759.
 6. Height (incomplete) 21.4 mm., width 8.8 mm. Locality 140. U. S. Nat. Mus. 495760.

8. *Lunatia* cf. *L. lewisii* (Gould). Height 68.5 mm., width 63 mm. Locality 75. U. S. Nat. Mus. 495761.

9. *Jaton festivus* (Hinds), n. var. Height (incomplete) 38.7 mm., width (almost complete) 24 mm. Locality 102. U. S. Nat. Mus. 495762.

10. *Calyptraea* cf. *C. inornata* (Gabb). Height (incomplete) 13 mm., diameter 26 mm. Locality 104. U. S. Nat. Mus. 495763. May be a worn specimen of *C.* cf. *C. filosa* (Gabb).

11. *Neverita reclusiana* (Deshayes). Height 36.6 mm., width 29 mm. Locality 120, *Trachycardium* zone. U. S. Nat. Mus. 495764.

12. *Tritonalia* cf. *T. lurida* (Middendorff). Height (incomplete) 22 mm., width 11.4 mm. Locality 106. U. S. Nat. Mus. 495765.

13. *Macoma affinis* Nomland, small var. cf. *M. a. plena* Stewart, n. var. Length 36.5 mm., height (almost complete) 27.5 mm., thckness 7 mm. Locality 126, between *Pecten* and *Neverita* zones. U. S. Nat. Mus. 495766.

14. *Goniobasis kettlemanensis* Arnold. Height (incomplete) 12 mm., width 5 mm. Locality 140. U. S. Nat. Mus. 495767.

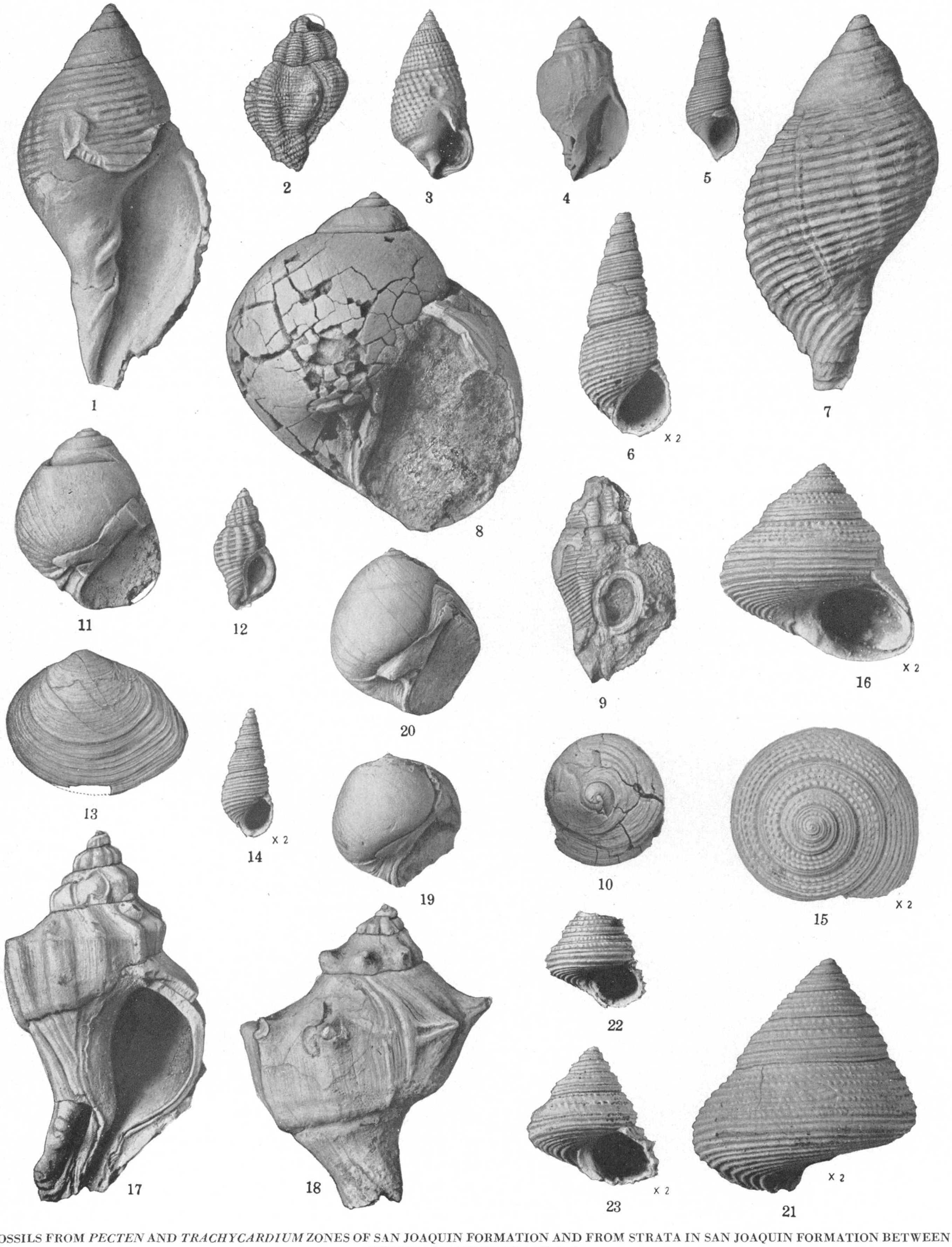
15, 16. *Calliostoma coalingense* Arnold. Height 19 mm., width 19 mm. Locality 81. U. S. Nat. Mus. 495768.

17, 18. *Forreria magister munda* Stewart, n. var. Locality 102.
 17. Height (almost complete) 75 mm., width (incomplete) 43 mm. U. S. Nat. Mus. 495769.
 18. Holotype. Height (incomplete) 59 mm., width 42 mm. U. S. Nat. Mus. 495770.

19, 20. *Neverita reclusiana* (Deshayes). Locality 120, *Trachycardium* zone.
 19. Short variety. Height (practically complete) 26.6 mm., width 26.4 mm. U. S. Nat. Mus. 495771.
 20. Height 33.8 mm., width 30 mm. U. S. Nat. Mus. 495772.

21. *Calliostoma kerri* Arnold. Height (almost complete) 29.5 mm., width (almost complete) 22 mm. Locality 87. U. S. Nat. Mus. 495773.

22, 23. *Calliostoma* cf. *C. gemmulatum* Carpenter. Locality 102a.
 22. Height (incomplete) 17.5 mm., width 20 mm. U. S. Nat. Mus. 495774.
 23. Height 13.5 mm., width 13 mm. U. S. Nat. Mus. 495775.



FOSSILS FROM *PECTEN* AND *TRACHYCARDIUM* ZONES OF SAN JOAQUIN FORMATION AND FROM STRATA IN SAN JOAQUIN FORMATION BETWEEN *PECTEN* AND *NEVERITA* ZONES.

PLATE 16

[Figures natural size unless otherwise designated]

FIGURE 1. *Macoma* cf. *M. secta* (Conrad). Length 72.5 mm., height 51.3 mm. Locality 135. U. S. Nat. Mus. 495776.

2. *Trachycardium* cf. *T. quadragenarium* (Conrad). Length 58 mm., height 52 mm., thickness about 20 mm. Locality 71. U. S. Nat. Mus. 495777.

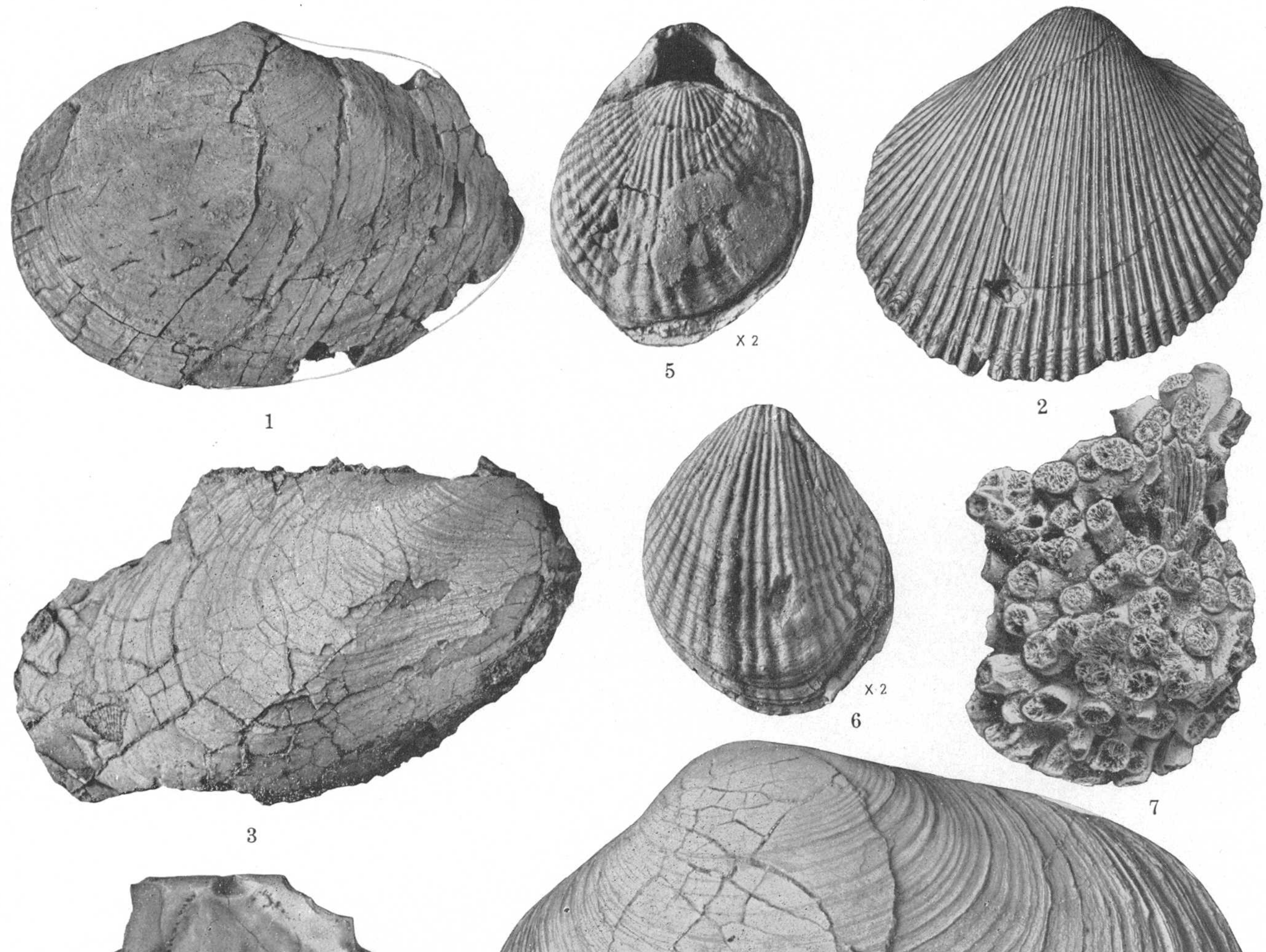
3. *Volsella* cf. *V. capax* (Conrad). Greatest length (incomplete) 78 mm., width 46 mm., thickness of right valve about 25 mm. Locality 87. U. S. Nat. Mus. 495778.

4. *Pecten coalingaensis* Arnold. Internal view of flatter valve. Length 61.5 mm., height 53 mm. Locality 79a. U. S. Nat. Mus. 495779.

5, 6. *Terebratalia* cf. *T. smithi* Arnold. Height 22.3 mm., width 18 mm., thickness of both valves 10 mm. Locality 79a. U. S. Nat. Mus. 495780.

7. *Astrangia coalingensis* Vaughan. Fragment of colony. Length 63.5 mm., width 46.5 mm. Locality 79. U. S. Nat. Mus. 495781.

8. *Saxidomus nuttallii latus* Stewart, n. var. Holotype. Length 111 mm., height 82 mm., thickness of both valves 53.5 mm. Locality 87. U. S. Nat. Mus. 495782.



FOSSILS FROM *PECTEN* ZONE OF SAN JOAQUIN FORMATION.

a correlation already made by Arnold and Anderson.[38a] Inasmuch as *P. coalingaensis* is the only *Pecten*, in the restricted sense, recognized in the Kettleman Hills, there should be no ambiguity in referring to the *Pecten coalingaensis* zone as the *Pecten* zone. The abbreviated name is appropriate for the zone, as *Pecten* was not found at other horizons.

The base of the zone is generally well-defined in areas where exposures are adequate. At many localities evidence for discontinuity is apparent at the base. The discontinuity may be of no greater physical significance than discontinuities found at the base of many other beds of sand and sandstone in the San Joaquin formation. At a few localities, however, fossiliferous sand appears to grade downward into nonfossiliferous sand, and it is difficult to determine the exact base of the zone. On the west flank of South Dome the zone is absent for a distance of 2⅓ miles.

Because the *Pecten* zone was identified over a larger area than any other faunal zone in the San Joaquin formation and because its fauna is so readily recognized, the San Joaquin formation is divided into lower and upper parts at the base of this zone—a subdivision corresponding to a faunal subdivision based on the sand dollars.

On the east flank of southern North Dome and Middle Dome and on the west flank of southern North Dome marine fossils occur in sand and pebbly sand, generally 125 to 150 feet above the base of the *Pecten* zone, about halfway between the *Pecten* and the *Acila* zones. This zone is designated "the *Trachycardium* zone." The type locality is on the north side of Arroyo Conchoso (locality 121, NE¼ sec. 30, T. 22 S., R. 18 E.), where the zone is about 20 feet thick. The strata between the *Pecten* and the *Trachycardium* zones consist chiefly of nonfossiliferous muddy silt. The fossils in the *Trachycardium* zone occur also in the *Pecten* zone. The *Trachycardium* zone might, therefore, be considered as the upper *Pecten* zone, but *Pecten* was not found in it. The name of the zone is not entirely satisfactory, because *Trachycardium* is also present in the *Pecten* zone. This genus, however, is a common fossil in the *Trachycardium* zone and has not been found at horizons above that zone or below the *Pecten* zone, with the exception of the conglomerate fossils mentioned under the heading "Strata between *Acila* zone and *Pecten* zone."

The *Trachycardium* zone is an important aid in interpreting the geology of the saddle between North and Middle Domes, where the *Pecten* zone is in some places obscure. On the east flank of Middle Dome the *Trachycardium* zone is generally only about 50 to 60 feet above the base of the *Pecten* zone. In part of this region the division between the upper and lower parts of the San Joaquin formation is for convenience placed at the base of the *Trachycardium* zone, for the *Pecten* zone is not well exposed and its base was recognized at only a few places.

The *Trachycardium* zone was generally recognized by the occurrence of large marine shells in the soil or in a ledge that interrupts smooth slopes. Details of the stratigraphy of the zone are not available except in artificial excavations.

East flank of North Dome.—Sections of the *Pecten* zone on the east flank of North Dome are shown on plate 12. The zone consists of coarse-grained sand and silty sand about 40 to 65 feet thick, both of which contain fossils. The stratigraphic relations and faunal content of different layers appear to change from place to place. In much of this region the stratigraphic position of the zone may be recognized by thin layers of dark-blue or black clay—mentioned by Arnold and Anderson—that immediately underlie the zone.[39] The layers of dark-colored clay may be only an inch thick, but weathered outcrops of silt associated with them form conspicuous bluish-black bands barren of vegetation. The beds of sand that lie between the layers of silt and clay are much thicker than indicated by weathered outcrops. The sand forming the base of the *Pecten* zone contains small pebbles, generally consisting of chert. This sand rests on underlying strata with an irregular contact and penetrates cracks or borings in the underlying strata. The base of the zone is generally more sharply defined than the top, which is placed at the top of fossiliferous sand. Typical *Pecten*-bearing sand is exposed in an excavation at Standard oil well 65–29–J (locality 72, sec. 29, T. 21 S., R. 17 E.; column 1, pl. 12), where the following section was measured.

Section of Pecten zone of San Joaquin formation at locality 72, sec. 29, T. 21 S., R. 17 E.

	Feet
7. Laminated somewhat irregularly bedded silt and silty sand; some persistent silt layers 1 inch thick	23
6. Sand similar to unit 4, but containing more limy nodules, chert pebbles, and silt fragments; few fossils (bone, *Chama?*, *Pecten*). This bed rises across the strata 51 inches in a horizontal distance of 24 feet, crossing the normal stratification at an angle of about 7°	½
5. Dirty sand containing *Pecten;* increases in thickness southward	2
4. Sand similar to unit 2, but containing iron concretions, limy nodules, and scattered corals	2
3. Coarse-grained sand	2½
2. Sand containing small angular chert pebbles and silt fragments. *Pecten* abundant, mostly fragments of large specimens; small specimens 3 cm. long unbroken	2+
1. Coarse-grained cross-bedded sand. Base not exposed	9+
Thickness of *Pecten* zone	41+

Sand dollars are more abundant in silty sand in the upper part of the zone than in the cleaner and coarser-grained sand containing *Pecten* and other fossils (pl.

[38a] Op. cit. (Bull. 398), p. 121.

[39] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 121.

12, columns 3, 4, 5, 7, 8). In the northern part of the anticline a layer containing large fossils (*Mytilus-Anadara* layer) appears to be at different horizons above the base of the zone (pl. 12, columns 2, 4). At locality 92, near Arroyo Doblegado, a brown grit containing barnacle fragments and shells is near the top of the zone (pl. 12, column 7). For a distance of about a quarter of a mile along the strike northwest and southeast of locality 98, between Arroyo Robador and Arroyo Pino, fresh-water fossils (*Goniobasis* and *Anodonta*) were found at the surface with the marine fauna of the *Pecten* zone. The fresh-water layer is presumably a lens near the base of the zone if not actually forming the base. Perhaps the *Anodonta* layer near locality 96, in sec. 23, T. 22 S., R. 18 E. (pl. 12, column 9) is part of the same fresh-water bed.

Just south of the Paso Robles-Hanford road an important faunal change in the *Pecten* zone is evident. Only a few fragments of *Pecten*, mostly fragments of large specimens of the flat valve possibly transported after death, were found. Another pecten, *Aequipecten*, is abundant (locality 101). Farther south at La Lomica the gastropods *Forreria* and *Jaton* are exceptionally abundant (locality 102). South of Arroyo del Poso fresh-water shells occur above a conglomerate that contains 3-inch yellow limestone cobbles (locality 103). Farther southeast along the strike at locality 103a fragments of marine fossils were found in the conglomerate, which is considered to represent the base of the *Pecten* zone.

An oyster bed is exposed at locality 100, south of Arroyo Pino, about 125 feet above the base of the *Pecten* zone. This bed, which contains fragments of *Trachycardium* and other fossils in addition to oyster shells and fragments, is assigned to the *Trachycardium* zone. Strata north and south of Arroyo del Paso, 100 feet or less above the base of the *Pecten* zone, also are assigned to the *Trachycardium* zone.

East flank of Middle Dome.—The *Pecten* zone is not well-exposed along the east flank of Middle Dome and may be poorly developed. A fossiliferous sand traced with some degree of certainty from a locality just south of La Salida southward to La Porteria and beyond is assigned to the *Trachycardium* zone, though it is only 50 or 60 feet above strata referred to the base of the *Pecten* zone. The section in this area is evidently thinner than farther north. At places *Trachycardium* is found in the *Trachycardium* zone, which is very fossiliferous at locality 106, just west of La Porteria. A conglomerate 50 or 60 feet lower in the section is regarded as the base of the *Pecten* zone. *Pecten* and *Aequipecten* occur in sand assigned to the *Pecten* zone about 50 feet below the *Trachycardium* zone 1,000 feet southeast of locality 108, and at other places *Aequipecten* occurs in sand in a similar stratigraphic position. A fossiliferous layer in or just beneath clay and above a layer of silt at the south end of Middle Dome is considered as the *Pecten* zone, but in the area where exposures are poor and fossils are scarce it is difficult to distinguish between the *Pecten* and *Trachycardium* zones. *Mya* occurs in this layer at locality 110, on the south slope of Boulder Hill—the only locality where *Mya* was observed in the *Pecten* or the *Trachycardium* zones on the east flank of the Kettleman Hills.

East flank of South Dome.—A wide band of silt in Las Perillas is identified as the *Pecten* zone. Fragments of *Pecten?* were found at the south line of sec. 15, T. 24 S., R. 19 E., and *Aequipecten* occurs at several places in secs. 22 and 26. Locality 111 is the southernmost locality at which the zone was identified on the east flank of the Kettleman Hills. A bed of conglomerate about 20 feet thick near the southeast corner of sec. 22 is thought to overlie the *Pecten* zone. It is suggestive of conglomerates that overlie the zone on the west flank of South Dome. At locality 112, near the edge of the alluvium of San Joaquin Valley, the fresh-water snail *Goniobasis* occurs in a layer possibly 75 feet below the *Pecten* zone. It is probably the layer referred to by Arnold and Anderson,[40] who suggested that it may represent the *Pecten coalingaensis* zone.

West flank of North Dome.—The *Pecten* zone increases in thickness from about 50 feet on the west flank of northern North Dome to about 100 feet in the saddle between North and Middle Domes. North of the Avenal-Lemoore road the zone may be identified as sand and silt overlying bands of blue clay, as on the opposite side of the anticline, but fossils are less abundant than on the east flank and at many places are absent. Farther south the zone is more fossiliferous. As on the east flank, sand dollars are abundant in silty sand overlying sand containing *Pecten*. The large-shelled *Mytilus-Anadara* layer was not found on the west flank.

In Arroyo Mellado (locality 117) and between Arroyo Mellado and Arroyo Chico a grit containing barnacle fragments seems to be about 50 feet above the base of the zone. It corresponds in stratigraphic position to a similar bed on the east flank near Arroyo Doblegado. At locality 119, near Arroyo Conchoso, where the base of the *Pecten* zone consists of coarse-grained fossiliferous sand overlying a thin bed of limy clay, pholad borers in the clay are oriented siphon end upward in life position, and the borings are filled with sand like that of the overlying *Pecten* zone. Nearby at locality 119a fresh-water shells, *Goniobasis* and *Anodonta*, occur in a bed that may be the equivalent of the limy clay at locality 119. Between Arroyo Ramoso and Arroyo Delgado (locality 122) fresh-water shells occur in a sandstone that may be considered the base of the *Pecten* zone. This sandstone overlies blue clay and underlies greenish-gray clay, which was traced with reasonable certainty southward almost to Middle Dome.

[40] Arnold, Ralph, and Anderson, Robert, op. cit., p. 138.

South of the Paso Robles-Hanford road cross-bedded sand containing a few pebbles and a few fossils form the basal part of the zone. *Pecten* and sand dollars occur in sand about 100 feet higher in the section (pl. 12, column 11). The zone is underlain by a thin layer of limestone and a conspicuous layer of bentonitic (?) clay, which extend southward for a distance of 2 miles. Farther south of locality 129 conglomerate at the base of the zone contains pebbles, 2 inches or less long, of black chert and igneous rocks and a few pebbles of yellow limestone. The number and size of the yellow limestone pebbles increase southward.

The *Trachycardium* zone was recognized near the west branch of Arroyo Conchoso and at localities extending southward to the saddle between North and Middle Domes. At the type locality on the slope west of Arroyo Conchoso (locality 121) it consists of 20 feet of fossiliferous sand about 125 feet above the base of the *Pecten* zone. Between Arroyo Raso and the Paso Robles-Hanford road the *Trachycardium* zone consists of a prominent cross-bedded grit or coarse-grained sand containing shell fragments. In a cut on the Paso Robles-Hanford road it overlies silty clay and underlies cross-bedded sand and consists in ascending order of 6 feet of regularly bedded fossiliferous sand, irregularly bedded less fossiliferous sand, and a fossiliferous layer a foot thick that nearby contains sand dollars. At this locality the *Trachycardium* zone is about 250 feet above the base of the *Pecten* zone. There is evidently a pronounced thickening of the strata between these two zones as contrasted with the thinning on the east flank between southern North Dome and Middle Dome. The thickening of the strata between the *Trachycardium* and *Acila* zones is not so pronounced.

West flank of Middle Dome.—Strata assigned to the *Pecten* zone are thicker on the west flank of Middle Dome than elsewhere, the thickness reaching a maximum of 175 feet (pl. 12, column 16). The increased thickness appears to be due principally to thick beds of conglomerate. The conglomerate mapped as the base of the zone is exposed at places along the foot of Las Alturas and in the northern part of El Caballete (pl. 12, columns 11–15). The conglomerate contains 3-inch cobbles of yellow limestone and white siliceous shale and is as much as 80 feet thick. Fossils are not abundant in this conglomerate, but at places *Pecten* and other fossils are present. Fresh-water fossils found at the surface with marine fossils in sec. 14, T. 23 S., R. 18 E., presumably come from a thin lens of fresh-water strata near the base of the zone. Farther south along El Caballete the base of the zone is placed at the base of gray sand or sandy silt (pl. 12, columns 16, 17), which are poorly exposed and are apparently non-fossiliferous.

Several thin beds of limestone, generally about 2 inches thick, occur in or below the *Pecten* zone. The lowest bed is in clay underlying the zone (pl. 12, columns 12, 14, 15). Along the crest of El Caballete southward from La Brecha a layer of limestone immediately underlies the conglomerate referred to the base of the zone (pl. 12, column 17). Locally it is gypsiferous and at locality 134, in sec. 8, T. 24 S., R. 19 E., it contains ostracodes. The line on the map (pl. 3) representing the base of the *Pecten* zone is the outcrop of this limestone, as the overlying sand and sandy silt into which the conglomerate appears to grade southward are not well exposed. In sec. 36, T. 23 S., R. 18 E., south of La Brecha, two beds of limestone are in the upper part of the zone (pl. 12, column 15). The upper limestone is generally platy. Farther south only one limestone is present in the upper part of the zone, and it disappears southward (pl. 12, column 16). At locality 132, in sec. 6, T. 24 S., R. 19 E., fragments of fossils occur in white sand and conglomerate overlying the one bed of limestone in this part of the section. The white sand and conglomerate correspond to the unit shown in column 16, plate 12. White siliceous shale pebbles, derived presumably from the Miocene McLure shale member of the Monterey to the west, are abundant in this conglomerate. Siliceous shale pebbles in such abundance were not observed below the *Pecten* zone. Fossiliferous sand and conglomerate at this horizon, more than 100 feet above the inferred base of the zone, were traced with a fair degree of certainty southward almost to Avenal Gap. In secs. 8 and 17, T. 24, S., R. 19 E., *Pecten* fragments, *Aequipecten*, and other fossils occur at this horizon.

West flank of South Dome.—Sections of the *Pecten* zone on the west flank of South Dome are shown on plate 12,. At Badger Hill (locality 137) a thin limestone containing ostracodes (?) is correlated with the limestone just below the base of the zone in southern Middle Dome. This limestone was traced southward with few gaps to the south end of the Kettleman Hills. It is a satisfactory horizon marker and forms a conspicuous outcrop, particularly when viewed from the south (pl. 18, *C*). At some outcrops it is gypsiferous and at others it consists of two beds about 5 feet apart stratigraphically.

In sec. 20, T. 24 S., R. 19 E., *Aequipecten* occurs in an 8-foot sand immediately above the limestone. This sand is overlain by about 90 feet of silt or clay, above which is a 30-foot white sand also containing *Aequipecten* (locality 138; pl. 12, column 18). In the adjoining sec. 29, *Pecten* and *Aequipecten* were found on the surface of sand about 20 feet above the limestone (pl. 12, column 19).

Southward from Badger Hill the *Pecten* zone thins and finally disappears, the upper part first. The sections in columns 18 to 26 on plate 12, show the gradual southward thinning in the stretch of 2¼ miles south of Badger Hill. As the thickness of the zone decreases typical *Pecten* zone fossils are replaced by *Mya*. Farther south for a distance of 2⅓ miles there is no *Pecten* zone, and the mapping is based on the limestone that immediately underlies the zone farther north. The absence of *Pecten* zone sand and conglomerate may be due to an erosional discontinuity or a nondepositional discontinuity. In view of the evident lenticularity of strata in the San Joaquin formation, however, the nonfossiliferous silt and clay overlying the limestone may have been deposited at the same time as sand and gravel farther north, and the absence of *Pecten* zone fossils may be due to the different environment.

On Los Morones the *Pecten* zone again appears (pl. 12, columns 27–32). At the north end of Los Morones the zone is represented by a ledge of limy mudstone containing many shell fragments. At its northern extremity this ledge is in contact with the underlying limestone layer, but southward the two beds are separated by silt and sand. A sandy bed in this interval, which locally contains fresh-water shells, appears to grade northward into a thin lens of limestone. The presence of *Mya* in the zone on Los Morones suggests a facies similar to that 2½ miles to the north, but there are also fresh-water layers and a marine fauna fairly typical of the *Pecten* zone, including abundant *Aequipecten* and fragments of *Pecten* (localities 139, 140, 140a, 140b). The fresh-water fossils at Los Morones were assigned to the Tulare formation by Arnold.[41]

FOSSILS

The fossils of the *Pecten* and *Trachycardium* zones are listed in the table opposite this page and the characteristic and abundant species are shown on plates 13–16, 39, 45, 46. The *Pecten* zone contains a relatively large marine fauna, larger than any other fauna in the San Joaquin and Etchegoin formations. Many species and genera of this fauna were not found at other horizons. Fossils are abundant in North Dome, less so in Middle Dome, and still less in South Dome except on Los Morones at the south end of the hills. The fauna of the *Trachycardium* zone is similar to that of the *Pecten* zone. The species in the *Trachycardium* zone occur in the *Pecten* zone, but many *Pecten* zone fossils are absent in the *Trachycardium* zone.

Pecten coalingaensis (pl. 13, figs. 1, 2, 17, 18; pl. 16, fig. 4) is a common fossil in the *Pecten* zone in North Dome but is rare farther south. This genus is not known to occur at other horizons. The specimen listed under the *Acila* zone was probably derived from older alluvium. Another member of the Pectinidae, *Aequipecten circularis impostor* (pl. 13, figs. 3, 4, 6–9), is abundant in the *Pecten* zone at localities in Middle Dome and South Dome and on the east flank of North Dome south of the Paso Robles-Hanford road but was not found north of Arroyo Pino. It also occurs in the *Trachycardium* zone. *Chama pellucida* (pl. 14, figs. 1–4, 10), *Jaton* cf. *J. festivus* (pl. 15, figs. 2, 9), the coral *Astrangia coalingensis* (pl. 16, fig. 7), and other less abundant species represent genera not found outside the *Pecten* zone. Relatively large oysters that have a strongly plicate upper valve, *Ostrea vespertina* (pl. 14, fig. 9), occur in the *Pecten* and *Trachycardium* zones but were not certainly identified at other horizons. *Neverita reclusiana* (pl. 15, figs. 11, 19, 20), which has an extensive stratigraphic range in the San Joaquin and Etchegoin formations, is particularly abundant in the *Pecten* zone at localities 93 and 117 and in the *Trachycardium* zone at locality 121.

Dendraster coalingaensis in its typical form (pl. 45, fig. 2) and the variety *gibbosus* (pl. 45, figs. 5, 6) occur in the *Pecten* zone and at lower horizons in the San Joaquin. *Merriamaster*, treated as a subgenus of *Dendraster*, is abundant in the *Pecten* and *Trachycardium* zones and was not found at lower horizons. One species, *D.* (*M.*) *perrini* (pl. 46, figs. 1, 2, 4, 7, 10, 12), appears to be confined to the *Pecten* and *Trachycardium* zones; another, *D.* (*M.*) *arnoldi* (pl. 46, figs. 3, 5, 6, 8, 11, 13), also occurs in the *Acila* zone.

The *Pecten* zone also contains a relatively large number of mammalian remains, generally isolated teeth and bones. Teeth of the extinct beaver *Castor californicus* were not found outside this zone. They are particularly abundant at locality 118.

OCCURRENCE ELSEWHERE IN SAN JOAQUIN VALLEY

The type region of the *Pecten coalingaensis* zone is in the Kreyenhagen Hills, which form the Coast Range foothills west of the Kettleman Hills. According to Arnold and Anderson,[42] the zone in the Kreyenhagen Hills is 300 to 400 feet below the top of their Etchegoin formation. Arnold and Anderson cited their locality 4712 as typical of the zone.[43] The fauna from their locality 4710 is more like that in the Kettleman Hills. In the Kreyenhagen Hills the zone has been traced from Zapata Creek southeastward for a distance of about 10 miles to a locality south of Big Tar Canyon.[44] (For locations see fig. 1.) The importance of the *Pecten* zone in the foothill region and the short stratigraphic range of its fauna were emphasized by Nomland,[45] who recognized it on Anticline Ridge in beds traceable to the type locality of the Etchegoin selected by Arnold and Anderson. The zone has also been identified in

[41] Arnold, Ralph, op. cit. (Bull. 396), pp. 47, 48 (locality 4715). Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 153 (locality 4715).

[42] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 119.

[43] Idem, p. 137.

[44] Kleinpell, W. D., in Reed, R. D., Geology of California, p. 240, fig. 47, Tulsa, Am. Assoc. Petroleum Geologists, 1933.

[45] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geology, Bull., vol. 10, pp. 213–214, 1917.

Fossils from Pecten zone and Trachycardium zone

[Identifications by Ralph Stewart unless otherwise stated. F, fragments; M, medium-sized specimens; P, paired valves; S, small specimens; W, worn specimens]

East flank of Kettleman Hills (North Dome: 71–102c; Middle Dome: 103–110; South Dome: 111–112)

Species	71	72	73	74	75	76	77	78	79	79a	80	81	82	83	84	85	85a	86	87	88	89	90	91	92	93	93a	94	96	97	98	99	100[1]	101	102	102a	102b	102c	103	103a	104	105	105a	106[1]	107	108	109	110	111	112
Coral: *Astrangia coalingensis* Vaughan (pl. 16, fig. 7)	X	X							X	X	?	X			X	X			X				X		X									X										?					
Worm tubes: *Serpula?* sp.																		X			X																												
Echinoids:																																																	
Dendraster coalingaensis Twitchell (pl. 45, figs. 1, 2)																																	W																
Dendraster coalingaensis gibbosus Kew (pl. 45, figs. 5, 6)										X		X																					X																
Dendraster (Merriamaster) perrini (Weaver) (pl. 46, figs. 1, 2, 4, 7, 10, 12)	S		S			X	X		X		X	X	S, cf.	X					X				X	X	X						X		X	X	X						cf.								
Dendraster (Merriamaster) arnoldi Twitchell (pl. 46, figs. 3, 5, 6, 8, 11, 13 (cf.))																																																	
Unidentified bryozoa																																		X															
Brachiopod: *Terebratalia* cf. *T. smithi* Arnold (pl. 16, figs. 5, 6)										X						X																																	
Gastropods:																																																	
Turcica caffea brevis Stewart, n. var.	X																																																
Calliostoma coalingense Arnold (pl. 15, figs. 15, 16)	X								X	X		X							X															X	X					X									
Calliostoma cf. *C. gemmulatum* Carpenter (pl. 15, figs. 22, 23)																																		X	X														
Calliostoma kerri Arnold (pl. 15, fig. 21)	X			X					X	X	X	X							X				X											X															
Littorina mariana Arnold																																																	
Fluminicola kettlemanensis Pilsbry																														X																			
Goniobasis kettlemanensis Arnold (pl. 15, figs. 5, 6, 14)																														X								X											X
Calyptraea cf. *C. inornata* (Gabb) (pl. 15, fig. 10)					W							W							X															X			F			X		X							
Neverita reclusiana (Deshayes) (pl. 15, figs. 11, 19, 20)	X		X		X						X					cf.			X				X		X		X		X	X	X	X	X	X		F	F	cf.	F	X	X	cf.	X	X	X		?		
Lunatia cf. *L. lewisii* (Gould) (pl. 15, fig. 8)	X		F		X							?							X												?		X	F															
Opalia varicostata Stearns																									X																								
"*Nassa*" *coalingensis* Arnold (pl. 15, fig. 3)					X					X		X							X		F		X	X	X		X			X	X	W		X	?		F							X					
"*Nassa*" cf. "*N.*" *waldorfensis* Arnold																																		X						cf.	X								
Siphonalia sp.																																				F													
Jaton cf. *J. festivus* (Hinds) (pl. 15, figs. 2, 9)			X																X				X							X				X	X								X	X	X				
Tritonalia cf. *T. lurida* (Middendorff) (pl. 15, fig. 12)																																											X						
Nucella etchegoinensis (Arnold)																																	F		X														
Forreria magister munda Stewart, n. var. (pl. 15, figs. 17, 18)																																	X	X	X														
Cancellaria altispira Gabb																																											X						
Cancellaria rapa Nomland (pl. 15, figs. 1, 7)					X																																												
Cancellaria cf. *C. tritonidea* Gabb																																												W					
Progabbia sp. (pl. 15, fig. 4)													X																																				
Olivella sp.																																	F	X	X													X	
Pseudotoma sp.					?																																												
Pelecypods:																																																	
Anadara trilineata (Conrad) of Arnold, and elongate flat variety (pl. 14, fig. 7)	X		X	F	P		X			S, cf.		X			X				X				P	X	S	S			X	S	X	X	X	X	X	F	F	X	F	X			X	X			X	X	
Mytilus coalingensis Arnold					P		X					W							P													W		X			F				F		WF					SWF	
Volsella cf. *V. recta* (Conrad) (pl. 13, fig. 15)					P																																												
Volsella cf. *V. capax* (Conrad) (pl. 16, fig. 3)																			X																														
Botula? sp. (pl. 13, fig. 14)													X																																				
Pecten coalingaensis Arnold (pl. 13, figs. 1, 2, 17, 18; pl. 16, fig. 4)	X	X	X	X	X	X			X	X	X	X	X	X		X		F	X		F		X	X	X		X		X	X	X		X	X	X	F			?							F			
Aequipecten circularis impostor (Hanna) (pl. 13, figs. 3, 4, 6–9)																									S	F							X	F		F					X						X	X	
Chlamys etchegoini (Anderson) (pl. 13, fig. 5)	X																																																
Hinnites sp.				F																																													
Patinopecten cf. *P. healeyi* (Arnold)																																																	
Ostrea vespertina Conrad (pl. 14, fig. 9)	S		S		S				S	S		S		X		X		X					S							X		S		MS	MS		F			S	S	S	X	S	X	F			
Taras sp.																								X																									
Anodonta sp.																														?								?											
Tellina? cf. *T.? oldroydi* Wiedey (pl. 14, fig. 8)					X																												?							X		X		?					
Macoma affinis small variety cf. *M. affinis plena* Stewart, n. var.																																																cf.	
Macoma cf. *M. nasuta* (Conrad) (pl. 14, fig. 5)					X					X	X																													X									
Macoma cf. *M. secta* (Conrad) (pl. 16, fig. 1)																																																	X
Macoma sp.												X							X						X									X															
Semele flavescens (Gould)?																																													F				
Semele rubropicta Dall	X																																												?				
Mactra? cf. *M.? coalingensis* Arnold																																		F															
Schizothaerus cf. *S. nuttallii* (Conrad)																			P															F	F										F				
Saxidomus nuttallii latus Stewart, n. var. (pl. 16, fig. 8)								P																																X					?			?	
Venerupis grata tarda Stewart, n. var. (pl. 13, figs. 10–13)																																																X	
Transennella cf. *T. tantilla* (Gould)																																	X	X															
Trachycardium cf. *T. quadragenarium* (Conrad) (pl. 16, fig. 2)	X			F	SP					X		W				X			X						F					X	F		X	X	WF	F					F			X					
Cerastoderma sp.																																												F					
Chama pellucida Broderip (pl. 14, figs. 1–4, 10)	X	?	X						X			X				X			X		F		X											X	X														
Mya cf. *M. dickersoni* Clark																																		FS		?		X									X	X	
Cryptomya cf. *C. quadrata* Arnold																																																	
Corbula cf. *C. gibbiformis* Grant and Gale																																																	
Solen sp.												X																					X	X			F			X									
Panope cf. *P. generosa* Gould (pl. 14, fig. 11)	W							F											WP																														
Pholadidea ovoidea (Gould) short var. (pl. 14, fig. 6)																																		X															
Zirfaea gabbii Tryon, var.																																																	
Unidentified ostracode (?)																																																	
Barnacles: *Balanus* sp.			X		X			F	X			X	X	X		X					X		X	X					F			X	X	X	X		X			X		X	X	X					
Fish:																																																	
Shark teeth														X		X	X						X	X						X	X			X		X													
Fish remains										[2]X		[2]X	X	[2]X		[2]X			[2]X		X		X		[2]X									[2]X	[2]X												[2]X		
Fish (?) teeth																X																																	
Sting ray (caudal spine; pl. 13, fig. 16)																		X																															
Turtle plate (?)																	X																																
Bird bone (cormorant ulna; identification by Alexander Wetmore)												X																																					
Mammals (identification by C. L. Gazin):																																																	
Beaver teeth (*Castor californicus* Kellogg)												[3]X		X		X				X								X																					
Mastodon bones and molar fragments (*Pliomastodon vexillarius* Matthew (?))												[4]X										F											F						X										
Peccary (cf. *Platygonus*; distal end of humerus)																					[5]X																												
Horse teeth (*Plesippus*)															[6]X		X				[5]X																												
Camel (camelid astragulus)					[7]X							[8]X																																					
Deer (cervid, distal end of cannon bone)												X																																					
Unidentified bones	X																		X		X	F			X									[9]X															
Unidentified tooth																																							X										

West flank of Kettleman Hills (North Dome: 113–130; Middle Dome: 130a–135; South Dome: 137–140b)

Species	113	114	114a	114b	115	116	117	118	118a	119	119a	120[1]	120a[1]	121[1]	122	123[1]	124	127[1]	128[1]	129	130	130a	130b	130c	132	134	135	137	138	139	140	140a	140b
Coral: *Astrangia coalingensis* Vaughan (pl. 16, fig. 7)		X	X		F					?																							
Worm tubes: *Serpula?* sp.		X																															
Echinoids:																																	
Dendraster coalingaensis Twitchell (pl. 45, figs. 1, 2)																		X			?												
Dendraster coalingaensis gibbosus Kew (pl. 45, figs. 5, 6)														X							X				F				cf.				
Dendraster (Merriamaster) perrini (Weaver) (pl. 46, figs. 1, 2, 4, 7, 10, 12)		X			X	X								X					X		cf.										F		
Dendraster (Merriamaster) arnoldi Twitchell (pl. 46, figs. 3, 5, 6, 8, 11, 13 (cf.))														X																			
Unidentified bryozoa																																	
Brachiopod: *Terebratalia* cf. *T. smithi* Arnold (pl. 16, figs. 5, 6)			X																														
Gastropods:																																	
Turcica caffea brevis Stewart, n. var.																																	
Calliostoma coalingense Arnold (pl. 15, figs. 15, 16)												X							X														
Calliostoma cf. *C. gemmulatum* Carpenter (pl. 15, figs. 22, 23)																																	
Calliostoma kerri Arnold (pl. 15, fig. 21)																																	
Littorina mariana Arnold																															X		
Fluminicola kettlemanensis Pilsbry															X																cf.		
Goniobasis kettlemanensis Arnold (pl. 15, figs. 5, 6, 14)											X				X																X		
Calyptraea cf. *C. inornata* (Gabb) (pl. 15, fig. 10)		X																	X						F								
Neverita reclusiana (Deshayes) (pl. 15, figs. 11, 19, 20)	X	X	cf.	cf.	X		X					X	X	X		X		X				cf.	cf.	cf.									
Lunatia cf. *L. lewisii* (Gould) (pl. 15, fig. 8)																																	
Opalia varicostata Stearns																																	
"*Nassa*" *coalingensis* Arnold (pl. 15, fig. 3)							X												cf.								cf.						
"*Nassa*" cf. "*N.*" *waldorfensis* Arnold																																	
Siphonalia sp.																																	
Jaton cf. *J. festivus* (Hinds) (pl. 15, figs. 2, 9)		X										X				X																	
Tritonalia cf. *T. lurida* (Middendorff) (pl. 15, fig. 12)		?																															
Nucella etchegoinensis (Arnold)																					F												
Forreria magister munda Stewart, n. var. (pl. 15, figs. 17, 18)																																	
Cancellaria altispira Gabb																																	
Cancellaria rapa Nomland (pl. 15, figs. 1, 7)																																	
Cancellaria cf. *C. tritonidea* Gabb																																	
Progabbia sp. (pl. 15, fig. 4)																																	
Olivella sp.																																	
Pseudotoma sp.		X																															
Pelecypods:																																	
Anadara trilineata (Conrad) of Arnold, and elongate flat variety (pl. 14, fig. 7)	X	X			F							X		X					X		F										S		
Mytilus coalingensis Arnold							F					W				X		X			WF								F		SWF		
Volsella cf. *V. recta* (Conrad) (pl. 13, fig. 15)																																	
Volsella cf. *V. capax* (Conrad) (pl. 16, fig. 3)																																	
Botula? sp. (pl. 13, fig. 14)																																	
Pecten coalingaensis Arnold (pl. 13, figs. 1, 2, 17, 18; pl. 16, fig. 4)		X	X	F	X			X		X	X						F				F	F	F	F							F	F	F
Aequipecten circularis impostor (Hanna) (pl. 13, figs. 3, 4, 6–9)																						X	X	X	F				X		X	X	F
Chlamys etchegoini (Anderson) (pl. 13, fig. 5)																																	
Hinnites sp.																																	
Patinopecten cf. *P. healeyi* (Arnold)																								F									
Ostrea vespertina Conrad (pl. 14, fig. 9)		S				S	S									S		X	S		X	M	X	X							X	X	
Taras sp.																																	
Anodonta sp.											?				?																		
Tellina? cf. *T.? oldroydi* Wiedey (pl. 14, fig. 8)																																	
Macoma affinis small variety cf. *M. affinis plena* Stewart, n. var.																															cf.		
Macoma cf. *M. nasuta* (Conrad) (pl. 14, fig. 5)												X													?								
Macoma cf. *M. secta* (Conrad) (pl. 16, fig. 1)																											X						
Macoma sp.														X																			
Semele flavescens (Gould)?																																	
Semele rubropicta Dall																																	
Mactra? cf. *M.? coalingensis* Arnold																																	
Schizothaerus cf. *S. nuttallii* (Conrad)																									P								
Saxidomus nuttallii latus Stewart, n. var. (pl. 16, fig. 8)																																	
Venerupis grata tarda Stewart, n. var. (pl. 13, figs. 10–13)																																	
Transennella cf. *T. tantilla* (Gould)																																	
Trachycardium cf. *T. quadragenarium* (Conrad) (pl. 16, fig. 2)			F		F							F		X					X														
Cerastoderma sp.																															?		
Chama pellucida Broderip (pl. 14, figs. 1–4, 10)		F			F			F		X																							
Mya cf. *M. dickersoni* Clark																														X	?		X
Cryptomya cf. *C. quadrata* Arnold												X													?								
Corbula cf. *C. gibbiformis* Grant and Gale																					X												
Solen sp.												X		X					X						F		X						
Panope cf. *P. generosa* Gould (pl. 14, fig. 11)																																	
Pholadidea ovoidea (Gould) short var. (pl. 14, fig. 6)										cf.																							
Zirfaea gabbii Tryon, var.				X	F																												
Unidentified ostracode (?)																										X							
Barnacles: *Balanus* sp.		X			X		X									X			X														
Fish:																																	
Shark teeth			X		X			X																									
Fish remains		X						[2]X	X					X																			X
Fish (?) teeth																																	
Sting ray (caudal spine; pl. 13, fig. 16)								X																									
Turtle plate (?)																																	
Bird bone (cormorant ulna; identification by Alexander Wetmore)																																	
Mammals (identification by C. L. Gazin):																																	
Beaver teeth (*Castor californicus* Kellogg)								X	X																								
Mastodon bones and molar fragments (*Pliomastodon vexillarius* Matthew (?))																																	
Peccary (cf. *Platygonus*; distal end of humerus)																																	
Horse teeth (*Plesippus*)	F																			F													
Camel (camelid astragulus)																																	
Deer (cervid, distal end of cannon bone)																																	
Unidentified bones																																	
Unidentified tooth																																	

[1] *Trachycardium* zone.
[2] "Bulbous fish growths" locally known as "fish flippers."
[3] About 200 feet south of locality 81.
[4] Locality 81a, 100 feet north of locality 81.
[5] 100 feet northwest of locality 89.
[6] Fragments southeast of locality 84, between Arroyo Hondo and Arroyo Pequeño.
[7] About 800 feet southeast of locality 75; collected by Richard Bramkamp.
[8] Camelid? tooth fragments, 1,500 feet southeast of locality 81.
[9] Horse carpal bone (magnum).

Priest Valley, in the Coast Ranges 35 miles northwest of North Dome.[46]

In view of its widespread outcrop the *Pecten* zone may be expected to occur as a marine zone in the San Joaquin Valley subsurface section. According to Barbat and Galloway,[47] a marine zone containing *Corbula* and *"Laevicardium" centifilosum* is present in the subsurface section. Barbat and Galloway correlated this zone with strata in North Dome that appear to represent the *Acila* zone. Inasmuch as the species in the subsurface zone are compatible with the *Pecten* zone fauna and inasmuch as the *Pecten* zone is known to have a more widespread outcrop than the *Acila* zone, a correlation with the *Pecten* zone is more probable. (See fig. 13.) This subsurface zone is presumably the same as that from which *Corbula gibbiformis* was described.[48]

STRATA BETWEEN *PECTEN* ZONE AND *NEVERITA* ZONE

STRATIGRAPHY AND LITHOLOGY

The strata between the *Pecten* and *Neverita* zones have a thickness of 450 to 700 feet. They are made up principally of buff and olive-gray sandy silt and gritty or pebbly sand. Clay is generally a minor constituent but at places is conspicuous.

The clay, silt, and sand immediately underlying the *Pecten* zone are described with that zone. In North Dome these strata include the layers of dark-colored clay that are useful in locating the *Pecten* zone, and on the west flank of Middle and South Domes a thin limestone serves the same purpose.

The aragonite concretions described by Reed[49] occur on Los Morones, at the south end of the Kettleman Hills, about 20 feet stratigraphically below the *Pecten* zone. According to Reed, they are found in poorly washed sand or silt and might have been formed under conditions similar to those on the floor of the Black Sea.

A band of olive-gray silty clay about 100 feet below the *Pecten* zone was mapped around the north end of North Dome. The mastodon remains described by Matthew[50] were collected on Elephant Hill from strata overlying this clay, not from a horizon 100 feet above the upper *Mulinia* zone (upper *Pseudocardium* zone of present report), as Matthew was informed.

Mya occurs in silty clay or silty sandstone about halfway between the *Pecten* and *Neverita* zones on both flanks of southern North Dome (localities 125, 126, 141), on the west flank of the saddle between North and Middle Domes, and on the west flank of northern South Dome. The fossiliferous layers are probably at different horizons in different regions; in fact, at locality 141, a quarter of a mile north of the Paso Robles-Hanford road on the east flank of North Dome, there appear to be four *Mya* layers[51] in a thickness of 90 feet. On the west flank of the North Dome-Middle Dome saddle a *Mya* layer crops out on the crest of the first row of low knolls east of the foot of Las Alturas. Toward the south it grades into nonfossiliferous sandstone. Also on the west flank of northern North Dome *Mya*-bearing sandstone is replaced southward by barren sandstone.

At about the same horizon or closer to the *Pecten* zone fresh-water fossils and leaves were found in silty clay and sandy silt at scattered localities in the three anticlines (localities 95, 125a, 131, 142).

At the north end of North Dome, where fossils were not found, sand and sandstone appear to be more abundant in this part of the section. Olive-buff, iron-stained dirty sandstone, similar to sandstone in the *Neverita* zone, crops out on a branch of Arroyo Largo on the north line of sec. 34, T. 21 S., R. 17 E. (pl. 17, *A*). The sandstone is 4 feet thick and is riddled with borings, some of which extend downward from the upper surface and are filled with sand like that in the overlying bed. The sandstone is overlain by olive-brown coarse-grained cross-bedded sand containing small pebbles of red, green, and black chert, also shown on plate 17, *A*. The angle between cross-bedded laminae and the normal dip is as much as 20°. An excavation at Standard oil well 21-33-J (sec. 33, T. 21 S., R. 17 E.) exposes similar sandstone and sand, possibly the same beds (pl. 17, *B*). In this excavation the cross-bedded sand cuts across the sandstone, reducing its thickness from 2½ feet to a foot in a horizontal distance of 50 feet.

A light-gray tuffaceous sandstone is the most conspicuous lithologic unit in North Dome in the interval between the *Pecten* and *Neverita* zones. It is lower in the section than the strata already described, about 50 to 75 feet above the top of the *Neverita* zone. It is shown at places on the geologic map (pl. 3), but it could be mapped over a larger area, especially on the west flank. The sandstone has an observed thickness of 15 to 25 feet. It is soft but generally forms a low cliff. Fresh glass shards were recognized wherever the sandstone was examined, and at places the shards are so abundant that the rock is virtually a sandy tuff. This sandstone generally contains molds of small *Anadara* and *Solen* and at places molds of *Olivella*. Diatoms were collected from laminae of silt in the sandstone and from silty clay a few feet below the sandstone (localities 143, 144). A section of the tuffaceous sand-

[46] Pack, R. W., and English, W. A., Geology and oil prospects of Waltham, Priest, Bitterwater, and Peachtree Valleys, Calif.: U. S. Geol. Survey Bull. 581, p. 158, 1914. Nomland, J. O., op. cit.

[47] Barbat, W. F., and Galloway, John, San Joaquin clay, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, p. 486, fig. 1 (p. 488), 1934.

[48] Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, p. 420, 1931.

[49] Reed, R. D., Aragonite concretions from the Kettleman Hills, Calif.: Jour. Geology, vol. 34, pp. 829-833, 2 figs., 1926.

[50] Matthew, W. D., A Pliocene mastodon skull from California, *Pliomastodon vexillarius* n. sp.: California Univ., Dept. Geol. Sci., Bull., vol. 19, pp. 335-348, pls. 41-44, 2 figs., 1930. Osborn, H. F., Proboscidea, vol. 1, pp. 161-163, figs. 106-108, 110, New York, 1936.

[51] These layers, of course, do not consist wholly of *Mya* shells. The term "*Mya* layer" is, however, a convenient designation for such beds and is less stilted than the term "*Mya*-bearing bed." The term "*Mya* bed," which is frequently used, conflicts with the usage of the term "bed" in formal stratigraphic nomenclature.

stone and immediately overlying and underlying beds was measured in a cut on the Paso Robles-Hanford road.

Section of strata in lower part of San Joaquin formation between Pecten and Neverita zones including gray tuffaceous sandstone, measured in cut on Paso Robles-Hanford road west of Arroyo Estrecho, northwestern part of sec. 6, T. 23 S., R. 19 E. (locality 143)

	Ft.	in.
Strata overlying gray tuffaceous sandstone:		
8. Massive fine-grained olive-brown sand with thin layers of laminated silt and dirty sand. Basal part contains clay pellets. Iron-stained layer 13 inches above base. Top not exposed	9+	
7. Thin-bedded silty clay, silt, and silty sandstone. The silty clay contains a few corroded diatoms. Borings filled with overlying sand extend down from top for an observed maximum distance of 7 inches	6	11
6. Moderately coarse grained olive-brown sand, and, especially in lower half, thin layers of cross-bedded silty sand and laminae of silt	8	
Gray tuffaceous sandstone:		
5. Gray, iron-stained tuffaceous sandstone, abundant glass shards in thin layers; includes laminae of fine-grained sand and diatomaceous silt. The sandstone has a few molds of small specimens of *Anadara* and *Solen* and is riddled with burrows filled with fine sand. Base not clearly exposed	24	

Section of strata in lower part of San Joaquin formation between Pecten and Neverita zones including gray tuffaceous sandstone, measured in cut on Paso Robles-Hanford road west of Arroyo Estrecho, northwestern part of sec. 6, T. 23 S., R. 19 E. (locality 143)—Continued

	Ft.	in.
Strata underlying gray tuffaceous sandstone:		
4. Silty clay and silt; may represent basal part of overlying sandstone. Contains diatoms (locality 143). Base not exposed		6+
3. Unexposed	10	
2. Moderately coarse grained olive-brown sand. Top not exposed	10+	
1. Laminated silty clay and silt. Silty clay contains diatoms. (Locality 143a represents lowest exposed part.) Base not exposed		5+

FOSSILS

The mollusks and leaves collected from strata between the *Pecten* and *Neverita* zones are listed in the following table. The mollusks consist chiefly of *Mya* and other marine forms that occur in brackish water and of fresh-water species. The *Mya* shells are generally cracked and broken and at places are replaced by gypsum. At locality 141, however, they include paired specimens. The gastropod operculum from locality 142 is of special interest, for it is the first specimen of *Scalez* recorded from an outcrop locality.

Fossils from strata in lower part of San Joaquin formation between Pecten zone and Neverita zone

[Mollusks from localities 125, 125a, 126, and 131 identified by Ralph Stewart; those from localities 141 and 142 identified by W. P. Woodring. Plants identified by R. W. Brown. P, paired valves]

Species	Localities						
	North Dome					Middle Dome	South Dome
	East flank		West flank			West flank	East flank
	95	141	125	125a	126	131[1]	142
Gastropods:							
Scalez petrolia Hanna and Gaylord							X
Fluminicola cf. *F. kettlemanensis* Pilsbry						X	
Goniobasis kettlemanensis Arnold				X		cf.	
Carinifex? sp							X
Pelecypods:							
Mytilus cf. *M. coalingensis* Arnold					X		
Anodonta sp			X	?			P
Gonidea sp				X			
Sphaerium sp				X			
Macoma affinis Nomland, small var. cf. *M. affinis plena* Stewart, n. var. (pl. 15, fig. 13)					X		
Mya cf. *M. dickersoni* Clark		P	X		X		
Solen sp					X		
Plants:							
Salix coalingensis Dorf (willow)	X						X
Umbellaria oregonensis Chaney? (pepperwood)							X
Platanus paucidentata Dorf (sycamore)							X

[1] Fossils observed but not collected.

The diatoms listed in the following table were identified by K. E. Lohman in collections from the gray tuffaceous sandstone and immediately underlying strata. Some of the species are shown on plates 22 and 23. According to Lohman, the flora is marine and includes many pelagic species.

Diatoms from strata in lower part of San Joaquin formation between Pecten and Neverita zones

[Identifications by K. E. Lohman. R, rare; F, few; C, common; A, abundant]

Species	Localities		
	North Dome		
	East flank		West flank
	143	143a	144
Melosira sulcata (Ehrenberg) Kützing	C	C	F
Melosira recedens Schmidt (pl. 23, figs. 13, 14)	A	C	
Melosira sol (Ehrenberg) Kützing	F		R
Melosira solida Eulenstein			R
Melosira granulata (Ehrenberg) Ralfs		R	
Melosira ambigua (Grunow) Müller	R		
Podosira hormoides (Montagne) Kützing var. *adriatica* Grunow	R		
Podosira febigeri Grunow		F	
Stephanopyxis turris (Greville and Arnott) Ralfs			F
Stephanopyxis turris var. *cylindrus* Grunow		F	
Stephanopyxis corona (Ehrenberg) Grunow			C
Endictya oceanica Ehrenberg		F	
Endictya robusta (Greville) Hanna and Grant	R?		
Thalassiosira decipiens (Grunow) Jorgensen			C
Cyclotella striata (Kützing) Grunow	R		
Coscinodiscus excentricus Ehrenberg		F	F
Coscinodiscus anguste-lineatus Schmidt			F
Coscinodiscus lineatus Ehrenberg	F	R	F
Coscinodiscus stellaris Roper			R
Coscinodiscus subtilis Ehrenberg (pl. 22, fig. 6)	F	F	F
Coscinodiscus kutzingii Schmidt		R	
Coscinodiscus cirrus Lohman	F		
Coscinodiscus denarius Schmidt		F	
Coscinodiscus obscurus Schmidt		F	F
Coscinodiscus radiatus Ehrenberg	F	F	F
Coscinodiscus gigas Ehrenberg		F	
Coscinodiscus asteromphalus Ehrenberg (pl. 22, fig. 3)	F	F	R
Coscinodiscus oculus-iridis Ehrenberg	C	F	F
Coscinodiscus pacificus Grunow			R
Coscinodiscus kurzii Grunow	F	F	C
Coscinodiscus cf. *C. elegans* Greville			R
Actinoptychus undulatus Ehrenberg	C	C	C
Actinoptychus cf. *A. areolatus* Ehrenberg	F		
Arachnoidiscus cf. *A. ehrenbergii* Bailey		R	
Asteromphalus brookei Bailey			R
Auliscus caelatus Bailey			R
Actinocyclus ehrenbergii Ralfs	C	A	F
Actinocyclus ehrenbergii var. *ralfsii* (W. Smith) Hustedt			F
Actinocyclus ehrenbergii var. *tenella* (Brebisson) Hustedt	C		F
Actinocyclus subtilis (Gregory) Ralfs			F
Liradiscus oblongus Grunow			R
Rhizosolenia sp		R	
Bacteriastrum hyalinum Lauder			F
Omphalotheca sp. (spore of *Chaetoceros?*)	R	F	C
Goniothecium rogersii Ehrenberg			R
Stephanogonia sp. (spore of *Chaetoceros?*)			F
Xanthiopyxis oblonga Ehrenberg			F
Xanthiopyxis cingulata Ehrenberg			R
Xanthiopyxis ovalis Lohman	R		C
Biddulphia cf. *B. granulata* Roper		R	
Biddulphia roperiana Greville		R	R
Biddulphia peruviana Grunow	R	R	
Biddulphia cf. *B. reticulata* Roper	R		
Terpsinoe americana (Bailey) Ralfs	R		
Hemidiscus ovalis Lohman (pl. 23, fig. 9)	F	C	
Opephora schwartzii (Grunow) Petit			F
Thalassionema nitzschioides Grunow	R	F	
Rhaphoneis amphiceros Ehrenberg			F
Rhaphoneis affinis Grunow			F
Rhaphoneis cf. *R. morsiana* Grunow			F
Rhaphoneis angularis Lohman			F
Rhaphoneis fatula Lohman (pl. 23, fig. 5)	C	C	
Grunoviella gemmata (Grunow) Van Heurck			R
Eunotia pectinalis (Kützing) Rabenhorst			R
Eunotia pectinalis var. *ventralis* (Ehrenberg) Hustedt	R		
Cocconeis scutellum Ehrenberg			R
Cocconeis scutellum var. *baldjikiana* Grunow	R	R	
Pleurosigma cf. *P. affine* Grunow		F	
Caloneis cf. *C. formosa* (Gregory) Cleve			R
Diploneis smithii (Brebisson) Cleve			F
Navicula cf. *N. cuspidata* Kützing	R		
Navicula pennata Schmidt (pl. 23, fig. 16)	F	F	F
Navicula pennata var. *kinkerii* Pantocsek		R	
Navicula lyra Ehrenberg			R
Pinnularia nobilis Ehrenberg			R
Gomphoneis mammilla (Ehrenberg) Cleve	R		
Nitzschia navicularis Grunow	F		R
Nitzschia granulata Grunow (pl. 23, fig. 10)	F	F	F

NEVERITA ZONE

STRATIGRAPHY AND LITHOLOGY

The *Neverita* zone is 450 to 700 feet below the *Pecten* zone. It consists of sandstone and sand and in North Dome, where it is best exposed, it has an average thickness of 50 to 75 feet. At places the zone is as much as 100 feet thick, and toward the south end of Middle Dome it decreases to about 30 feet. In South Dome a sand doubtfully identified as the *Neverita* zone is 20 feet thick.

The type locality of the *Neverita* zone is on the east side of Arroyo Bifido northward from the south line of sec. 35, T. 21 S., R. 17 E. (pl. 18, *A*). The name of the zone is unsatisfactory, for *Neverita* occurs at various horizons in the San Joaquin formation, and at places it is more abundant in the *Pecten* and *Trachycardium* zones than in the *Neverita* zone itself. Nevertheless, this genus is common in the *Neverita* zone and it is not known to occur at lower horizons in the San Joaquin formation except in the Cascajo conglomerate member, which contains broken and worn specimens. Moreover, the faunal association characteristic of the *Neverita* zone was not found at other horizons. The *Neverita* zone has been informally designated the *Natica-Mya* zone by some field geologists.

The *Neverita* zone includes two lithologic types: (1) sandstone and (2) a much thicker loose sand. (1) The sandstone is buff, iron-stained, medium-grained, poorly sorted, and dirty. Though uncemented, aside from lumps that have a ferruginous or calcareous cement, it is firm enough to form low cliffs on steep slopes. It is generally massive; at some places, however, it has discontinuous silt partings and at others it includes thin beds of olive-brown sand. The sandstone contains small pebbles, consisting principally of black chert and white quartz, that are scattered or are concentrated in lenses, particularly at the base. Layers of fossils occur in the sandstone at different horizons at one locality or apparently at the same horizon at different localities, representing different faunal associations. (2) The sand is coarse-grained, relatively well sorted and clean, and olive brown. Ferruginous cement forms irregular lumps. The sand also contains pebbles and is locally cross-bedded. Much of the sand is barren of fossils, but sand dollars are more abundant in the sand, especially near the base, than in the sandstone. The approximate mineral composition of a sample of sandstone and sand, as determined by M. N. Bramlette, is given below.

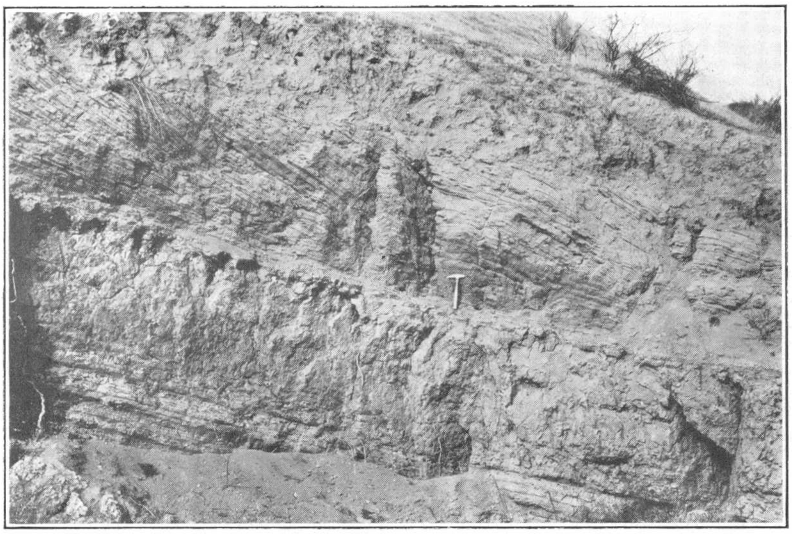
Approximate mineral composition of sand and sandstone in Neverita zone of San Joaquin formation

[Determined by M. N. Bramlette]

Mineral groups	Relative abundance	Sand [1]		Sandstone [2]	
Heavy minerals.	Abundant.	Magnetite. Green hornblende. Augite. Brown hornblende.	30 ± percent.	Magnetite. Augite. Green hornblende. Brown hornblende.	15–20 percent.
	Common.	Epidote. Titanite. Apatite.		Epidote. Actinolite.	
	Rare.	Zircon. Glaucophane.		Titanite. Garnet. Apatite. Zircon. Glaucophane. Tourmaline.	
Light minerals.	Abundant.	"Zeolitic" mineral. Andesine. Quartz.	70 ± percent.	"Zeolitic" mineral. Fresh, zoned andesine. Labradorite. Quartz.	80–85 percent.
	Common.	Orthoclase. Serpentine. Microcrystalline rock aggregates.		Orthoclase. Serpentine. Chlorite. Clay minerals.	
	Rare.				

[1] Collected from west side of Arroyo Bifido, sec. 35, T. 21 S., R. 17 E., by John Galloway.

[2] Collected from head of branch of Arroyo Largo, western part of sec. 3, T. 22 S., R. 17 E., unit 5 of section on p. 44.

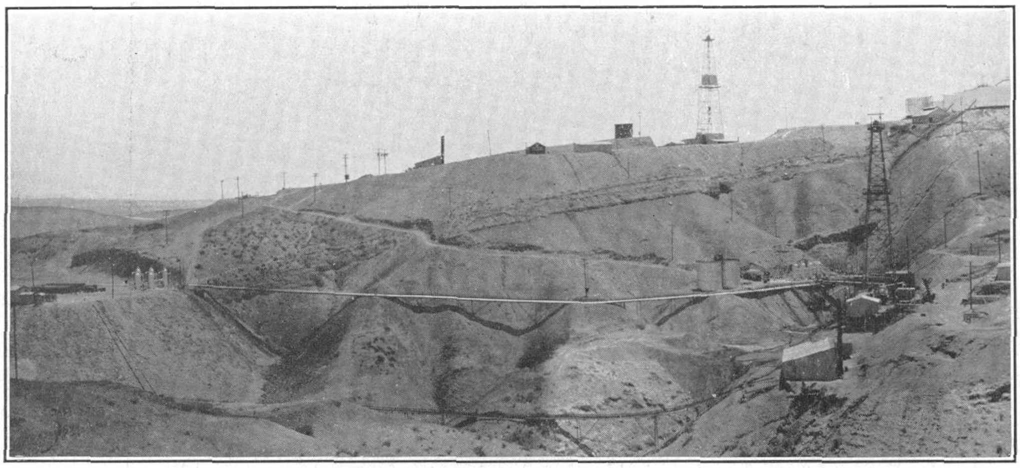


A. SANDSTONE AND CROSS-BEDDED SAND OF SAN JOAQUIN FORMATION ON BRANCH OF ARROYO LARGO AT NORTH LINE OF SEC. 34, T. 21 S., R. 17 E.

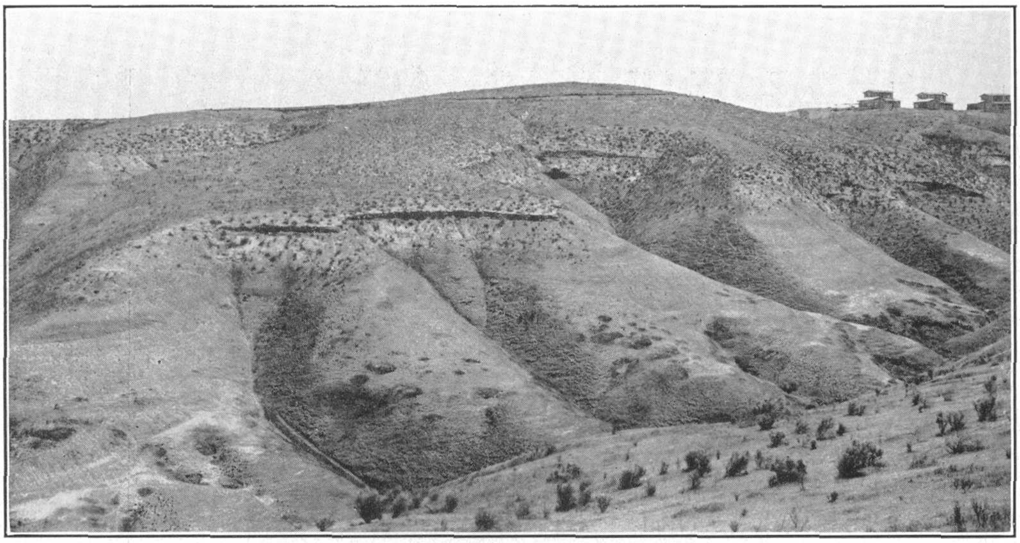
B. SANDSTONE OF SAN JOAQUIN FORMATION RIDDLED WITH BORINGS. EXCAVATION AT STANDARD WELL 21-33-J, SEC. 33, T. 21 S., R. 17 E.

C. SECOND *MYA* LAYER ABOVE *LITTORINA* ZONE OF ETCHEGOIN FORMATION ON ROAD NORTHWEST OF DOUBLE HILL IN SEC. 2, T. 22 S., R. 17 E.

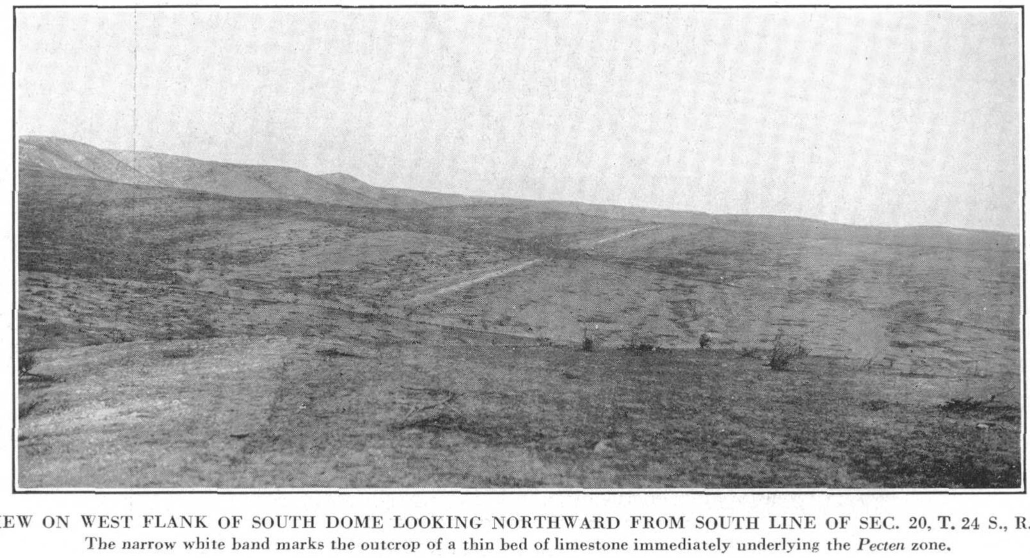
SANDSTONE AND SAND IN SAN JOAQUIN AND ETCHEGOIN FORMATIONS OF NORTH DOME.



A. NEVERITA ZONE AT TYPE LOCALITY ON EAST SIDE OF ARROYO BIFIDO, SEC. 35, T. 21 S., R. 17 E.
Basal sandstone and lower part of overlying sand form low cliff under derrick on skyline.



B. NEVERITA ZONE ON EAST SIDE OF BRANCH OF ARROYO LARGO IN WESTERN PART OF SEC. 3, T. 22 S., R. 17 E.
Basal sandstone forms low cliff; overlying sand extends to top of ridge.



C. VIEW ON WEST FLANK OF SOUTH DOME LOOKING NORTHWARD FROM SOUTH LINE OF SEC. 20, T. 24 S., R. 19 E.
The narrow white band marks the outcrop of a thin bed of limestone immediately underlying the *Pecten* zone.

NEVERITA AND *PECTEN* ZONES OF SAN JOAQUIN FORMATION.

LIMY SANDSTONE FROM *NEVERITA* LAYER OF BASAL SANDSTONE OF *NEVERITA* ZONE SHOWING CHARACTERISTIC FAUNAL ASSOCIATION.

From butte in southeastern part of sec. 33, T. 21 S., R. 17 E., locality 163. Natural size.

a. *Neverita reclusiana* (Deshayes)
b. *Olivella* cf. *O. pedroana* (Conrad)
c. *Anadara trilineata* (Conrad) of Arnold
d. *Volsella* fragments

PLATE 20

[Figures natural size unless otherwise designated]

FIGURES 1–5. *Neverita reclusiana* (Deshayes).

1. Exfoliated specimen. Height (incomplete) 32.5 mm., width (incomplete) 31 mm. Locality 148a. U. S. Nat. Mus. 495318.
2. Variety. Height (virtually complete) 36 mm., width (almost complete) 33 mm. Locality 171. U. S. Nat. Mus. 495319.
3. Height 34.6 mm., width 29.8 mm. Locality 171. U. S. Nat. Mus. 495320.
4. Variety. Height 23 mm., width (almost complete) 21.8 mm. Locality 152. U. S. Nat. Mus. 495321.
5. Height (incomplete) 23.2 mm., width (incomplete) 20.8 mm. Locality 149. U. S. Nat. Mus. 495322.

6. *Calyptraea* cf. *C. inornata* (Gabb). Height about 18 mm., greatest diameter 26 mm. Locality 155. U. S. Nat. Mus. 495324.

7. *Mitrella gausapata* (Gould). Height (incomplete) 10.5 mm., width (almost complete) 5.8 mm. Locality 165. U. S. Nat. Mus. 495323.

8, 9. *Olivella* cf. *O. pedroana* (Conrad). Locality 145.

8. Height (incomplete) 13.2 mm., width 7.3 mm. U. S. Nat. Mus. 495325.
9. Height 12 mm., width 5.5 mm. U. S. Nat. Mus. 495326.

10, 11. *Dendraster gibbsii* (Rémond), small var. Locality 164.

10. Length 35.1 mm., width 42.3 mm., height 7.7 mm. (also shown on pl. 22, fig. 3). U. S. Nat. Mus. 495335.
11. Length 39.6 mm., width 42.9 mm., height 7.9 mm. (also shown on pl. 22, fig. 5). U. S. Nat. Mus. 495336.

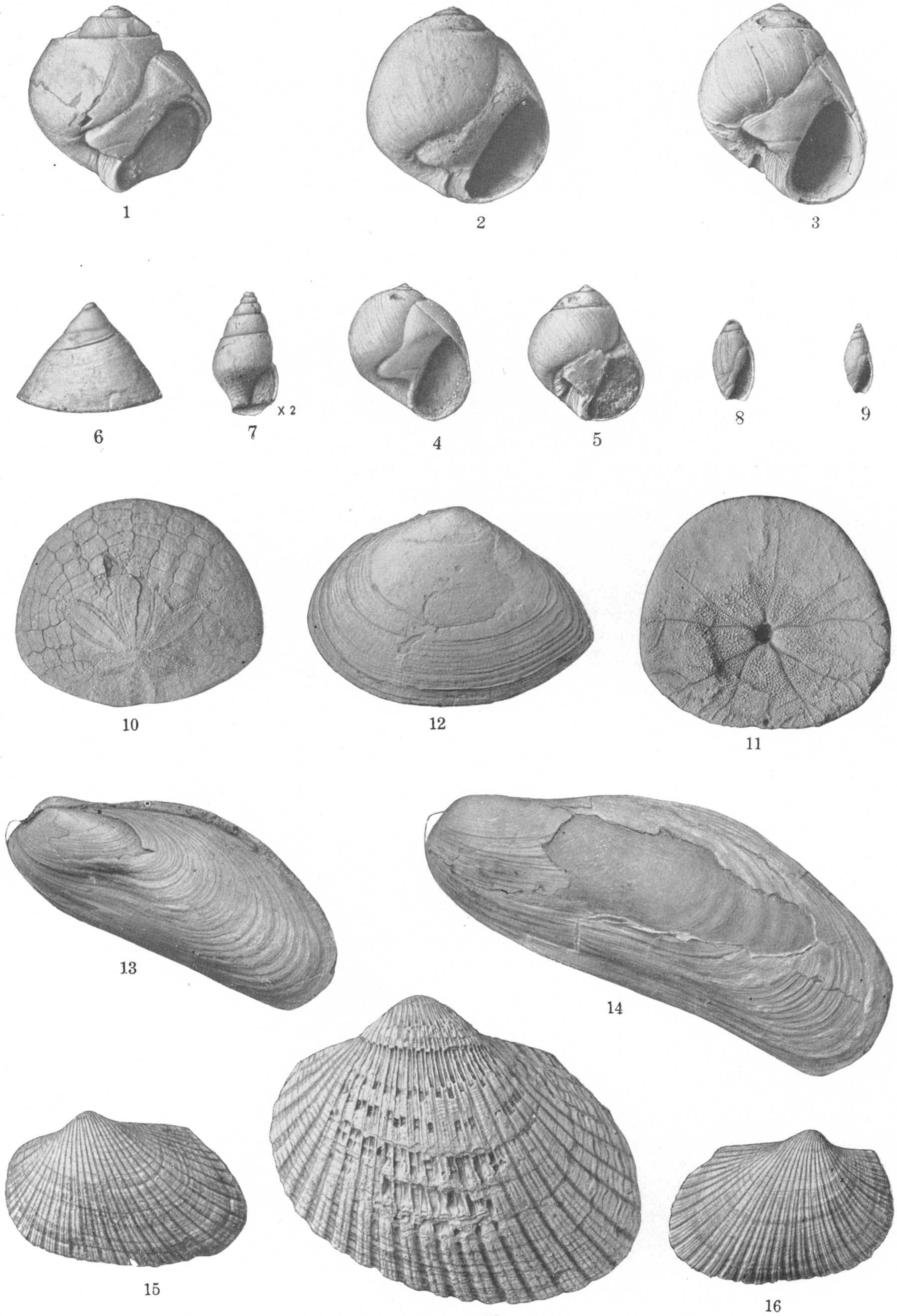
12. *Macoma* cf. *M. nasuta* (Conrad). Length 49.8 mm., height 34.7 mm., thickness of both valves about 14 mm. Locality 161. U. S. Nat. Mus. 495327.

13, 14. *Volsella* cf. *V. recta* (Conrad).

13. Greatest length 61.9 mm., width 27 mm., thickness of both valves 19.9 mm. Locality 148. U. S. Nat. Mus. 495330.
14. Greatest length (almost complete) 86 mm., width 34.8 mm., thickness of both valves 26.7 mm. Locality 153. U. S. Nat. Mus. 495328.

15–17. *Anadara trilineata* (Conrad) of Arnold.

15. Elongate flat variety. Length 40.9 mm., height 26.4 mm., thickness 9.7 mm. Locality 154. U. S. Nat. Mus. 495329.
16. Elongate flat variety. Length 41 mm., height 27 mm., thickness 10 mm. Locality 154. U. S. Nat. Mus. 495331.
17. Length 67.5 mm., height 52.5 mm., thickness 22 mm. Locality 161. U. S. Nat. Mus. 495332.



FOSSILS FROM *NEVERITA* ZONE OF SAN JOAQUIN FORMATION.

PLATE 21

[Figures natural size unless otherwise designated]

FIGURES 1, 2. *Platyodon colobus* Woodring, n. sp. Locality 151.

1. Type. Length (incomplete) 66.8 mm., height (almost complete) 51.5 mm., thickness of both valves about 40 mm. U. S. Nat. Mus. 495333.

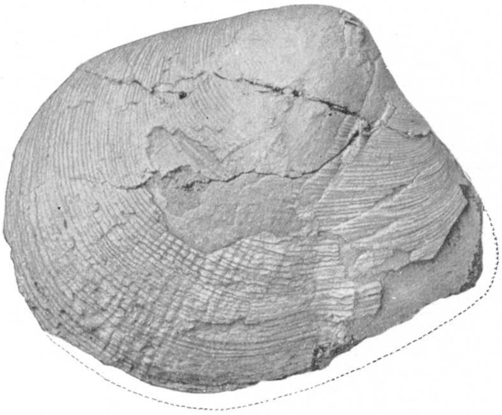
2. Length (incomplete) 67 mm., height 55.5 mm., thickness about 29 mm. U. S. Nat. Mus. 495334.

3–6. *Dendraster gibbsii* (Rémond), small var.

3. Length 35.1 mm., width 42.3 mm., height 7.7 mm. (also shown on pl. 21, fig. 10). Locality 164. U. S. Nat. Mus. 495335.

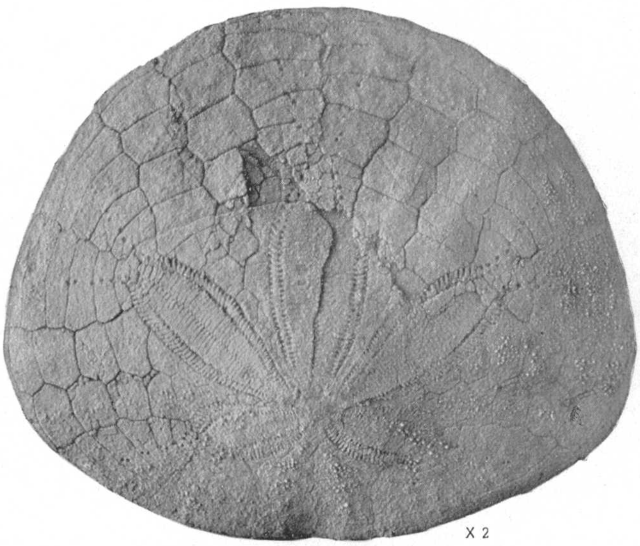
4, 5. Length 39.6 mm., width 42.9 mm., height 7.9 mm. (also shown on pl. 21, fig. 11). Locality 164. U. S. Nat. Mus. 495336.

6. Length 34 mm., width 38.5 mm., height (crushed) 6.5 mm. Locality 163a. U. S. Nat. Mus. 495337.



1

2



X 2

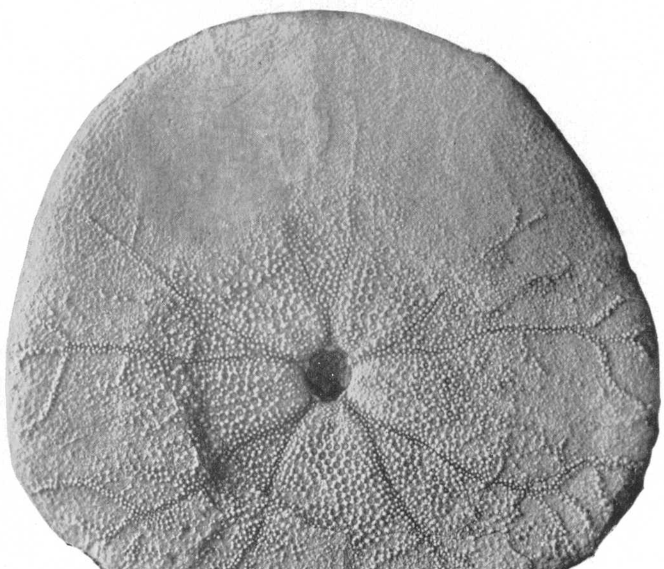
3

X 2

6

X 2

4



X 2

5

FOSSILS FROM *NEVERITA* ZONE OF SAN JOAQUIN FORMATION.

PLATE 22

FIGURE 1. *Coscinodiscus obscurus* Schmidt. Diameter 0.118 mm. Locality 168, *Neverita* zone. U. S. G. S. diatom catalog No. 1524–7.

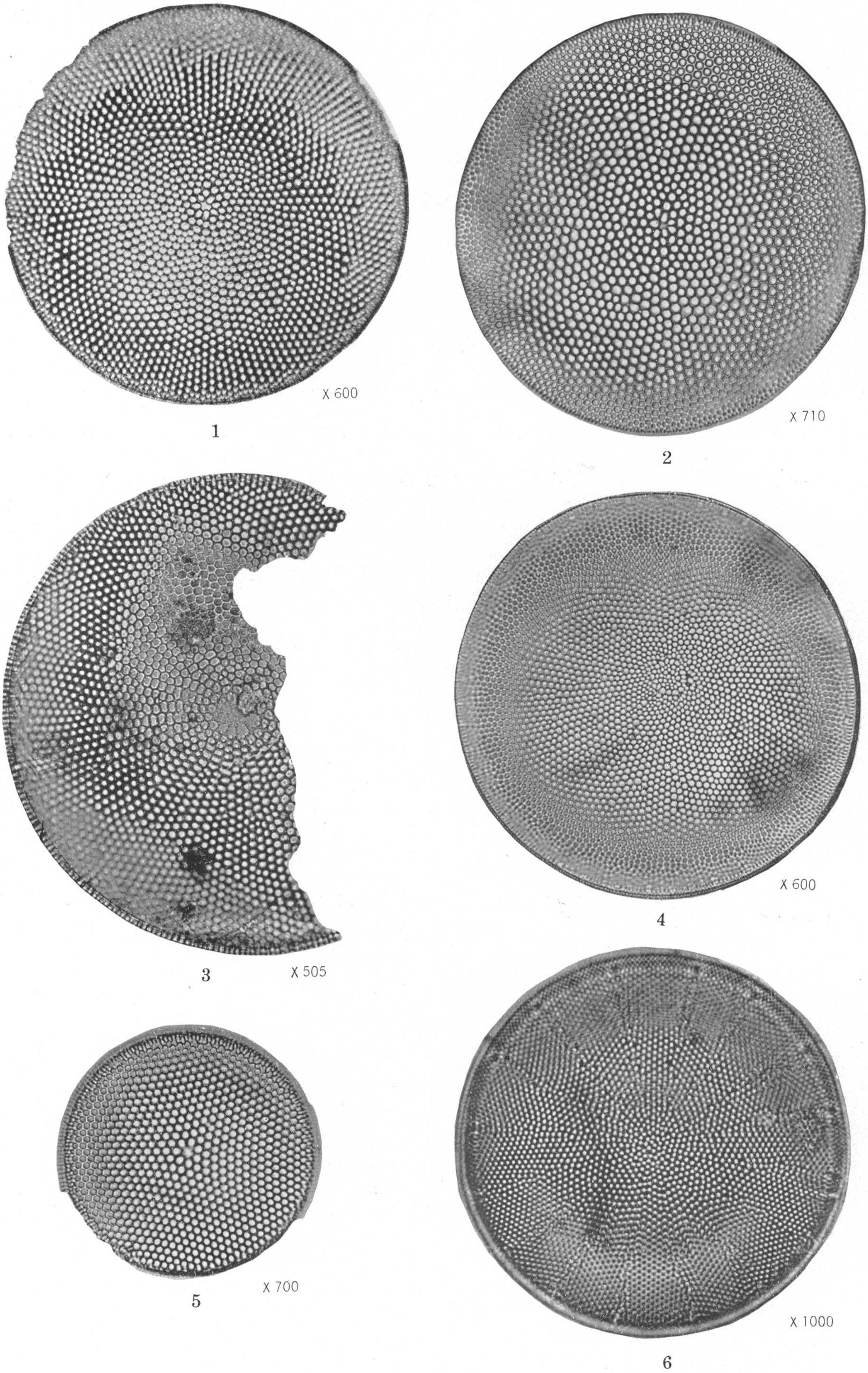
2. *Coscinodiscus kurzii* Grunow. Diameter 0.105 mm. Locality 173, *Neverita* zone. U. S. G. S. diatom catalog No. 1630–3.

3. *Coscinodiscus asteromphalus* Ehrenberg. Diameter 0.170 mm. Locality 143a, clay underlying tuffaceous sandstone between *Pecten* and *Neverita* zones. U. S. G. S. diatom catalog No. 1508–4.

4. *Coscinodiscus cirrus* Lohman. Holotype. Diameter 0.121 mm. Locality 173, *Neverita* zone. U. S. G. S. diatom catalog No. 1630–1.

5. *Coscinodiscus excentricus* Ehrenberg. Diameter 0.066 mm. Locality 173, *Neverita* zone. U. S. G. S. diatom catalog No. 1630–2.

6. *Coscinodiscus subtilis* Ehrenberg. Diameter 0.071 mm. Locality 144, tuffaceous sandstone, between *Pecten* and *Neverita* zones. U. S. G. S. diatom catalog No. 1507–1.



DIATOMS FROM *NEVERITA* ZONE OF SAN JOAQUIN FORMATION AND FROM STRATA IN SAN JOAQUIN FORMATION BETWEEN *PECTEN* AND *NEVERITA* ZONES.

PLATE 23

FIGURE 1. *Actinocyclus ehrenbergii* Ralfs. Diameter 0.063 mm. Locality 173, *Neverita* zone. U. S. G. S. diatom catalog No. 1630–4.

2. *Stephanopyxis corona* (Ehrenberg) Grunow. Diameter 0.037 mm. Locality 168, *Neverita* zone. U. S. G. S. diatom catalog No. 1524–6.

3. *Actinoptychus undulatus* Ehrenberg. Diameter 0.065. Locality 168, *Neverita* zone. U. S. G. S. diatom catalog No. 1524–4.

4. *Epithemia turgida* (Ehrenberg) Kützing. Length 0.091 mm., width 0.019 mm. Locality 168, *Neverita* zone. U. S. G. S. diatom catalog No. 1524–8.

5. *Rhaphoneis fatula* Lohman. Holotype. Length 0.046 mm., width 0.008 mm. Locality 143a, clay underlying tuffaceous sandstone, between *Pecten* and *Neverita* zones. U. S. G. S. diatom catalog No. 1508–3.

6–8. *Rhaphoneis angularis* Lohman. Locality 168, *Neverita* zone.
- 6. Holotype. Length 0.142 mm., width 0.020 mm. U. S. G. S. diatom catalog No. 1524–1.
- 7. Paratype. Length 0.119 mm., width 0.020 mm. U. S. G. S. diatom catalog No. 1524–2.
- 8. Paratype. Length 0.066 mm., width 0.020 mm. U. S. G. S. diatom catalog No. 1524–3.

9. *Hemidiscus ovalis* Lohman. Holotype. Length 0.028 mm., width 0.021 mm. Locality 143a, clay underlying tuffaceous sandstone, between *Pecten* and *Neverita* zones. U. S. G. S. diatom catalog No. 1508–1.

10. *Nitzschia granulata* Grunow. Length 0.038 mm., width 0.016 mm. Locality 143, tuffaceous sandstone, between *Pecten* and *Neverita* zones. U. S. G. S. diatom catalog No. 1522–1.

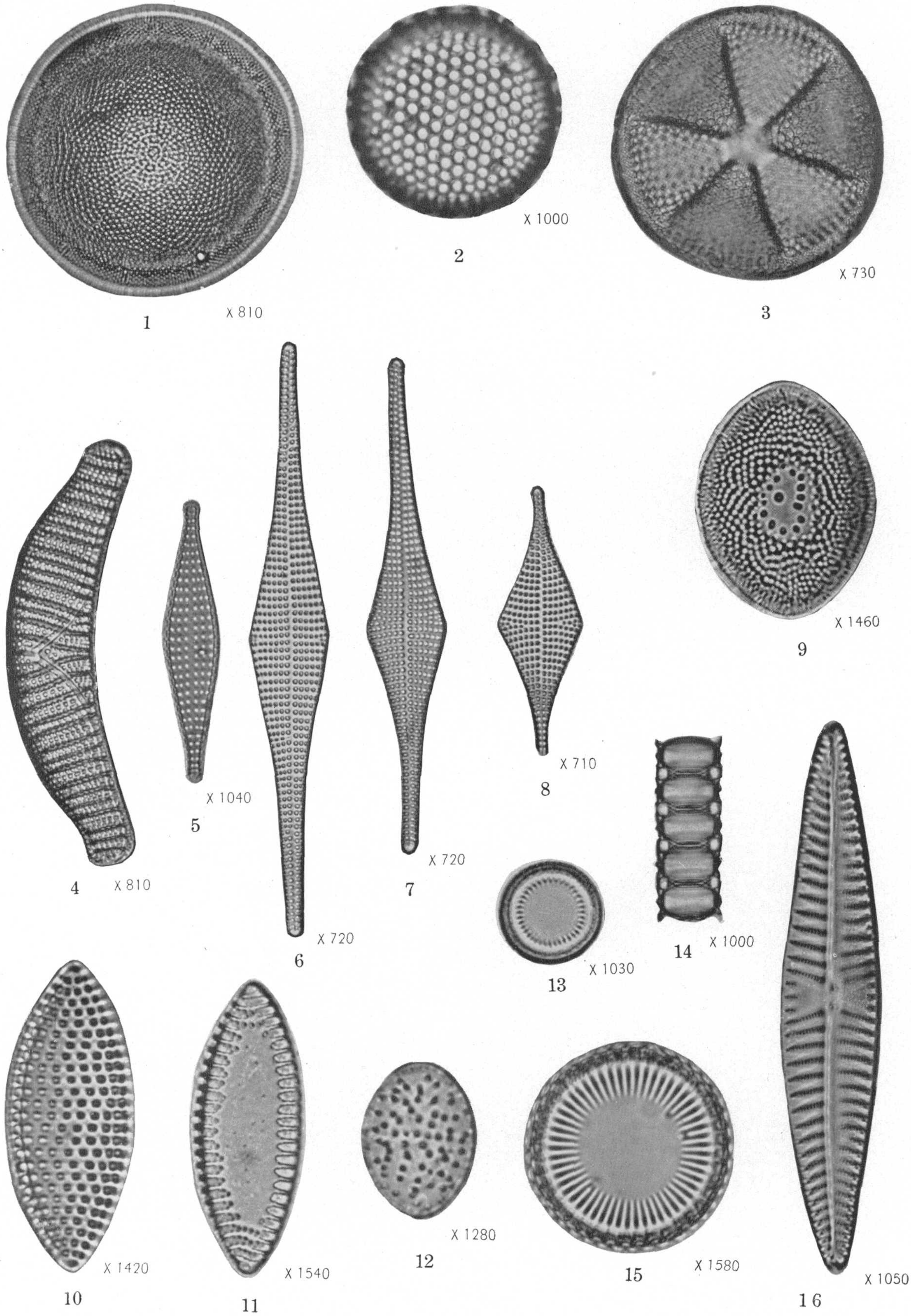
11. *Nitzschia navicularis* Grunow. Length 0.033 mm., width 0.012 mm. Locality 168, *Neverita* zone. U. S. G. S. diatom catalog No. 1524–9.

12. *Xanthiopyxis ovalis* Lohman. Holotype. Length 0.021 mm., width 0.015 mm. Locality 168, *Neverita* zone. U. S. G. S. diatom catalog No. 1517–1.

13, 14. *Melosira recedens* Schmidt. Locality 143, tuffaceous sandstone, between *Pecten* and *Neverita* zones.
- 13. Valve view. Diameter 0.017 mm. U. S. G. S. diatom catalog No. 1522–3.
- 14. Zone view, four frustules and two valves. Diameter 0.011 mm., length over all 0.032 mm. U. S. G. S. diatom catalog No. 1522–2.

15. *Melosira sulcata* (Ehrenberg) Kützing. Diameter 0.023 mm. Locality 168, *Neverita* zone. U. S. G. S. diatom catalog No. 1524–5.

16. *Navicula pennata* Schmidt. Length 0.090 mm., width 0.017 mm. Locality 144, tuffaceous sandstone, between *Pecten* and *Neverita* zones. U. S. G. S. diatom catalog No. 1507–2.



DIATOMS FROM *NEVERITA* ZONE OF SAN JOAQUIN FORMATION AND FROM STRATA IN SAN JOAQUIN FORMATION BETWEEN *PECTEN* AND *NEVERITA* ZONES.

PLATE 24

[Figures natural size unless otherwise designated]

FIGURE 1. *Solen perrini* Clark. Length (incomplete) 57 mm., height 21 mm., thickness 7.3 mm. Locality 175, upper oolite of San Joaquin formation. U. S. Nat. Mus. 495338.

2. *Mya* cf. *M. dickersoni* Clark. Length 74.5 mm., height 47 mm., thickness (not including chrondophore) 14 mm. Locality 175, upper oolite of San Joaquin formation. U. S. Nat. Mus. 495339.

3. *Macoma affinis plena* Stewart, n. var. Length 36.4 mm., height 30 mm., thickness 8 mm. Locality 175, upper oolite of San Joaquin formation. U. S. Nat. Mus. 495340.

4–6. *Psephidia* n. sp.? Locality 175, upper oolite of San Joaquin formation.
- 4. Length 3.9 mm., height 4 mm., thickness of both valves 2.4 mm. U. S. Nat. Mus. 495341.
- 5. Specimen partly covered with oolitic coat. Length 3.1 mm., height 3.1 mm., thickness of both valves 1.8 mm. U. S. Nat. Mus. 495342.
- 6. Length 2.6 mm., height 2.5 mm., thickness 0.9 mm. U. S. Nat. Mus. 495343.

7. *Anadara trilineata* (Conrad) of Arnold, var. cf. *canalis* (Conrad). Length 55.5 mm., height 44.5 mm., thickness 18 mm. Locality 178, *Cerastoderma*-bearing sandstone of San Joaquin formation. U. S. Nat. Mus. 495344.

8, 9. *Cerastoderma* cf. *C. meekianum* (Gabb). Length 57.6 mm., height 59.6 mm., thickness about 22.5 mm. Locality 178, *Cerastoderma*-bearing sandstone of San Joaquin formation. U. S. Nat. Mus. 495345.

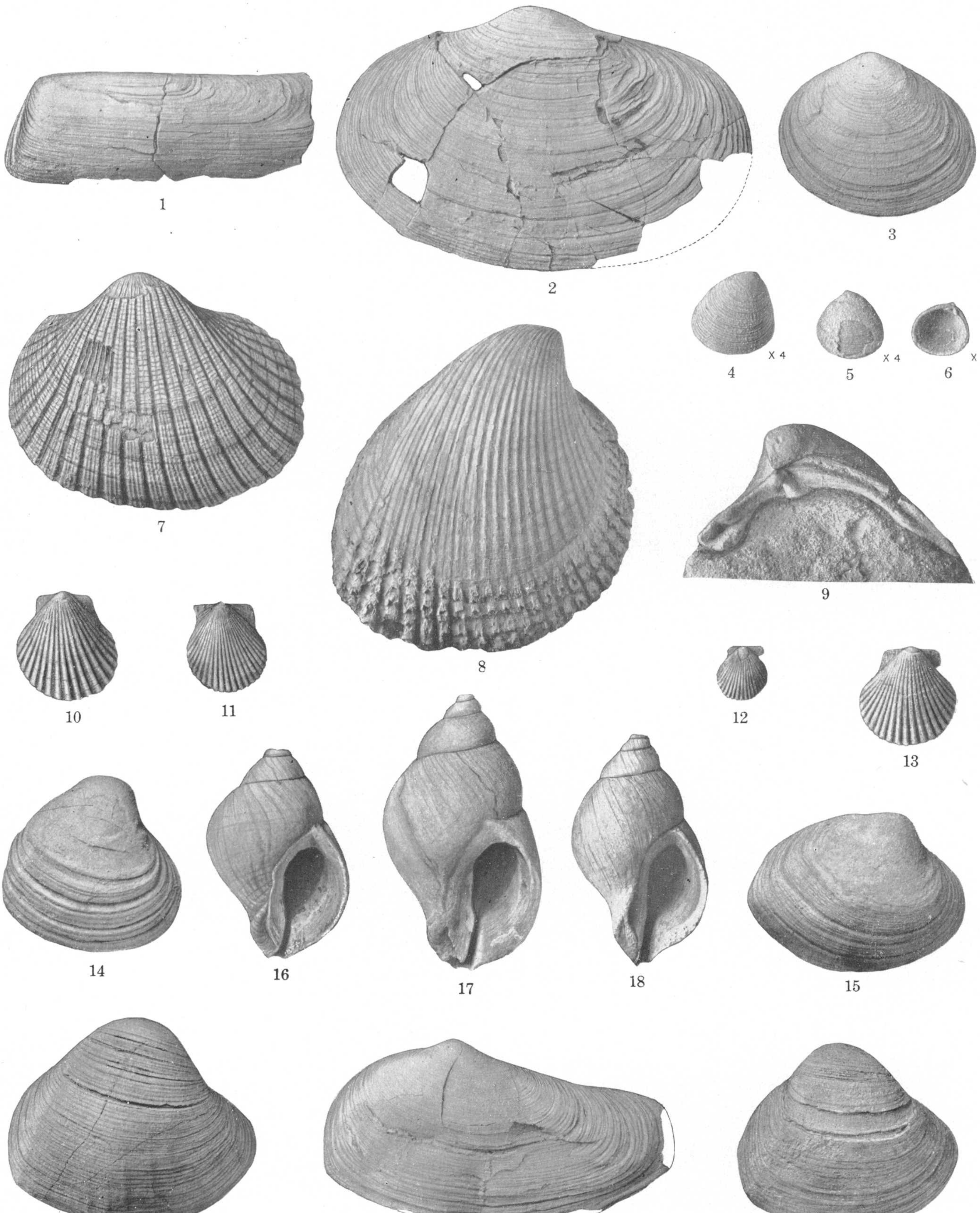
10–13. *Aequipecten circularis eldridgei* (Arnold). Locality 214, Cascajo conglomerate member of San Joaquin formation.
- 10. Length 18.4 mm., height 19.9 mm., thickness 5.3 mm. U. S. Nat. Mus. 495346.
- 11. Length 14.9 mm., height 16.6 mm., thickness 3.7 mm. U. S. Nat. Mus. 495347.
- 12. Length 9.3 mm., height 9.6 mm., thickness 2.5 mm. U. S. Nat. Mus. 495348.
- 13. Length 17.8 mm., height 18.1 mm., thickness 5.7 mm. U. S. Nat. Mus. 495349.

14, 15. *Pseudocardium densatum* (Conrad) of Arnold, vars. Locality 203, Cascajo conglomerate member of San Joaquin formation.
- 14. Right valve. Length 33.2 mm., height (almost complete) 32 mm., thickness 13 mm. U. S. Nat. Mus. 495350.
- 15. Right valve. Length 40 mm., height 30 mm., thickness 12.8 mm. U. S. Nat. Mus. 495351.

16–18. *Nucella etchegoinensis* (Arnold). Cascajo conglomerate member of San Joaquin formation.
- 16. Height (incomplete) 38.7 mm., width 26 mm. Locality 209. U. S. Nat. Mus. 495352.
- 17. Height (incomplete) 52 mm., width 28.6 mm. Locality 204. U. S. Nat. Mus. 495353.
- 18. Height (incomplete) 43 mm., width 25 mm. Locality 203. U. S. Nat. Mus. 495354.

19, 20. *Pseudocardium densatum* (Conrad) of Arnold, medium-sized var. *Pseudocardium-Anadara* zone of Etchegoin formation.
- 19. Right valve. Length 46 mm., height 38.7 mm., thickness 17.5 mm. Locality 345. U. S. Nat. Mus. 495355.
- 20. Right valve. Length 40.9 mm., height 34.8 mm., thickness 15 mm. Locality 344. U. S. Nat. Mus. 495356.

21. *Mya* cf. *M. dickersoni* Clark. Length (almost complete) 62 mm., height (incomplete and somewhat crushed) 32.3 mm., thickness (not including chondrophore) 10 mm. Locality 346. *Pseudocardium-Anadara* zone of Etchegoin formation. U. S. Nat. Mus. 495357.



FOSSILS FROM LOWER PART OF SAN JOAQUIN FORMATION AND UPPER PART OF ETCHEGOIN FORMATION.

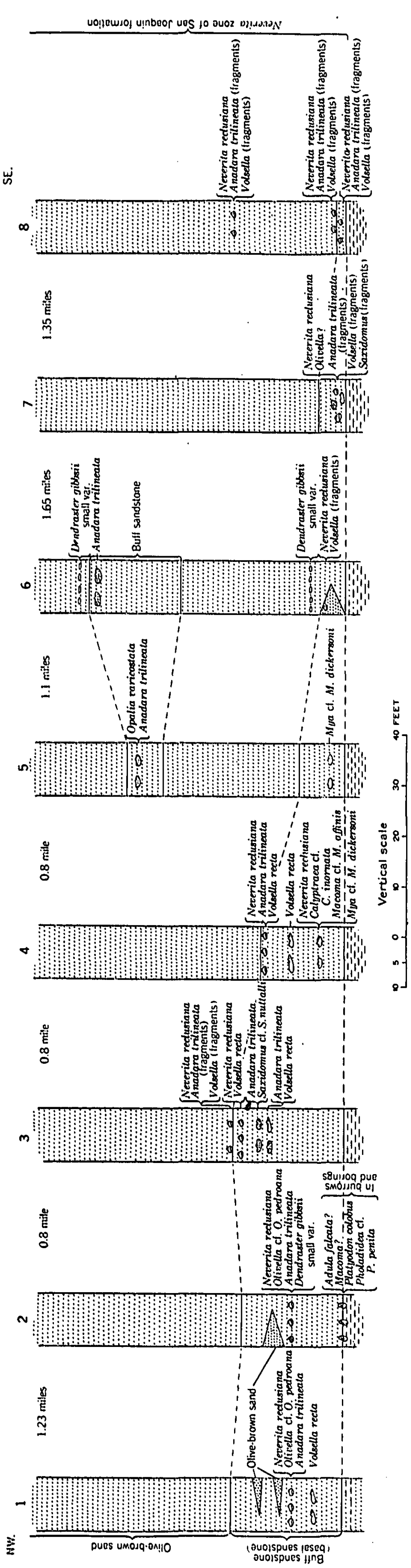


FIGURE 3.—Sections showing fossiliferous layers in *Neverita* zone of San Joaquin formation on east flank of North Dome. Upper part of sand not represented in sections. Figures between columns represent distances between sections.

1. Avenal-Lemoore road, 450 feet southwest of Standard oil well 47-35-5, sec. 35, T. 21 S., R. 17 E.
2. Branch of Arroyo Torcido, northern part of sec. 1, T. 22 S., R. 17 E. (composite section, localities 150, 151).
3. Ridge southeast of Arroyo Torcido, southwestern part of sec. 6, T. 22 S., R. 18 E.
4. Northwest of Arroyo Hondo, northeastern part of sec. 7, T. 22 S., R. 18 E. (locality 155).
5. Between forks of Arroyo Hondo, near center of sec. 8, T. 22 S., R. 18 E. (locality 158).
6. Northwest of Arroyo Doblegado, northwestern part of sec. 16, T. 22 S., R. 18 E. (locality 160).
7. North side of Arroyo Robador, northern part of sec. 22, T. 22 S., R. 18 E. (locality 162).
8. Branch of Arroyo Robador, northwestern part of sec. 26, T. 22 S., R. 18 E.

According to Bramlette, the greater percentage of heavy minerals in the sand and the greater abundance of the "zeolitic" mineral in the sandstone constitute the principal differences in mineral composition. Both kinds of rock contain pyroclastic debris of the composition of augite andesite and hornblende andesite, though volcanic glass was not recognized in either. The "zeolitic" mineral is probably an alteration product of glass and appears to be one of the heulandite-clinoptilolite group. The matrix of the sandstone consists of a feltlike mass of this mineral in fine crystals about 0.02 millimeter long. This mineral gives the sandstone the dirty appearance that in the field was attributed to silt and clay. It also serves as a binder for the sand grains.

North Dome.—On the east flank of North Dome a fossiliferous sandstone, designated the basal sandstone, generally lies at the base of the *Neverita* zone. (See fig. 3.) The basal sandstone has an observed thickness of 5 to 25 feet. It contains one or more layers of fossils, a *Neverita* layer in the upper part generally being the most conspicuous. The basal sandstone rests on clay or silty sandstone. Where the base is well exposed the contact is sharp and slightly irregular. At several localities burrowing and boring fossils were found in living positions penetrating the underlying stratum (fig. 3, column 2).

On the ridge southeast of Arroyo Torcido a lens of coarse-grained cross-bedded blue sandstone that rapidly thickens to 15 feet appears in the basal sandstone, as shown in figure 4. The blue sandstone fills channels 5 feet deep.

Across Arroyo Doblegado and nearby the basal sandstone is absent, but a similar fossiliferous sandstone, in which *Neverita* was not found, occurs at a horizon 30 feet or more above the base of the *Neverita* zone (fig. 3, columns 5, 6). Farther southeast the basal sandstone again appears (fig. 3, columns 7, 8). Toward the south end of the anticline exposures are poor in the area where the zone would be expected to occur, and the zone was not recognized.

On the west flank of North Dome the basal sandstone has generally only one layer of fossils, a *Neverita* layer. (See fig. 5.) The layer is near the base of the sandstone except at the north end of the anticline, where it is near the top. The basal sandstone and the lower part of the overlying sand are well exposed on the two little buttes in the southeastern part of sec. 33, T. 21 S., R. 17 E. (fig. 5, column 2), and on the east side of the branch of Arroyo Largo in the western part of sec. 3, T. 22 S., R. 17 E. (pl. 18, *B;* fig. 5, column 3). The section below was measured at the latter locality.

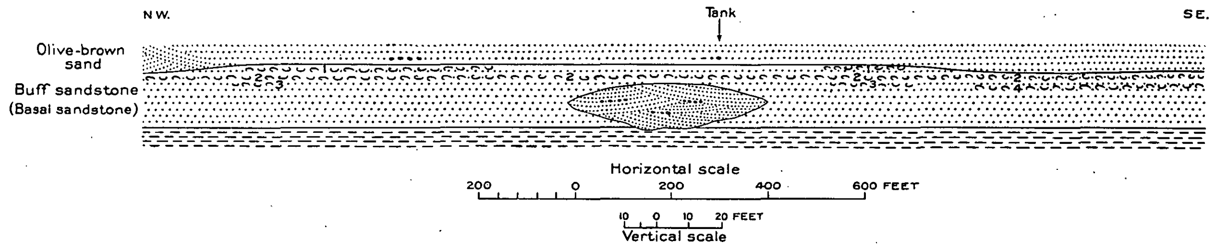


FIGURE 4.—Lower part of *Neverita* zone of San Joaquin formation on ridge southeast of Arroyo Torcido, southwestern part of sec. 6, T. 22 S., R. 18 E. Nos. 1 to 4 indicate fossiliferous layers. The broad shallow channels at the top of the basal sandstone were not observed but are based on the position of the base of the overlying sand with reference to fossiliferous layers in the basal sandstone.

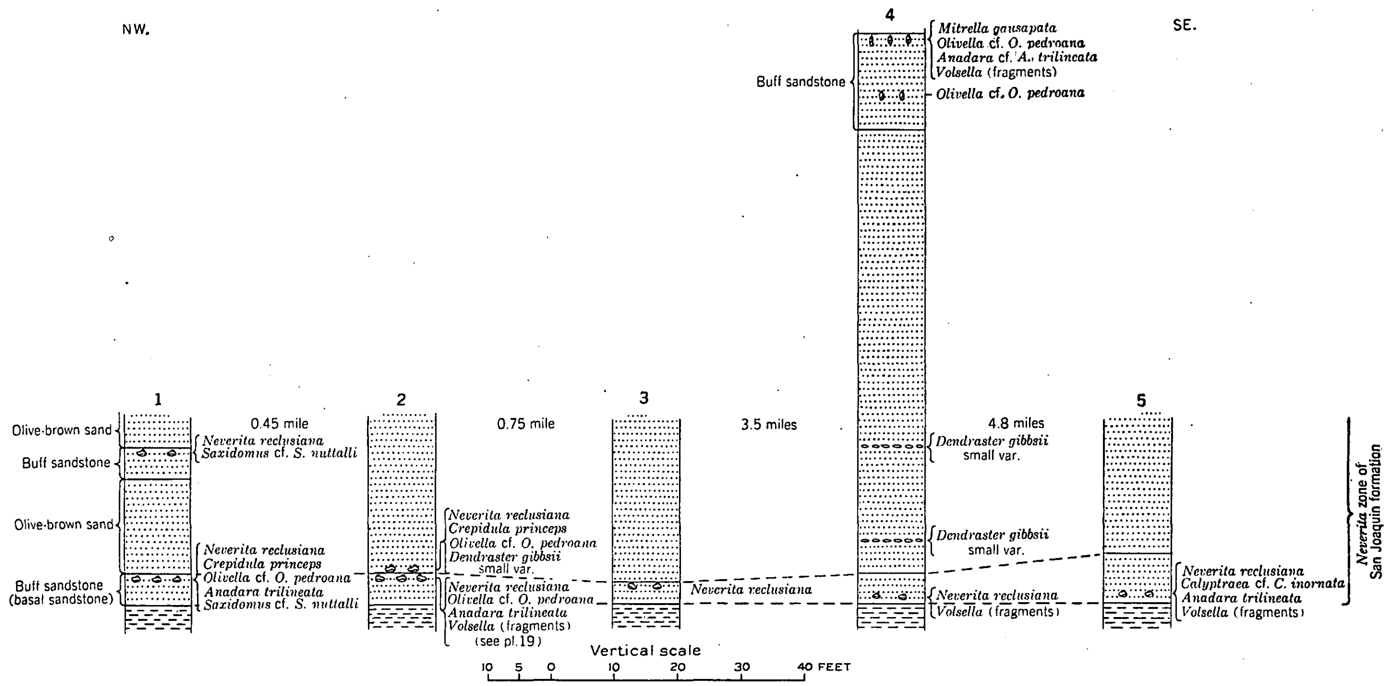


FIGURE 5.—Sections showing fossiliferous layers in *Neverita* zone of San Joaquin formation on west flank of North Dome. Full thickness of sand represented only in column 4. Figures between columns represent distances between sections.

1. Branch of Arroyo Vadosa, northeastern part of sec. 33, T. 21 S., R. 17 E.
2. Butte in southeastern part of sec. 33, T. 21 S., R. 17 E. (localities 163, 163a).
3. Branch of Arroyo Largo, western part of sec. 3, T. 22 S., R. 17 E.
4. Branch of Arroyo Mellado near north line of sec. 24, T. 22 S., R. 17 E. (localities 164, 164a, 165).
5. Southern part of sec. 34, T. 22 S., R. 18 E.

Neverita zone of San Joaquin formation and underlying strata at head of branch of Arroyo Largo in western part of sec. 3, T. 22 S., R. 17 E.

	Ft.	in.
Neverita zone:		
6. Coarse-grained cross-bedded olive-brown sand; base sharply defined. Only few feet at base clearly exposed; total thickness estimated	75	
5. Medium-grained poorly sorted apparently dirty, cliff-making buff sandstone (basal sandstone). Contains few scattered *Neverita* 6 inches to a foot below top. Small pebbles having a maximum length of half an inch and consisting principally of black chert abundant in lower half. Rests with sharp irregular contact on underlying bed. Pebbles or pellets several inches long of silt like that in underlying bed at contact. Borings filled with sand and pebbles extend down from contact; cross sections of borings as much as 10 inches below contact	3	6

Neverita zone of San Joaquin formation and underlying strata at head of branch of Arroyo Largo in western part of sec. 3, T. 22 S., R. 17 E.—Continued

	Ft.	in.
Strata underlying *Neverita* zone:		
4. Gray silt and fine-grained silty sand	2	6
3. Very coarse grained, pebbly cross bedded olive-brown sand, silty partings in upper part. Channels and sand-filled borings 2 inches long extend down from sharp irregular contact at base	6	6
2. Greenish-gray silt and fine silty sand	1	8
1. Moderately coarse grained, cross-bedded, olive-brown sand. Base not exposed; underlain by clay and silt farther down arroyo	3+	

The basal sandstone seems to be absent for a distance of 1½ miles northwestward from Arroyo Delgado, opposite the region on the east side of the anticline where it is missing. At the south end of the anticline the zone is not well exposed. It can be recognized, however, in part of this area by the occurrence of scattered clusters of *Neverita*, accompanied at a few places by *Anadara*, both apparently weathered out of the basal sandstone.

At the north end of the anticline a buff sandstone, similar to the basal sandstone and containing *Neverita*, is exposed for a short distance at the head of the arroyo northeast of the center of sec. 33, T. 21 S., R. 17 E., at a horizon 15 feet above the basal sandstone (fig. 5, column 1). On Arroyo Mellado and its first tributary to the southeast a fossiliferous buff sandstone lies at the very top of the zone, 70 feet above the basal sandstone (fig. 5, column 4).

Middle Dome.—On the east side of the North Dome-Middle Dome saddle the *Neverita* zone consists of a basal sandstone 2 to 3 feet thick overlain by sand. The basal sandstone contains a *Neverita* layer near the top. Between Arroyo Conejo and the branch of Arroyo Culebrino in the northeastern part of sec. 19, T. 23 S., R. 19 E., the zone was not recognized. Farther south the zone forms a narrow band of sandy soil containing scattered *Neverita* and other fossils. At locality 168, in sec. 33, T. 23 S., R. 19 E., corresponding to a stratigraphic position 25 feet above the base of the zone, diatomaceous white silty clay was collected from debris at the mouths of rodent burrows. This material presumably represents thin layers in the sand but was not seen in outcrop.

On the west flank of Middle Dome fossils occur in a sandstone at the base of the zone that resembles the buff sandstone of North Dome or is light gray, coarser-grained, cleaner, and lime-cemented. At locality 171, in sec. 24, T. 23, S., R. 18 E., the specimens of *Neverita* are in better condition than at any other locality representing the zone. For a distance of 1½ miles south of the northern part of sec. 25, T. 23 S., R. 18 E., a coarse-grained, poorly sorted, ferruginous, nonfossiliferous sandstone that forms a narrow band of sandy soil was identified as the *Neverita* zone. The zone was not recognized in Pepper Grass Valley. Farther south a band of sandy soil, on which specimens of *Neverita* were found in the southern part of sec. 5, T. 24 S., R. 19 E., was mapped as the *Neverita* zone. Southward from sec. 25, T. 23 S., R. 18 E., the sandy soil contains angular chips and pebbles of white siliceous shale, presumably derived from the Miocene McLure shale member of the Monterey shale of Reef Ridge. At locality 173, in sec. 8, T. 24 S., R. 19 E., diatomaceous white silty clay was collected from rodent-burrow debris at a position corresponding to a horizon 10 feet above the base of the zone. In this region the zone is about 30 feet thick, unless the dip is steeper than supposed. The zone was not identified in the area of meager exposures at the south end of the anticline.

South Dome.—A sand about 20 feet thick, forming a band of sandy soil around the north end of South Dome, may represent the *Neverita* zone. It is at about the horizon of the zone, but no fossils were found other than diatoms in rodent-burrow debris, a feature in which this sand resembles sand in the *Neverita* zone of southern Middle Dome.

FOSSILS

Fossils from the *Neverita* zone are listed in the following table. The characteristic and abundant species are shown on plates 19–21.

The fauna of the *Neverita* zone consists of marine forms. The modern analogs of some of the species, however, live also in brackish water.

A *Neverita* layer in the basal sandstone, in which *Neverita reclusiana* (pl. 20, figs. 1–5), *Olivella* cf. *O. pedroana* (pl. 20, figs. 8, 9), *Anadara trilineata* (pl. 20, figs. 15–17), and *Volsella* cf. *V. recta* (pl. 20, figs. 13, 14) are the most abundant fossils, contains the most characteristic and widespread faunal association. This association is shown on plate 19, a photograph of a slab of limy sandstone from the *Neverita* layer in the basal sandstone at locality 163. All these species occur in the *Pecten* zone but not in the same limited faunal association. At places this association occurs in the sand overlying the basal sandstone. *Platyodon colobus* (pl. 21, figs. 1, 2) is the only species of the zone that was not found at other horizons. A *Volsella* layer, a *Saxidomus-Anadara* layer, a *Mya-Calyptraea* layer, and a *Mya* layer occur also at places in the basal sandstone. The *Mya* layer, which may represent brackish water, occurs at or near the base of the zone.

The species in sandstones above the basal sandstone occur also in the basal sandstone, except *Opalia varicostata*.

Sand dollars are more abundant in the sand than in the sandstone. The most common form is a small variety of *Dendraster gibbsii* (pl. 20, figs. 10, 11; pl. 21, figs. 3–6). No form of *D. gibbsii* has been recognized at higher horizons.

Fossils from Neverita zone of San Joaquin formation

[Identifications by W. P. Woodring unless otherwise stated. F, fragments; P, paired valves; S, small specimens]

Species	Localities																														
	Sandstone at base of zone																				Sandstones above base of zone			Sand								
																								Base of sand			Above base of sand					
	North Dome														Middle Dome					North Dome			North Dome			North Dome					Middle Dome
	East flank													West flank	East flank		West flank			East flank		West flank	East flank	West flank		East flank			West flank		West flank
	146	146a	148	148a	149	150	151	152	153	154	155	156	157	162	166	167	169	170	171	172	158	161	165	145	163	163a	147	159	160	164	164a	170a
Echinoids (identifications by Ralph Stewart):																																
Dendraster gibbsii (Rémond), small var. (pl. 20, figs. 10, 11; pl. 21, figs. 3–6)																								X	X	X	X	X	X	X	X	X
Dendraster coalingaensis gibbosus Kew				?		?				X																						
Dendraster coalingaensis Twitchell, small variety with flat petals																								X						X		
Bryozoa (identifications by R. S. Bassler):																																
Schizoporella sp														X																		
Membranipora sp												X																				
Gastropods:																																
Calyptraea cf. *C. inornata* (Gabb) (pl. 20, fig. 6)											X		X						X	X												
Crepidula princeps Conrad																									X							
Neverita reclusiana (Deshayes) (pl. 20, figs. 1–5)		X		X	X	X		X		X	X	X	X	X				X	X	X				X	X							
Lunatia cf. *L. lewisii* (Gould)										X																						
Opalia varicostata Stearns																					X											
Nucella? sp																			F													
Mitrella gausapata (Gould) (pl. 20, fig. 7)																			X	?			X	X								
Olivella cf. *O. pedroana* (Conrad) (pl. 20, figs. 8, 9)		X		X	X	X				X				?F					X	X			X	X	X							
Pelecypods:																																
Anadara trilineata (Conrad) of Arnold (pl. 20, fig. 17) and elongate flat variety (pl. 20, figs. 15, 16)				X	X	X		P		X		X	P					F	F	X	X	P	X	X								
Volsella cf. *V. recta* (Conrad) (pl. 20, figs. 13, 14)	P		P						P	X			?F	?F				?P	?P	?P				P								
Adula falcata (Gould)?							P																									
Macoma cf. *M. nasuta* (Conrad) (pl. 20, fig. 12)												X										P										
Macoma cf. *M. affinis* Nomland											X																					
Macoma? sp							P																									
Saxidomus sp														F																		
Mya cf. *M. dickersoni* Clark											X	P								?S												
Platyodon colobus Woodring, n. sp. (pl. 21, figs. 1, 2)							P																									
Solen perrini Clark?																		F		F												
Panope cf. *P. generosa* Gould																				X												
Pholadidea cf. *P. penita* (Conrad)							P																									
Fish: "Bulbous growths"																			X	X												
Marine mammals (identifications by Remington Kellogg):																																
Porpoise (left humerus)																X																
Porpoise (right periotic)																	X															
Whalebone whale (posterior process of left periotic)															X																	
Eared seal (distal end of right humerus)															X																	

Diatoms identified by K. E. Lohman from material collected in southern Middle Dome are listed in the following table. Lohman states that the flora is dominantly marine but includes a few fresh-water and brackish-water forms. The characteristic species of this flora are shown on plates 22 and 23.

Diatoms from Neverita zone of San Joaquin formation in Middle Dome

[Identifications by K. E. Lohman. R, rare; F, few; C, common; A, abundant]

Species	Localities	
	East flank	West flank
	168	173
Melosira sulcata (Ehrenberg) Kützing (pl. 23, fig. 15)	F	C
Melosira recedens Schmidt	R	F
Melosira polaris Grunow	R	------
Melosira cf. *M. clavigera* Grunow	R	------
Melosira cf. *M. islandica* Müller	R	R
Melosira italica (Ehrenberg) Kützing	------	R
Stephanopyxis turris (Greville and Arnott) Ralfs	R	------
Stephanopyxis turris var. *cylindrus* Grunow	------	R
Stephanopyxis corona (Ehrenberg) Grunow (pl. 23, fig. 2)	F	F
Thalassiosira decipiens (Grunow) Joergensen	F	------
Cyclotella striata (Kützing) Grunow	R	------
Stephanodiscus astraea (Ehrenberg) Grunow	R	F
Coscinodiscus excentricus Ehrenberg (pl. 22, fig. 5)	C	C
Coscinodiscus lineatus Ehrenberg	F	------
Coscinodiscus stellaris Roper	R	F
Coscinodiscus subtilis Ehrenberg	F	F
Coscinodiscus kützingii Schmidt	------	F
Coscinodiscus cirrus Lohman (pl. 22, fig. 4)	C	C
Coscinodiscus spinuligerous Rattray	F	------
Coscinodiscus curvatulus Grunow	------	R
Coscinodiscus denarius Schmidt	------	R
Coscinodiscus rothii (Ehrenberg) Grunow var. *normani* (Gregory) Van Heurck	R	------
Coscinodiscus obscurus Schmidt (pl. 22, fig. 1)	C	F
Coscinodiscus radiatus Ehrenberg	F	F
Coscinodiscus gigas Ehrenberg	------	C
Coscinodiscus cf. *C. janischii* Schmidt	------	R
Coscinodiscus biangulatus Schmidt	F	------
Coscinodiscus asteromphalus Ehrenberg	C	C
Coscinodiscus asteromphalus var. *omphalantha* (Ehrenberg) Grunow	------	C
Coscinodiscus oculus-iridis Ehrenberg	------	F
Coscinodiscus kurzii Grunow (pl. 22, fig. 2)	F	F
Actinoptychus undulatus Ehrenberg (pl. 23, fig. 3)	C	A
Actinoptychus sp	R	------
Aulacodiscus cf. *A. argus* (Ehrenberg) Schmidt	------	R
Aulacodiscus brownei Norman	R	------
Actinocyclus ehrenbergii Ralfs (pl. 23, fig. 1)	C	F
Actinocyclus ehrenbergii var. *crassa* (W. Smith) Hustedt	F	------
Actinocyclus ehrenbergii var. *tenella* (Brebisson) Hustedt	------	F
Actinocyclus subtilis (Gregory) Ralfs	------	C
Rhizosolenia sp	F	R
Chaetoceros incurvum Bailey	R	------
Periptera tetracladia Ehrenberg (spores of *Chaetoceros?*)	------	F
Syndendrium diadema Ehrenberg (spores of *Chaetoceros?*)	------	R
Xanthiopyxis ovalis Lohman (pl. 23, fig. 12)	F	F
Biddulphia aurita (Lyngbye) Brebisson and Godey	F	F
Hemidiscus ovalis Lohman	------	F
Thalassionema nitzschioides Grunow	F	F
Rhaphoneis angularis Lohman (pl. 23, figs. 6–8)	F	F
Pleurosigma cf. *P. affine* Grunow	F	------
Pleurosigma strigosum W. Smith	------	F
Diploneis elliptica (Kützing) Cleve	R	------
Navicula pennata Schmidt	F	R
Epithemia turgida (Ehrenberg) Kützing (pl. 23, fig. 4)	F	------
Hantzschia amphioxys (Ehrenberg) Grunow	F	------
Nitzschia navicularis Grunow (pl. 23, fig. 11)	R	------
Nitzschia granulata Grunow	R	R

STRATA BETWEEN *NEVERITA* ZONE AND CASCAJO CONGLOMERATE MEMBER

STRATIGRAPHY AND LITHOLOGY

The strata between the *Neverita* zone and the Cascajo conglomerate, consisting chiefly of silt, sand, sandstone, and clay, have a thickness of 200 to 425 feet. Thin beds of tuff and oolite are minor but conspicuous constituents.

At scattered localities on both flanks of North Dome a *Mya* layer is about 20 feet below the *Neverita* zone. In North Dome it is convenient to number the *Mya* layers near the base of the San Joaquin formation and near the top of the Etchegoin formation in their stratigraphic order above the *Littorina* zone of the Etchegoin—the most reliable stratigraphic datum plane. This *Mya* layer near the base of the *Neverita* zone is, accordingly, designated the fourth *Mya* layer above the *Littorina* zone. (See North Dome stratigraphic column, pl. 3, and fig. 6.) At the south end of North Dome a tuff is in the same stratigraphic position. At places *Mya* molds occur at the base of the tuff or immediately below it. The tuff is light-colored and is 2 or 3 feet thick. According to M. N. Bramlette, it consists principally of fresh glass and contains a little andesine, hornblende, and augite. Near the plunging crest of the anticline the tuff is more readily traced than the *Neverita* zone.

Along the west flank of northern North Dome from La Cumbre (sec. 10, T. 22 S., R. 17 E.) southward to a branch of Arroyo Chico in sec. 13, T. 22 S., R. 17 E., another *Mya* layer—the third *Mya* layer above the *Littorina* zone—lies 150 to 175 feet below the *Neverita* zone. At places it is overlain by blue sandstone. At scattered localities on the east flank of the anticline northward from a branch of Arroyo Doblegado a *Mya* layer at a horizon about 100 feet below the *Neverita* zone is correlated with the third *Mya* layer on the opposite flank.

The following section of strata between the *Neverita* zone and a blue sandstone doubtfully identified as the Cascajo conglomerate, somewhat generalized owing to incomplete exposures, was measured in a road cut near the southwest corner of sec. 6, T. 22 S., R. 18 E.

Section of strata in lower part of San Joaquin formation between Neverita zone and Cascajo conglomerate member (?) in road cut near southwest corner of sec. 6, T. 22 S., R. 18 E.

	Feet
Neverita zone.	
Sandy silt, including lens of blue sandstone at base	50
Gray sand and silt	35
Green clay and silt. Probably includes equivalent of third *Mya* layer above *Littorina* zone of Etchegoin formation	15
Brown sand and grit with some pebbles and thin layers of clay	30
Alternating brown sand and silt	60
Cascajo conglomerate member (?). Coarse-grained cross-bedded blue sandstone with layers of pebbles	20
Thickness of strata between *Neverita* zone and Cascajo conglomerate (?)	190

A thin bed of oolite crossing Arroyo Robador in sec. 22, T. 22 S., R. 18 E., and extending southward for a distance of half a mile, is the essential equivalent of the third *Mya* layer, for it also is about 100 feet below the *Neverita* zone. This oolite is designated the upper oolite to distinguish it from the oolite in the *Littorina* zone of the Etchegoin formation. It has a thickness of 4 or 5 feet and consists of oolites, shell fragments, and shells. The oolites are made up of sand grains and also apparently of bits of clay coated with calcareous layers of varying thickness. Many of the sand grains forming the cores have angular edges, but the oolites are subspherical or subelliptical. *Mya* is the most common fossil. Farther south on the east slope of Broken Hill and on the east side of North Dome-Middle Dome saddle oolite containing broken *Mya* shells is correlated with the oolite on Arroyo Robador.

An oolite in Middle Dome is also correlated with the upper oolite on Arroyo Robador. On the east flank of the anticline, where the section is relatively thin, the oolite is about 60 feet below the *Neverita* zone. Between Arroyo Culebrino and the foot of Parejo Hill the apparent equivalent of the oolite is a buff silt containing fragments of *Mya*. Oolites are progressively more abundant southward from the fault at the south end of Parejo Hill, and in sec. 33, T. 23 S., R. 19 E., the bed of oolite is well developed, though it also contains uncoated sand grains. At a locality on the west slope of the ridge in sec. 33 blocks of oolite are embedded in the soil at three levels, possibly owing to slumping. Southward from the south line of T. 23 the oolite bed is replaced by nonfossiliferous buff silt and clay.

On the west flank of Middle Dome oolite was observed at the north end of the anticline in the northern part of sec. 13, T. 23 S., R. 18 E. It seems to grade southward into *Mya*-bearing silty clay, which is about 150 feet below the *Neverita* zone. South of Arroyo Culebrino the equivalent of the *Mya*-bearing clay appears to be included in nonfossiliferous clay that forms a prominent strike ridge. On weathered exposures this clay is buff, but in fresh exposures at least part of it is olive gray. It is about 200 feet below the *Neverita* zone and is considered the essential equivalent of the oolite on the east flank that is only 60 feet below the *Neverita* zone. The entire San Joaquin formation thins across the anticline, but no other part of the formation thins so much.

On a branch of Arroyo Hondo (locality 177) and on a branch of Arroyo Doblegado (locality 178)—both on the east flank of North Dome—a sandstone containing large specimens of *Cerastoderma* is exposed about 60 feet below the *Mya* layer that is correlated with the third *Mya* layer. At locality 177 the fossils are in a 4-inch lens of hard pebbly sandstone in soft gray dirty sandstone. At locality 178 they also occur in a hard layer in soft olive-brown sandstone. In the east fork of Arroyo del Camino—on the west flank of North Dome—about 50 feet below the third *Mya* layer is a pebbly sandstone containing *Cerastoderma* in the same part of the section.

FOSSILS

Fossils from the third *Mya* layer, the upper oolite, and the *Cerastoderma*-bearing sandstone are listed in the following table. Some of the species are shown on plate 24.

Fossils from strata in lower part of San Joaquin formation between Neverita zone and Cascajo conglomerate member

[Identifications by W. P. Woodring unless otherwise stated. F. fragments; P, paired valves

Species	Localities				
	Third *Mya* layer	Upper oolite		*Cerastoderma*-bearing sandstone	
	192	175	176	177	178
Echinoid (identification by Ralph Stewart): *Dendraster coalingaensis gibbosus* Kew?					X
Gastropods:					
Calyptraea cf. *C. inornata* (Gabb)	[1]?	X			
Odostomia cf. *O. io* Dall and Bartsch		X			
Pelecypods:					
Anadara trilineata (Conrad) of Arnold var. cf. *A. canalis* (Conrad) (pl. 24, fig. 7)					X
Macoma affinis Nomland					X
Macoma affinis plena Stewart, n. var. (pl. 24, fig. 3)	X	X			
Psephidia n. sp.? (pl. 24 figs. 4-6)		P	P		
Cerastoderma cf. *C. meekianum* (Gabb) (pl. 24, figs. 8, 9)		?F		X	X
Cerastoderma sp., small	X				
Mya cf. *M. dickersoni* Clark (pl. 24, fig. 2)	[1] X	X	?F		
Solen perrini Clark (pl. 24, fig. 1)		X			
Ostracodes (identifications by R. S. Bassler):					
Cytheridea sp			X		
Cytherideis sp			X		
Undetermined otoliths			X		

[1] Observed but not collected.

Odostomia was not found at horizons other than the upper oolite. The small venerid *Psephidia* (pl. 24, figs. 4–6) occurs in the upper oolite and in the Cascajo conglomerate. The absence of *Littorina* and *Amnicola*-like fresh-water gastropods also serves to distinguish the upper oolite from the oolite in the *Littorina* zone of the Etchegoin formation. The form of *Anadara trilineata* in the *Cerastoderma*-bearing sandstone has more centrally located beaks than forms at higher horizons in the San Joaquin formation and is similar to a variety from the Etchegoin formation.

In addition to the fossils listed, others were observed or collected in this part of the section. Leaves occur in clayey silt exposed in a cut at Standard well 47–35–J, sec. T. 21 S., R. 17 E., at a horizon about 50 feet below the *Neverita* zone. The leaf-bearing bed is 10 feet below a layer containing *Volsella* and immediately above a 2-foot bed of blue silty clay. A fragment of an upper cheek tooth of a horse, collected a few feet below the *Neverita* zone at locality 174, represents, according to C. L. Gazin, *Pliohippus* or *Plesippus*. An ear bone from locality 169, representing a horizon 35 feet above the upper oolite, is identified by Remington Kellogg as belonging to an extinct porpoise.

CASCAJO CONGLOMERATE MEMBER

STRATIGRAPHY AND LITHOLOGY

The base of the San Joaquin formation is placed at the base of a unit consisting of conglomerate and sandstone, generally blue, here designated the Cascajo conglomerate member. Cascajo Hill, on the west flank of South Dome, is the type locality of the Cascajo conglomerate. The average thickness of the Cascajo is 50 feet, but at places it is considerably greater. Throughout the Kettleman Hills the Cascajo and underlying sandstones are relatively resistant rocks and form a series of hills and ridges.

In northern South Dome the Cascajo contains the small pecten *Aequipecten circularis eldridgei*. On the basis of the occurrence of this fossil, which has not been found at other horizons in the outcrop section, it is suggested that the Cascajo is equivalent to sand and gravel that unconformably overlie Miocene shale near McKittrick,[52] on the west border of the San Joaquin Valley 50 miles southeast of the Kettleman Hills, the type locality of *A. circularis eldridgei*. If this correlation is correct, the widespread deposition of gravel in the Kettleman Hills at the horizon of the Cascajo appears to be the result of deformation in the adjoining Coast Ranges. Should this small pecten be found at other horizons the suggested correlation would be less certain. Even in that event the base of the Cascajo might be considered an appropriate horizon for drawing the base of the San Joaquin formation in the Kettleman Hills.

The Cascajo conglomerate disappears below the surface in the saddles between the three anticlines in the Kettleman Hills and the correlation of strata assigned to this member in the three anticlines is not entirely satisfactory. The correlation rests on the occurrence of sandstone and conglomerate in an appropriate part of the section and on the occurrence of fossils at scattered localities. The fossils in Middle and North Domes do not include, however, *A. circularis eldridgei* but do include fragments of a larger *Aequipecten*, probably related to *A. circularis impostor* of the *Pecten* zone. In North Dome sandstone and conglomerate

[52] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, Calif.: U. S. Geol. Survey Bull. 406, p. 80, 1910. Pack, R. W., The Sunset-Midway oil field, Calif., pt. 1, Geology and oil resources: U. S. Geol. Survey Prof. Paper 116, p. 46, 1920.

assigned to the Cascajo cut across underlying strata and may be interpreted as resting on successively older beds. Scour discontinuities of this character are not unusual in the San Joaquin and Etchegoin formations. The interpretation of exceptionally deep local scouring at the base of conglomerate assigned to the Cascajo is aided by the presence in the underlying strata of several recognizable faunal and lithologic units within a short stratigraphic distance. Along the greater part of the east flank of North Dome and along the south part of the west flank conglomerate and sandstone are present at the inferred horizon of the Cascajo, but a mappable boundary was not recognized. For this reason throughout North Dome the San Joaquin-Etchegoin boundary is shown on the geologic map (pl. 3) at the base of a lower apparently more persistent tuffaceous blue sandstone designated the first blue sandstone above the *Littorina* zone of the Etchegoin formation, except at places on the west flank where the first blue sandstone appears to have been cut out by the Cascajo. This cartographic representation of the boundary should present no serious difficulty, for the stratigraphic thickness involved is not more than about 100 feet. Within this thickness the beds of conglomerate and sandstone may occur as irregular lenses rather than as continuous layers.

The Cascajo and the underlying blue sandstones are the highest relatively persistent blue sandstones and conglomerates. Lenses of blue sandstone occur at higher horizons, particularly in the interval between the *Pecten* and *Neverita* zones. Downward in the section from the Cascajo throughout the Etchegoin formation many of the coarse-grained sandstones are blue. These blue sandstones are a noteworthy feature in the Kettleman Hills and other parts of the Coalinga region. It has been recognized that the blue color is due to a film on the sand grains, and the suggestion has been made that the film consists of vivianite,[53] of opal or chalcedony, fine volcanic dust, or clayey material.[54] Samples from several blue sandstones in the Kettleman Hills were examined by M. N. Bramlette, who found that the mineral forming the film has a mean index of refraction of 1.56, nearly parallel extinction, and negative elongation. It is soft and can readily be scraped off the grains and is slightly soluble in hydrochloric acid. According to Bramlette, these properties indicate that the mineral is neither vivianite nor opal. He suggests that it is probably a chloritic or clay mineral and that there seems to be a relation between the film-forming mineral and hypersthene andesite tuff. The blue sandstones examined contain a notable quantity of pyroclastic material of this composition, whereas pyroclastic material in sandstones of the San Joaquin and Etchegoin formations that are not blue consists of augite or hornblende andesitic tuff.

North Dome.—The stratigraphic relations of sandstone and conglomerate assigned to the Cascajo in North Dome were interpreted by the occurrence of these

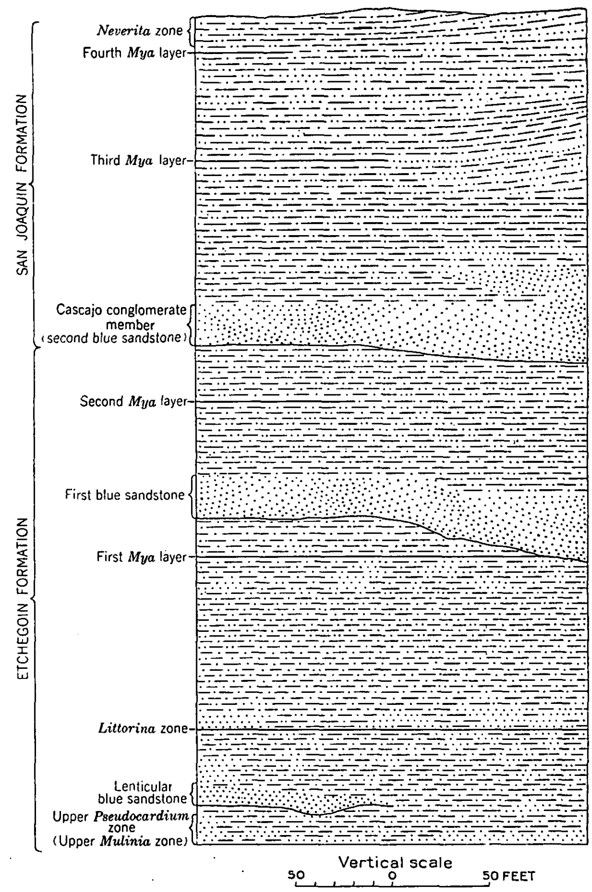


FIGURE 6.—Generalized section of strata in lower part of San Joaquin formation and in upper part of Etchegoin formation in northern North Dome.

strata with reference to the *Littorina* zone of the underlying Etchegoin formation and to the following units in Etchegoin strata overlying the *Littorina* zone, designated in the order of their position above the *Littorina* zone, first *Mya* layer, first blue sandstone, second *Mya* layer. These units are shown in figure 6. The Cascajo normally overlies the second *Mya* layer in the regions where this *Mya* layer occurs and is normally the second blue sandstone above the *Littorina* zone. As stated above, for the purpose of clearer cartographic representation the San Joaquin-Etchegoin boundary is shown on plate 3 at the base of the first blue sandstone, except locally on the west flank where the first blue sandstone is thought to be cut out by the Cascajo. The differentiation of the first blue sandstone and Cascajo, however, is uncertain at places.

The succession shown in figure 6 is well developed at the north end of North Dome. Coarse-grained cross-bedded blue sandstone and grit containing layers of pebbles are assigned to the Cascajo. The pebbles consist chiefly of black chert. On the north side of

[53] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 97.

[54] 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. 82–83, 1915.

Double Hill sandstone of this character is 33 feet above the second *Mya* layer. (See section, p. 57.) At many places on the east flank southward from Double Hill sandstone that may be assigned to the Cascajo is not well exposed or is distinguished with difficulty from the first blue sandstone. At scattered localities coarse-grained blue sandstone and conglomerate that probably represent the Cascajo occur in about the same stratigraphic position. These occurrences may be exposures of a continuous stratum or they may represent separate lenses in slightly different parts of the section. At locality 194 worn shells and small sand dollars were collected from irregularly bedded blue and gray coarse-grained sandstone corresponding in stratigraphic position to the Cascajo. Sandstone in about the same stratigraphic position at other localities on the east flank contains worn fragments of *Anadara*.

At the north end of the west flank conglomerate and sandstone identified as the Cascajo overlie the second *Mya* layer. The irregular contact at the base of the conglomerate is well exposed along the road to Standard well 41–3–P, near the north line of sec. 3, T. 22 S., R. 17 E. (pl. 25, *A*). At this locality the base of the conglomerate is 7 feet above the second *Mya* layer. Five hundred feet to the east the base is 20 feet above the second *Mya* layer and a *Macoma* layer occurs in the intervening silt. On the west slope of the ridge northeast of La Cumbre pebbly blue sandstone, assigned to the Cascajo, rests on the first blue sandstone with an irregular contact having a relief of 5 feet. At locality 191, near Arroyo Somero, poorly preserved sand dollars occur in coarse-grained blue sandstone 50 feet above the first *Mya* layer. On the divide between Arroyo Somero and Arroyo Chico blue conglomerate is just above the first *Mya* layer. On the south slope of El Chichon blue conglomerate rests on strata below the first *Mya* layer, but 400 feet to the west in the bottom of a tributary of Arroyo Chico it again is 50 feet above the first *Mya* layer. South of El Piso a blue sandstone directly overlies the first *Mya* layer and locally cuts across it.

At the head of Arroyo Delgado on the west side of Cerro Alto blue sandstone, considered the Cascajo, cuts across the first blue sandstone (pl. 25, *B*). At locality 185, in Arroyo Delgado, the blue sandstone contains fossils, including fragments of *Aequipecten* and the small cup-shaped brachiopod *Discinisca*. Near the head of the arroyo the base of the blue sandstone is about 60 feet above the *Littorina* zone. Down the arroyo 600 feet away the base of the sandstone is 170 feet above the downward projection of the *Littorina* zone. The stratigraphic relations at this locality, shown in figure 7, are apparently due to subaqueous erosion and lenticular deposition. If the lenticular blue sandstone underlying the first blue sandstone shown in figure 7 is represented at other localities where the relations to the first blue sandstone are not known, it would be difficult to distinguish it from the Cascajo.

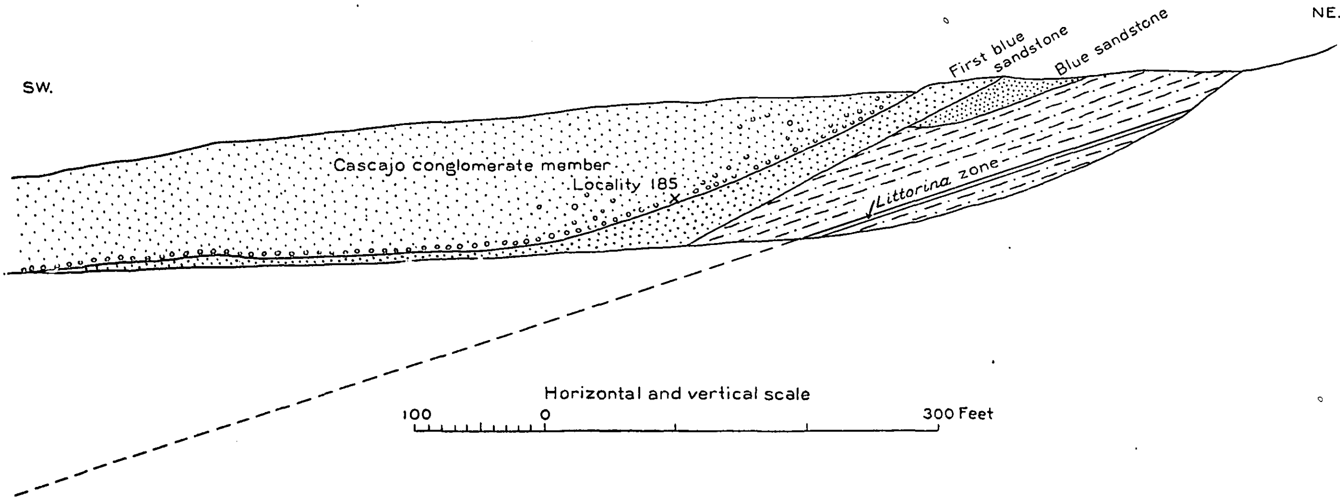


FIGURE 7.—Stratigraphic relations of Cascajo conglomerate member of San Joaquin formation in Arroyo Delgado, on west flank of North Dome.

At the head of a branch of Arroyo Delgado (locality 184) the contact between the sandstone identified as the Cascajo and sandy silt overlying the first blue sandstone is well exposed. Between localities 184 and 183 the first blue sandstone appears to be cut out by blue sandstone assigned to the Cascajo. At locality 183, on the south side of Cerro Ultimo, cross-bedded blue sandstone and grit contain fossils, including fragments of *Aequipecten* and *Discinisca*. Farther south blue sandstone and conglomerate assignable to the Cascajo are not well exposed.

The summit of El Lobo, east of the outcrops just described and separated from them by faults, is formed of coarse-grained blue sandstone and grit. *Discinisca* was found at the base of this sandstone (locality 186). On the west side of El Lobo the blue sandstone is about 25 feet above the *Littorina* zone. On the east side it is about 25 feet above a *Mya-Pseudocardium* layer. The *Littorina* zone may grade laterally into the

Mya-Pseudocardium layer, but on the basis of stratigraphic relations near the type locality of the *Littorina* zone the *Mya-Pseudocardium* layer is thought to be 20 feet below the *Littorina* zone. The blue sandstone on El Lobo may be the Cascajo, or it may correspond to the lenticular blue sandstone underlying the first blue sandstone shown in figure 7, despite the occurrence of the brachiopod.

The stratigraphic relations at the scattered exposures of blue sandstone and conglomerate on the west flank of North Dome may be interpreted as indicating that the Cascajo conglomerate formed a continuous stratum. Under this interpretation the same conglomerate is 20 feet above the second *Mya* layer at the north end of the anticline and southward cuts across the second *Mya* layer, the first blue sandstone, the first *Mya* layer, and down to the *Littorina* zone. Figure 8 is a reconstruction under this interpretation of the strata exposed in Arroyo Ramoso and on El Lobo. An equally plausible or perhaps more plausible interpretation is that the exposures of blue sandstone and conglomerate represent lenses not only in different parts of the section above the first blue sandstone but also below the first blue sandstone. There is no doubt that blue sandstone and conglomerate mapped as the Cascajo cut across underlying strata, for such relations can be seen in single outcrops. It is not certain, however, that as much as 100 to 150 feet of strata were removed at places during, or before, the deposition of the sand and gravel.

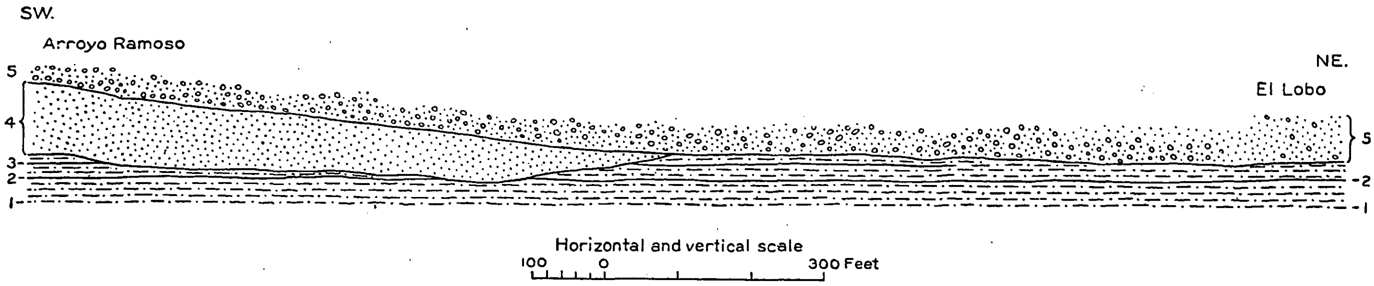


FIGURE 8.—Reconstruction of strata exposed in Arroyo Ramoso and on El Lobo under interpretation that blue sandstone and conglomerate at both localities represent Cascajo conglomerate member of San Joaquin formation. 1, Upper *Pseudocardium* zone; 2, *Mya-Pseudocardium* layer; 3, *Mya* layer (?=*Littorina* zone); 4, First blue sandstone; 5, Cascajo conglomerate member of San Joaquin formation (blue sandstone and conglomerate).

Middle Dome.—At the north end of South Dome the Cascajo conglomerate overlies the readily recognized *Pseudocardium-Anadara* zone in the Etchegoin formation. The Cascajo conglomerate in Middle Dome is identified by its stratigraphic relation to this zone and by the fossils that occur in the conglomerate. Most of these fossils are represented in the Cascajo of South Dome. If the tuffaceous blue sandstone, designated the first blue sandstone above the *Littorina* zone in North Dome, occurs in Middle Dome, it was doubtless mapped as part of the Cascajo. The bluish-gray leaf-bearing sandstone exposed on Arroyo Culebrino at the north end of Middle Dome (see section, p. 71) is probably equivalent to the first blue sandstone. In view of the rather uniform stratigraphic interval between the *Pseudocardium-Anadara* zone and the base of sandstone and conglomerate identified as the Cascajo, it is doubtful whether in Middle Dome the stratigraphic relations of the Cascajo to underlying beds are as complex as they appear to be in parts of North Dome. The apparent simplicity may, however, be due to less satisfactory exposures than in North Dome.

The soft sandstone cropping out on the ridge east of La Bajada, on the east side of the saddle between North and Middle Domes, may be part of the Cascajo or part of the first blue sandstone of North Dome. The *Pseudocardium-Anadara* zone, however, was not recognized in this region, and the identification of the sandstone is uncertain. The structure in this area of meager exposures may be more complicated than supposed. Two strike faults of unknown displacement dip westward, and other faults may be present.

On the east side of Middle Dome the Cascajo as mapped consists of soft sandstone, hard sandstone, and conglomerate. Its thickness of 50 to 75 feet is only a rough estimate, as the upper part generally is not exposed and forms the sand-covered dip slope of strike ridges. The sandstone and conglomerate form the crest of Parejo Hill, but south of Arroyo Recodo they crop out far down on the east slope of the ridge forming the continuation of Parejo Hill.

The soft sandstone is blue or bluish gray and at places may correspond to the first blue sandstone of North Dome. At the north end of the anticline soft sandstone contains a few imprints of leaf fragments. The hard sandstone is gray, medium-grained, and weathers out in small rectangular blocks. This kind of sandstone is a conspicuous feature at the north and south ends of Parejo Hill. The conglomerate, which occurs as lenses or makes up the greater part of the member, consists of small pebbles, mostly black chert, that have an average length of about a quarter of an inch. At places the conglomerate has hardly any sand matrix. At the north end of the anticline conglomerate lenses contain "bulbous fish growths" and silicified wood. Fossils, including *Aequipecten*, were found in conglomerate at two localities on the east side of the anticline (localities 197, 198), and fragments of *Mya* shells were observed in the northern part of section 4, T. 24 S., R. 19 E., near the south end of the anticline.

On the west side of Middle Dome the Cascajo as mapped consists principally of sandstone, much of which has lenses of small pebbles. The thickness apparently increases southward from about 50 feet at the north end to a maximum of 140 feet in the southern part of section 31, T. 23 S., R. 19 E., and then rapidly decreases to 50 feet or less. The change in thickness is apparently due to lensing in the upper part of the sandstone. Hard, blocky sandstone like that already described crops out near the top of the sandstone at many places. Fossils, including *Aequipecten*, were collected at localities 199, 200, and 202. Silt that appears to form a lens in the sandstone and conglomerate mapped as the Cascajo extends northwestward for a distance of about a mile beginning at a place about 1,000 feet northwest of locality 202. *Anadara* and *Venerupis* shells, replaced by gypsum, occur in the upper part of the silt.

South Dome.—The type locality of the Cascajo conglomerate is on Cascajo Hill on the west side of South Dome, where the conglomerate is about 50 feet thick. Northward from Cascajo Hill the conglomerate forms a curving row of low ridges, El Arco. In this region the pebbles are a little larger than in Middle Dome. Most of them are three-quarters of an inch to an inch long, but some are 1½ inches. Black, red, and green chert and white quartz are the most abundant constituents. East of the crest of the anticline the Cascajo is thinner and is not so conspicuous topographically. *Aequipecten* and other fossils were collected at localities extending northward from Cascajo Hill to the crest of the anticline and eastward to the highway near the east edge of the hills. East of this highway a soft sandstone was mapped as the Cascajo.

Pebbles are less abundant south of Cascajo Hill. Toward the south end of the hills soft gray sandstone that contains hard ferruginous masses and scattered pebbles was identified as the Cascajo. Two broken pumice pebbles were found on the outcrop of the sandstone. "Bulbous fish growths" and bone fragments are the only fossils observed south of Cascajo Hill.

FOSSILS

Marine fossils were found in the Cascajo conglomerate of northern South Dome and at a few places in the conglomerate and sandstone identified as the Cascajo in Middle and North Domes. These fossils are listed in the following table, and a few of the species are shown on plates 24 and 39.

Most of the fossils are worn, and many of them consist of worn fragments. Probably all the specimens were transported for some distance before burial and many of them may have been transported as fossils. Transported dead shells that occur in conglomerate cannot be satisfactorily distinguished, however, from shells transported as fossils. It is improbable that the forms of *Aequipecten* occurring in the Cascajo were transported as fossils, for this genus is not known to occur in underlying Pliocene strata in the Kettleman Hills or in the foothills to the west. Other species represented by complete or virtually complete specimens, particularly those belonging to genera that live among stones—such as *Nucella etchegoinensis* (pl. 24, figs. 16–18)—or are attached to solid objects, were probably transported as dead shells.

The small *Aequipecten circularis eldridgei* (pl. 24, figs. 10–13) was found only at the north end of South Dome. Fragments of a larger *Aequipecten*, identified as *Aequipecten* cf. *A. circularis impostor*, were collected in the three anticlines. Varieties of *Pseudocardium densatum* occur in the Cascajo of South and Middle Domes and are abundant on Cascajo Hill. Worn fragments of thick-shelled specimens were doubtless transported as fossils. Complete specimens may also have been transported as fossils. A short trigonal form of this species (pl. 24, fig. 14) is similar to forms in the underlying *Pseudocardium-Anadara* zone. An elongate form (pl. 24, fig. 15), however, is rare in the underlying strata. The brachiopod *Discinisca* (pl. 39, figs. 1, 6) was collected at three localities in North Dome, but it is uncertain whether locality 186 represents the same horizon as the other two.

OCCURRENCE ELSEWHERE IN SAN JOAQUIN VALLEY

Pebbles in the Cascajo conglomerate member consist of rocks similar to those cropping out in the adjoining Coast Ranges. If the material was derived from the Coast Ranges, similar conglomerate would be expected to occur in the Kreyenhagen Hills, at the foot of the Coast Ranges west of the Kettleman Hills. According to observations by Ralph Stewart, conglomerate occurs in a corresponding part of the section at least locally in Jacalitos Dome and along Canoas Creek, overlying a *Mya* zone that probably corresponds to the *Littorina* zone of the Kettleman Hills. This *Mya* zone overlies the upper *Pseudocardium* zone (upper *Mulinia* zone of Arnold and Anderson).

The proposed correlation of the Cascajo conglomerate with sand and gravel containing *Aequipecten circularis eldridgei* near McKittrick suggests that a marine zone corresponding to the Cascajo may occur in the subsurface section of southern San Joaquin Valley. Barbat and Galloway [55] recorded a *Pecten-Mytilus* zone, which contains "*Pecten*" *eldridgei*, in the subsurface section 100 feet above the upper *Mulinia* zone and immediately overlying the fresh-water lower *Scalez* zone. In view of its stratigraphic position and fossils the *Pecten-Mytilus* zone is considered the equivalent of the Cascajo. (See fig. 13.)

[55] Barbat, W. F., and Galloway, John, San Joaquin clay, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, p. 486, 1934.

Fossils from Cascajo conglomerate member of San Joaquin formation

[Unless otherwise stated, collections from North Dome identified by Ralph Stewart; those from Middle Dome and South Dome identified by W. P. Woodring. F, fragments; P, paired valves]

Species	Localities																								
	North Dome					Middle Dome						South Dome													
	183	185	186	191	194	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216
Coral (identification by J. E. Hoffmeister): *Coenocyathus?* sp.														F											
Echinoids (identifications by Ralph Stewart):																									
Dendraster cf. *D. gibbsii* (Rémond)	X																								
Dendraster cf. *D. coalingaensis* Twitchell				X					F					X											
Dendraster cf. *D. coalingaensis macer* Stewart, n. var.					X																				
Dendraster coalingaensis Twitchell, small variety with flat petals					X																				
Brachiopod: *Discinisca* sp. (pl. 39, figs. 1, 6)	X	X	X																						
Gastropods:																									
Tegula? cf. *T. dubiosa* Grant and Gale															F										
Calliostoma sp.												F													
Littorina sp.												X													
Fluminicola sp.											X														
Calyptraea cf. *C. inornata* (Gabb)	X														F										
Crepidula princeps Conrad?												F													
Neverita reclusiana (Deshayes)?											X	F	F		F						F	F	F	F	F
Lunatia cf. *L. lewisii* (Gould)?	X											X											F		F
Opalia varicostata Stearns												F													
Jaton? sp.											F														
Nucella etchegoinensis (Arnold) (pl. 24, figs. 16-18)												X	X		X		X	X	X	X			F		
Olivella cf. *O. pedroana* (Conrad)	X				X						F														
Pelecypods:																									
Pododesmus cf. *P. macroschisma* (Deshayes)	X					F	F					F										F	F	F	
Anadara trilineata (Conrad) of Arnold	X					F, cf.				X	X	X		?F	F						F, cf.	F	X	X	F
Anadara trilineata (Conrad) of Arnold var. cf. *canalis* (Conrad)					X																				
Mytilus cf. *M. coalingensis* Arnold	F						F				X											F	F	X	F
Aequipecten circularis eldridgei (Arnold) (pl. 24, figs. 10-13)																					F	X	X	X	X
Aequipecten cf. *A. circularis impostor* (Hanna)	F	F				F	F		?F														F		
Patinopecten lohri (Hertlein)?												F		F	F										
Ostrea sp. (small)	X	X			F	X	X	F	F						F			F	F			F	F		
Taras cf. *T. parilis* (Conrad)																								F	
Macoma sp.					F										?F										
Pseudocardium densatum (Conrad) of Arnold, varieties (pl. 24, figs. 14, 15)						P	F				F	X	X	X	F			?F			F	F	F	X	F
Venerupis cf. *V. laciniata hannibali* (Howe)										P		X		F											
Psephidia, n. sp.?											X														
Cerastoderma sp.					X										F										
Mya cf. *M. dickersoni* Clark					F						X	F	?F	?F	F						?F	F	F	F	F
Solen perrini Clark?	F										F	F		F	F						F			F	
Panope? sp.																								F	
Zirfaea cf. *Z. gabbi* Tryon	?F											F			F						F	F	F		?F
Barnacles:																									
Balanus sp. (detached compartments)	X				X		X		X			X	X	X	X			X	X		X	X	X		
Balanus cf. *B. hesperius* Pilsbry												X													
Undetermined fish remains:																									
"Bulbous growths"							X	X	X		X	X			X		X	X	X	X	X	X	X		
Other remains (plates, spines, vertebrae)												X												X	
Shark teeth								X					X			X		X					X		
Skate tooth																								X	
Land mammal (identification by C. L. Gazin): Horse? (tooth fragments)																X		X							
Marine mammals (identifications by Remington Kellogg):																									
Porpoise (fragment of right periotic)								X																	
Eared seal (distal end of metapodial)								X																	

ETCHEGOIN FORMATION

When the Etchegoin "beds" were named [56] no type locality was designated. The name was derived from the Etchegoin Ranch, formerly located about 3 miles north of Anticline Ridge,[57] in the foothills northwest of the Kettleman Hills. Arnold and Anderson established a type locality for the Etchegoin formation on Anticline Ridge and defined the formation in the type region as consisting of sand, gravel, and clay above the base of the *Glycymeris* zone.[58] In the type region Arnold and Anderson's Etchegoin formation evidently includes the San Joaquin formation, but the San Joaquin formation has not yet been differentiated on Anticline Ridge. According to Barbat and Galloway's identification of the upper *Mulinia* zone (upper *Pseudocardium* zone of present report) on Anticline Ridge,[59] the *Glycymeris* zone is not far below the upper *Mulinia* zone and may be the stratigraphic equivalent of the *Siphonalia* zone of North Dome. Perhaps part of the nonmarine formation on Anticline Ridge mapped by Arnold and Anderson as the Jacalitos formation [60] may be the equivalent of some of the marine Etchegoin in the Kettleman Hills.

On the advance edition of the geologic map of the Kettleman Hills issued in 1934 the designation "Etchegoin sandstone" was used. In view of the absence of a prevailing type of lithology in North Dome and in the upper part of the formation in Middle and South Domes the designation "Etchegoin formation" is preferable.

The Etchegoin formation embraces the oldest strata cropping out in the Kettleman Hills. In North Dome the formation has an exposed maximum thickness of about 700 feet; in Middle Dome the estimated exposed thickness is about 600 feet; and in South Dome the exposed Etchegoin has the considerably greater estimated thickness of about 1,800 feet. The Etchegoin of North Dome consists chiefly of silty sand, silt, and sandstone. In Middle and South Domes the formation consists predominantly of sandstone, but the upper part of the formation also includes silt, clay, and conglomerate. The stratigraphic units recognized in the Kettleman Hills and their thickness are given below.

[56] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 178, 1905.
[57] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 113.
[58] Idem, pp. 113-114.
[59] Barbat, W. F., and Galloway, John, op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 484.
[60] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull 398), pp. 107-108.

Stratigraphic units in Etchegoin formation of Kettleman Hills

North Dome

Unit	Lithology	Thickness (feet)
Strata overlying *Littorina* zone, including first *Mya* layer, second *Mya* layer, and first blue sandstone.	Silty sand, sandy silt, and blue tuffaceous sandstone.	100
Littorina zone.	Oolitic limestone, brown sandstone.	5
Strata between *Littorina* zone and upper *Pseudocardium* zone.	Silt, sand, and local blue sandstones.	60
Upper *Pseudocardium* zone.	Sand, silty sand.	25
Strata between upper *Pseudocardium* zone and *Siphonalia* zone.	Sandy silt and local blue conglomerate.	70
Siphonalia zone.	Brown sandy silt, silty sand, and local blue sandstones.	150
Macoma zone.	Light-colored tuffaceous silt and generally a blue sandstone.	50
Patinopecten zone.	Brown sandy silt and silty sand.	100
Strata underlying *Patinopecten* zone.	Brown silt and sand, lenses of blue sandstone.	100
Approximate total exposed thickness		700

Middle Dome

	Unit	Lithology	Thickness (feet)
Upper part.	Strata overlying *Pseudocardium-Anadara* zone.	Sandy silt, silty clay, and lenses of sandstone.	50
Upper part.	*Pseudocardium-Anadara* zone.	Silty sandstone.	10
Upper part.	Strata underlying *Pseudocardium-Anadara* zone.	Sandy silt, silty clay, sandstone, and conglomerate.	350
Lower part.		Soft sandstone; near top light-colored tuffaceous silt.	200
Approximate total exposed thickness			600

South Dome

	Unit	Lithology	Thickness (feet)
Upper part.	Strata overlying *Pseudocardium-Anadara zone.*	Sandy silt and silty clay.	50
Upper part.	*Pseudocardium-Anadara* zone.	Silty sandstone.	10
Upper part.	Strata underlying *Pseudocardium-Anadara* zone.	Sandy silt, silty clay, and sandstone.	300
Lower part.		Soft sandstone, hard sandstone, and conglomeratic sandstone.	1,500
Approximate total exposed thickness.			1,800

As shown in the preceding table, the North Dome faunal zones were not recognized in Middle and South Domes, where fossils are far less abundant than in North Dome. In the description of the Etchegoin, North Dome is treated as a unit and Middle and South Domes as another unit.

NORTH DOME

The upper part of the Etchegoin formation of North Dome above the *Siphonalia* zone is divided into thin faunal zones (*Littorina* and upper *Pseudocardium* zones) and strata that are nonfossiliferous or contain relatively few fossils. In fact, the division is similar to that adopted for the San Joaquin formation. The remaining three zones (*Siphonalia, Macoma,* and *Patinopecten* zones) are different from the overlying zones, as they embrace a considerable thickness of strata containing several or many fossiliferous layers. These three zones are not so easily recognized as the *Littorina* and upper *Pseudocardium* zones. Indefinite as they are, the three zones were useful in mapping the structure of the axial region of the anticline. The position of faults was inferred from the distribution of the zones, and subsequent search for the fault planes was successful at so many localities that considerable confidence in the zones is justified. Where all three zones are present in a section they are usually recognizable as two units of brown strata separated by a unit of light-colored strata. The *Siphonalia* zone consists mostly of brown sandy silt, though in some sections it includes blue sandstones; the *Macoma* zone is made up of light-gray to white tuffaceous silt and generally includes a blue sandstone; and the *Patinopecten* zone consists chiefly of brown silty sand. If the light-colored *Macoma* zone is not present, the abundance of *Patinopecten* usually distinguishes the *Patinopecten* zone from the *Siphonalia* zone. At the base of the *Patinopecten* zone in some sections is a layer containing large barnacles, assigned to *Tamiosoma*. The barnacles locally occur upright, in the position in which they lived, forming clusters of varying size that may appropriately be called barnacle reefs (pl. 27, *A*). Similar barnacle reefs are present in the *Macoma* zone at the north end of the anticline and in strata underlying the *Patinopecten* zone. Barnacles and barnacle fragments are abundant in the *Siphonalia* zone, but reefs were not found in this zone. The sand dollar *Dendraster gibbsii* is abundant in the *Siphonalia, Macoma,* and *Patinopecten* zones. In fact, these three zones might be designated the *Dendraster gibbsii* zone, for this sand dollar is rare, if present at all, in overlying Etchegoin strata in North Dome. This species may also occur, however, in the underlying Jacalitos formation, and a form of it is present in the lower part of the San Joaquin.

The interval between the *Macoma* and *Littorina* zones appears to increase in thickness in the north part of North Dome. This may be due to an increase in thickness of the strata of the *Siphonalia* zone or to misidentification of the *Macoma* zone in the northern outcrops. The *Macoma* zone was not traced continuously from the north end to the type locality, and it is possible that the *Macoma* zone of the north end corresponds to tuffaceous strata 50 feet below the type *Macoma* zone. However, no indication of the typical *Macoma* zone above strata identified as the *Macoma* zone was recognized in the northern part of the anticline.

A representative section of the Etchegoin is exposed on the ridge extending southward from El Rascador on the east flank of the anticline, where the formation has an exposed thickness of about 550 feet (pl. 26, *A;* pl. 28, column 9). On the top of El Rascador is a blue sandstone identified as the Cascajo conglomerate member of the San Joaquin formation. Downward in the section is a thin-bedded blue sandstone (first blue sandstone) followed in order by the five faunal zones shown in the table on page 55. The lowest strata exposed are in the bottom of the north fork of Arroyo Doblegado, where blue sandstone and brown silty sand containing *Pseudocardium* underlie the *Patinopecten* zone.

The most satisfactory horizon indicator in the Etchegoin is the *Littorina* zone, which is near the top of the formation. Consequently the *Littorina* zone is taken as the datum plane for comparison of sections and for correlations, and the accuracy of the correlations tends to diminish as the stratigraphic distance from the *Littorina* zone increases. Sections of Etchegoin strata below the *Littorina* zone are shown on plate 28.

STRATA OVERLYING *LITTORINA* ZONE

Stratigraphy and lithology.—The Etchegoin strata overlying the *Littorina* zone consist of sandy silt, silty sand, and a relatively persistent tuffaceous blue sandstone. The thickness of the strata varies, especially on the west flank of North Dome, apparently owing to the cutting out of beds by conglomerate identified as the Cascajo conglomerate member of the San Joaquin. Under the interpretation shown in figure 8 the Cascajo rests virtually on the equivalent of the *Littorina* zone at El Lobo. The average thickness of the Etchegoin above the *Littorina* zone is, however, about 100 feet. At the north end of North Dome the thickness is fully twice as great, as shown in figure 6. This 200-foot section at the north end of the anticline includes the following three mappable units, named in succession above the *Littorina* zone: first *Mya* layer, first blue sandstone, second *Mya* layer. The following section showing these units was measured in a road cut on the north side of Double Hill. The road is not shown on the topographic base of plate 3.

Section of strata in Etchegoin formation above Littorina zone exposed in road cut on north side of Double Hill, north of center of sec. 2, T. 22 S., R. 17 E.

	Feet
San Joaquin formation, Cascajo conglomerate member:	
Cross-bedded blue sandstone containing some pebbles and 1-foot fragments of green clay at base. Scour discontinuity at base	20±
Etchegoin formation:	
Cross-bedded gray sand with few clay partings. Contact at base abrupt	3
Gray sand and silt; some ferruginous concretions and lighter-colored layers. Numerous discontinuities within this unit. Contact at base abrupt	10½
Gray pebbly silt. Contact at base abrupt	1½
Greenish gravel with pebbles as much as 2 inches long and some shale partings. Contact at base abrupt	3⅓
Greenish-gray sand and silt with concretionary layers. Contact at base abrupt	7½
Brownish-gray pebbly silt with scattered pebbles as much as 2 inches long. Contact at base abrupt and marked by 1-inch borings 1 foot long	2⅓
Gray poorly sorted sand. Contact at base abrupt	2
Greenish clay. At base a gradational mixture of clay and sand; borings 1 inch in diameter, extending 20 inches into underlying sand	3
Second *Mya* layer. Greenish-gray massive sand. Shells in living positions and fragments of shells near top. Contact at base abrupt	9
Light-gray sand and silt. Contact at base abrupt	1½
Grayish-green silt with two dark clay streaks near top. Contact at base fairly distinct	8
Dark-green clay. Contact at base gradational	1¾
Gray sand. Contact at base gradational	6
Dark-gray sand with some lighter layers of finer material. Contact not observed	6
Greenish clay with some darker streaks; somewhat silty near top. Contact at base abrupt	7
Cross-bedded greenish sand. Contact at base abrupt	2
Gray sand with streaks of lighter material. Contact at base abrupt	1
First blue sandstone:	
Fine-grained, well sorted blue sandstone; some layers cross-bedded	20
Fine-grained, laminated bluish sand with some light-colored clay (?) layers	13½
First *Mya* layer. Gray silty sand containing small *Mya* or *Macoma*	1
Fine-grained gray sand. Upper part laminated; lower 4 feet massive. Contact at base abrupt	16
Green clay. Contact at base abrupt	2
Gray massive sand. *Mya* casts near middle. Contact at base abrupt	¾
Gray tough clay. Borings filled with overlying sand	1
Gray tough clay. Contact at base fairly distinct	¾
Coarse-grained green sand. Clay layers near top. Scour discontinuity at base	10
Laminated light-gray clay. Contact at base abrupt	4
Soft gray sand containing *Mya* in living positions about 1 foot from top. Base not exposed. Base of section about 20 feet above *Littorina* zone	5+
Thickness of Etchegoin strata overlying *Littorina* zone	169±

The second *Mya* layer was observed only around the north end of the anticline from La Cumbre to Double Hill. Its absence farther south on the east flank is attributed mainly to different environmental conditions during deposition, but its absence on the west flank is assumed to be due to removal of strata before the deposition of blue conglomerate identified as the Cascajo conglomerate. The presence of large *Mya* shells, standing upright in the position of living shells, usually distinguishes the second *Mya* layer (pl. 17, *C*) from the first *Mya* layer.

The first blue sandstone is a cliff-forming blue or grayish blue thin-bedded, fine-grained tuffaceous sandstone, generally 10 to 25 feet thick. Part of the sandstone is locally cross-bedded. The lighter-colored or almost white layers presumably contain more volcanic material than the darker layers. At some outcrops the sandstone is separated from underlying sandy silt by a scour discontinuity, but in general it appears to be a more sandy facies of the underlying silt. This sandstone was mapped around North Dome, and for the most part its base is shown on the geologic map (pl. 3) as the San Joaquin-Etchegoin boundary. Though it is more persistent than other sandstones in this part of the section, lenticular sandstones at slightly different horizons may have been mapped as the same bed, and at places the separation from the overlying Cascajo conglomerate is uncertain. Along part of the west flank the first blue sandstone appears to be cut by blue sandstone and conglomerate identified as the Cascajo.

The following section of the upper part of the Etchegoin, including the first blue sandstone, was measured in a road cut near the southwest corner of sec. 6, T. 22 S., R. 18 E., in a region where the second *Mya* layer is not present. This section, a continuation of the section on page 48, is somewhat generalized owing to incomplete exposures.

Section of strata in Etchegoin formation overlying Littorina zone in road cut near southwest corner of sec. 6, T. 22 S., R. 18 E.

	Feet
San Joaquin formation, Cascajo conglomerate member (?).	
Coarse-grained, cross-bedded blue sandstone with layers of pebbles.	
Etchegoin formation:	
Gray sand	2
Gray silt with some green clay. Probably includes equivalent of second *Mya* layer	20
Cross-bedded blue sandstone	6
Sandy silt	6
Blue sandstone	2
Laminated silt	6
Blue sandstone	6
Silt	15
First blue sandstone. Gritty blue sandstone	10
Tuffaceous (?) silt	3
First *Mya* layer	¼
Gray silt	50
Blue sandstone. Lens about ¼ mile long	20
Not exposed	5
Littorina zone.	
Thickness of Etchegoin strata overlying *Littorina* zone	151¼

At locality 196, in a branch of Arroyo Robador, leaf imprints occur at the base of the first blue sandstone. Leaf imprints also were found in the first blue sandstone at the south end of the anticline on the east side of El Collado and near the north end of the ridge between the forks of Arroyo del Paso.

The first *Mya* layer, consisting of fragments of shells and small shells in silty sand, was traced from the north end of the anticline southward to a locality east of El Taco on the east flank and as far as La Cima on the west flank. It may extend farther south on the east flank, for a *Mya* layer on the west flank of Arroyo Hondo may be the first *Mya* layer, and this layer may also be present just under the first blue sandstone on the south side of Arroyo Doblegado. At places on the west flank blue conglomerate assigned to the Cascajo rests on the first *Mya* layer or cuts across it, and the absence of the layer in part of this area may be interpreted as the result of deeper scouring. The first *Mya* layer is immediately below the first blue sandstone or a few feet below it. It is too close to the first blue sandstone to be shown on a map of the scale of plate 3.

A section of the strata below the first *Mya* layer, measured in a road cut on the east side of the first hill east of Double Hill, is shown below. The road is not shown on plate 3.

Section of strata in upper part of Etchegoin formation between first Mya layer and Littorina zone exposed in road cut on east side of first hill east of Double Hill, sec. 2, T. 22 S., R. 17 E.

	Feet
Light gray tuffaceous sand. Contact at base distinct but not well exposed	½
First *Mya* layer. Greenish sand; *Mya* shells in living positions and numerous small shells. Contact at base apparently a thin gradational zone	1¼
Rather fine grained blue sand. Contact at base abrupt, at least locally	3½
Grayish sand with light-gray clay or silt layers, particularly in upper part. Fossil leaves 8 inches below top (locality 193b). Contact at base abrupt	15½
Bluish-gray clay stained yellow, including a 9-inch layer of concretionary sand containing small clay fragments. Contact at base abrupt	4¼
Greenish sand. Scour discontinuity (?) at base	4
Grayish-brown sand. A 2-inch layer contains scattered casts of fresh-water gastropods (*Amnicola?*)	4
Greenish sand. A layer of *Mya* shells in living positions 10 inches above base and a 4-inch concretionary layer 6 inches above *Mya* layer. Contact at base locally gradational	4¼
Greenish sand with streaks of gray and brown sand	2½
Bluish laminated silt; gray and brown and more sand in upper part. Contact at base marked by 1-inch layer of sand penetrating underlying clay 6 inches along cracks and borings (?)	16
Greenish clay. A 1-inch dark purple layer 3 feet above base and a ¼-inch pink layer 8 inches higher. Upper 18 inches lighter-colored and sandy. Contact at base marked by two ¼-inch brown layers 2 inches apart	9
Bluish clay about 1½ feet thick grading upward into laminated silt. Contact at base abrupt	15½

Section of strata in upper part of Etchegoin formation between first Mya layer and Littorina zone exposed in road cut on east side of first hill east of Double Hill, sec. 2, T. 22 S., R. 17 E.—Continued

	Feet
Gray-green clay with coarser-grained layers about a foot apart. Contact at base abrupt	7
Gray sand grading upward into silt. Base about 20 feet above *Littorina* zone	6
Approximate thickness of strata between first *Mya* layer and *Littorina* zone	113

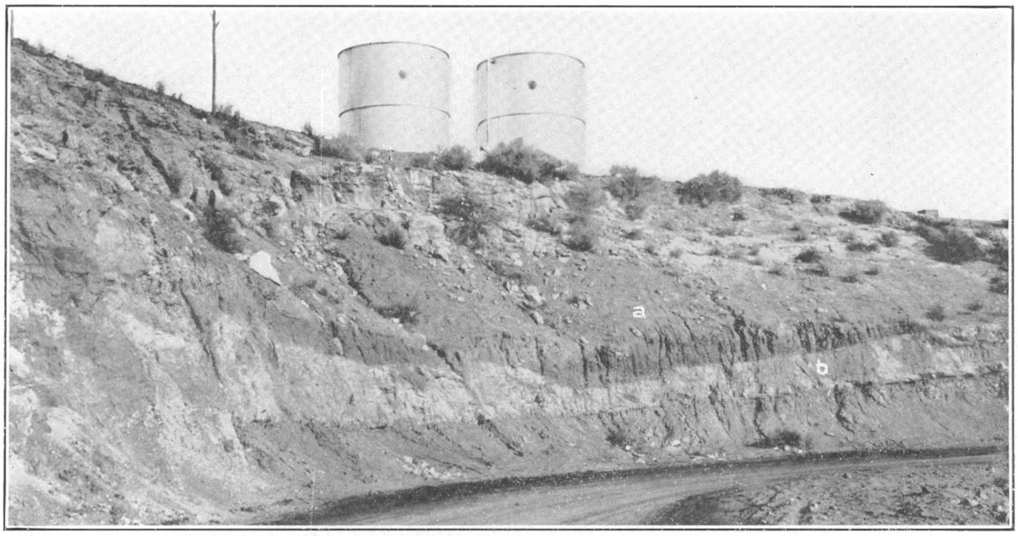
Fossils.—The leaves collected from the first blue sandstone at locality 196 and those from a horizon below the first *Mya* layer at locality 193a represent a willow, identified by R. W. Brown as *Salix coalingensis* Dorf.

In addition to the *Mya* shells in the first and second *Mya* layers, *Mya* occurs at lower horizons above the *Littorina* zone, as shown in the sections on pages 57 and 58. In the section measured on the first hill east of Double Hill fresh-water snails occur 35 feet below the first *Mya* layer. At locality 189, on the west flank of the anticline near Arroyo Conchoso, the fresh-water mussel *Anodonta* was found a foot above the first *Mya* layer. Half a mile to the northwest at locality 189a *Anodonta* is present at about the same horizon. Ten feet lower in the section *Solen* and *Mya* occur, and 25 feet still lower are fresh-water snails (*Amnicola?*). Fresh-water fossils *Anodonta* and *Amnicola* also occur on the east side of La Tusa, in the faulted axial region of the anticline in the southern part of sec. 12, T. 22 S., R. 17 E. This fresh-water horizon is 40 feet above the *Littorina* zone. Nomland [61] described *Anodonta nitida* from this locality and assigned it to a stratigraphic position below the upper *Mulinia* zone—a quite reasonable interpretation at that time, as the faulting of North Dome had not been studied. Perhaps this fresh-water bed at La Tusa is the equivalent of the lower fresh-water bed at locality 189a about 50 feet above the *Littorina* zone, but inasmuch as fresh-water fossils occur at several horizons above the *Littorina* zone the correlation is uncertain.

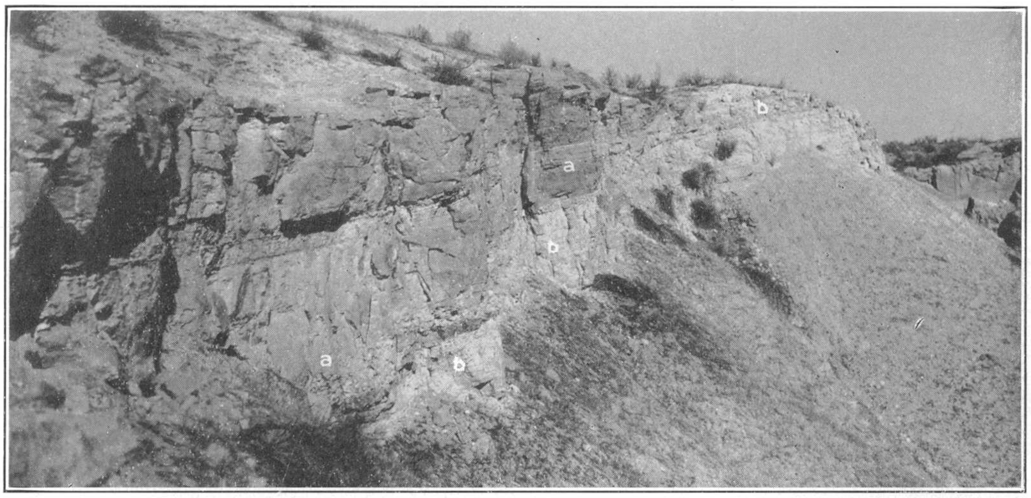
LITTORINA ZONE

Stratigraphy and lithology.—The *Littorina* zone, generally 5 feet or less in thickness, is normally about 100 feet below conglomerate and sandstone identified as the Cascajo conglomerate member forming the base of the San Joaquin formation, but it may have been removed locally before the conglomerate was deposited. At the north end of the anticline it appears to be 200 feet below the Cascajo (fig. 6). The difference in thickness of the strata separating the *Littorina* zone and the Cascajo may be interpreted as the result of scouring by currents during, or just preceding, the deposition of the Cascajo, but the measurement may have been exaggerated by possible local misidentification of the Cascajo.

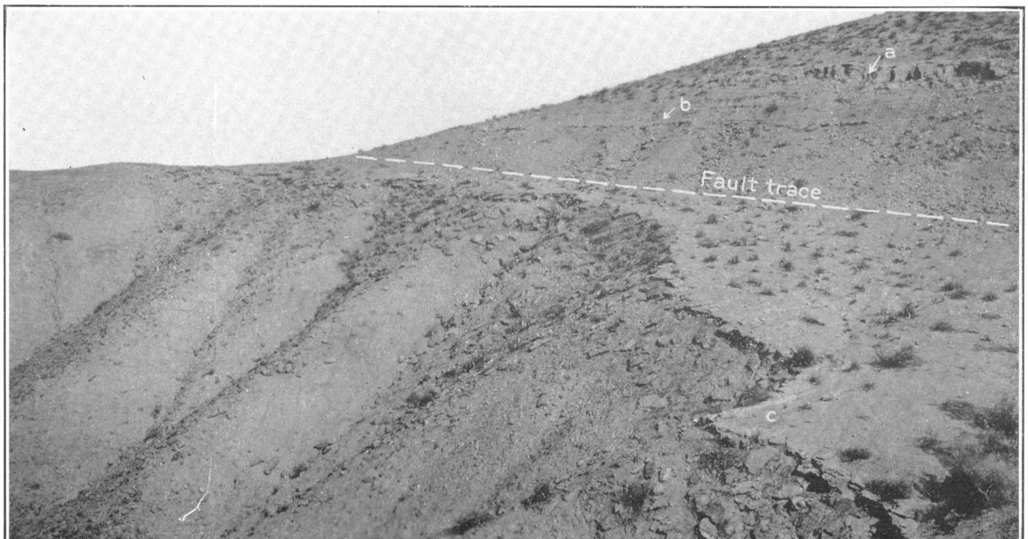
[61] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geology, Bull., vol. 10, pp. 215–216, 231, pl. 9, fig. 2, 1917.



A. CASCAJO CONGLOMERATE MEMBER OF SAN JOAQUIN FORMATION NEAR STANDARD WELL 41–3–P, NEAR NORTH LINE OF SEC. 3, T. 22 S., R. 17 E.
a. Cascajo conglomerate. Note irregular contact at base.
b. Silt and silty sand of Etchegoin formation including second *Mya* layer.

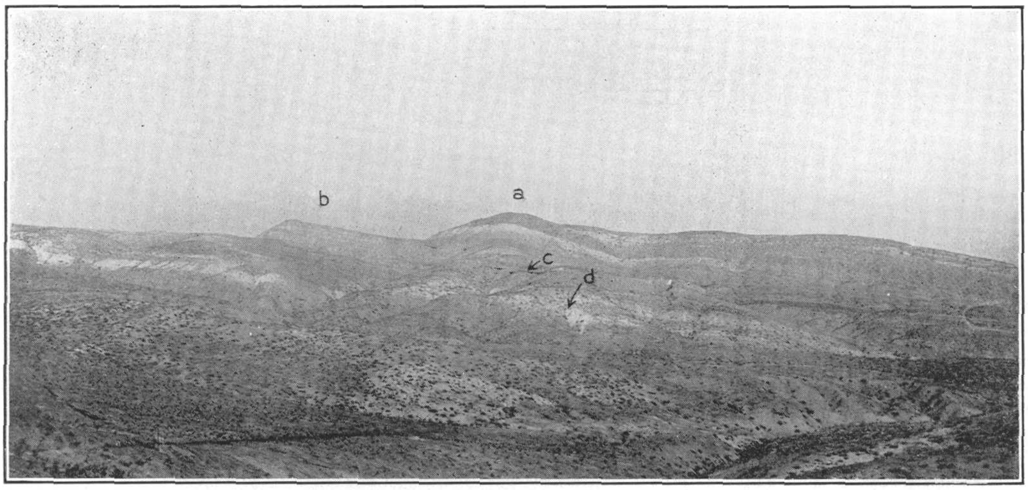


B. BLUE SANDSTONE OF CASCAJO CONGLOMERATE MEMBER OF SAN JOAQUIN FORMATION CUTTING ACROSS FIRST BLUE SANDSTONE OF UNDERLYING ETCHEGOIN FORMATION AT HEAD OF ARROYO DELGADO ON WEST SIDE OF CERRO ALTO, SEC. 28, T. 22 S., R. 18 E.
a. Cascajo conglomerate.
b. First blue sandstone.



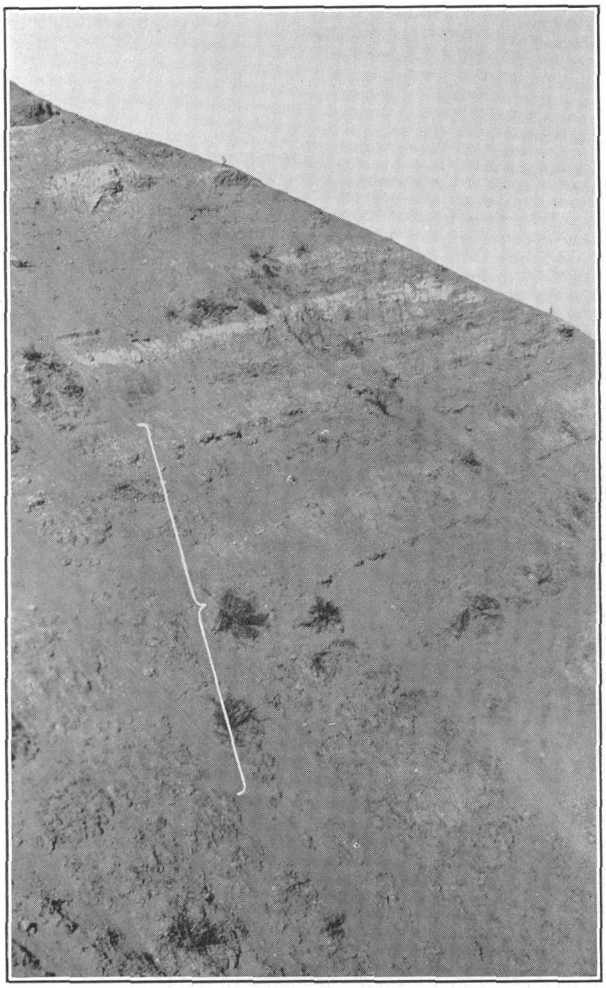
C. TYPE LOCALITY OF *LITTORINA* ZONE OF ETCHEGOIN FORMATION AT EL PISO, ON WEST SIDE OF LA CIMA, SEC. 19, T. 22 S., R. 18 E.
a. First blue sandstone.
b. First *Mya* layer.
c. *Littorina* zone.
The first *Mya* layer and first blue sandstone are normally about 100 feet above the *Littorina* zone.

STRATA IN LOWER PART OF SAN JOAQUIN FORMATION AND UPPER PART OF ETCHEGOIN FORMATION OF NORTH DOME.



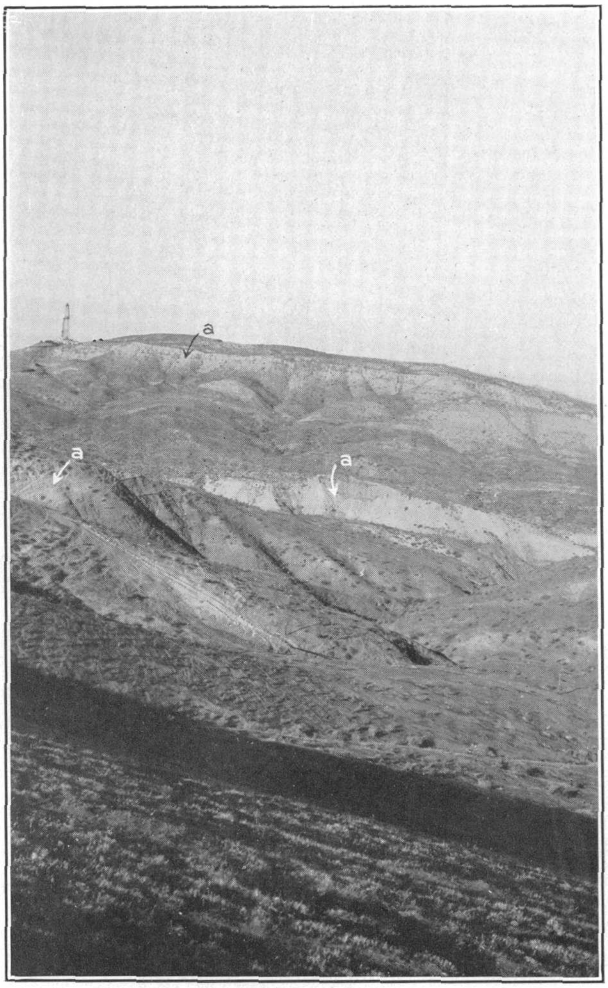
A. VIEW LOOKING NORTHEASTWARD TOWARD EL RASCADOR, IN SEC. 17, T. 22 S., R. 18 E.

a. Cascajo conglomerate member of San Joaquin formation.
b. *Littorina* zone.
c. *Mytilus* layer in *Siphonalia* zone.
d. Tuffaceous sand of *Macoma* zone.



B. FOSSILIFEROUS LAYERS IN UPPER *PSEUDOCARDIUM* ZONE ON EAST SIDE OF EL LEON, SEC. 20, T. 22 S., R. 18 E.

The bracket shows the limits of the zone.

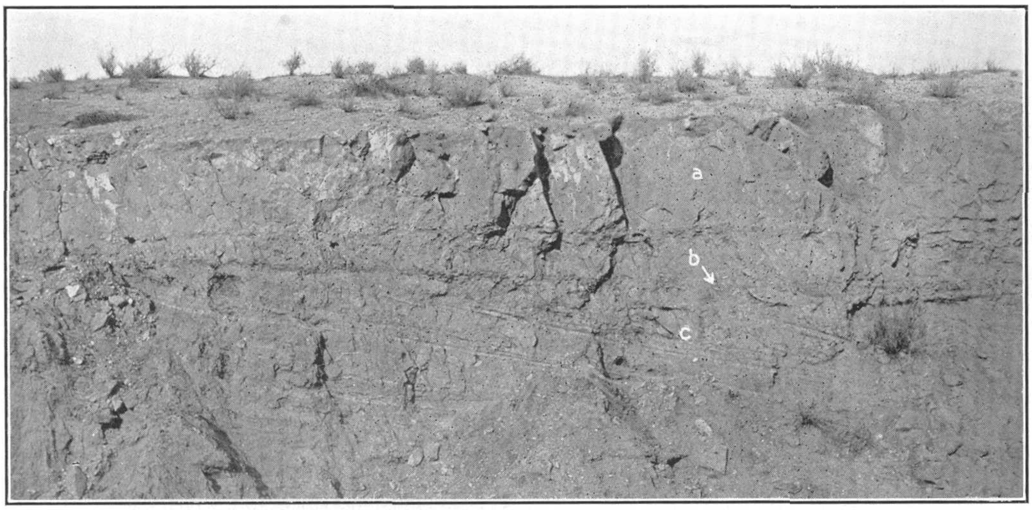


C. VIEW LOOKING NORTHWARD FROM LA ALETA TOWARD LAS PAREDES, IN SEC. 17, T. 22 S., R. 18 E.

Shows three outcrops of white tuffaceous sand of *Macoma* zone (a) separated by faults.

STRATA IN ETCHEGOIN FORMATION OF NORTH DOME.

A. BARNACLE REEF UNDERLYING *PATINOPECTEN* ZONE ON SOUTH SLOPE OF EL TOLETE, SEC. 7, T. 22 S., R 18 E.

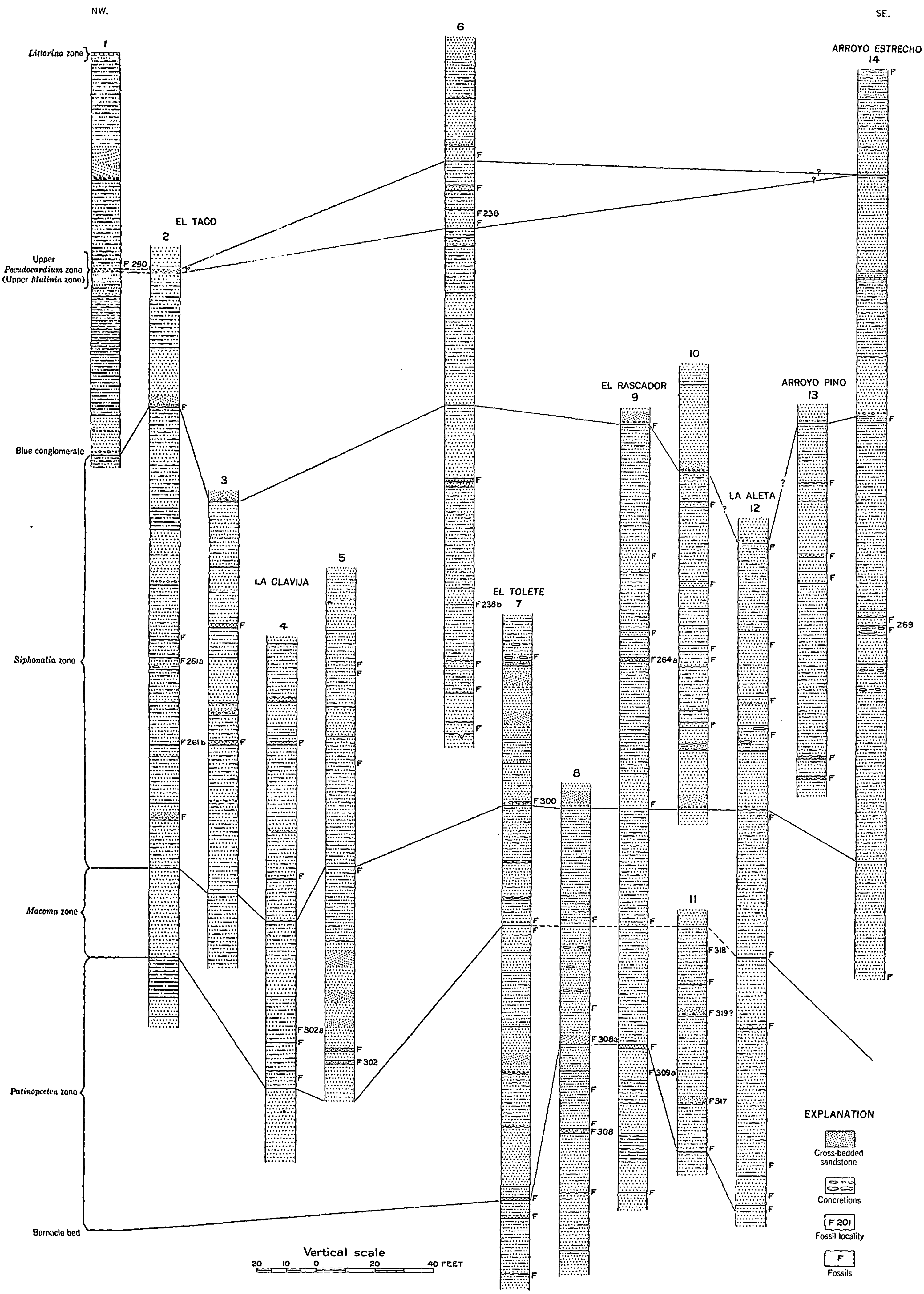


B. IRREGULAR BEDDING IN *SIPHONALIA* ZONE ON ARROYO ESTRECHO, SW¼ SEC. 35, T. 22 S., R. 18 E.

a. Massive sandstone.
b. *Mytilus* layer.
c. Sandy silt.

C. *PSEUDOCARDIUM* IN IRREGULARLY BEDDED SILT IN UPPER PART OF *SIPHONALIA* ZONE ON NORTH SLOPE OF ARROYO PINO, SE¼ SEC. 26, T. 22 S., R. 18 E.

STRATA IN ETCHEGOIN FORMATION OF NORTH DOME.



SECTIONS OF STRATA IN ETCHEGOIN FORMATION OF NORTH DOME UNDERLYING *LITTORINA* ZONE.

1. Locality 250, NE¼ sec. 2, T. 22 S., R. 17 E.
2. Locality 261a, south side of ridge 1,300 feet northwest of El Taco, SW¼ sec. 1, T. 22 S., R. 17 E.
3. Southeast side of El Taco, secs. 1 and 12, T. 22 S., R. 17 E.
4. West side of La Clavija, north center of sec. 12, T. 22 S., R. 17 E.
5. Locality 302, NE¼ sec. 12, T. 22 S., R. 17 E.
6. Locality 238, south center of sec. 20, T. 22 S., R. 18 E.
7. Locality 300, south side of El Tolete, SE¼ sec. 7, T. 22 S., R. 18 E. Type locality of *Macoma* and *Patinopecten* zones.
8. Locality 308, east of Las Paredes, north center of sec. 17, T. 22 S., R. 18 E.
9. Locality 264a, south of El Rascador, NE¼ sec. 17, T. 22 S., R. 18 E.
10. Forks of Arroyo Doblegado, near northeast corner of SW¼ sec. 16, T. 22 S., R. 18 E. Type locality of *Siphonalia* zone.
11. Locality 317, SE¼ sec. 17, T. 22 S., R. 18 E.
12. Composite section on south side of La Aleta, NE¼ sec. 20, T. 22 S., R. 18 E.
13. Locality 266, Arroyo Pino, SE¼ sec. 26, T. 22 S., R. 18 E.
14. Locality 269, Arroyo Estrecho, SW¼ sec. 36, T. 22 S., R. 18 E.

The *Littorina* zone at many localities may be divided into two parts, an upper part containing a mixture of fresh-water and marine fossils and including a brown oolitic limestone and a lower part containing marine fossils. Aside from the oolitic limestone, the zone consists of gray or brown sandstone. The oolitic limestone is a hard layer 6 inches to a foot thick that weathers out as slabs or forms dip slopes. It has been called the pavement bed or sidewalk bed. It forms a conspicuous layer that is easily traced over the greater part of North Dome. Because it is so thin it permits the most exact correlation of strata on opposite sides of the anticline,

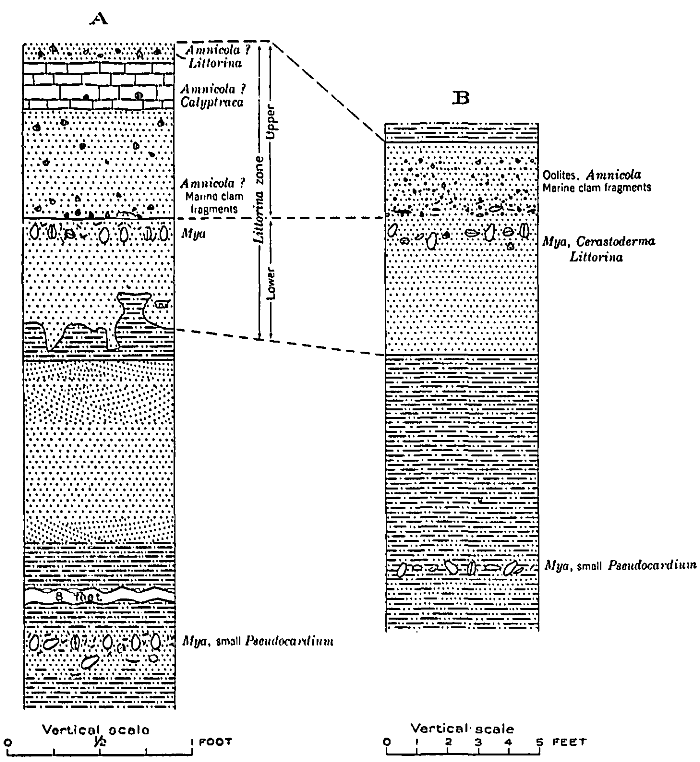


FIGURE 9.—Sections of *Littorina* zone of Etchegoin formation and immediately underlying strata on west and east flanks of North Dome. The fossils are not drawn to scale, and their position is generalized.

A. West flank; 400 feet southeast of El Piso, sec. 19, T. 22 S., R. 17 E.
B. East flank; excavation for well location near southwest corner of sec. 6, T. 22 S., R. 18 E.

and its surface is shown by contours on the geologic structure map (pl. 51). The zone is interbedded with silt and clay between the overlying first blue sandstone and the underlying blue sandstones associated with the upper *Pseudocardium* zone. Where the oolite layer is absent the exact position of the zone in the interval between the more conspicuous outcrops of the underlying and overlying blue sandstones may be difficult to determine.

Littorina is not confined to this zone, and, therefore, the name of the zone is not ideal. This genus occurs in the underlying upper *Pseudocardium* zone and also at several horizons in the San Joaquin formation. It is, however, a common fossil in the *Littorina* zone and at localities where the two parts are present occurs in both the lower marine part and the upper fresh-water part. Fresh-water fossils occur in overlying Etchegoin strata, but *Littorina* has not been found with them. The marine faunal association in the oolite in the lower part of the San Joaquin formation (described as the upper oolite under the heading "Strata between *Neverita* zone and Cascajo conglomerate member") resembles that in the lower part of the *Littorina* zone, but *Littorina* is absent.

At El Piso, on the west side of La Cima, the type locality of the *Littorina* zone (locality 218; pl. 25, *C*), the upper part of the zone consists of the hard oolite, half a foot thick, overlain by pebbly cross-bedded sandstone, one foot of which is exposed. The sandstone also contains some oolites. Some indication of cross-bedding is evident in the oolite layer, which contains at least some sand grains. The oolites are brown and smooth, many have concentric layers, and some are hollow. In the lower part of the zone is a gray sandstone, a foot of which is exposed. The upper part of the gray sandstone is very fossiliferous, and the lower part is silty.

Sections of the *Littorina* zone and immediately underlying strata are shown in figure 9. The following section, which includes the zone, was measured at the locality represented in figure 9, B:

Section of strata in upper part of Etchegoin formation, including Littorina zone, exposed in excavation for well location near southwest corner of sec. 6, T. 22 S., R. 18 E.

	Feet
Strata overlying *Littorina* zone:	
Thin-bedded gray sand. Discontinuity at base	9
Laminated silty clay weathering greenish gray. Numerous brown streaks and seams of gypsum half an inch to 2 inches wide cutting bedding or parallel to it. Discontinuity at base	23
Littorina zone:	
Greenish-gray oolitic and fossiliferous sandstone. Discontinuity at base	7
Strata underlying *Littorina* zone:	
Gray laminated silt. *Mya* in living positions a foot above base and few small *Pseudocardium*. Discontinuity at base	8
Greenish-gray rather massive silt. May correspond to greenish band beneath *Littorina* zone at some weathered outcrops. Contact at base gradational	5
Greenish sand	6

The zone was traced with little difficulty except on the west flank of the anticline between Cerro Alto and El Leon and at the extreme north and south ends of the anticline.

In the area between the north slope of Cerro Alto and El Leon the typical *Littorina* zone was not recognized along the main outcrop west of the strike faults, and the observations seem to indicate that in parts of the area at least the zone was eroded away before or during the deposition of the Cascajo conglomerate (?) or the first blue sandstone. In part of this region a layer containing *Mya* and shell fragments, locally truncated by a blue sandstone, is thought to represent the *Littorina* zone Locally an inconspicuous layer containing *Mya* and small *Pseudocardium* is about 20 feet lower in the section. In view of the faunal association this *Mya-Pseudocardium* layer, rather than the overlying *Mya* layer, is considered the equivalent of the *Mya-Pseudocardium* layer that at places on both flanks of the anticline is 7 to 10 feet below the base of the *Littorina* zone. (See fig. 9.)

Localities near the northwest corner of sec. 2, T. 22 S., R. 17 E., and in the bottom of Arroyo Bifido half a mile to the east are the northernmost observed occurrences of the zone, but oolites were not recognized at these localities. At locality 224, farther south near Cerro Lodoso, the oolite layer, which is practically horizontal, appears to grade westward in a distance of 10 to 15 feet into a limy clay containing *Mya* and *Pseudocardium*. The continuity of the strata was not established, but it is evident that at this locality *Pseudocardium* occurs in the *Littorina* zone or just below it. Farther to the west and across a fault a layer with *Mya* and *Pseudocardium* appears to represent the *Littorina* zone.

No oolites were observed in the zone toward the south end of the anticline. The zone was reasonably well identified as far south as Broken Hill on the east flank and Drillers Ridge on the west flank. Farther south a layer containing *Mya*, *Pseudocardium*, and *Anadara* at localities 226 and 238a and a *Mya* layer at locality 228 were mapped as the *Littorina* zone. The fossiliferous strata at these localities may correspond to the *Mya-Pseudocardium* layer about 10 feet below the *Littorina* zone shown in figure 9, but the *Littorina* zone was not found above them. However, a *Littorina* zone association was found still farther south on the Paso Robles-Hanford road just west of the Arroyo del Paso crossing. At that locality *Littorina*, *Mya*, and *Calyptraea* occur in a 2-inch layer of silt containing some grit and gypsum. As no complete exposures were found in this region, it is quite possible that both the *Mya-Pseudocardium* layer and at least the lower part of the *Littorina* zone may be present.

The faulted outcrops of the *Littorina* zone afford the most conspicuous evidence for the troughlike structure of the crest of North Dome. The most striking example of the repetition of the zone by faulting is on the south slope of Las Paredes. At this locality the oolite layer, with the upper *Pseudocardium* zone 40 feet below it, caps a hill and is about 300 feet lower stratigraphically than the main outcrop at the foot of El Rascador. Similar faulting on the west side of La Muralla is more accessible. North of La Cima the *Littorina* zone, including the oolite layer, is repeated four times. An assumption that these outcrops represent as many *Littorina* zones in different stratigraphic positions is made untenable not only by observations on some of the fault planes but also by the repetition of other identifiable strata in the separate fault blocks.

Fossils.—Fossils from the *Littorina* zone are listed in the following table, and three of the species are shown on plates 29 and 39.

Fossils from Littorina zone of Etchegoin formation

[Identifications by Ralph Stewart. F, fragments; P, paired valves; S, small specimens]

Species	Localities								
	218	219	221	223	225	226	227	229	238a
Gastropods:									
Littorina mariana Arnold (pl. 29, figs. 8, 9)	X	X			X		X		X
Amnicola? sp	X	X			X				
Calyptraea cf. *C. inornata* (Gabb)	X	X					X		
Pelecypods:									
Anadara sp						X		X	
Macoma affinis plena Stewart n. var. (pl. 29, fig. 12)	X		X	X					P
Pseudocardium sp				F		X		X	
Cerastoderma cf. *C. meekianum* (Gabb) small var. (pl. 29, fig. 3)	P			?	F				
Mya cf. *M. dickersoni* Clark	P	X		P	X	P	X	X	S
Solen sp	P								

Where the *Littorina* zone consists of an upper part and a lower part fresh-water fossils were not found in the lower part; that is, they do not occur below the oolite. Many of the marine fossils in the lower part are in living positions and may have been killed by freshening of the water. *Littorina mariana* (pl. 29, figs. 8, 9), *Mya* cf. *M. dickersoni*, the small *Macoma affinis plena* (pl. 29, fig. 12), and a small variety of *Cerastoderma* cf. *C. meekianum* (pl. 29, fig. 3) are the most abundant fossils in the lower part of the zone or in the fossiliferous layers of the zone at localities where the upper part is not present. The fresh-water snail in the upper part of the zone, identified as *Amnicola?*, is abundant, but the specimens are not well enough preserved to be identified with certainty. It is reasonably certain, however, that they represent a fresh-water form.

The marine fossils associated with the fresh-water snails consist of fragments of clams, aside from the gastropods *Littorina* and *Calyptraea*. These marine fossils may be accounted for by assuming that they were derived from the underlying part of the zone. Some of the marine fossils in the upper part of the zone, however, notably *Littorina*, may have been able to survive in brackish or almost fresh water.

Anadara was not found in the *Littorina* zone itself but in the *Mya-Pseudocardium* layer mapped as the zone toward the south end of North Dome.

Though *Pseudocardium* is abundant in strata only about 60 feet below the *Littorina* zone, its absence from the *Littorina* zone is very striking and is characteristic of the whole area of North Dome with but few known possible exceptions. These exceptions represent localities near the extremities of the anticline, where the oolite was not observed. At these localities poorly preserved medium-sized specimens of *Pseudocardium* associated with *Mya* occur in a layer mapped as the *Littorina* zone. It seems likely, however, that the layer containing *Pseudocardium* near the south end of the anticline is not the exact equivalent of the *Littorina* zone, and perhaps the similar layer near the north end is also not the exact equivalent. In Arroyo Largo (locality 246) at the northwest end of the anticline an isolated outcrop contains fresh-water snails and *Pseudocardium*. This outcrop may represent the *Littorina* zone, but it was mapped as the upper *Pseudocardium* zone.

STRATA BETWEEN *LITTORINA* ZONE AND UPPER *PSEUDOCARDIUM* ZONE

The strata between the *Littorina* and *Pseudocardium* zones have a thickness of 40 to 70 feet. They consist chiefly of sandy silt and silty clay, but at some localities include a considerable thickness of sand and sandstone. On the south side of La Palomera a thin lens of practically pure tuff, consisting principally of volcanic glass, occurs about 20 feet above the upper *Pseudocardium* zone. The *Mya-Pseudocardium* layer occurring locally about 10 feet below the *Littorina* zone is mentioned under the heading "*Littorina* zone" and is shown in figure 9. About 500 feet south of the type locality of the *Littorina* zone this layer contains *Calyptraea* and *Macoma?* as well as *Mya* and *Pseudocardium*.

At some localities a pebbly blue sandstone or conglomerate overlies the upper *Pseudocardium* zone and locally cuts across the upper part of the zone. In fact, at places near the north end of North Dome and in the entire area at the south end of the anticline the upper *Pseudocardium* zone is cut out by conglomerate in this part of the section, or the zone grades laterally into conglomerate. Barbat and Galloway [62] placed the San Joaquin-Etchegoin boundary at this horizon—at the base of lenticular blue sandstone overlying the upper *Pseudocardium* zone. Barbat and Galloway's classification has the advantage of drawing the boundary immediately above the upper limit of abundant *Pseudocardium*. It has also the further advantage of placing in the San Joaquin formation the earliest fresh-water deposits occurring in the *Littorina* zone and overlying strata. Their classification, however, is difficult to apply in Middle and South Domes unless the term "upper *Pseudocardium* zone" is loosely used, as, in fact, it may be in other areas.

The following section of strata between the *Littorina* and upper *Pseudocardium* zones was measured at the southeast end of El Leon.

Section of strata in upper part of Etchegoin formation between Littorina and upper Pseudocardium zones at southeast end of El Leon (locality 238)

	Feet
Littorina zone: Greenish-gray sandstone, many shells in upper part—*Littorina*, *Mya* (in living positions), and small *Macoma*	1
Greenish-gray sand with some indurated purplish-brown layers and a 2-foot pebble bed at base. Pebbles consisting of chert and quartz mostly less than half an inch long. Scour discontinuity at base	11
Grayish-blue and purple clayey silt with a light-gray clay about 2 feet thick at top and a purplish sand about a foot thick at base	12
Dark-gray sand, weathering light gray	6
Poorly exposed gray sandy silt	14
Coarse-grained sandstone, greenish in upper part, bluish in lower part. Pebbles and laminated sandstone near base	15
Upper *Pseudocardium* zone (see continuation of section p. 62).	
Thickness of strata between *Littorina* and upper *Pseudocardium* zones	58

Sycamore and willow leaves, identified by R. W. Brown as *Platanus paucidentata* and *Salix coalingensis*, were found at locality 271a, near the south end of the anticline, in blue sandstone estimated to be just above the horizon of the upper *Pseudocardium* zone.

UPPER *PSEUDOCARDIUM* ZONE (UPPER *MULINIA* ZONE)

Stratigraphy and lithology.—The upper *Pseudocardium* zone is about 175 feet below the top of the Etchegoin formation. It consists generally of fossiliferous sandstone containing abundant large *Pseudocardium* but at places also includes nonfossiliferous silty sand and silty clay. The thickness is variable. At localities where the zone is well developed it is about 25 feet thick.

This zone essentially marks the upper limit of *Pseudocardium* in North Dome. It roughly corresponds to the upper *Mulinia* zone of Arnold and Anderson,[63] who indicated the upper *Mulinia* zone on their geologic map of the Kettleman Hills by a red line.[64] Arnold and Anderson's upper *Mulinia* zone evidently included more than the upper *Pseudocardium*, however, for they cited a thickness of 150 feet for

[62] Barbat, W. F., and Galloway, John, San Joaquin clay, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 480 (table), 482, 1934.

[63] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 119, 122, 123, 136

[64] Idem, pl. 1.

their zone in North Dome.[65] Both the Kreyenhagen Hills and Kettleman Hills were mentioned in the description of the upper *Mulinia* zone, and no type locality has been designated. Unless better sections are found in the Kreyenhagen Hills, it is suggested that the south end of El Leon (locality 238) be considered the type locality of the upper *Pseudocardium* zone.

The name of the zone is changed because the species for which it is named, *Mulinia densata,* is now assigned to *Pseudocardium.* The change in nomenclature is not so drastic as it may appear to be, for the fossil has been cited as *Pseudocardium gabbi*[66] and as *Mactra* (*Pseudocardium*) *densata.*[67]

The upper *Pseudocardium* zone was not examined in detail because of its proximity to the *Littorina* zone, which is usually more easily mapped. It was examined and mapped, however, at many localities. At the south end of North Dome it appears to be absent, and at the extreme north end the facies is not typical.

The standard section of the upper *Pseudocardium* zone in North Dome is exposed at locality 238 at the south end of El Leon, where the following section was measured (pl. 26, *B*).

Section of upper Pseudocardium zone of Etchegoin formation at south end of El Leon (locality 238)

	Ft.	in.
Upper *Pseudocardium* zone. Overlain by coarse-grained sandstone; (For upward continuation of section, see p. 61):		
Gray fossiliferous sandstone with bed of *Pseudocardium* forming prominent 2-foot layer. Large and small *Pseudocardium* and a few small sand dollars. Contact at base abrupt, sand filling borings penetrating underlying clay	6	
Gray sandy clay. Contact at base not well exposed	8	
Gray silty sandstone with three fossiliferous layers. Contact at base abrupt:		
More or less barren	2	
Upper fossiliferous layer.		
Large thin sand dollars. (Some *Pseudocardium, Cerastoderma,* and *Glycymeris* farther south)	1	
More or less barren	6	
Middle fossiliferous layer.		
Mytilus, Saxidomus, Anadara, and oysters.		
(Probably represented at locality 237a, 800 feet south, by a bed containing oysters, *Anadara, Saxidomus,* and *Pseudocardium*)	1	

Section of upper Pseudocardium zone of Etchegoin formation at south end of El Leon (locality 238)—Continued

	Ft.	in.
Upper *Pseudocardium* zone—Continued.		
Gray silty sandstone with three fossiliferous layers—Continued.		
More or less barren	4	
Lower fossiliferous layer. Medium-sized *Pseudocardium, Cerastoderma, Saxidomus,* a few fragments of sand dollars, and oysters. (About 200 feet to the south the *Saxidomus* are in living positions with their posterior ends pointing upward)		2
Barren	1	
Thickness of upper *Pseudocardium* zone	29+	

In this section the zone is 29 feet thick and the top is 58 feet below the *Littorina* zone. This stratigraphic position for the upper *Pseudocardium* zone, about 60 feet below the *Littorina* zone, is fairly consistent along the greater part of the west flank of the anticline. A readily accessible locality is on the south side of the Skyline road east of El Chichon (locality 240), where the following section was measured. In this section the zone is only 5 feet thick and consists of buff silty sandstone containing three fossiliferous layers, probably corresponding to the 15-foot gray silty sandstone at the base of the section on El Leon.

Section of upper Pseudocardium zone of Etchegoin formation on south side of Skyline road east of El Chichon (locality 240)

	Ft.	in.
Barren buff silty sandstone. Locally cut out by overlying coarse-grained pebbly blue sandstone	1	4
Fossiliferous layer. Mostly broken *Pseudocardium*		10
Barren buff silty sandstone		8
Fossiliferous layer. Scattered *Pseudocardium*		2
Barren buff silty sandstone	1	6
Main fossiliferous layer (locality 240). *Pseudocardium, Anadara, Venerupis, Solen,* oysters, and thin sand dollars		6
Thickness of upper *Pseudocardium* zone	5	

Another accessible locality where the zone is well exposed is on the southwest end of Discovery Ridge, on the top of a small hill just above the road (locality 242). At this locality the zone is closer to the axis of the anticline owing to displacement by faults. At locality 243, northeast of Cerro Lodoso, the zone is marked by two fossiliferous layers 15 feet apart.

At the north end of the anticline, in Arroyo Largo and its tributaries, the upper *Pseudocardium* zone, like the *Littorina* zone, is not easily mapped, partly owing to poor exposures but also apparently owing to a change in facies. Several layers in this region containing *Pseudocardium* and other fossils probably represent the zone. The most notable feature in this region is the occurrence in some layers of great numbers of the small pelecypod *Transennella.*

[65] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 122.

[66] Pack, R. W., The Sunset-Midway oil field, Calif., pt. 1, Geology and oil resources: U. S. Geol. Survey Prof. Paper 116, p. 45, 1920.

[67] Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, p. 403, 1931.

At locality 250, on the east flank of the anticline east of Double Hill, the zone, represented by a 1-foot brown silty sandstone containing *Pseudocardium*, is 72 feet below the *Littorina* zone. It is unlikely that this 1-foot fossiliferous sandstone is the equivalent of the 29-foot section on El Leon. The 1-foot sandstone may be the equivalent of the basal part of the El Leon section and the 30 feet of nonfossiliferous brown silty sandstone overlying the 1-foot sandstone may correspond to the remainder of the El Leon section. The nonfossiliferous silty sandstone is overlain by cross-bedded pebbly blue sandstone.

The zone was not definitely recognized south of the south branch of Arroyo Robador on the east flank of the anticline and south of a locality east of Cerro Ultimo on the west flank. Strata in the estimated stratigraphic position of the zone around the south end of the anticline are apparently nonfossiliferous. A conglomerate that forms the northeastward-trending row of hills just south of Arroyo Estrecho and east of Pipe Hill is thought to be in the stratigraphic position of the zone. Possibly the zone is cut out by this conglomerate. If so, the conglomerate corresponds to the pebbly blue sandstone overlying the zone at localities farther north.

In the faulted trough of the anticline near the axis the upper *Pseudocardium* zone is represented by a *Pseudocardium-Mya* layer 40 feet below the *Littorina* zone south of Las Paredes, and by a sandstone containing *Pseudocardium* and thin sand dollars also 40 feet below the *Littorina* zone west of La Muralla. A bed containing small *Anadara*, oysters, and fragments of *Pseudocardium* on top of the knoll 500 feet south of the north quarter corner of sec. 18, T. 22 S., R. 18 E., is correlated with the upper *Pseudocardium* zone.

Fossils.—The fossils collected from the upper *Pseudocardium* zone are listed in the following table. The characteristic species are shown on plates 29, 30, 39 to 41.

Fossils from upper Pseudocardium zone (upper Mulinia zone) of Etchegoin formation

[Identifications by Ralph Stewart. F, fragments; P, paired valves; S, small specimens]

Species	Localities																			
	237	238	239	239a	239b	240	241	242	243	243a	244	245	247	248	249	250	251	252	252a	253
Echinoid: *Dendraster coalingaensis macer* Stewart, n. var. (pl. 39, fig. 9; pl. 40, figs. 1, 5; pl. 41, figs. 1, 2, 4)	X	X				X	X	X	X						X					X
Gastropods:																				
Margarites cf. *M. pupillus* (Gould)			X										F			X	X			
Littorina mariana Arnold				X		?		X												
Fluminicola kettlemanensis Pilsbry?				X		X											X			
Amnicola? sp												X								
Bittium asperum (Gabb) (pl. 29, fig. 15)	X			cf.		X	X				?		F			cf.	cf.			
Calyptraea cf. *C. inornata* (Gabb)				X												S				
Calyptraea cf. *C. filosa* (Gabb)													X							
Crepidula cf. *C. onyx* Sowerby																S				
Lunatia cf. *L. lewisii* (Gould)									X											
Mitrella cf. *M. gausapata* (Gould)				X		?										?	X			
Pelecypods:																				
Anadara trilineata (Conrad) of Arnold, short inflated var. (pl. 29, figs. 2, 6)		X	X	X		P	X							X	X	X		S		X
Glycymeris grewingki Dall (pl. 29, figs. 10, 11)		X				P										X				X
Mytilus sp		X			X															
Ostrea atwoodii Gabb (pl. 29, figs. 1, 13)														X		X				
Ostrea sp		X	X			X	X	X	X						X	X		X		
Lucinoma cf. *L. acutilineata* (Conrad) (pl. 29, fig. 7)	X		?					X						X		X				
Taras sp				?																
Macoma affinis Nomland									cf.	P	cf.					cf.				
Pseudocardium densatum (Conrad) of Arnold, var. cf. *gabbii* Rémond (pl. 29, fig. 16; pl. 30)	X	X	X		X	P	X	X	X	P	X	X	X	X	X	X	X		X	
Saxidomus sp	X	X																		
Venerupis laciniata hannibali (Howe) (pl. 29, fig. 5)					X	X														
Transennella cf. *T. tantilla* (Gould)			?	P		X			X			X	F	X		X				
Cerastoderma cf. *C. meekianum* (Gabb) (pl. 29, fig. 14)		X					X		X				X	X						
Mya cf. *M. dickersoni* Clark	X								P	P	X				P	F				
Solen sp	P		F			P									X	P				
Pandora cf. *P. punctata* Conrad (pl. 29, fig. 4)			X	X																

The fauna of the upper *Pseudocardium* zone is a small marine fauna. Fresh-water snails were found with the marine fossils at several localities in the northern part of the anticline. Petrified wood occurs in the zone, particularly on the east flank of the anticline near the north end. Remains of land mammals are, however, rare. Fragments of a horse tooth at locality 243a may have come from the zone.

The upper *Pseudocardium* zone is usually identified by the great abundance of *Pseudocardium densatum*. This species is also abundant at lower horizons, but at these lower horizons *Mya* is very scarce. The usual form of *Pseudocardium densatum* in the upper *Pseudocardium* zone (pl. 29, fig. 16; pl. 30) is similar to the variety *gabbii*. The thin sand dollar *Dendraster coalingaensis macer* (pl. 39, fig. 9; pl. 40, figs. 1, 5; pl. 41, figs. 1, 2, 4) was found only in this zone. The zone is further characterized by the highest occurrence of *Glycymeris grewingki* (pl. 29, figs. 10, 11), *Ostrea atwoodii* (pl. 29, figs. 1, 3), *Lucinoma* cf. *L. acutilineata* (pl. 29, fig. 7), and *Venerupis laciniata hannibali* (pl. 29, fig. 5), and by the occurrence of a short inflated form of *Anadara trilineata* (pl. 29, figs. 2, 6).

Occurrence in San Joaquin Valley subsurface section.—The uppermost occurrence of abundant *Pseudocardium* in the subsurface section in the southern San Joaquin Valley has been correlated with the upper *Pseudocardium* zone.[68] According to Barbat and Galloway's composite subsurface section, the subsurface upper *Pseudocardium* zone underlies fresh-water deposits including the lower *Scalez* zone. The fresh-water deposits are in the stratigraphic position of the *Littorina* zone, or of fresh-water strata overlying the *Littorina* zone, and occur below a marine zone suggested in the present report as the equivalent of the Cascajo conglomerate member at the base of the San Joaquin formation. The succession of zones in the composite subsurface section, therefore, is essentially the same as in a composite North Dome-South Dome section. In subsurface sections that have this succession of zones the correlation of the upper *Pseudocardium* zone with the upper *Pseudocardium* zone of North Dome is reasonably certain. In subsurface sections that lack this succession of zones, however, the uppermost occurrence of *Pseudocardium* may not invariably represent the same horizon. The doubtful stratigraphic quality of the uppermost occurrence of *Pseudocardium* is illustrated in the Kettleman Hills. In North Dome this genus occurs rarely in, or just below, the *Littorina* zone. In Middle and South Domes it occurs in the Cascajo conglomerate member of the San Joaquin formation, possibly as transported fossils, and is abundant in a zone considered the essential equivalent of the *Littorina* zone. Though the thickness of strata involved in these uppermost occurrences of *Pseudocardium* in the Kettleman Hills is negligible for purposes of regional correlation, in other sections the thickness may be greater.

STRATA BETWEEN UPPER *PSEUDOCARDIUM* ZONE AND *SIPHONALIA* ZONE

The strata between the upper *Pseudocardium* and *Siphonalia* zones have a thickness of 45 to 80 feet, generally about 70 feet. Nonfossiliferous sandy silt and sandstone predominate in this part of the section. At some localities a blue conglomerate immediately overlies the *Siphonalia* zone and cuts out strata in the zone. Locally the blue conglomerate contains *Pseudocardium*, sand dollars, and mastodon remains, generally tusk fragments. A section of these strata measured at the south end of El Leon, where the blue conglomerate is not present, is given below (pl. 28, column 6).

[68] Barbat, W. F., and Galloway, John, op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 487, fig. 1 (p. 488).

Section of strata in Etchegoin formation between upper Pseudocardium zone and Siphonalia zone at south end of El Leon (locality 238)

	Feet
Upper *Pseudocardium* zone. (For upward continuation of section, see p. 62.)	
Laminated sandy silt. Contact at base abrupt	3
Light-gray clay, sandy at base	3
Poorly exposed laminated sandy silt	15
Greenish sand, weathering dark brown	10
Dark-gray and some light-gray laminated sandy silt	20
Fine-grained dark gray sand. Contact at base abrupt. Probably corresponds to blue conglomerate elsewhere overlying *Siphonalia* zone	9
Greenish sand and poorly bedded silt assigned to *Siphonalia* zone.	
Thickness of strata between upper *Pseudocardium* zone and *Siphonalia* zone	60

SIPHONALIA ZONE

Stratigraphy and lithology.—Brown silt and fossiliferous brown silty sand and sandstone, 100 to 150 feet thick, are designated the *Siphonalia* zone. The top of the zone is 135 to 200 feet below the *Littorina* zone. At some localities the *Siphonalia* zone is overlain by blue conglomerate that cuts across strata in the zone. At localities where the blue conglomerate is absent the top of the zone is placed at the top of fossiliferous strata, as in the section at the south end of El Leon (pl. 28, column 6). Locally a blue sandstone, at the base of which is a scour discontinuity, forms the base of the zone, and at places lenses of blue sandstone occur in the zone. A layer of tuff less than a foot thick is present near the top of the zone, and a fossiliferous gravel occurs near the base of the zone in the northern part of the anticline.

The type locality of the *Siphonalia* zone is on Arroyo Doblegado, near the northeast corner of the SW¼ sec. 16, T. 22 S., R. 18 E. At this locality the zone is 113 feet thick, including a blue sandstone at the base, and is overlain by blue conglomerate (pl. 28, column 10). The name of the zone is derived from a large gastropod, *Siphonalia kettlemanensis*. This species has not been found above the zone, though the genus occurs in the upper part of the San Joaquin formation. The *Siphonalia* zone is the highest zone in the Etchegoin formation containing large gastropods. Many pelecypods found in the zone are also large, a large *Mytilus* being one of the most abundant fossils. Sand dollars are abundant in the zone, generally in lenses of sand practically devoid of other fossils. Mastodon remains, generally fragments of tusks and molar teeth but at one locality a skull, occur near the top of the zone as well as in the overlying blue conglomerate. Fossil plants were also found in the upper part of the zone.

The zone includes several fossiliferous layers. Usually but one main layer is present in a given section, but fossils may be present at intervals through a thickness of more than 100 feet. The main layers are shown locally on the geologic map (pl. 3). The correlation of the layers has not been attempted, and it is doubtful whether they could be satisfactorily correlated, for the main layer becomes nonfossiliferous when traced laterally a few hundred feet, and it is in different parts of the section at different localities. At some outcrops, where two fossiliferous layers or sets of layers occur about 50 feet apart, the zone may be divided into two parts. At some localities, notably on the west side of La Aleta and in Arroyo Estrecho, the fossiliferous layers or ledges are not parallel to each other or to the general stratification of adjacent strata. At a locality in Arroyo Estrecho, shown on plate 27, *B*, a *Mytilus* layer underlying and essentially parallel to massive sandstone truncates sandy silt. Irregular bedding of this nature, which is apparently a local phenomenon, was also observed in the *Pecten* zone of the San Joaquin formation.

Because of the thickness of the zone and the lenticular nature of the fossiliferous layers the *Siphonalia* zone is not such a satisfactory horizon marker as the *Littorina* and upper *Pseudocardium* zones. The apparent complexity of the *Siphonalia* zone is partly due to its position in faulted strata but may also be due to different conditions of sedimentation than those of the higher zones.

A section of the *Siphonalia* zone at the type locality is shown below.

Section of Siphonalia zone of Etchegoin formation at type locality in road cut at forks of Arroyo Doblegado near northeast corner SW¼ sec. 16, T. 22 S., R. 18 E.

	Feet
16. Gray silty sand with irregular half-inch layer of clay. Overlain by a 40-foot blue conglomerate consisting of cross-bedded coarse-grained sandstone with pebbles and clay fragments near base and 15 feet above base. Base of blue conglomerate marked by a discontinuity. Top of *Siphonalia* zone 65 feet below upper *Pseudocardium* zone, a 5-foot fossiliferous sandstone	10
15. Concretionary fossiliferous layer. Mostly *Pseudocardium*, but some *Venerupis* and *Macoma*. Matrix similar to adjacent strata or a little coarser	2
14. Sandy silt. Discontinuity at base	5
13. Laminated silty gray sand	20
12. Gray sand with pebbles and few fossils. *Macoma*, large *Glycymeris*, and small *Cerastoderma*, the last two represented by paired valves. Discontinuity at base marked by sand penetrating underlying sand in borings	2
11. Silty sand similar to unit 13	7
10. Gray silty fossiliferous sand. Chiefly paired *Pseudocardium*, which form a layer near top and another near bottom; paired *Solen*, *Venerupis*, and small *Mytilus* just below upper layer	5
9. Massive silty sand	8

Section of Siphonalia zone of Etchegoin formation at type locality in road cut at forks of Arroyo Doblegado near northeast corner SW¼ sec. 16, T. 22 S., R. 18 E.—Continued.

	Feet
8. Fossiliferous sandstone. Large *Mytilus*, *Pseudocardium*, paired *Schizothaerus*, large *Cerastoderma*, large "*Nassa*," *Venerupis*, *Glycymeris*, large *Anadara*. Just above indurated layer sand contains small sand dollars, *Glycymeris*, and small *Crepidula*	2
7. Gray sand similar to unit 8; large *Pseudocardium* and large and abundant sand dollars in lower 2 feet	5
6. Silty sand, few laminations	15
5. Fossiliferous sandstone. Upper part contains many shell fragments. Fauna apparently similar to that of unit 8	4
4. Sand with thin layers of clay at top and bottom. Lowest part of sand bluish	2
3. Massive coarse-grained blue sandstone	5
2. Laminated silt	1
1. Massive coarse-grained blue sandstone with pebbles chiefly about 5 feet above base. Cross-bedded near base and much finer grained at top. Discontinuity at base. Underlain by laminated grayish-green silt probably representing top of *Macoma* zone	20
Thickness of *Siphonalia* zone	113

In this section there are two main fossiliferous layers 20 feet apart, and large sand dollars are abundant just below the upper layer.

The following section was measured on the south side of La Aleta (locality 283; pl. 28, column 12).

Section of Siphonalia zone of Etchegoin formation on south side of La Aleta, NE¼ sec. 20, T. 22 S., R. 18 E. (locality 283)

	Feet
Brownish bedded silt, *Pseudocardium* near top. Overlain by blue sandstone, conglomeratic at base; base marked by discontinuity	30
Fossiliferous sand; *Glycymeris*, *Tellina*, *Cerastoderma*, and *Siliqua*	½
Bluish sand containing abundant *Pseudocardium*, also *Venerupis*, *Mytilus*, and *Solen*	15
Brown and blue silty sand. Paired *Mytilus* filled with green clay forms layer near top. Ledges containing barnacles, *Mytilus*, sand dollars, and oysters, and a 5-foot bed of blue sand near base. Discontinuity at base	25
Blue sandstone with few pebbles. Discontinuity at base. (Underlain by light gray micaceous silty sand of *Macoma* zone, containing *Macoma* and sand dollars near top)	20
Thickness of *Siphonalia* zone	90½

At the south end of El Leon, where the following section (pl. 28, column 6) is exposed, the blue conglomerate overlying the zone is not present.

Incomplete section of Siphonalia zone of Etchegoin formation at south end of El Leon, sec. 20, T. 22 S., R. 18 E.

	Feet
Greenish sand and poorly bedded silt. Three feet above base a 3-inch layer containing large *Pseudocardium* and small "*Nassa*." Contact at base abrupt. (For upward continuation of section see p. 64)	28
Poorly exposed laminated silt	35

Incomplete section of Siphonalia zone of Etchegoin formation at south end of El Leon, sec. 20, T. 22 S., R. 18 E.—Continued

	Feet
Fine-grained gray sand. Fossiliferous layer near top containing *Cerastoderma*, *Tellina*, *Calliostoma*, large "*Nassa*," and large *Siliqua*	6
Not exposed	18
Sandstone ledge containing *Pseudocardium*, *Mytilus*, barnacles, and sand dollars. Contact at base abrupt	1
Light-gray sand with some silt in middle. A few oysters, *Pseudocardium*, and sand dollars near base	9
Light-gray sand	12
Sandstone ledge containing barnacles and *Mytilus* resting on gray sand containing numerous fragments of barnacles and *Mytilus*. The contact is practically parallel to the bedding, but large knobs of the ledge material extend about a foot into underlying sand, evidently filling pits in the surface of the sand. Base of zone not exposed	4
Exposed thickness of *Siphonalia* zone	113

The blue conglomerate overlying the zone seems to be absent also on the west side of Los Jinetes, where the following section is exposed, but it is present 1,500 feet to the northwest on the hill between La Rusa and the Skyline road.

Incomplete section of Siphonalia zone of Etchegoin formation on west side of Los Jinetes, sec. 13, T. 22 S., R. 17 E. (locality 287)

	Feet
12. Dark-purple sandstone containing *Venerupis* and *Crepidula*	½
11. Irregularly bedded sand and pebbles; *Glycymeris*, *Venerupis*, and fragments of a sand dollar near base	10
10. Poorly exposed sand and silt, including a lens containing *Pseudocardium*	20
9. Poorly exposed sand and silt	25
8. Fossiliferous sandstone stained purple, containing *Macoma*, *Schizothaerus*, and barnacles	½
7. Sand containing barnacles	1
6. Silt	1
5. Sand similar to unit 7, but no barnacles observed	½
4. Unexposed, probably silt	2
3. Silty sand containing *Macoma*	⅙
2. Poorly exposed silt	8
1. Pebbly sand; poorly preserved shells in concretionlike knobs. Base of zone not exposed	5
Exposed thickness of *Siphonalia* zone	73⅔

The following incomplete section, measured at locality 291, shows only a *Pseudocardium* layer in the zone.

Incomplete section of Siphonalia zone of Etchegoin formation at locality 291, center of sec. 12, T. 22 S., R. 17 E.

	Feet
Yellowish sandy silt. Overlain by blue conglomerate, the base of which is marked by a discontinuity	50
Pseudocardium layer in sand	1
Yellowish sandy silt	18
Blue sandstone. Discontinuity at base. Base of zone not exposed	24
Exposed thickness of *Siphonalia* zone	93

Fossils.—The characteristic fossils of the *Siphonalia* zone are shown on plates 31 to 33, 39, 40, and 44. The occurrence of the species is indicated in the accompanying chart.

The fauna of the *Siphonalia* zone is marine and includes a large proportion of large-shelled forms. *Mytilus coalingensis* (pl. 32, figs. 3, 4), which occurs at other horizons in the San Joaquin and Etchegoin formations, is one of the largest and most abundant species. *Siphonalia kettlemanensis* (pl. 31, figs. 1, 7), "*Nassa*" *moranianus*, and *Forreria magister* were not found above the *Siphonalia* zone. A variety of *Forreria magister*, however, occurs in the *Pecten* zone of the San Joaquin formation. *Turritella vanvlecki* (pl. 31, fig. 2), "*Nassa*" *miser iniqua*, *Apolymetis* cf. *A. dombei* (pl. 32, fig. 2), and the first *Arca* of the *A. noae* group to be recorded from the Coalinga district are not known to occur at other horizons in the Kettleman Hills, but these fossils are rare. An undetermined species of *Siliqua* (pl. 33, fig. 3) is widespread in the *Siphonalia* zone and occurs also at lower horizons. The form of *Anadara trilineata* in the *Siphonalia* zone (pl. 31, fig. 9) has more centrally located beaks than *A. trilineata* proper and resembles Conrad's figure of *A. canalis*. A form having a similar outline occurs in the lower part of the San Joaquin formation. At some localities *Pseudocardium densatum* is as abundant in certain layers as it is in the upper *Pseudocardium* zone (pl. 27, *C*). The usual form is a variety similar to *P. d. gabbii*, some specimens that have a long anterior end (pl. 39, fig. 8) resemble Conrad's figure of *P. densatum*. The fragments of *Lyropecten* cf. *L. estrellanus* found on the surface at locality 282a probably represent a single valve. As this locality is near a former habitation this pecten may have been transported by man.

The typical form of the sand dollar *Dendraster gibbsii* (pl. 40, fig. 2) is abundant in the *Siphonalia* zone and was not found at higher horizons, except possibly in the immediately overlying blue conglomerate, and these specimens may have been derived from strata in the *Siphonalia* zone during the deposition of the conglomerate. A small sand dollar from the *Siphonalia* zone, characterized by large spine bases like those of *Merriamaster*, is considered a variety of *D. gibbsii*—*D. gibbsii mirus* (pl. 44, figs. 4, 5).

MACOMA ZONE

Stratigraphy and lithology.—The *Macoma* zone consists typically of light-gray massive cliff-forming tuffaceous sand and silt about 50 feet thick. The top of the zone is 250 to 350 feet below the *Littorina* zone. Owing to its light-gray color the zone is a conspicuous unit between the prevailingly brown *Siphonalia* and *Patinopecten* zones. (See pl. 26, *A*, *C*.) Plate 26, *C*, a view looking northward toward Las Paredes, shows three outcrops of the zone separated by faults. Layers containing *Macoma* more or less characterize the zone, but for the most part fossils are not conspicuous. At places the zone includes lenses of cross-bedded blue sandstone. Though the zone is locally indefinite, it is readily recognized in the central part of North Dome and is useful in determining the structure.

PLATE 29

[Figures natural size unless otherwise designated]

FIGURE 1. *Ostrea atwoodii* Gabb. Length 51 mm., height 61 mm., thickness 16 mm. Locality 248, upper *Pseudocardium* zone. U. S. Nat. Mus. 495783.

2. *Anadara trilineata* (Conrad) of Arnold, short inflated var. Length 38 mm., height 33 mm., thickness 13 mm. Locality 224, upper *Pseudocardium* zone. U. S. Nat. Mus. 495784.

3. *Cerastoderma* cf. *C. meekianum* (Gabb), small var. Length 41 mm., height 36 mm., thickness about 10 mm. Locality 220, *Littorina* zone. U. S. Nat. Mus. 495785.

4. *Pandora* cf. *P. punctata* Conrad. Length 30 mm., height 19 mm., thickness 4.3 mm. Locality 239a, upper *Pseudocardium* zone. U. S. Nat. Mus. 495786.

5. *Venerupis laciniata hannibali* (Howe). Length 47 mm., height 41 mm., thickness 13 mm. Locality 239b, upper *Pseudocardium* zone. U. S. Nat. Mus. 495787.

6. *Anadara trilineata* (Conrad) of Arnold, short inflated var. Length 35.5 mm., height 33 mm., thickness 13.6 mm. Locality 250, upper *Pseudocardium* zone. U. S. Nat. Mus. 495788.

7. *Lucinoma* cf. *L. acutilineata* (Conrad). Length 43 mm., height 39.6 mm., thickness of both valves 18.5 mm. Locality 250, upper *Pseudocardium* zone. U. S. Nat. Mus. 495789.

8, 9. *Littorina mariana* Arnold. Locality 218, *Littorina* zone.
- 8. Height (incomplete) 16 mm., width 12 mm. U. S. Nat. Mus. 495790.
- 9. Height (incomplete) 10 mm., width 8.2 mm. U. S. Nat. Mus. 495791.

10, 11. *Glycymeris grewingki* Dall. Locality 253, upper *Pseudocardium* zone.
- 10. Length 33 mm., height 34 mm., thickness 10 mm. U. S. Nat. Mus. 495792.
- 11. Length 30 mm., height 30 mm., thickness 8.3 mm. U. S. Nat. Mus. 495793.

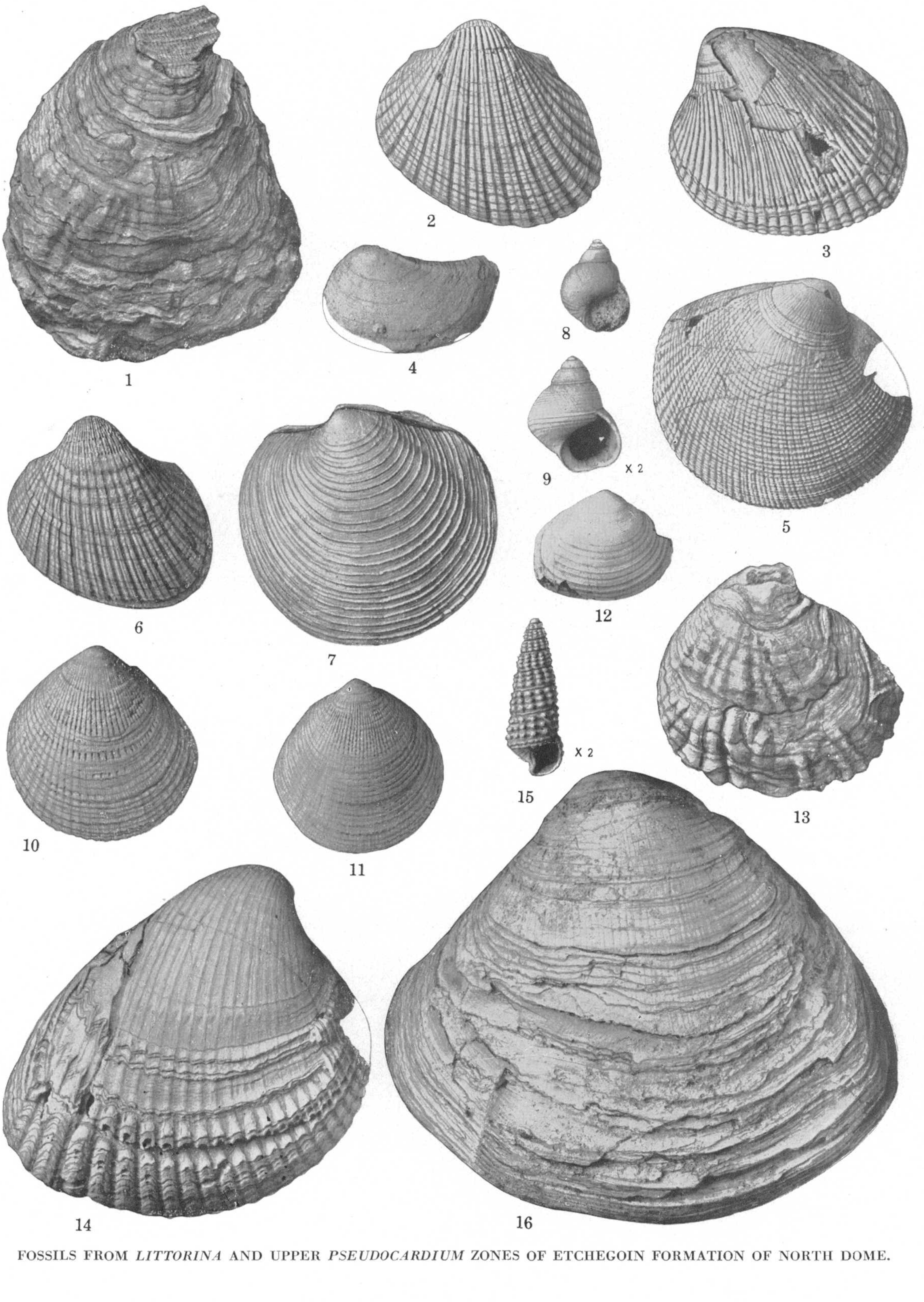
12. *Macoma affinis plena* Stewart, n. var. Length (almost complete) 24.6 mm., height 19 mm., thickness about 6 mm. Locality 218, *Littorina* zone. U. S. Nat. Mus. 495794.

13. *Ostrea atwoodii* Gabb. Length 42 mm., height 40 mm., thickness 12.5 mm. Locality 250, upper *Pseudocardium* zone. U. S. Nat. Mus. 495795.

14. *Cerastoderma* cf. *C. meekianum* (Gabb). Length 63 mm., height 57 mm., thickness 23 mm. Locality 250, upper *Pseudocardium* zone. U. S. Nat. Mus. 495796. This specimen has about 28 anterior ribs and a thick internal callus.

15. *Bittium asperum* (Gabb). Height (incomplete) 13.7 mm., width 5 mm. Locality 239a, upper *Pseudocardium* zone. U. S. Nat. Mus. 495797.

16. *Pseudocardium densatum* (Conrad) of Arnold, var. cf. *gabbii* Rémond. Length 95 mm., height 81 mm., thickness 35 mm. Locality 252a, upper *Pseudocardium* zone. U. S. Nat. Mus. 495798.



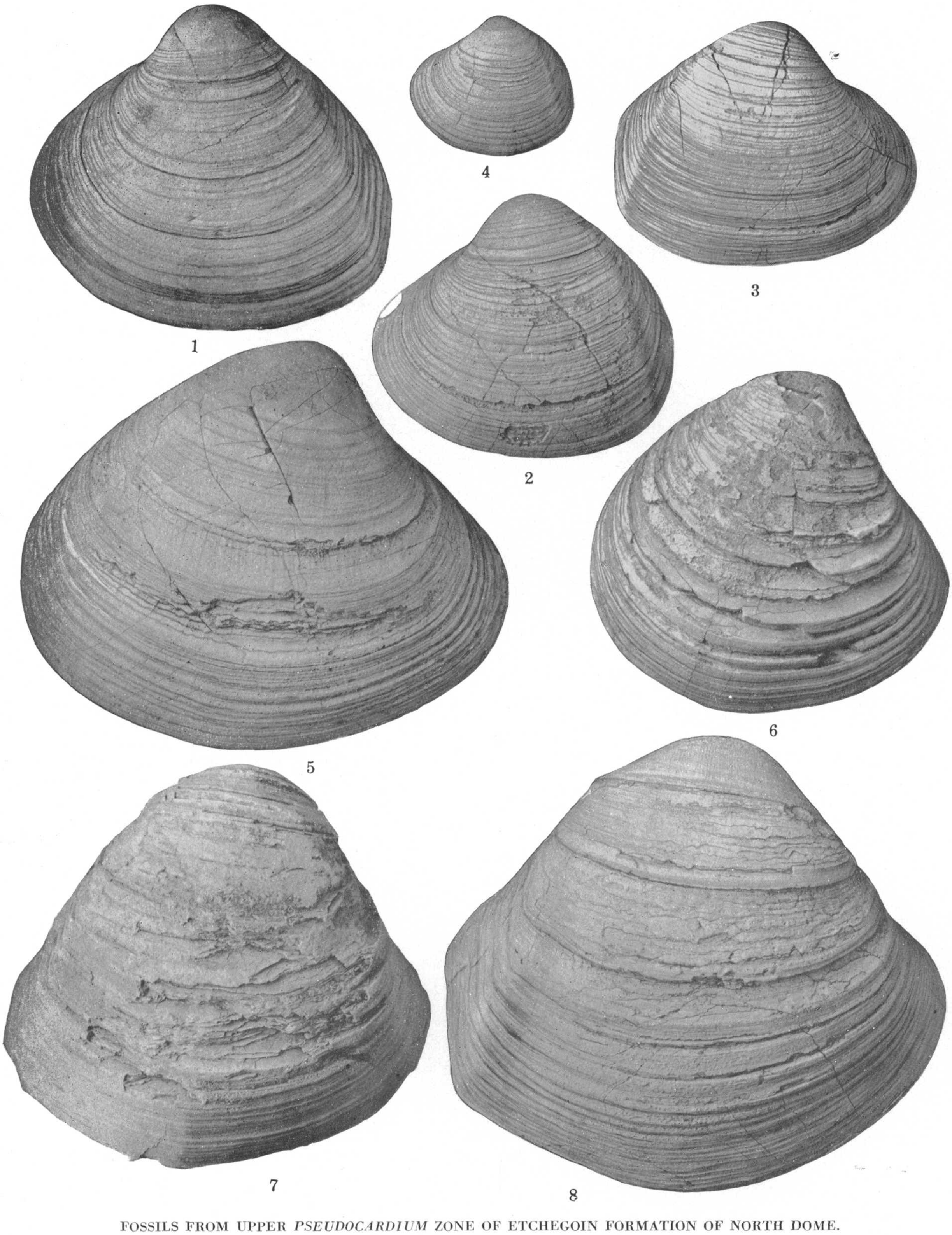
FOSSILS FROM *LITTORINA* AND UPPER *PSEUDOCARDIUM* ZONES OF ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 30

[Figures natural size]

FIGURES 1–8. *Pseudocardium densatum* (Conrad) of Arnold, var. cf. *gabbii* Rémond. Locality 252a.

1. Length 64 mm., height 58 mm., thickness 20 mm. U. S. Nat. Mus. 495799.
2. Length 54 mm., height 48 mm., thickness 19 mm. U. S. Nat. Mus. 495800.
3. Length 54 mm., height 44 mm., thickness 17 mm. U. S. Nat. Mus. 495801.
4. Length 29 mm., height 25 mm., thickness 9.4 mm. U. S. Nat. Mus. 495802.
5. Length 87 mm., height 73 mm., thickness 27 mm. U. S. Nat. Mus. 495803.
6. Length 64 mm., height 60 mm., thickness 25 mm. U. S. Nat. Mus. 495804.
7. Length 79 mm., height 73 mm., thickness 33 mm. U. S. Nat. Mus. 495805.
8. Length 92 mm., height 84 mm., thickness 40 mm. U. S. Nat. Mus. 495806.



FOSSILS FROM UPPER *PSEUDOCARDIUM* ZONE OF ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 31

[Figures natural size unless otherwise designated]

FIGURES 1, 7. *Siphonalia kettlemanensis* (Arnold).

1. Height (incomplete) 83 mm., width (incomplete) 51 mm. Locality 283. U. S. Nat. Mus. 495807.
7. Height (incomplete) 74 mm., width 55 mm. Locality 270. U. S. Nat. Mus. 495808.

2. *Turritella vanvlecki* Arnold. Worn specimen. Height (incomplete) 30 mm., width 11 mm. Locality 282. U. S. Nat. Mus. 495809.

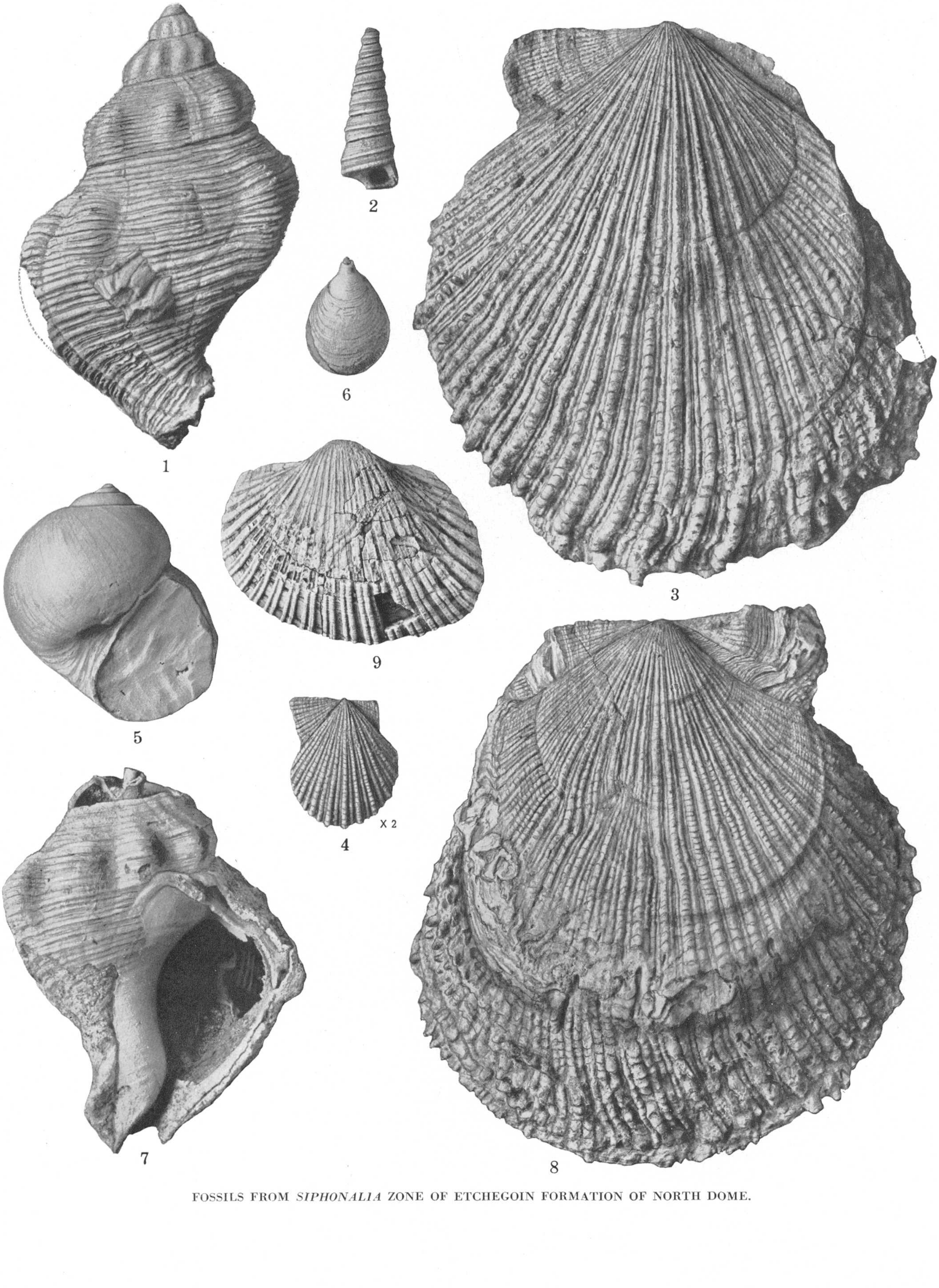
3, 4, 8. *Hinnites* cf. *H. crassa* Conrad.

3. Length 98 mm., height 104 mm., thickness of both valves 37 mm. Locality 274a. U. S. Nat. Mus. 495810.
4. Length 10.6 mm., height 12.6 mm., thickness 2.3 mm. Locality 282a. U. S. Nat. Mus. 495811.
8. Length 100 mm., height 106 mm., thickness of both valves 37 mm. Locality 274a. U. S. Nat. Mus. 495812.

5. *Lunatia* cf. *L. lewisii* (Gould). Height 47 mm., width 44 mm. Locality 287. U. S. Nat. Mus. 495813.

6. *Crepidula* cf. *C. onyx* Sowerby. Worn specimen. Length (incomplete) 23 mm. Locality 287. U. S. Nat. Mus. 495814.

9. *Anadara trilineata* (Conrad) of Arnold, var. cf. *canalis* (Conrad). Length 48.5 mm., height 37.3 mm., thickness of both valves 29 mm. Locality 264. U. S. Nat. Mus. 495815



FOSSILS FROM *SIPHONALIA* ZONE OF ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 32

[Figures natural size unless otherwise designated]

FIGURE 1. *Chlamys etchegoini* (Anderson). Left valve of double-valve specimen. Length 87 mm., height 88 mm., thickness of both valves 38 mm. Locality 279. U. S. Nat. Mus. 495816.

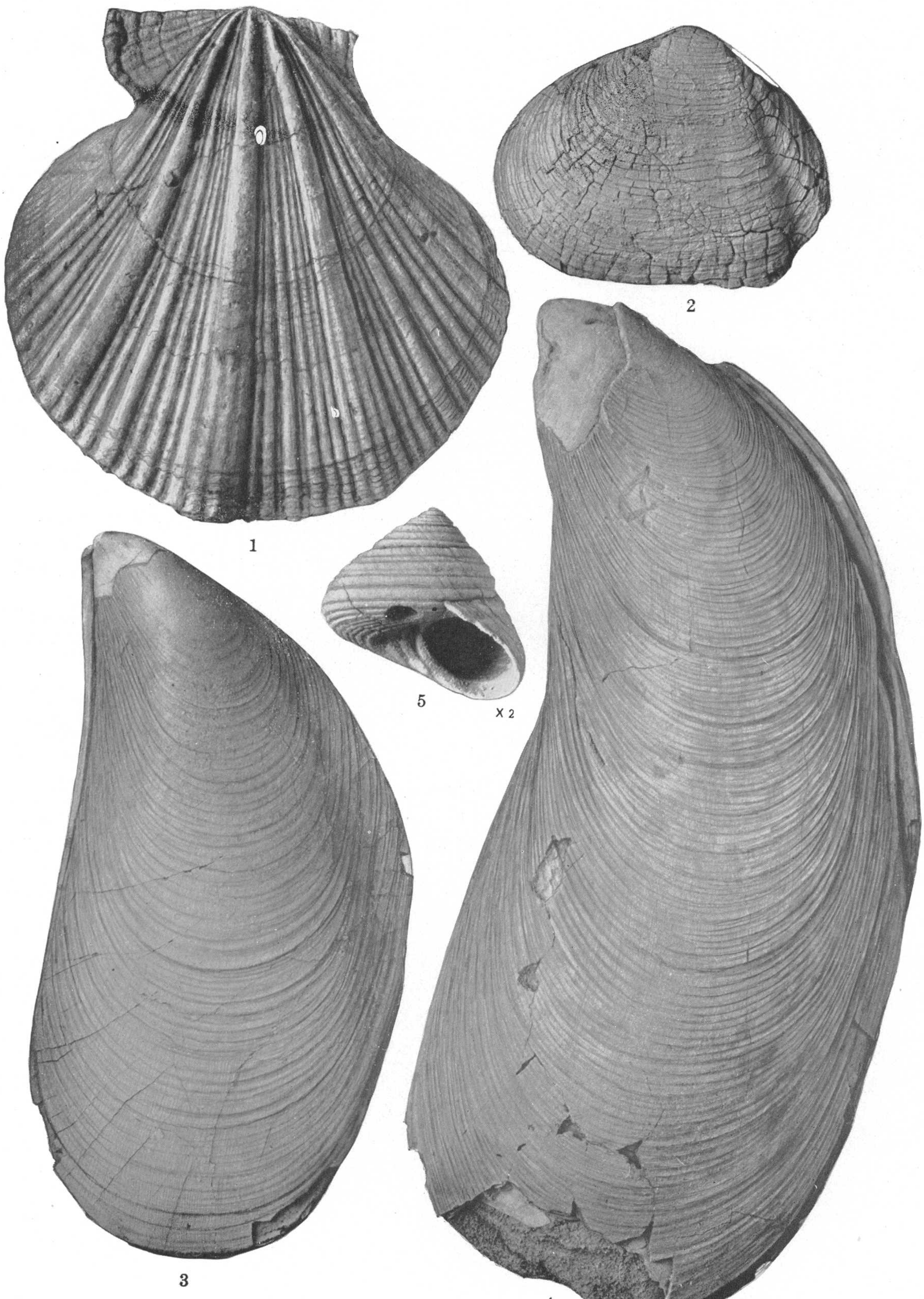
2. *Apolymetis* cf. *A. dombei* (Hanley). Left valve of double-valve specimen. Length 58 mm., height 45 mm., thickness of both valves 22 mm. Locality 264. U. S. Nat. Mus. 495817.

3, 4. *Mytilus coalingensis* Arnold. Locality 270.

3. Left valve of double-valve specimen. Greatest length (almost complete) 122 mm., width 58 mm., thickness of both valves 35 mm. U. S. Nat. Mus. 495818.

4. Left valve of double-valve specimen. Greatest length (incomplete) 184 mm., width 75 mm., thickness of both valves 73 mm. U. S. Nat. Mus. 495819.

5. *Calliostoma coalingense privum* Stewart, n. var. Type. Height 16.5 mm., width 18.2 mm. Locality 270. U. S. Nat. Mus. 495820.



FOSSILS FROM *SIPHONALIA* ZONE OF ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 33

[Figures natural size]

FIGURE 1. *Mactra ? coalingensis* Arnold. Right valve. Length 72 mm., height 57 mm., thickness about 12 mm. Locality 263. U. S. Nat. Mus. 495821.

2. *Tellina* cf. *T. bodegensis* Hinds. Right valve. Length 64 mm., height 35 mm., thickness about 6 mm. Locality 284. U. S. Nat. Mus. 495822.

3. *Siliqua* sp. Incomplete right valve. Length 49 mm., height 20 mm., thickness about 3 mm. Locality 294. U. S. Nat. Mus. 495823.

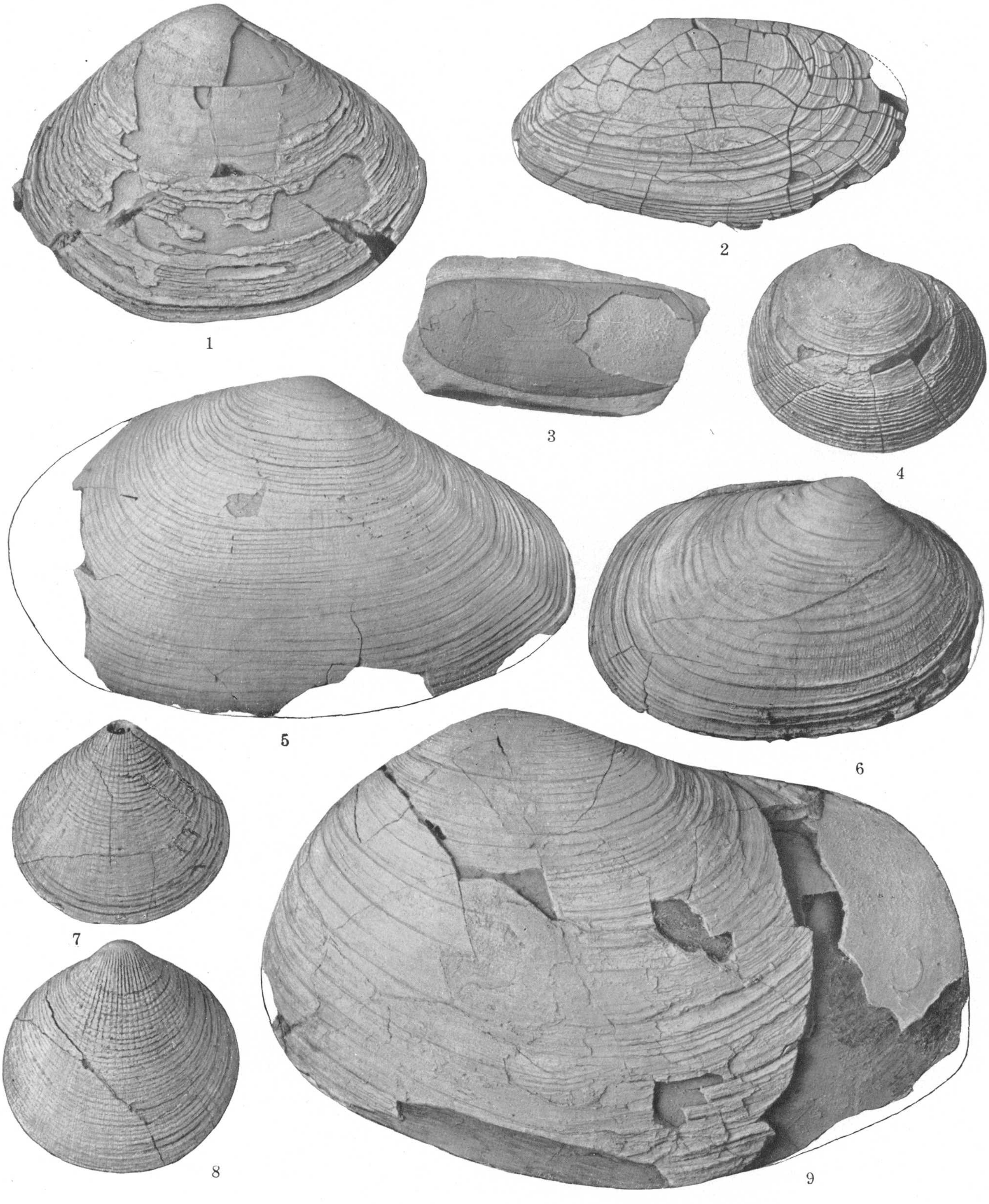
4. *Semele* n. sp.? Length 43 mm., height 37 mm., thickness of both valves 18 mm. Locality 272a. U. S. Nat. Mus. 495824. This specimen has concentric lamellae resembling *S. formosa* Sowerby but has a more rounded posterior end.

5. *Tellina ?* cf. *T. ? oldroydi* Wiedey. Length (incomplete) 88 mm., height 58 mm., thickness about 12 mm. Locality 266. U. S. Nat. Mus. 495825.

6. *Saxidomus nuttalli latus* Stewart, n. var. Length 68 mm., height 48 mm., thickness of both valves (worn) 27 mm. Locality 287. U. S. Nat. Mus. 495826.

7, 8. *Glycymeris grewingki* Dall. Locality 266.
   7. Length 38 mm., height 36.5 mm., thickness 10 mm. U. S. Nat. Mus. 495827.
   8. Length 41.5 mm., height 41 mm., thickness 11 mm. U. S. Nat. Mus. 495828.

9. *Schizothaerus* cf. *S. nuttallii* (Conrad). Length 118 mm., height 85 mm., thickness about 18 mm. Locality 287. U. S. Nat. Mus. 495829.



FOSSILS FROM *SIPHONALIA* ZONE OF ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 34

[Figures natural size unless otherwise designated]

FIGURES 1–4. *Macoma affinis* Nomland. Locality 306, *Macoma* zone.

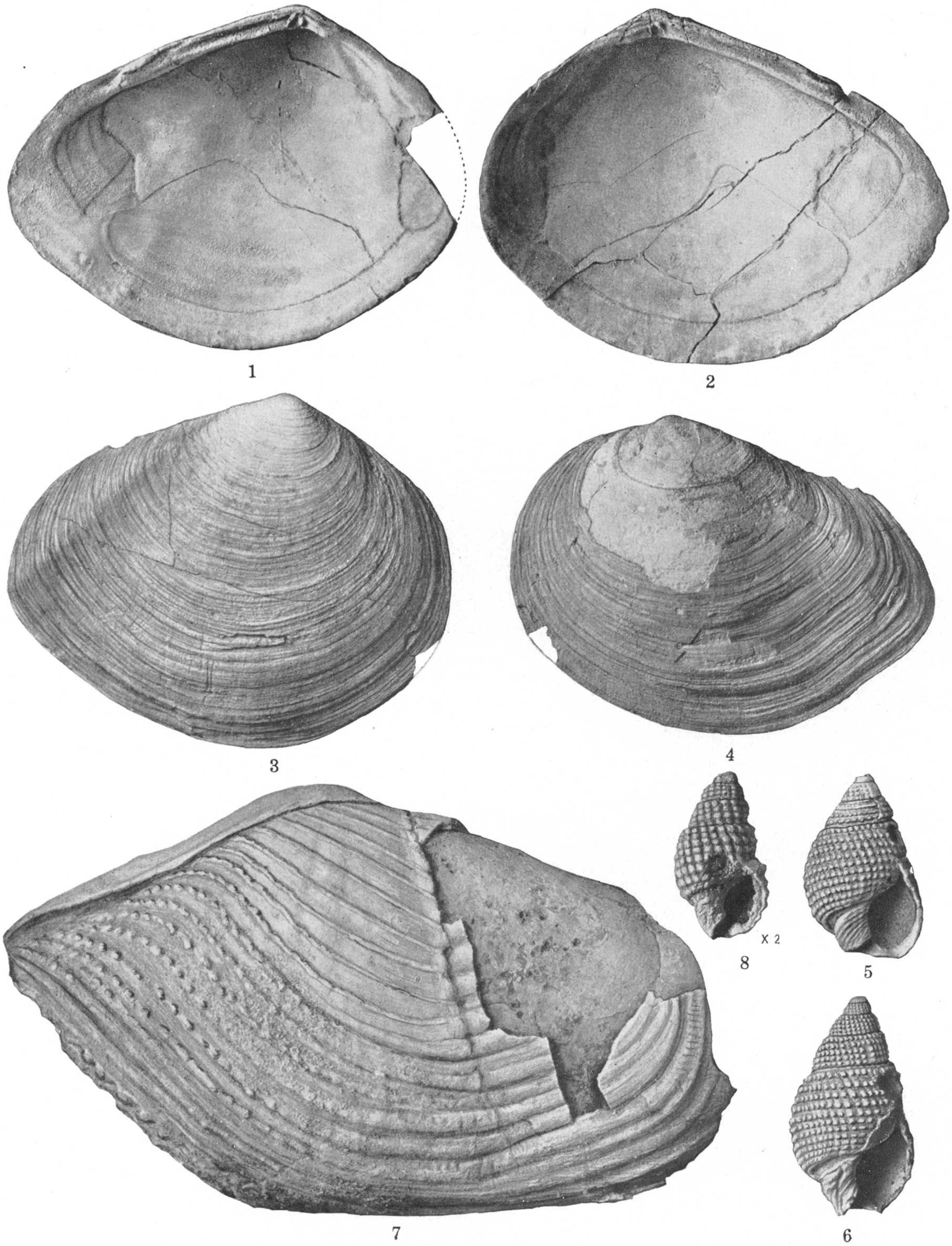
1. Left valve. Length (incomplete) 73.5 mm., height 55.4 mm., thickness 12.5 mm. U. S. Nat. Mus. 495830.
2. Right valve. Length 75 mm., height 55 mm., thickness 13 mm. U. S. Nat. Mus. 495831.
3. Right valve. Length 73.5 mm., height 55.4 mm., thickness 13 mm. U. S. Nat. Mus. 495832.
4. Left valve. Length 71 mm., height 54 mm., thickness about 12 mm. U. S. Nat. Mus. 495833.

5, 6. "*Nassa*" *moraniana* Martin. Etchegoin formation of North Dome, locality uncertain.

5. Height (incomplete) 28 mm., width 19 mm. U. S. Nat. Mus. 495834.
6. Height (incomplete) 35 mm., width (slightly crushed) 20 mm. U. S. Nat. Mus. 495835.

8. "*Nassa*" *miser iniqua* Stewart, n. var. Type. Height (almost complete) 13.6 mm., width 8 mm. Locality 300b. *Patinopecten* zone. U. S. Nat. Mus. 495836.

7. *Zirfaea gabbi* Tryon, var. Left valve of double-valve specimen. Length (incomplete) 119 mm., height 70 mm., thickness of both valves 74 mm. Locality 306a, *Macoma* zone. U. S. Nat. Mus. 495837.



FOSSILS FROM *MACOMA* AND *PATINOPECTEN* ZONES OF ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 35

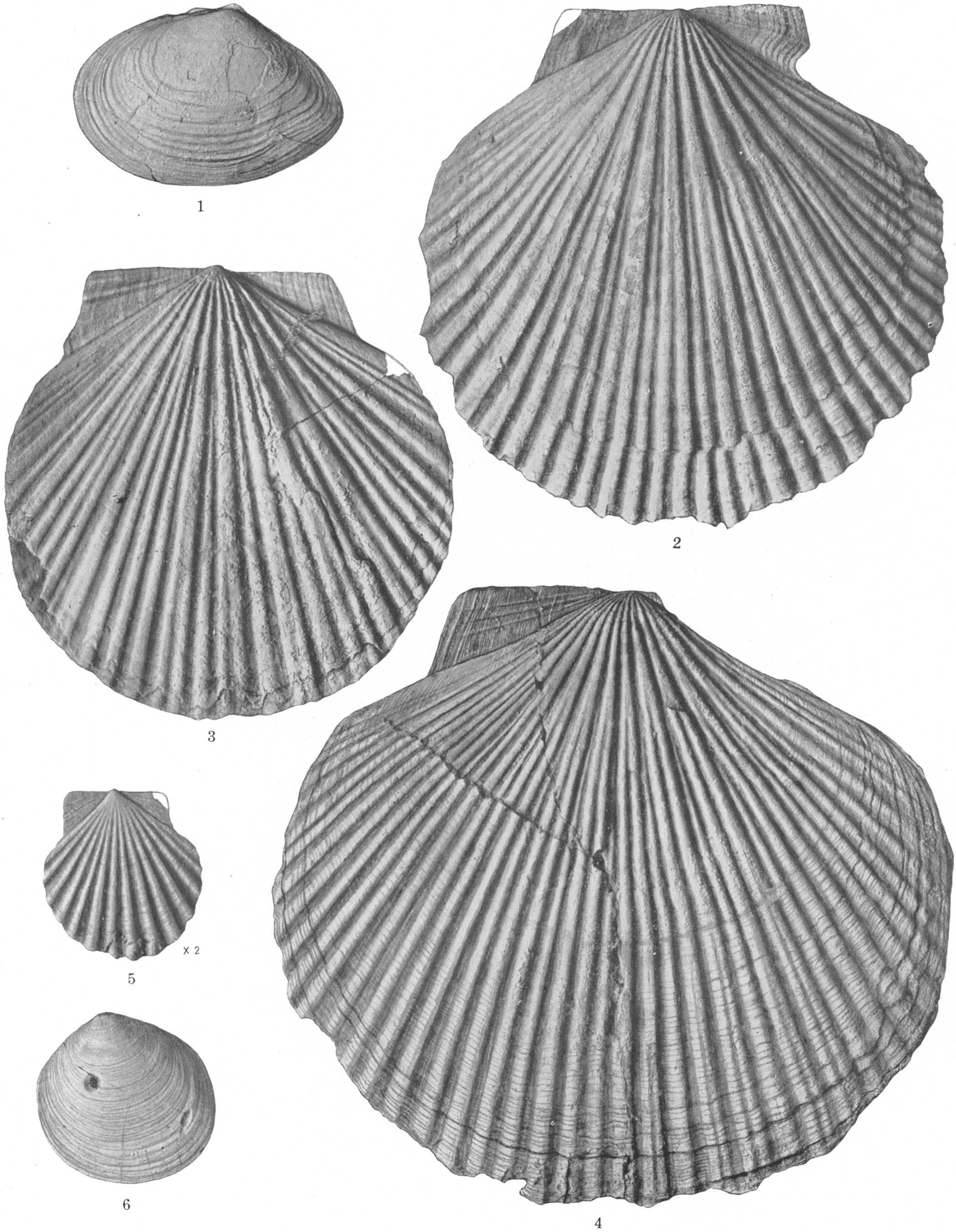
[Figures natural size unless otherwise designated]

FIGURE 1. *Macoma* cf. *M. indentata* Carpenter. Left valve of double-valve specimen. Length 51 mm., height 33 mm., thickness of both valves 16 mm. Locality 308. U. S. Nat. Mus. 495838.

2–5. *Patinopecten lohri* (Hertlein).

2. Right valve. Length 101 mm., height 97 mm. Locality 317a. U. S. Nat. Mus. 495839.
3. Left valve. Length 86 mm., height 86 mm. Locality 320a. U. S. Nat. Mus. 495840.
4. Right valve. Length 127 mm., height 114 mm. Locality 316. U. S. Nat. Mus. 495841.
5. Length 14.8 mm., height 15.8 mm. Locality 308. U. S. Nat. Mus. 495842.

6. *Taras* cf. *T. parilis* (Conrad). Left valve of double-valve specimen. Length 35 mm., height 33 mm., thickness of both valves about 15 mm. Locality 316. U. S. Nat. Mus. 495843.



FOSSILS FROM *PATINOPECTEN* ZONE OF ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 36

[Figures natural size]

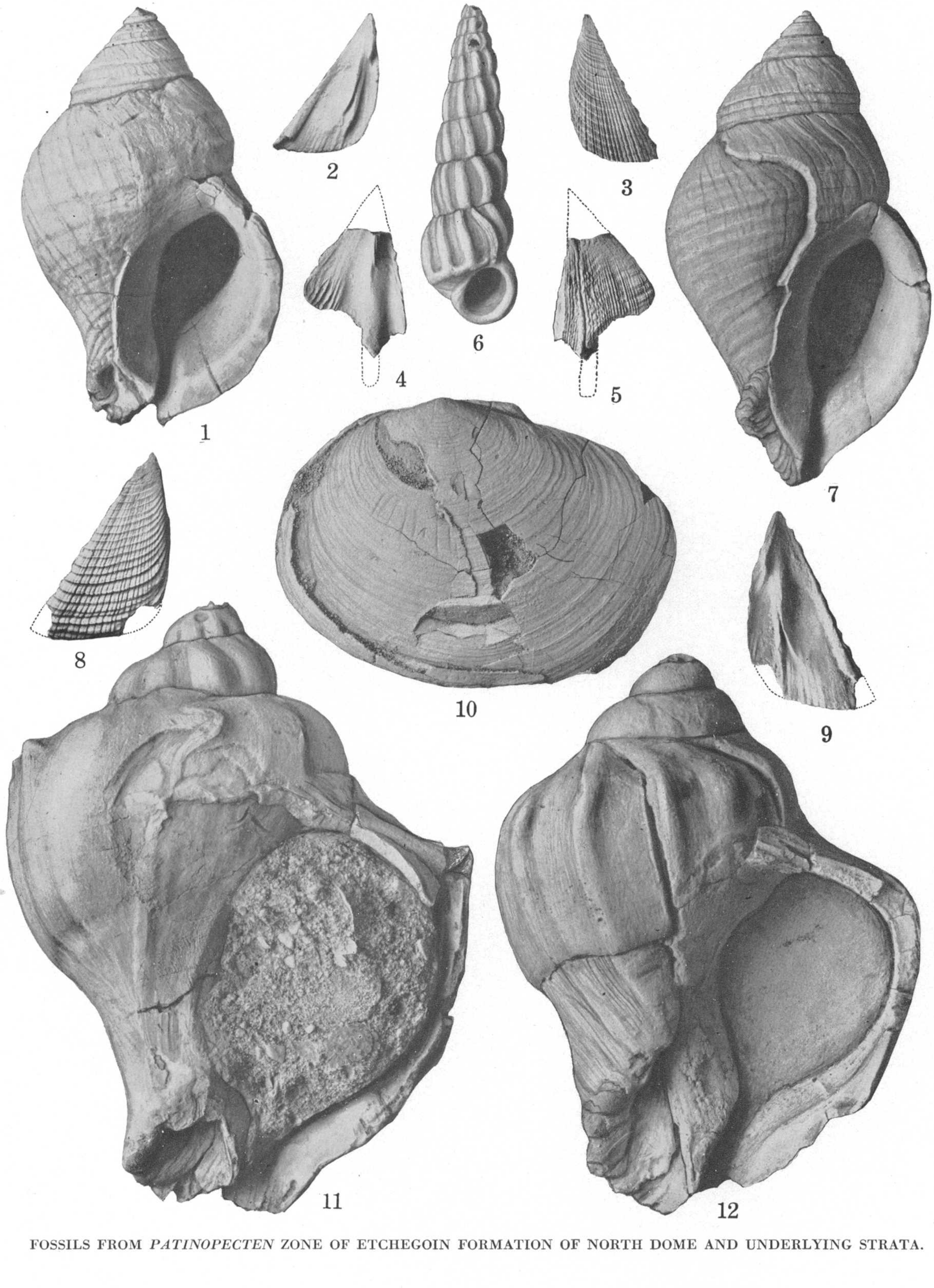
FIGURES 1, 7. *Nucella etchegoinensis* (Arnold), ribbed var. Locality 337, *Patinopecten* zone.
1. Height (incomplete) 73 mm., width 47 mm. U. S. Nat. Mus. 495844.
7. Height 83 mm., width 47 mm. U. S. Nat. Mus. 495845.

2–5, 8, 9. *Balanus* (*Tamiosoma*) cf. *B.* (*T.*) *gregarius* (Conrad). Locality 300c, strata underlying *Patinopecten* zone.
2, 3. Scutum. Length 29 mm., width (incomplete) 19.5 mm. U. S. Nat. Mus. 497415.
4, 5. Broken tergum. Length 24 mm., width 15.5 mm. U. S. Nat. Mus. 497416.
8, 9. Scutum. Length (incomplete) 20 mm., width 16 mm. U. S. Nat. Mus. 497414.

6. *Opalia varicostata* Stearns. Height (incomplete) 52 mm., width 17 mm. Locality 317, *Patinopecten* zone. U. S. Nat. Mus. 495846.

10. *Sanguinolaria* cf. *S. nuttallii* Conrad. Left valve of crushed double-valve specimen. Length 66 mm., height 48 mm. Locality 308, *Patinopecten* zone. U. S. Nat. Mus. 495847.

11, 12. *Forreria magister* (Nomland).
11. Height (incomplete) 94 mm., width 71 mm. Locality 336, *Patinopecten* zone. U. S. Nat. Mus. 495848.
12. Height (incomplete) 101 mm., width 75 mm. Locality 310, *Patinopecten* zone. U. S. Nat. Mus. 495849. Though not shown in the figure, traces of the lower spines are preserved on this specimen. They are not observable on fig. 11 and may not have been present on that specimen.



FOSSILS FROM *PATINOPECTEN* ZONE OF ETCHEGOIN FORMATION OF NORTH DOME AND UNDERLYING STRATA.

Fossils from Siphonalia zone of Etchegoin formation

[Identifications by Ralph Stewart unless otherwise stated. F, fragments; P, paired valves; S, small specimens; W, worn specimens]

Localities 238b–275:

Species	238b	255	256	257	257a	258	259	260	262	263[1]	264	264a	264b	265	266	266a	267	268	269	270	270a	270b	271	272	272a	274	274a	275
Echinoids:																												
Dendraster gibbsii (Rémond) (pl. 40, fig. 2)				X								X	X			S			X							X		X
Dendraster gibbsii mirus Stewart, n. var. (pl. 44, figs. 4, 5)																												
Gastropods:																												
Calliostoma coalingense Arnold																												
Calliostoma coalingense privum Stewart, n. var. (pl. 32, fig. 5)	X											cf.								X						X		
Margarites cf. *M. pupillus* (Gould)										X		F																
Pachypoma cf. *P. precursor* Dall												X																
Turritella vanvlecki Arnold (pl. 31, fig. 2)														cf.				X										
Calyptraea sp			X																	X		X						
Calyptraea cf. *C. filosa* (Gabb)												X																
Crepidula cf. *C. onyx* Sowerby (pl. 31, fig. 6)										X		X								X								
Ianacus? sp																												
Lunatia cf. *L. lewisii* (Gould) (pl. 31, fig. 5)			X				X			S		S	F			SF			X	S								
Opalia varicostata Stearns																												
"*Nassa*" *moraniana* Martin			X				cf.			cf.	F	S							F									
"*Nassa*" *miser iniqua* Stewart, n. var	cf.											F																
Siphonalia kettlemanensis (Arnold) (pl. 31, figs. 1, 7)			X													SF				?W								
Tritonalia? sp															X													
Nucella etchegoinensis (Arnold)																												
Forreria magister (Nomland)			X							?		X			S													
Progabbia sp																												
Pelecypods:																												
Arca sp																					X							
Anadara trilineata (Conrad) of Arnold, var. cf. *canalis* (Conrad) (pl. 31, fig. 9)		X	P				P			sp.	P	X	F													X		
Glycymeris grewingki Dall (pl. 33, figs. 7, 8)		X								S	S	X	S		X	SP			X	S						X		
Mytilus coalingensis (Arnold) (pl. 32, figs. 3, 4)	X		F				P					X	F		P	X		X	X	P	X	P		X		X		
Chlamys etchegoini (Anderson) (pl. 32, fig. 1)															X													
Hinnites cf. *H. crassa* Conrad (pl. 31, figs. 3, 4, 8)			X				X					F	F		X		P	X	X	X	X	X					X	
Patinopecten lohri (Hertlein)						X											X	X				X						
Lyropecten cf. *L. estrellanus* (Conrad) (transported by man?)																												
Ostrea atwoodii Gabb			X									X	X		X		X											
Tellina cf. *T. bodegensis* Hinds (pl. 33, fig. 2)	X									F			P															
Tellina? cf. *T.*? *oldroydi* Wiedey (pl. 33, fig. 5)															X													
Macoma affinis Nomland			P							cf. P																		
Macoma sp																												
Apolymetis cf. *A. dombei* (Hanley) (pl. 32, fig. 2)			P				P				P																	
Semele n. sp.? (pl. 33, fig. 4)																									X			
Mactra? *coalingensis* Arnold (pl. 33, fig. 1)			?							X			X			F												
Pseudocardium densatum (Conrad) of Arnold (pl. 39, fig. 8) and var. cf. *gabbii* Rémond				X								X	F		X	X			X				X					
Schizothaerus cf. *S. nuttalii* (Conrad) (pl. 33, fig. 9)			P							cf.	X	X																
Saxidomus nuttalli latus Stewart, n. var. (pl. 33, fig. 6)							P													P								
Compsomyax cf. *C. subdiaphana* (Carpenter)																												
Venerupis laciniata hannibali (Howe)			X				P				P	X	F							SP								
Cerastoderma sp	X	X	X				P			X	X								X							X		
Trachycardium n. sp			X									X																
Sanguinolaria sp										P																		
Mya cf. *M. dickersoni* Clark?																												
Solen sp		X	P				P			X	F	X				X			F									
Siliqua sp. (pl. 33, fig. 3)	X	P														F			X									
Panope sp			P				P				P																	
Zirfaea sp																												
Pandora sp												F							X									
Barnacle: *Balanus* sp	X	X	X									X			X		X	X	X					X		X		
Unidentified fish remains: "Bulbous growths"																												
Land mammals:																												
Mastodon remains:																												
Molar fragments		X																										
Tusk fragments								X												X								
Skull																												
Horse tooth (Pliohippus?)																												
Marine mammals:																												
Vertebrae				X																								
Limb bones			F						X																			
Plants (identifications by R. W. Brown):																												
Salix coalingesis Dorf (willow)																												
Alnus merriami Dorf (alder)					X																							
Quercus hannibali Dorf (live oak)																												
Platanus paucidentata Dorf (sycamore)																												
Garrya masoni Dorf (tassle bush)																												
Fraxinus caudata Dorf (ash)																												

Localities 275a–333a:

Species	275a	276	277	278	278a	278b	279	280	281	282	282a	283	284	285	285a	286	287	288	288a	289	290	291	292	293	294	294a	294b	295	296	297	298	299	299a	333a
Echinoids:																																		
Dendraster gibbsii (Rémond) (pl. 40, fig. 2)							X					X	cf.								S			X	X					X				
Dendraster gibbsii mirus Stewart, n. var. (pl. 44, figs. 4, 5)	X																																	
Gastropods:																																		
Calliostoma coalingense Arnold																					cf.													
Calliostoma coalingense privum Stewart, n. var. (pl. 32, fig. 5)													X				X																	
Margarites cf. *M. pupillus* (Gould)																	X																	
Pachypoma cf. *P. precursor* Dall																																		
Turritella vanvlecki Arnold (pl. 31, fig. 2)										X																								
Calyptraea sp																																		
Calyptraea cf. *C. filosa* (Gabb)																																		
Crepidula cf. *C. onyx* Sowerby (pl. 31, fig. 6)													X				X																	
Ianacus? sp																	X																	
Lunatia cf. *L. lewisii* (Gould) (pl. 31, fig. 5)													S				X				X		X											
Opalia varicostata Stearns																														X				
"*Nassa*" *moraniana* Martin													X				X																	
"*Nassa*" *miser iniqua* Stewart, n. var	X																X																	
Siphonalia kettlemanensis (Arnold) (pl. 31, figs. 1, 7)				X									X				cf.				X		cf.			X								
Tritonalia? sp																																		
Nucella etchegoinensis (Arnold)																							X											
Forreria magister (Nomland)																					cf.		X											
Progabbia sp													X																					
Pelecypods:																																		
Arca sp																																		
Anadara trilineata (Conrad) of Arnold, var. cf. *canalis* (Conrad) (pl. 31, fig. 9)																	P						X			X								
Glycymeris grewingki Dall (pl. 33, figs. 7, 8)												X	X				X																	
Mytilus coalingensis (Arnold) (pl. 32, figs. 3, 4)				X			P	X		X	X	X																				X		
Chlamys etchegoini (Anderson) (pl. 32, fig. 1)					X		X	X																										
Hinnites cf. *H. crassa* Conrad (pl. 31, figs. 3, 4, 8)							P	X		X																								
Patinopecten lohri (Hertlein)																																		
Lyropecten cf. *L. estrellanus* (Conrad) (transported by man?)											X																							
Ostrea atwoodii Gabb							X	X				X					X																	
Tellina cf. *T. bodegensis* Hinds (pl. 33, fig. 2)												X	X																					
Tellina? cf. *T.*? *oldroydi* Wiedey (pl. 33, fig. 5)																																		
Macoma affinis Nomland																	P																	
Macoma sp																X									X									
Apolymetis cf. *A. dombei* (Hanley) (pl. 32, fig. 2)																																		
Semele n. sp.? (pl. 33, fig. 4)																																		
Mactra? *coalingensis* Arnold (pl. 33, fig. 1)																	?																	
Pseudocardium densatum (Conrad) of Arnold (pl. 39, fig. 8) and var. cf. *gabbii* Rémond				X					X		X	X				X	X				X		X			X				X				
Schizothaerus cf. *S. nuttalii* (Conrad) (pl. 33, fig. 9)				?													P									X								
Saxidomus nuttalli latus Stewart, n. var. (pl. 33, fig. 6)								X									P						X		X									
Compsomyax cf. *C. subdiaphana* (Carpenter)																	P																	
Venerupis laciniata hannibali (Howe)												X						P								X								
Cerastoderma sp												X	X				X						X			X				X		X		
Trachycardium n. sp																																		
Sanguinolaria sp																																		
Mya cf. *M. dickersoni* Clark?																										X								
Solen sp												X														X								
Siliqua sp. (pl. 33, fig. 3)				X								X		X				X														X		
Panope sp																																		
Zirfaea sp																														X				
Pandora sp																																		
Barnacle: *Balanus* sp							X	X		X	X						X						X			X								
Unidentified fish remains: "Bulbous growths"																						cf.					X							
Land mammals:																																		
Mastodon remains:																																		
Molar fragments									X							X						X												
Tusk fragments		X	X															X										X						
Skull																																	X	
Horse tooth (Pliohippus?)																				X									X					
Marine mammals:																																		
Vertebrae						X																												
Limb bones																								X							X			
Plants (identifications by R. W. Brown):																																		
Salix coalingesis Dorf (willow)															X				X															X
Alnus merriami Dorf (alder)																			X															
Quercus hannibali Dorf (live oak)																			X															
Platanus paucidentata Dorf (sycamore)																			X															X
Garrya masoni Dorf (tassle bush)																			X															
Fraxinus caudata Dorf (ash)																			X															

[1] Species listed from this locality were observed in the field but not collected, with the exception of *Tellina* cf. *T. bodegensis*, *Macoma* cf. *M. affinis*, and *Sanguinolaria* sp.

The type locality of the *Macoma* zone is on the south side of El Tolete, sec. 7, T. 22 S., R. 18 E. (pl. 28, column 7), where the zone is 40 feet thick. The name *Macoma* zone is unsatisfactory, for *Macoma* occurs throughout the San Joaquin and Etchegoin formations. This genus is, however, more abundant in the *Macoma* zone than in the other Etchegoin zones.

Samples from the *Macoma* zone were examined by M. N. Bramlette, who reports that they contain much andesitic volcanic material. The sands are tuffaceous and contain andesitic phenocrysts and volcanic glass, though most of the original glass is more or less altered. Thin layers of fine-grained impure tuff, designated clay in the field, have a larger percentage of glass, as much as 50 percent, and also contain diatoms and sponge spicules. The light color of the *Macoma* zone is apparently due to a larger proportion of volcanic material than in the brown rocks of the *Siphonalia* and *Patinopecten* zones.

The section below was measured at the type locality of the *Macoma* zone, on the south side of El Tolete (pl. 28, column 7).

Section of Macoma zone of Etchegoin formation at type locality on south side of El Tolete, sec. 7, T 22 S., R. 18 E.

	Feet
Light-gray tuffaceous sand containing few impressions of marine fossils. Contact at base abrupt, marked by borings. Overlain by 14 feet of bluish sand with a 6-inch concretionary fossiliferous layer at base	20
Light-gray fine-grained volcanic ash. Contact at base abrupt, marked by borings	¼
Light-gray tuffaceous sand. Contact at base abrupt, marked by borings	10
Light-gray fine-grained volcanic ash. Contact at base abrupt, marked by borings	½
Light-gray tuffaceous sand. Small pebbles, *Calliostoma*, *Mytilus*, and sand dollars at base. Discontinuity at base. Underlain by laminated slightly tuffaceous sandy silt of *Patinopecten* zone	9½
Thickness of *Macoma* zone	40¼

At locality 302, southwest of La Clavija, the *Macoma* zone is considerably thicker and the base is not exposed (pl. 28, column 5). The greater thickness is due to the presence of cross-bedded blue sandstone, as shown in the following section:

Section of Macoma zone of Etchegoin formation at locality 302, southwest of La Clavija, NE ¼ sec. 12, T. 22 S., R. 17 E.

	Feet
Bluish silty sand and light-colored probably tuffaceous layers. *Macoma* at top. Overlain by brown sandy silt and blue sandstone of *Siphonalia* zone	25
Cross-bedded blue sandstone	40
Dark reddish-brown sandstone. *Pseudocardium* and *Macoma* in lower part	1
Silty sand. *Macoma* and *Pseudocardium* near base. Contact at base abrupt, marked by fragments of underlying tuff in the sand and by borings penetrating tuff	3½
Fine-grained tuff. Contact at base abrupt	1
Light-gray sand containing *Macoma*. Base not exposed	6+
Exposed thickness of *Macoma* zone	76½+

152190—40——6

On the west side of La Muralla, sec. 21, T. 22 S., R. 18 E., the *Macoma* zone is faulted against the *Littorina* zone.

Toward the north end of North Dome strata identified as the *Macoma* zone do not have the characteristic light color. Large fossils (*Forreria, Nucella, Mytilus,* and barnacles) are more abundant than farther south, and *Macoma* is less prevalent.

Fossils.—Some of the fossils of the *Macoma* zone are shown on plates 34, and 42 to 44. The species are listed in the table on the following page.

The fauna of the *Macoma* zone is smaller than that of the *Siphonalia* zone. Possibly the most important difference between the two faunas is the abundance of *Macoma affinis* (pl. 34, figs. 1–4) in the *Macoma* zone. *Venerupis* cf. *V. tenerrima* was not found at other horizons.

The following marine diatoms, collected at locality 302, were identified by K. E. Lohman:

Diatoms from Macoma zone of Etchegoin formation at locality 302

Melosira sulcata (Ehrenberg) Kützing.
Coscinodiscus excentricus Ehrenberg.
Coscinodiscus radiatus Ehrenberg.

According to Lohman, the diatoms are badly corroded, suggesting leaching by alkaline solutions. Better specimens and a larger flora may be represented in samples collected later but not yet examined.

PATINOPECTEN ZONE

Stratigraphy and lithology.—The *Patinopecten* zone, named for the almost flat circular pecten that is abundant at certain localities, consists of brownish sandy silt and silty sand generally about 100 feet thick. At places the zone as identified is 40 feet thick. Lithologically these strata resemble those in the *Siphonalia* zone, but they underlie the light-colored *Macoma* zone. The top of the *Patinopecten* zone is about 400 feet below the *Littorina* zone. At some outcrops sandstone and conglomerate, the base of which is marked by a scour discontinuity, occur about 50 feet below the top of the *Patinopecten* zone. This may be a logical horizon to separate the *Macoma* and *Patinopecten* zones, but the sandstone and conglomerate could not be recognized in all the areas where this part of the Etchegoin formation crops out. Fossiliferous layers, particularly massive silty sand containing a layer of large barnacles or a *Mytilus*-barnacle layer, are taken as the base of the *Patinopecten* zone. At many localities the barnacles stand upright and form reefs. The barnacles are generally attached to small *Mytilus* shells or to *Mytilus* fragments. At places a *Pseudocardium* layer appears to be the equivalent of a barnacle layer. The stratigraphic position of the barnacle layer mapped as the base of the zone is not everywhere the same with reference to the *Macoma* zone, as shown in the sections on plate 28. The barnacle layers are probably at

Fossils from Macoma zone of Etchegoin formation

[Identifications by Ralph Stewart unless otherwise stated. P, paired valves; W, worn specimens]

Species	Localities												
	261[1]	273	283[2]	300[3]	300a	302	302a	302b	303	305	306	306a	321
Echinoid: *Dendraster gibbsii* (Rémond)		X	X	X				X		X	X		
Gastropods:													
Calliostoma sp	?			cf.									
"*Nassa*" sp								S			X		
Siphonalia sp				[4] X							W		
Nucella etchegoinensis (Arnold), ribbed var										X			
Forreria magister (Nomland)										X	W		
Olivella sp								X					
Pelecypods:													
Glycymeris sp											P		
Mytilus coalingensis Arnold				cf.	P						P		
Taras cf. *T. parilis* (Conrad)								P					
Macoma affinis Nomland (pl. 34, figs. 1–4)	cf.		X		X	cf.					P		P
Pseudocardium densatum (Conrad) of Arnold, var. cf. *gabbii* Rémond	X			X		X		X			X		
Schizothaerus sp					X								
Saxidomus? sp				X									
Venerupis cf. *V. tenerrima* (Carpenter)				P	P								
Venerupis sp				X									
Cerastoderma sp					?								
Solen sp								P					
Siliqua sp								P					
Panope sp					X								
Zirfaea gabbi (Tryon) var. (pl. 34, fig. 7)											?	X	
Barnacle: *Balanus* (*Tamiosoma*) cf. *B.* (*T.*) *gregarius* (Conrad)										X			
Decapod crustacean (identification by M. J. Rathbun): *Cancer antennarius* Stimpson				X									
Turtle fragments (identification by C. W. Gilmore)									X				
Land mammal (identification by C. L. Gazin): *Nannippus?* or *Calippus?* (ungual phalanx (hoof) of small horse)				X									
Marine mammals (identification by Remington Kellogg):													
Porpoise vertebrae				X				X					
Limb bone of sea lion?								X					
Ear bone of whalebone whale							X						

[1] In *Mytilus*-barnacle layer 300 feet along strike northwest of locality 300.
[2] Same locality as 283 but 60 feet lower stratigraphically.
[3] Same locality as 300 but 1 to 40 feet lower stratigraphically.
[4] Observed in the field but not collected.

different horizons at different localities and the base of the zone, therefore, is probably not a stratigraphic datum plane. The barnacle layers, however, are easily mapped, and the thickness of strata involved in their stratigraphic position is probably not greater than about 50 feet. In at least one locality a barnacle layer occurs below the base of the *Patinopecten* zone as mapped.

Fossiliferous layers in the zone and a concretionary sandstone near the top of the zone are shown locally on the geologic map (pl. 3).

The type locality of the *Patinopecten* zone is on the south side of El Tolete, sec. 7, T. 22 S., R. 18 E., which is also the type locality of the *Macoma* zone. The name of the zone is not entirely satisfactory, for *Patinopecten* is found locally in underlying strata, in the *Siphonalia* zone, and occurs rarely in the *Pecten* zone and in the Cascajo conglomerate member of the San Joaquin formation. This genus, however, is more abundant in the *Patinopecten* zone than in other parts of the section and at some outcrops is practically the only fossil in the sandy silt above the barnacle layer mapped as the base of the zone.

The following section (pl. 28, column 7) was measured at the type locality:

Section of Patinopecten zone of Etchegoin formation at type locality on south side of El Tolete, south central part of sec. 7, T. 22 S., R. 18 E.

	Feet
9. Slightly tuffaceous sandy silt with some pebbles. Overlain by light-gray tuffaceous sand of *Macoma* zone, the base of which is marked by a discontinuity. (For upward continuation of section see p. 67)	3
8. Greenish sand, somewhat purplish at top; few small sand dollars	6
7. Obscurely bedded sand with pebbles and small sand dollars at base. Contact at base abrupt	7
6. Laminated sandy silt, somewhat concretionary	18
5. Grayish-green sand with sand dollars; some cross bedding. One-inch pebbles and shell fragments in thin gravel at base. Base marked by scour discontinuity, gravel penetrating underlying silt to depth of 2 feet along cracks and borings. A *Panope* filled with pebbles from this gravel was observed with posterior end upright	16
4. Laminated brown sandy silt with sand dollars and *Patinopecten* and streaks of altered tuffaceous sandy silt	18
3. Concretionary gray sand. One specimen of *Tellina* observed	20
2. Greenish-brown sandy silt with few pebbles	4
1. Brown silty sand with *Venerupis* and barnacle fragments (*Tamiosoma?*)	½
Thickness of *Patinopecten* zone	92½

Unit 4 in the preceding section, 50 feet below the top of the zone, includes streaks of light-colored sandy silt similar in field appearance to material in the *Macoma* zone. According to M. N. Bramlette, a zeolitic mineral that probably represents an alteration product of volcanic glass is abundant in this sandy silt.

At the southeast end of Las Paredes (pl. 28, column 8), south of El Rascador (pl. 28, column 9), and along the west side of La Loba a barnacle layer 40 to 50 feet below the base of the *Macoma* zone was mapped as the base of the *Patinopecten* zone. Along the south side of Las Paredes the *Patinopecten* zone is faulted against the upper *Pseudocardium* and *Littorina* zones. On the south side of La Muralla a *Pseudocardium* layer about 75 feet below the top of the zone appears to be the equivalent of the barnacle layer farther north and was mapped as the base of the zone. At locality 315, in a tributary of Arroyo Doblegado, the zone is 84 feet thick, and a barnacle layer occurs at the base (pl. 28, column 12). At La Cuna the upper part of the zone is characterized by a brown concretionary sandstone. The concretions are cylindrical and are as much as 3 feet long and a foot in diameter. Their long axis is approximately at right angles to the bedding. At localities 328 and 329, on tributaries of Arroyo Murado, a fossiliferous layer probably near the top of the zone contains large, worn specimens of *Crepidula*. At locality 330 nearby a 1-foot conglomerate 6 feet below a barnacle layer was mapped as the base of the zone. Toward the north end of North Dome a *Mytilus-Venerupis* layer was mapped as the base of the zone.

Fossils.—Fossils from the *Patinopecten* zone are shown on plates 35, 36, 40, 42, 43. The species are listed in the table on the following page.

The abundance of *Patinopecten lohri* (pl. 35, figs. 2–5) in the *Patinopecten* zone is the most apparent difference between the faunas of the *Patinopecten* and *Siphonalia* zones. Several species, however—notably *Crepidula* cf. *C. princeps*, *Pseudotoma* sp., *Macoma* cf. *M. vanvlecki*, and *Macoma* cf. *M. indentata* (pl. 35, fig. 1)—were found in the *Patinopecten* zone but not in the *Siphonalia* zone. These forms are present in the underlying Jacalitos formation, but the characteristic Jacalitos species are absent.

Large barnacles assigned to *Tamiosoma* are more abundant in the *Patinopecten* zone than at other horizons but occur in overlying and underlying Etchegoin strata.

STRATA UNDERLYING *PATINOPECTEN* ZONE

The oldest strata exposed in North Dome underlie the *Patinopecten* zone. They consist of brown silt and sand and lenses of blue sandstone and have a maximum thickness of about 100 feet. The fossils in this part of the section are similar to those in the *Patinopecten* and *Siphonalia* zones. *Patinopecten* is not abundant. *Pseudocardium* layers occur in this part of the section, as in overlying strata. The barnacle reef shown on plate 27, *A*, occurs in a faulted wedge 1,000 feet west of the locality where the section on page 68 was measured. This barnacle reef corresponds to a barnacle layer 40 feet below the base of the *Patinopecten* zone in the section just mentioned. The opercular valves illustrated on plate 36, figs. 2–5, 8, 9, were collected at the locality shown on plate 27, *A*.

MIDDLE DOME AND SOUTH DOME

The faunal zones in the Etchegoin formation of North Dome were not recognized in Middle and South Domes, where fossils, aside from diatoms, are rare except at horizons in the upper part of the formation. Even in the upper part of the formation *Pseudocardium* is the only abundant fossil. The difference in relative abundance of fossils is strikingly shown by the absence of sand dollars in Middle and South Domes. It is improbable that the scarcity of fossils in the lower part of the formation is due to the prevalence of nonmarine deposits, for marine diatoms were observed at many places in layers, generally a fraction of an inch thick, and in small fragments of tuffaceous light-colored silt in the sandstone constituting the lower part of the formation, which otherwise is generally barren. Pelagic species are included in the diatom flora represented in a sample collected from such material. At a few places marine mollusks were found in the sandstone.

In Middle Dome the Etchegoin formation has an estimated exposed thickness of about 600 feet. In South Dome a considerably greater thickness, estimated as about 1,800 feet, appears to be represented. In both anticlines the formation is divided into an upper part, consisting of silty rocks and subordinate beds of sandstone and conglomerate, and a lower part, in which sandstone is the prevailing rock. The *Pseudocardium-Anadara* zone in the upper part of the formation is a readily recognized thin zone in both anticlines. If a tuffaceous silt near the top of the lower part of the formation in Middle Dome is the equivalent of tuffaceous sand and silt in the *Macoma* zone of North Dome, the division between the upper and lower parts in Middle Dome—and presumably also in South Dome—is at a horizon about 50 feet above the top of the *Macoma* zone of North Dome, but this correlation is uncertain.

UPPER PART OF FORMATION

STRATA OVERLYING *PSEUDOCARDIUM-ANADARA* ZONE

Stratigraphy and lithology.—The strata overlying the *Pseudocardium-Anadara* zone have a thickness of about 50 feet in Middle Dome and perhaps a little less in South Dome. In Middle Dome they consist of buff silt and silty clay and minor lenses of sandstone (fig. 10). At the base is silty clay that forms a narrow layer virtually barren of vegetation. Weathered outcrops in South Dome indicate that silty rocks predominate in the corresponding part of the section there also.

Fossils from Patinopecten zone of Etchegoin formation

[Identifications by Ralph Stewart unless otherwise stated. F, fragment; P, paired valves; S, small specimens; W, worn specimens]

Species	Localities																															
	300a	307	308	309	309a	310	312	313	314	315	316	317	317a	318	319	319a	320	320a	322	323	328	329	330	332	333	335	336	337	338	338a	340	342	343
Echinoids:																																	
Dendraster gibbsii (Rémond) (pl. 40, figs. 3, 4; pl. 42, figs. 1-5; pl. 43, figs. 1, 2; pl. 44, fig. 6)	X	?			X			X			X					X				cf.	S	S	X	X			X						X
Dendraster gibbsii humilis Kew (pl. 43, fig. 3)		X																													X		
Gastropods:																																	
Calliostoma coalingense privum Stewart, n. var.	X	F			X		[1] X				X	X								X		X	X				X	X					[1] X
Crepidula cf. *C. princeps* Conrad		W	W																		X												
Lunatia sp.			S	X																		X				?	X						
Opalia varicostata Stearns (pl. 36, fig. 6)												X																					
"*Nassa*" cf. "*N.*" *moraniana* Martin	S																				X		F										
"*Nassa*" *miser iniqua* Stewart, n. var. (pl. 34, fig. 8)	X																																
Siphonalia cf. *S. kettlemanensis* (Arnold)	X						X														X					?	X						
Nucella etchegoinensis (Arnold), ribbed var. (pl. 36, figs. 1, 7)							X																		X			X					
Forreria magister (Nomland) (pl. 36, figs. 11, 12)	W		S		X																					X	X						
Pseudotoma sp.																				W													
Pelecypods:																																	
Anomia sp.					X																												
Anadara trilineata (Conrad) of Arnold, var. cf. *canalis* (Conrad)	X					X																P											
Mytilus coalingensis Arnold					X						X								W	F	F	P	F			P	X	X					[1] X
Adula cf. *A. falcata* (Gould)																			X														
Hinnites cf. *H. crassa* Conrad	W																																[1] X
Patinopecten lohri (Hertlein) (pl. 35, figs. 2-5)	X	F	X		X	X	[1] X	X	X		X		X					X				P										X	[1] X
Ostrea atwoodii Gabb					X																		X			X							
Taras cf. *T. parilis* (Conrad) (pl. 35, fig. 6)			X																														
Macoma affinis Nomland																					P	P											
Macoma cf. *M. vanvlecki* Arnold																					P												
Macoma cf. *M. indentata* Carpenter (pl. 35, fig. 1)				X																													
Macoma sp.								X													S	X				X							
Mactra? cf. *M.? coalingensis* Arnold										X																							
Pseudocardium densatum (Conrad) of Arnold var. cf. *gabbii* Rémond	X			X	X	X					X											P						X					
Schizothaerus cf. *S. nuttallii* (Conrad)																					?P												
Saxidomus sp.						?																				P							
Venerupis laciniata hannibali (Howe)																							F			P		X					
Cerastoderma sp.			F													X					F												
Trachycardium n. sp.	X																																
Sanguinolaria cf. *S. nuttallii* Conrad (pl. 36, fig. 10)			X																														
Siliqua sp.																X																	
Panope sp. cf. *P. generosa* Gould	P	W																															
Zirfaea sp.		WF	WF																	F			F										
Pholadidea cf. *P. penita* (Conrad)																			W														
Barnacles:																																	
Balanus sp.					X																												
Balanus (*Tamiosoma*) cf. *B.* (*T.*) *gregarius* (Conrad)	X	F			X		[1] X				X	X								X		X	X				X	X					[1] X
Unidentified fish remains: "Bulbous growths"																														X			
Land mammals (identifications by C. L. Gazin):																																	
Horse teeth (*Pliohippus*)															X																		
Deerlike remains (cervid?):																																	
Horn fragment														X																			
Jaw fragment with two worn molars														X																			
Tooth																						X											
Marine mammals (identifications by Remington Kellogg):																																	
Porpoise? vertebra															X																		
Bone fragment, probably marine mammal																		X															

[1] Observed in field but not collected.

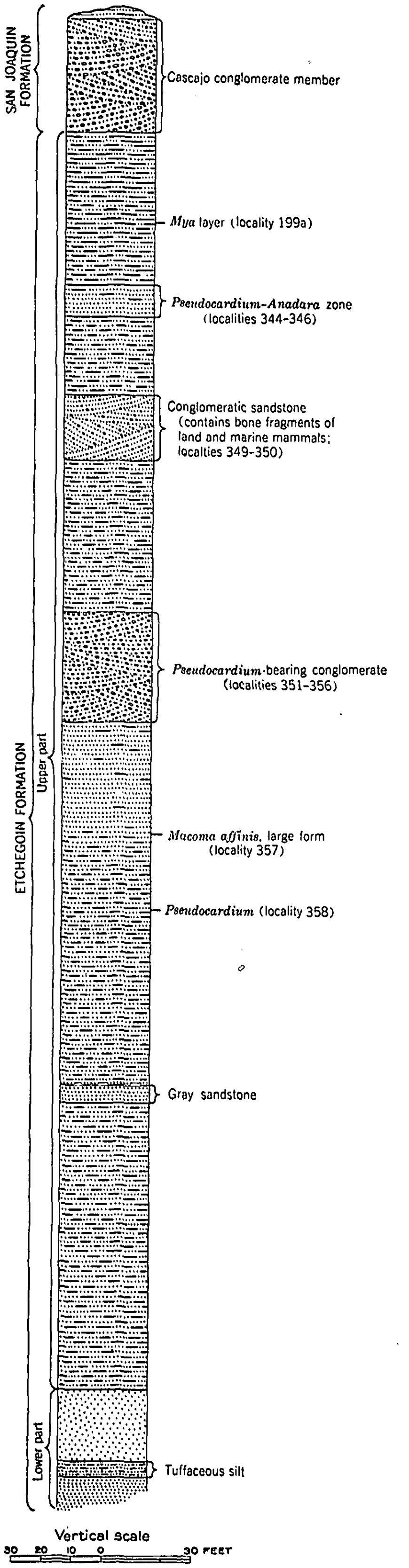


FIGURE 10.—Generalized section of upper part of Etchegoin formation of Middle Dome.

The following section was measured in Middle Dome on the east side of Arroyo Culebrino at the sharp northward bend adjoining the south line of sec. 18, T. 23 S., R. 19 E.

Section of strata at base of San Joaquin formation and in upper part of Etchegoin formation on Arroyo Culebrino in southwestern part of sec. 18, T. 23 S., R. 19 E.

	Ft.	*in.*
San Joaquin formation:		
Cascajo conglomerate member:		
Coarse-grained cliff-making bluish-gray sandstone with few imprints of leaf fragments. Possibly corresponds to first blue sandstone of North Dome. Overlain by pebbly sandstone containing worn "bulbous fish growths" and silicified wood. Top not exposed	10+	
Etchegoin formation:		
Strata overlying *Pseudocardium-Anadara* zone:		
Poorly exposed buff sandstone	8	
Hard gray iron-stained sandstone; lenses out to southeast		2–4
Poorly exposed buff silt and clay and soft sandstone	42	
Pseudocardium-Anadara zone:		
Gray dirty sandstone containing abundant *Pseudocardium* and a few *Anadara* and *Mya*	8	

A section measured on the ridge south of Arroyo Culebrino in the northeastern part of sec. 24, T. 23 S., R. 18 E., is as follows:

Section of Etchegoin strata overlying Pseudocardium-Anadara zone on ridge south of Arroyo Culebrino in northeastern part of sec. 24, T. 23 S., R. 18 E.

	Feet
Buff silt, clay, and muddy sandstone, the latter containing imperfectly cemented spherical concretions. Thickness estimated. Overlain by Cascajo conglomerate member forming base of San Joaquin formation	30
Bluish-gray lumpy sandstone	4
Buff silty clay, including a layer of ironstone concretions 5 feet below top. Underlain by *Pseudocardium-Anadara* zone	35
Thickness of Etchegoin strata overlying *Pseudocardium-Anadara* zone	69

At locality 199a, along the upper course of Arroyo Culebrino, a *Mya* layer about 30 feet below the Cascajo conglomerate member forming the base of the San Joaquin formation is exposed on the hanging wall of a fault. This *Mya* layer may correspond to one of the *Mya* layers between the *Littorina* zone and the first *Mya* layer in the North Dome section. A *Mya* layer was also found at two other localities on the west side of northern Middle Dome and farther east on Arroyo Culebrino near the south line of sec. 18, T. 23 S., R. 19 E. *Mya* apparently occurs at about the same horizon at the north end of South Dome, for *Mya*-bearing sandstone float was found between the outcrops of the Cascajo conglomerate and *Pseudocardium-Anadara* zone near locality 214.

Fossils.—The fossils collected from the *Mya* layer at locality 199a are as follows:

Fossils from Mya layer in Etchegoin strata overlying Pseudocardium-Anadara zone at locality 199a

[Identifications by W. P. Woodring]

Macoma affinis Nomland (paired specimen).
Cerastoderma sp. (imperfect specimen).
Mya cf. *M. dickersoni* Clark (paired specimens and single valves).

PSEUDOCARDIUM-ANADARA ZONE

Stratigraphy and lithology.—The *Pseudocardium-Anadara* zone consists of 5 to 10 feet of gray or buff silty sandstone about 50 feet below the top of the Etchegoin formation. It is readily recognized by the abundance of a relatively small form of *Pseudocardium* associated with a few *Anadara* and *Mya*, both generally represented by fragments. The zone was mapped in Middle Dome and at the north end of South Dome. The type locality is along Arroyo Culebrino in northern Middle Dome at the place where the section on page 71 was measured.

The zone corresponds probably to the layer containing *Mya*, *Pseudocardium*, and *Anadara* that was mapped as the *Littorina* zone toward the south end of North Dome. The strata are in the same general part of the section and have the same faunal association. Inasmuch as the *Pseudocardium-Anadara* zone is the most reliable stratigraphic unit in the Etchegoin formation of Middle and South Domes, it was contoured for the geologic structure map (pl. 51). For practical purposes this datum may be regarded as the equivalent of the datum of the *Littorina* zone of North Dome. Fossiliferous strata in this part of the section may represent a series of overlapping lenses at slightly different horizons, but the thickness involved is not great enough to affect the representation of the structure.

At many localities in Middle Dome, as on Parejo Hill, the fossils weathered out of the *Pseudocardium-Anadara* zone form a band littered with broken *Pseudocardium* shells, among which may be found a few fragments of *Anadara* and *Mya*. At other places the zone is identified by a few fossils strewn in the soil. In such areas, as on the east slope of the ridge in the eastern part of sec. 4, T. 24 S., R. 19 E., the mapping is uncertain. Fresh exposures of the zone were observed at the type locality, at locality 344, which is farther west on Arroyo Culebrino, and on a tributary of the same stream in the northeastern part of sec. 19, T. 23 S., R. 19 E. At these localities the fossils occur in silty sandstone 5 to 10 feet thick. *Mya* is generally most abundant at the top of the zone or is confined to the top. Immediately north of the fault 75 feet north of the east quarter corner of sec. 25, T. 23 S., R. 18 E., a layer of *Mya* shells, replaced by gypsum, is exposed at the top of the zone. On the east flank of the anticline southward across the south line of T. 23, *Mya* is more abundant than elsewhere, and immediately south of the crest of the 520-foot hill in sec. 4, T. 24 S., R. 19 E., *Mya* is more abundant than *Pseudocardium*. A few oolites were recovered from the matrix of fossils collected at locality 346, in the northern part of the anticline.

In South Dome fossils are not so conspicuous as in Middle Dome, but the same faunal association is represented. According to the width of the band of fossils, the zone is probably not much more than 5 feet thick. On the east side of the anticline the zone was traced almost to the edge of the alluvium covering the San Joaquin Valley; on the west side it appears to grade southward into nonfossiliferous silty sandstone and silt in sec. 33, T. 24 S., R. 19 E.

Fossils.—Fossils from the *Pseudocardium-Anadara* zone are listed in the following table, and the *Pseudocardium* and *Mya* are shown on plate 24.

Fossils from Pseudocardium-Anadara zone of Etchegoin formation

[Identifications by W. P. Woodring. F, Fragments; P, paired valves; S, small specimens]

Species	Localities				
	Middle Dome			South Dome	
	344	345	346	347	348
Gastropods:					
Crepidula princeps Conrad?		F			
Undetermined small gastropod	F				
Pelecypods:					
Anadara trilineata (Conrad) of Arnold			cf.	S	F
Pseudocardium densatum (Conrad) of Arnold, medium-sized var. (pl. 24, figs. 19, 20)	P	X	X	P	F
Cerastoderma cf. *C. meekianum* (Gabb), small var	X				F
Mya cf. *M. dickersoni* Clark (pl. 24, fig. 21)	P		X	F	F

The shells in the *Pseudocardium-Anadara* zone are generally broken. That this condition is the result of weathering is indicated by the fresh fractures and by the occurrence of whole specimens in unweathered exposures. *Pseudocardium densatum*, by far the most abundant species, is represented by a variety of small or medium size (pl. 24, figs. 19, 20). This is the highest horizon at which *Pseudocardium* is abundant in Middle and South Domes, aside from the local occurrence of specimens, possibly of detrital origin, in the Cascajo conglomerate. The *Pseudocardium-Anadara* zone corresponds approximately to the highest horizon at which

Pseudocardium occurs in North Dome, and the North Dome occurrences also represent shells generally of small or medium size. Young shells were not found in other beds in Middle Dome or South Dome. A worn unbroken shell from locality 347, in South Dome, is like thick-shelled specimens from the underlying *Pseudocardium*-bearing sandstone, and a fragment from locality 345, in Middle Dome, represents a large thick-shelled form like the one in the underlying conglomerate. These shells may be detrital constituents or may be residual from patches of older alluvium removed by erosion.

Anadara trilineata and *Mya* cf. *M. dickersoni* are generally represented by fragments. A few unbroken small shells of *Anadara* were collected at locality 347. The *Mya* shown on plate 24, figure 21, is exceptionally elongate and inequilateral.

The other fossils are represented by single specimens at one locality.

STRATA UNDERLYING *PSEUDOCARDIUM-ANADARA* ZONE

Stratigraphy and lithology.—In Middle Dome the strata in the upper part of the Etchegoin underlying the *Pseudocardium-Anadara* zone have a thickness of about 350 feet. They consist principally of silty rocks but include a conglomeratic sandstone and a conspicuous conglomerate. Lenses of blue or gray sandstone occur locally in the silt.

A soft coarse-grained cross-bedded bluish-gray sandstone containing local lenses of small pebbles is about 35 feet below the *Pseudocardium-Anadara* zone. On Parejo Hill this sandstone has a thickness of 25 feet, but the thickness is variable and at places the sandstone appears to be absent. At localities where this sandstone contains pebbles it resembles a conglomerate lower in the section, though it is generally thinner and less persistent than the conglomerate and has fewer pebbles. The sandstone also apparently lacks the clusters of large thick-shelled *Pseudocardium* that occur in the conglomerate. A few isolated specimens of this form of *Pseudocardium* were found on the outcrop of the sandstone, but none were observed in place. On the east side of the anticline in sec. 33, T. 23 S., R. 19 E., and in the adjoining part of sec. 4, T. 24 S., R. 19 E., the sandstone is unusually thick and conglomeratic and forms the crest of the ridge extending southeastward from Parejo Hill. In the faulted area on the west side of southern Middle Dome the sandstone is lithologically similar to the underlying conglomerate. This sandstone is in about the same part of the section as the blue sandstone that in parts of North Dome overlies the upper *Pseudocardium* zone and may represent the base of the San Joaquin formation according to Barbat and Galloway's classification. The upper *Pseudocardium* zone, however, was not recognized in Middle Dome.

The *Pseudocardium*-bearing conglomerate about 100 feet below the *Pseudocardium-Anadara* zone is the most persistent unit in this part of the section in Middle Dome. It is shown on the geologic map (pl. 3), but at places it may have been confused with the overlying sandstone. The conglomerate consists of soft coarse-grained cross-bedded bluish-gray or ferruginous sandstone that has layers or lenses of small pebbles. At most places it contains scattered clusters of a large thick-shelled form of *Pseudocardium,* generally at the base but locally also above the base. This conglomerate is well exposed on the west slope of Parejo Hill, where it has a thickness of 35 feet. Elsewhere it is fully 50 feet thick, but the thickness is variable and apparently changes within short distances. The specimens of *Pseudocardium* were probably derived from underlying strata, for they occur in scattered clusters and are not associated with other marine fossils except at two localities where a few molds occur. This conglomerate is probably the equivalent of a blue conglomerate overlying the *Siphonalia* zone at many localities in North Dome. The conglomerate in North Dome also contains *Pseudocardium* shells that are probably not in place.

Sandstone and silty sandstone immediately underlying the *Pseudocardium*-bearing conglomerate are well exposed on the west slope of the hill in the northwestern part of sec. 19, T. 23 S., R. 19 E., where the accompanying section was measured.

Section of strata in Etchegoin formation underlying Pseudocardium-bearing conglomerate on west slope of hill in northwestern part of sec. 19, T. 23 S., R. 19 E.

	Ft.	In.
Pseudocardium-bearing conglomerate:		
Greatly fractured coarse-grained cross-bedded bluish-gray sandstone. Some layers contain small chert pebbles; others consist of dirty sandstone. No fossils observed. Top not exposed	24+	
Strata underlying *Pseudocardium*-bearing conglomerate:		
Thin-bedded buff and grayish-buff sandstone and silty sandstone, coarser toward top. Some layers are thick-bedded and a few are cross-bedded. Grades upward into the conglomerate	7	6
Iron-stained, grayish-buff sandstone containing small chert pebbles and ferruginous borings. Most of the pebbles are less than half an inch long		8
Light-buff to grayish-buff moderately coarse grained sandstone, lower part cross-bedded. Includes cemented masses of irregular shape and varying size. Uppermost foot forms ledge	6	
Soft grayish-buff silty sandstone, massive except near top; 3½ feet below top a layer of ferruginous concretionary lenses	23	6
Soft buff sandstone containing scattered large paired *Macoma* (locality 357)	2	6
Poorly exposed soft muddy sandstone and silt.		

At locality 358 and at a few other places the large thick-shelled form of *Pseudocardium* occurring in the *Pseudocardium*-bearing conglomerate is abundant in silty sandstone at horizons a few feet to 50 feet below the conglomerate. The similar shells in the conglomerate may have been derived from these strata. At the localities where they occur they are more abundant than in the conglomerate, but they are more widespread in the conglomerate. These fossiliferous strata underlying the conglomerate correspond presumably to the *Siphonalia* zone of North Dome.

The remainder of the upper part of the Etchegoin in Middle Dome consists of poorly exposed silty rocks. About halfway between the conglomerate and the base of the upper part is a thin gray sandstone recognized along the west side of the anticline and locally on the east side.

In South Dome the strata in the upper part of the Etchegoin underlying the *Pseudocardium-Anadara* zone have a thickness of about 300 feet. As in Middle Dome, they consist principally of silty rocks. The *Pseudocardium*-bearing conglomerate and overlying conglomeratic sandstone of Middle Dome were not recognized. At the north end of South Dome a sandstone containing abundant *Pseudocardium* is 15 to 20 feet below the *Pseudocardium-Anadara* zone. Fossils are particularly abundant in this sandstone at Oyster Hill (locality 360) and nearby. At Oyster Hill the fossils occur in the uppermost 3 to 5 feet of gray tuffaceous sandstone that is about 25 feet thick and has a middle layer of soft coarse-grained bluish-gray sandstone. A sample of the gray sandstone was examined by M. N. Bramlette, who reported that it contains fresh glass, some of which is brown and has an index of refraction near 1.53, suggesting a more basic composition than that of most of the glass examined from the Kettleman Hills. The sample also contains much andesine and altered biotite, some hypersthene, augite, and hornblende, and a few diatoms and sponge spicules. If the South Dome section is abbreviated, this *Pseudocardium*-bearing sandstone may correspond roughly to the upper *Pseudocardium* zone of North Dome, but the form of *Pseudocardium* is smaller and shorter than that in the upper *Pseudocardium* zone, and no other fossils were found. Toward the south on both flanks of South Dome the *Pseudocardium*-bearing sandstone grades into nonfossiliferous strata. A nonfossiliferous gray sandstone at this horizon near the center of sec. 33, T. 24 S., R. 19 E., contains more abundant glass shards than the part of the fossiliferous sandstone sample at Oyster Hill.

South Dome strata in the upper part of the Etchegoin below the horizon of the *Pseudocardium*-bearing sandstone consist of buff silt and silty clay and lenses of tuffaceous gray sandstone, all of which are generally poorly exposed. Diatoms occur in gray silty clay at scattered localities on the west side of the anticline, principally at horizons close to the base of the upper part of the formation. At locality 361 and elsewhere the diatoms are accompanied by molds of Foraminifera of the genus *Elphidium*.

Fossils.—Fossils collected from strata in the upper part of the Etchegoin underlying the *Pseudocardium-Anadara* zone are listed in the following table, and the forms of *Pseudocardium densatum* are shown on plate 37.

The usual form of *Pseudocardium densatum* in the *Pseudocardium*-bearing conglomerate and underlying strata in Middle Dome is a variety similar to *P. d.*

Fossils from strata in upper part of Etchegoin formation underlying Pseudocardium-Anadara zone

[Identifications by W. P. Woodring unless otherwise stated. F, fragments; M, paired molds; P, paired valves]

Species	Localities												
	Middle Dome											South Dome	
	Above conglomeratic sandstone	Conglomeratic sandstone		*Pseudocardium*-bearing conglomerate						Below *Pseudocardium*-bearing conglomerate		*Pseudocardium*-bearing sandstone	
	348a	349	350	351	352	353	354	355	356	357	358	359	360
Gastropod: *Crepidula princeps* Conrad										[1] X			
Pelecypods:													
Anadara trilineata (Conrad) of Arnold, var. cf. *canalis* (Conrad)?										[1] F			
Macoma affinis Nomland, large form										P			
Macoma sp								M					
Pseudocardium densatum (Conrad) of Arnold and variety cf. *gabbii* Rémond (pl. 37, figs. 7–10)				X	P	X	X	?M			X		
Pseudocardium densatum (Conrad) of Arnold and short variety (pl. 37, figs. 3–6)												P	X
Mya? sp								M	M				
Land mammals (identifications by C. L. Gazin):													
Mastodon limb bone	X												
Horse tooth fragment									X				
Artiodactyl horn core?		[2] X											
Camelid? calcaneum								X					
Marine mammal (identifications by Remington Kellogg): Eared seal limb bones			X										

[1] Float specimens.
[2] On surface close to outcrop of *Pseudocardium-Anadara* zone, but probably weathered out of the conglomeratic sandstone nearby.

PLATE 37

[Figures natural size]

FIGURES 1, 2. *Volsella* cf. *V. modiolus* (Linné). Double-valve specimens with crushed anterior end. Locality 368, lower part of Etchegoin, South Dome.

1. Greatest length (incomplete) 39 mm., width 21.9 mm., thickness of both valves 18.2 mm. U. S. Nat. Mus. 495364.
2. Greatest length (incomplete) 55.3 mm., width 30.8 mm., thickness of both valves 23 mm. U. S. Nat. Mus. 495365.

3. *Pseudocardium densatum* (Conrad) of Arnold. Left valve. Length 40.7 mm., height 33.7 mm., thickness 12.6 mm. Locality 360, *Pseudocardium*-bearing sandstone, South Dome. U. S. Nat. Mus. 495361.

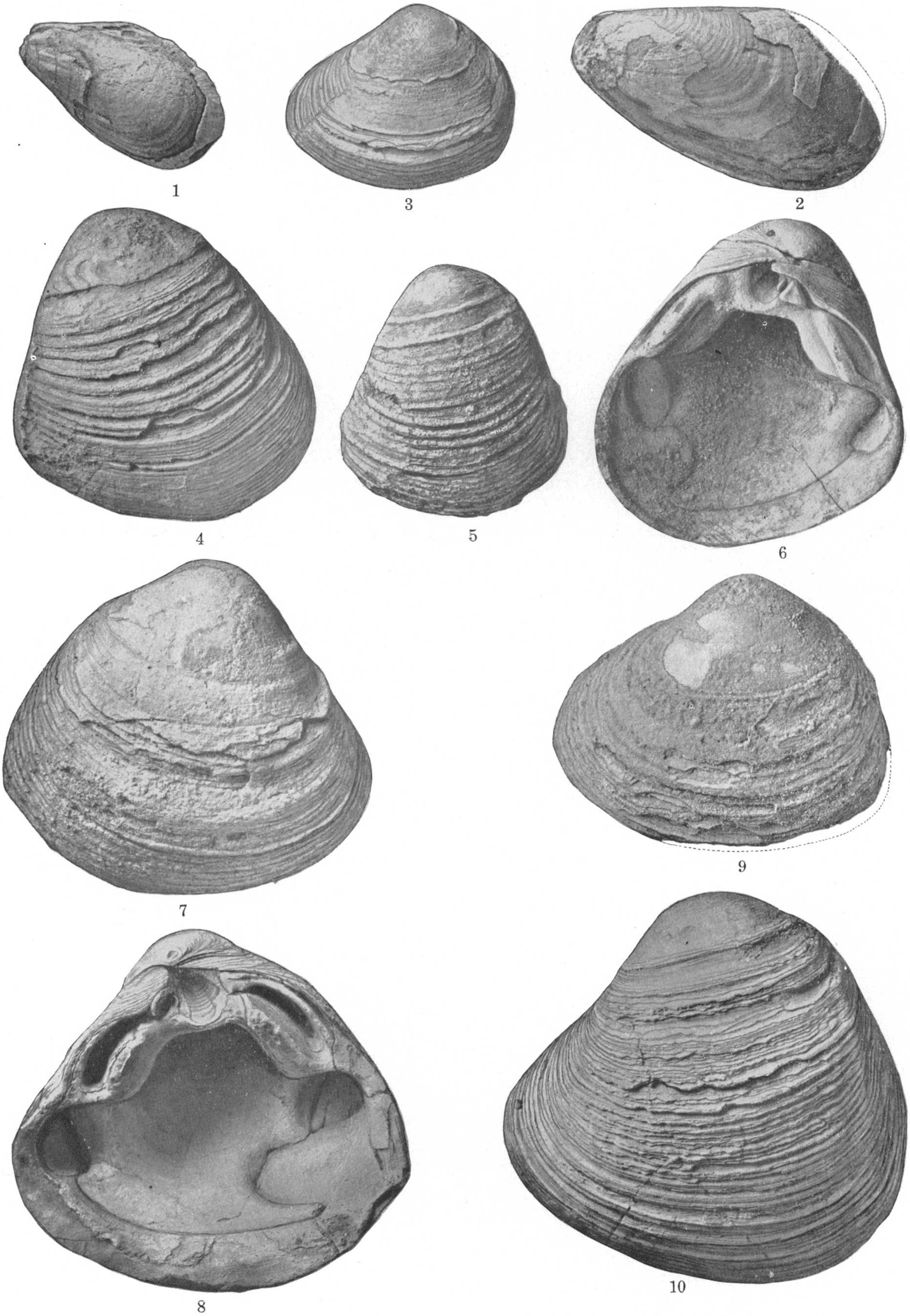
4–6. *Pseudocardium densatum* (Conrad) of Arnold, short var. Locality 360, *Pseudocardium*-bearing sandstone, South Dome.

4, 6. Left valve. Length 54.5 mm., height 57 mm., thickness 27 mm. U. S. Nat. Mus. 495362.
5. Left valve. Length 42 mm., height 47 mm., thickness 20.5 mm. U. S. Nat. Mus. 495363.

7, 8. *Pseudocardium densatum* (Conrad) of Arnold, var. cf. *gabbii* Rémond. Right valve; posterior arm of cardinal broken. Length 67.5 mm., height 61 mm., thickness 25 mm. Locality 354, *Pseudocardium*-bearing conglomerate, Middle Dome. U. S. Nat. Mus. 495358.

9. *Pseudocardium densatum* (Conrad) of Arnold. Left valve. Length (almost complete) 61.5 mm., height (incomplete) 49 mm., thickness 21 mm. Locality 352, *Pseudocardium*-bearing conglomerate, Middle Dome. U. S. Nat. Mus. 495359.

10. *Pseudocardium densatum* (Conrad) of Arnold, var. cf. *gabbii* Rémond. Left valve. Length 74.5 mm., height 70 mm., thickness 31 mm. Locality 358, below *Pseudocardium*-bearing conglomerate, Middle Dome. U. S. Nat. Mus. 495360.



FOSSILS FROM ETCHEGOIN FORMATION OF MIDDLE AND SOUTH DOMES.

PLATE 38

FIGURE 1. *Coscinodiscus kurzii* Grunow. Diameter 0.135 mm. Locality 364. U. S. G. S. diatom catalog No. 1515–1.

2. *Coscinodiscus asteromphalus* Ehrenberg var. *omphalantha* (Ehrenberg) Grunow. Diameter 0.266 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–4.

3. *Coscinodiscus inclusus* Rattray. Diameter 0.040 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–8.

4. *Endictya robusta* (Greville) Hanna and Grant. Diameter 0.057 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–5.

5. *Coscinodiscus excentricus* Ehrenberg. Diameter 0.066 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–7.

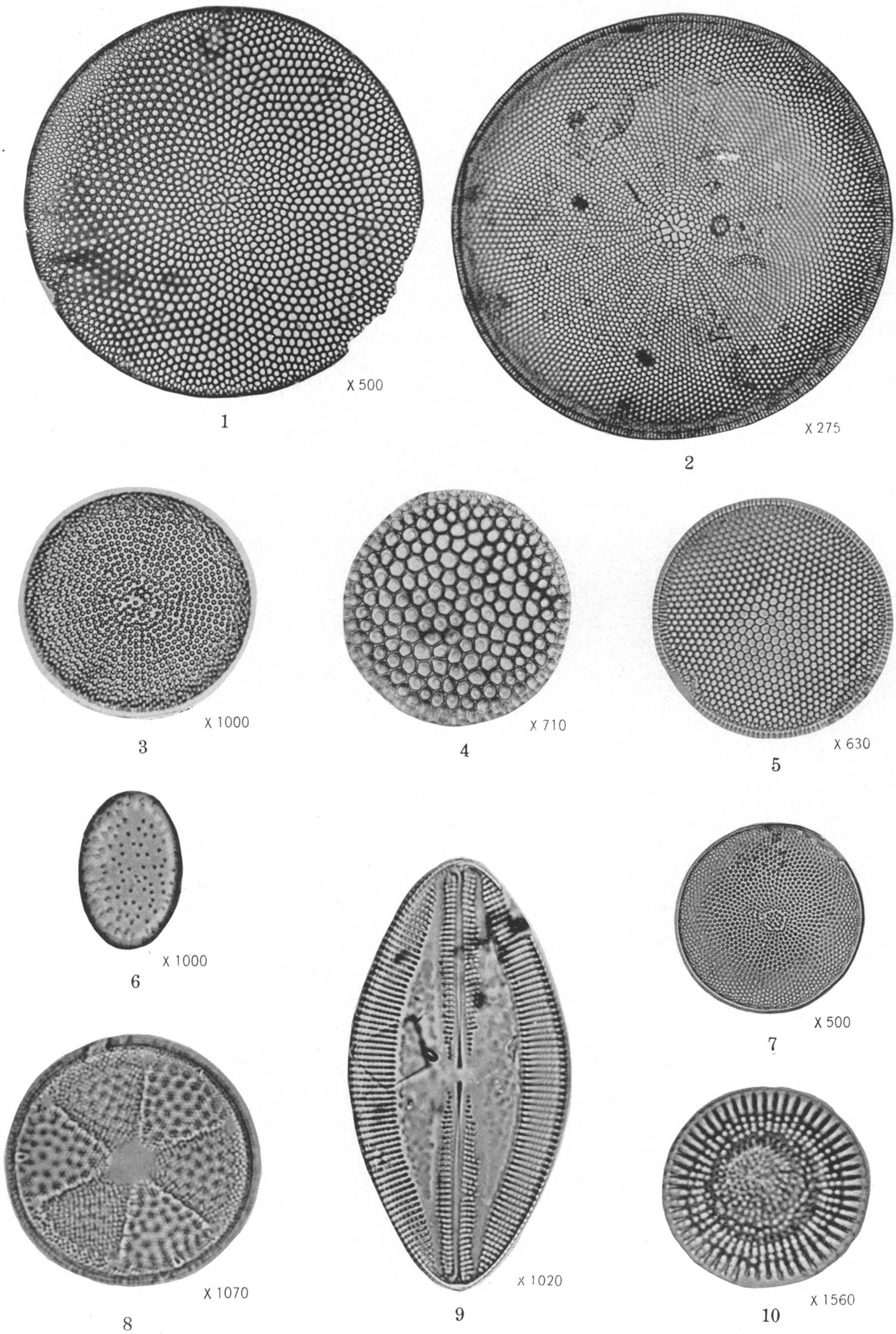
6. *Xanthiopyxis ovalis* Lohman. Length 0.027 mm., width 0.018 mm. Locality 364. U. S. G. S. diatom catalog No. 1515–2.

7. *Coscinodiscus vetustissimus* Pantocsek. Diameter 0.066 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–6.

8. *Actinoptychus undulatus* Ehrenberg. Diameter 0.041 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–5.

9. *Navicula clavata* Gregory var. *elliptica* Schmidt. Length 0.072 mm., width 0.038 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–9.

10. *Stephanodiscus dubius* (Fricke) Hustedt. Diameter 0.023 mm. Locality 361. U. S. G. S. diatom catalog No. 1523–3.



DIATOMS FROM ETCHEGOIN FORMATION OF SOUTH DOME.

gabbii (pl. 37, figs. 7, 8, 10). A few specimens have an elongate anterior end (pl. 37, fig. 9) and resemble Conrad's figure of *P. densatum.* Likewise, the usual form in the *Pseudocardium*-bearing sandstone of South Dome is a shorter and generally smaller variety (pl. 37, figs. 4–6), but a few specimens (pl. 37, fig. 3) are similar to Conrad's figure of *P. densatum. Pseudocardium* was not found at lower horizons in either anticline.

The large form of *Macoma affinis* in strata underlying the *Pseudocardium*-bearing conglomerate also occurs in the *Siphonalia, Macoma,* and *Patinopecten* zones of North Dome.

The following diatoms from locality 361 were identified by K. E. Lohman. Some of the characteristic species are shown on plate 38. Lohman reports that this flora is dominantly marine but that it includes a number of fresh-water and brackish-water species, most of which are rare.

Diatoms from upper part of Etchegoin formation at locality 361

[Identifications by K. E. Lohman. R, rare; F, few; C, common; A, abundant]

Melosira sulcata (Ehrenberg) Kützing (R).
Melosira sol (Ehrenberg) Kützing (R).
Melosira solida Eulenstein (R.)
Melosira solida multiformis Frenguelli (R).
Melosira granulata (Ehrenberg) Ralfs (R).
Stephanopyxis turris (Greville and Arnott) Ralfs (R).
Stephanopyxis bruni Schmidt var. (R).
Endictya robusta (Greville) Hanna and Grant (pl. 38, fig. 4) (F).
Stephanodiscus dubius (Fricke) Hustedt (pl. 38, fig. 10) (F).
Coscinodiscus excentricus Ehrenberg (pl. 38, fig. 5) (A).
Coscinodiscus lineatus Ehrenberg (F).
Coscinodiscus subtilis Ehrenberg (F).
Coscinodiscus bisculptus Rattray (R).
Coscinodiscus vetustissimus Pantocsek (pl. 38, fig. 7) (F).
Coscinodiscus inclusus Rattray (pl. 38, fig. 3) (R).
Coscinodiscus asteromphalus Ehrenberg *omphalantha* (Ehrenberg) Grunow (pl. 38, fig. 2) (F).
Coscinodiscus kurzii Grunow (C).
Actinoptychus undulatus Ehrenberg (pl. 38, fig 8.) (A).
Periptera tetracladia Ehrenberg (F). }
Syndendrium diadema Ehrenberg (F). } Spores of *Chaetoceros?*
Dicladia capreolus Ehrenberg (F). }
Omphalotheca sp. (R).
Hercotheca cf. *H. mammillaris* Ehrenberg (F).
Dossetia sp. (F).
Lithodesmium sp. (R).
Biddulphia roperiana Greville (R).
Tetracyclus lacustris Ralfs (R).
Thalassionema nitzschioides Grunow (F).
Rhaphoneis amphiceros Ehrenberg (R).
Rhaphoneis angularis Lohman (F).
Cocconeis scutellum Ehrenberg *baldjikiana* Grunow (F)
Diploneis elliptica (Kützing) Cleve (R).
Navicula marina Ralfs (F).
Navicula hennedyi W. Smith (R.)
Navicula clavata Gregory *elliptica* Schmidt (pl. 38, fig. 9) (R).
Pinnularia cf. *P. subcapitata* Gregory (R).
Pinnularia borealis Ehrenberg (R).
Cymbella lanceolata (Ehrenberg) Kirchner (R).
Cymbella mexicana (Ehrenberg) Cleve (R).
Nitzschia etchegoinia Hanna and Grant (R).
Nitzschia navicularis Grunow (R).
Nitzschia granulata Grunow (F).

LOWER PART OF FORMATION

Stratigraphy and lithology.—The lower part of the Etchegoin formation of Middle Dome apparently consists almost entirely of sandstone, but exposures are meager, and much of the area of low relief in the interior of the anticline is covered with loose sand. An attempt was made to map the boundary between the upper and lower parts of the formation, but the results are not satisfactory, and at the north end of the anticline normal contacts and faults may have been confused. In areas of simple structure this boundary may be mapped with a reasonable degree of assurance even in the absence of exposures. The soil derived from the sandstone in the lower part of the formation has a heavier growth of vegetation than the soil derived from the silt in the upper part. But because seeds germinate more rapidly in the more impervious silty soil than in the sandy soil, the silty soil takes on a green cover soon after the first rains of the short winter rainy season earlier than the sandy soil.

Two principal kinds of sandstone were observed in the interior of Middle Dome: gray dirty sandstone and bluish-gray cleaner sandstone. Both kinds of sandstone are tuffaceous and much of the gray sandstone has a claylike matrix. Both kinds are soft, aside from imperfectly cemented lumps in gray sandstone, some of which have a ferruginous cement. Hard brown calcareous concretions are characteristic of the uppermost part of the sandstone. A pit near the Bolsa Chica well in sec. 30, T. 23 S., R. 19 E., exposes unconsolidated cross-bedded bluish-gray sandstone that has thin irregular diatom-bearing layers less than an inch thick of tuffaceous sandy silt, and also finer-grained gray sandstone containing fragments of diatom-bearing gray silt and irregular borings filled with coarse sandstone. A sample of gray sandstone from this pit examined by M. N. Bramlette contains fresh volcanic glass and andesine, some hornblende, augite, and hypersthene, and a few diatoms and sponge spicules. North of the prominent fault near the southwest corner of sec. 19, T. 23 S., R. 19 E., the upper part of the sandstone is coarse-grained and contains small pebbles. In these features it is similar to the *Pseudocardium*-bearing conglomerate, but the sandstone is nonfossiliferous and the conglomerate containing the thick-shelled *Pseudocardium* is in normal position farther west. Some small pebbles are also present in the upper part of the sandstone on the west slope of the ridge lying west of Parejo Hill. On the east side of the anticline and also at the north end a tuffaceous fine-grained white silt that has a few diatom impressions is 30 feet below the top of the sandstone. (See fig. 10.) This silt is probably an altered tuff and may correspond to tuffaceous silt in the *Macoma* zone of North Dome, but tuffaceous material is so abundant throughout the section that the correlation is uncertain. The tuffaceous silt has been prospected for bleaching clay near the north line of sec. 4, T. 24 S., R. 19 E. According to preliminary tests by P. G. Nutting, it is not of commercial grade, but in the natural state has better bleaching properties than the white clay at the base of the Tulare formation.

In contrast with the abundance of fossils in this part of the section in North Dome, the sandstone in Middle Dome appears to be almost barren. Two broken paired molds of *Patinopecten* that retain a little shell material were seen on the outcrop of the upper part of the sandstone in the north-central part of sec. 30, T. 23 S., R. 18 E. Molds of two small mollusks were collected at locality 362.

The interior of South Dome is an area of low relief, much of which is covered with loose sand, and exposures are meager. Moreover, fossil zones and distinctive lithologic units that could be followed for a considerable distance are rare. Fossiliferous and nonfossiliferous beds that were traced for any distance are shown on the geologic map (pl. 3). No lithologic unit was traced from one side of the anticline to the other south of the southern part of sec. 27, T. 24 S., R. 19 E. If the westward dip is uniform and if there is no duplication by faulting as far east as El Vejon, the lower part of the Etchegoin of South Dome is about 1,500 feet thick—much thicker than in North and Middle Domes. An additional thickness of several hundred feet may be represented east of El Vejon. This part of the Etchegoin appears to consist almost entirely of sandstone, but it might include unexposed fine-grained rock. As in Middle Dome, the contact between the two parts of the Etchegoin is drawn at the top of the sandstone. Most of the sandstone is soft, gray, and tuffaceous, but some is hard and some is conglomeratic.

The highest fossiliferous bed shown on the geologic map (pl. 3) is the sandstone on the west side of the anticline in sec. 3, T. 25 S., R. 19 E., that contains broken specimens of a large *Crepidula*. At one place there are three *Crepidula*-bearing sandstones in a stratigraphic thickness of 15 feet. Each of these beds consists of soft gray sandstone containing fossils at the top.

Tuffaceous fine-grained white silt containing a few diatoms is exposed on the ridge in the angle between the highway and the secondary road in the southeastern part of sec. 27, T. 24 S., R. 19 E. This silt may be the equivalent of similar silt in Middle Dome and like it may possibly correspond to tuffaceous silt in the *Macoma* zone of North Dome.

A hard gray sandstone that forms a series of little cuestas across the plunging north end of the anticline adjoining the east line of sec. 28, T. 24 S., R. 19 E., is found by M. N. Bramlette to be an andesitic tuffaceous sandstone containing phenocrysts of augite, hornblende, and andesine and a little hypersthene. The glass is somewhat altered by the development of zeolite (?) crystals, and some opal (?) cement is present. The hardest rock in South Dome is an olive-gray sandstone that extends across the plunging crest in the southern part of sec. 27, T. 24 S., R. 19 E., north of Las Lomas. According to M. N. Bramlette it resembles the sandstone just described but is firmly cemented with opal.

Soft tuffaceous gray sandstone containing molds of small specimens of *Patinopecten* is exposed in a pit in the northern part of sec. 34, T. 24 S., R. 19 E. (locality 363). Gray sandstone, the upper part of which is iron-stained and contains a few small pebbles, crops out on the east slope of the 513-foot ridge in the northeastern part of sec. 3, T. 25 S., R. 19 E. Large badly weathered broken bones occur at the base of this sandstone. The gray part of the sandstone contains sand-filled borings and fragments of diatom-bearing gray silt. Layers and fragments of diatom-bearing gray silt occur in tuffaceous gray sandstone in this part of the section, and diatoms were found through an apparent thickness of several hundred feet. Material of this character was collected at locality 364, which represents a horizon estimated to be almost 1,500 feet below the top of the Etchegoin. At places, as in the upper part of the formation, the diatoms are accompanied by impressions of *Elphidium*.

Paired specimens of *Patinopecten*—molds that have a little shell material—occur in hard coarse-grained ferruginous sandstone mapped for a short distance in the southeastern part of sec. 34, T. 24 S., R. 19 E. (locality 365), and adjoining parts of sec. 3. This sandstone, which shows the strike in this region, was unfortunately not recognized on the east side of the anticline.

A zone of sandstone and conglomeratic sandstone, representing a maximum thickness of at least 80 feet, possibly considerably more, is present on the west slope of the ridge lying on the west side of El Vejon. The approximate top and base of this sandstone are shown on the geologic map (pl. 3), but the contacts are not well exposed. Much of this material consists of gray tuffaceous sandstone containing lenses of tuffaceous silt that are generally less than 2 inches thick. At or near the top are lenses of conglomerate in gray ferruginous sandstone. The pebbles have an average length of about a quarter of an inch and a maximum length of half an inch and consist principally of black and green chert, white quartz, and a little white siliceous shale. Thinner lenses of pebbles occur in the sandstone. At the north end of the exposures the sandstone apparently rises in the section through the addition of lumpy gray iron-stained sandstone. Toward the south the pebbles in the upper part of the sandstone disappear. Bone fragments are the only fossils observed in the conglomerate, which was not recognized on the crest or east limb of the anticline. Gray sandstone on the west slope of the 420-foot hill in the western part of sec. 35, T. 24 S., R. 19 E., contains scattered small pebbles, though they are less abundant than in the sandstone just described.

Gray tuffaceous sandstone exposed near the south line of T. 24 along the line between secs. 34 and 35, presumably at a horizon below the conglomerate, contains fragments of diatom-bearing silt. Loose blocks of sandstone at the Ohio Smith well near the southwest corner of sec. 35, T. 24 S., R. 19 E., probably dug up there, have molds of *Calyptraea, Anadara,* and *Patinopecten.*

Fossiliferous gray sandstone on the west slope of El Vejon and in nearby areas underlies the conglomerate and appears to represent the lowest part of the outcropping section. *Volsella* occurs in the upper part of these fossiliferous beds (locality 358). *Crepidula* is abundant in a gray sandstone that was mapped for a considerable distance and is estimated to be 25 feet lower (locality 369). Arnold and Anderson observed the fossiliferous beds and collected from them.[69] No exposures were found on the sand-covered east slope of El Vejon. Gray tuffaceous sandstone excavated at the abandoned well in the southwestern part of sec. 1, T. 25 S., R. 19 E. (locality 370), has hard fossiliferous calcareous masses and scattered pebbles of chert, quartz, and siliceous shale that have a maximum length of 1½ inches. This sandstone is assumed to be lower in the section than sandstones on El Vejon.

Fossils.—Fossils from the lower part of the Etchegoin of Middle and South Domes are listed in the following table, and the *Volsella* from El Vejon is illustrated on plate 37.

[69] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 134 (locality 4669), 136 (locality 4857).

Fossils from lower part of Etchegoin formation

[Identifications by W. P. Woodring unless otherwise stated. F, fragments; P, paired valves]

Species	Localities								
	Middle Dome	South Dome							
	362	363	365	366	367	368	369	4857 [1]	370
Bryozoon (identification by R. S. Bassler): *Membranipora* sp							X		
Gastropods:									
Crepidula princeps Conrad			X			X	X	X	X
Lunatia? sp							X	X	
"*Nassa*" cf. "*N.*" *moraniana* Martin, large form						X	X	X	X
Siphonalia? cf. *S.?* *portolaensis* (Arnold)				X			X	X	
Forreria coalingensis (Arnold)				?F		X		X	
Mitrella sp	X								
Pelecypods:									
Acila sp	X								
Anadara trilineata (Conrad) of Arnold, var. cf. *canalis* (Conrad)?						X	P	P	
Mytilus coalingensis Arnold?						P			
Volsella cf. *V. modiolus* (Linné) (pl. 37, figs. 1, 2)						P			
Patinopecten lohri (Hertlein)		X	P			F	F	F	?
Lucinoma sp			P						
Macoma cf. *M. affinis* Nomland			P						
Macoma cf. *M. nasuta* (Conrad)			P			?P			
Venerupis sp						P			
Venerid? cf. *Venerupis*					P				
Cerastoderma? sp									X
Sanguinolaria cf. *S. nuttallii* Conrad								X	
Siliqua sp								P	
Panope sp						P	P		
Barnacle: *Balanus* (*Tamiosoma*) cf. *B.* (*T.*) *gregarius* (Conrad)					X			X	

[1] U. S. G. S. locality 4857. "Extreme southeast end of Kettleman Hills, in secs. 11 and 12, T. 25 S., R. 19 E.; *Pecten oweni* beds, probably lowest Etchegoin"; Ralph Arnold, collector.

The molds of *Acila* from locality 362 are the only specimens of this genus observed in the Kettleman Hills below the *Acila* zone in the upper part of the San Joaquin formation.

The fossiliferous sandstones on El Vejon and nearby, presumably the oldest strata exposed in the Kettleman Hills, are characterized by a large form of "*Nassa*" cf. "*N.*" *moraniana, Siphonalia?* cf. *S.?* *portolaensis, Forreria coalingensis, Volsella* cf. *V. modiolus* (pl. 37, figs. 1, 2), and a large barnacle assigned to *Tamiosoma. Siphonalia?* cf. *S.?* *portolaensis, Forreria coalingensis,* and *Volsella* cf. *V. modiolus* were not found elsewhere in the Kettleman Hills. "*Nassa*" cf. "*N.*" *moraniana, Sanguinolaria, Siliqua,* and *Tamiosoma* occur in the Etchegoin of North Dome. *Forreria coalingensis* occurs in the lower part of the Etchegoin in the Kreyenhagen Hills and in the underlying Jacalitos formation.[70]

The diatoms from locality 364 were identified by K. E. Lohman, who prepared the following list and the illustrations on plate 38.

[70] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 133 (locality 4749). Nomland, J. O., Fauna from the lower Pliocene at Jacalitos Creek and Waltham Canyon, Calif.: California Univ., Dept. Geology, Bull., vol. 9, p. 203, 1916; The Etchegoin Pliocene of middle California: Idem, vol. 10, pp. 213, 221, 1917.

Diatoms from lower part of Etchegoin formation at locality 364

[Identifications by K. E. Lohman. R, rare; F, few; C, common; A, abundant]

Melosira solida Eulenstein *haitensis* Grunow (R).
Melosira granulata (Ehrenberg) Ralfs (R).
Melosira granulata curvata Grunow (R).
Stephanopyxis turris (Greville and Arnott) Ralfs (R).
Coscinodiscus excentricus Ehrenberg (F).
Coscinodiscus subtilis Ehrenberg (F).
Coscinodiscus boliviensis Grunow (F).
Coscinodiscus asteromphalus Ehrenberg (C).
Coscinodiscus asteromphalus omphalantha (Ehrenberg) Grunow (C).
Coscinodiscus oculus-iridis Ehrenberg (F).
Coscinodiscus kurzii Grunow (pl. 38, fig. 1) (F).
Coscinodiscus cf. *C. cribrosus* Truan and Witt (F).
Actinoptychus splendens (Shadbolt) Ralfs var. (R).
Actinoptychus undulatus Ehrenberg (C).
Actinocyclus ehrenbergii Ralfs (C).
Actinocyclus ehrenbergii tenella (Brebisson) Hustedt (F).
Liradiscus oblongus Grunow (F).
Chaetoceros incurvum Bailey (R).
Periptera tetracladia Ehrenberg (R). }
Syndendrium diadema Ehrenberg (F). } Spores of *Chaetoceros?*
Dicladia capreolus Ehrenberg (F). }
Omphalotheca sp. (C).
Xanthiopyxis cingulata Ehrenberg (R).
Xanthiopyxis ovalis Lohman (pl. 38, fig. 6) (A).
Lithodesmium cf. *L. cornigerum* Brun (R).
Thalassionema nitzschiodes Grunow (R).
Pleurosigma cf. *P. affine* Grunow (R).
Epithemia turgida (Ehrenberg) Kützing (R).
Nitzschia granulata Grunow (R).

Lohman reports that this flora is dominated by marine species and that the large number of pelagic forms suggests fairly open water. The few rare fresh-water and brackish-water species were presumably carried into the sea by streams.

SOURCE OF VOLCANIC MATERIAL IN EXPOSED FORMATIONS

Volcanic material is abundant throughout the exposed section in the Kettleman Hills, with the possible exception of the upper part of the Tulare formation, which was not examined for this constituent. The tuffaceous material is generally mixed with detrital debris. Relatively pure tuffs, however, occur in the lower *Amnicola* zone of the Tulare formation on the east side of Middle Dome, about 125 feet above the base of the *Pecten* zone of the San Joaquin formation on the east side of North Dome, 20 feet below the *Neverita* zone at the south end of North Dome, and in the Etchegoin formation of North Dome at horizons 20 feet above the upper *Pseudocardium* zone and near the top of the *Siphonalia* zone. White tuffaceous silt that apparently represents altered relatively pure tuff occurs at the base of the Tulare formation, in the *Macoma* zone of the Etchegoin formation of North Dome, and in the Etchegoin of Middle and South Domes. The occurrence of the relatively pure tuffs as lenses of short lateral extent indicates that they are the result of local conditions of sedimentation. The more widespread distribution of white tuffaceous silt at the base of the Tulare and in the *Macoma* zone of the Etchegoin represents periods of greater volcanic activity or uniform conditions of sedimentation over a larger area.

The tuffs are clearly water-laid, and some of them contain marine fossils. Coarse-grained volcanic material is absent. Inasmuch as no volcanic flows of Pliocene age are known in the Coast Ranges to the windward (westward) of the Kettleman Hills, it is inferred that this volcanic material was derived from a source at a considerable distance and that it represents widespread ash falls resulting from violent explosions. The region in the Coast Ranges north of San Francisco Bay and the Lassen Peak district at the south end of the Cascade Range appear to be the most likely sources. The vents from which the Pliocene volcanic material in the vicinity of San Francisco Bay was derived have not been recognized, but apparently they lay north of the bay, where thick flows of rhyolite, andesite, basalt, and tuffs thin southward.[71] In this region the Sonoma andesite, which consists of flows and tuffs, interfingers with marine strata containing Pliocene fossils and unconformably overlies the Petaluma formation, which contains *Neohipparion*. The stratigraphic relations of the Sonoma and Petaluma formations were described by Morse and Bailey.[72] The tuffs and flows in the Pinole tuff and Orinda formation in the hills east of San Francisco Bay probably represent the same source. These two formations contain Pliocene vertebrates.

The volcanic history of the Lassen Peak district has been described by Williams.[73] The Tuscan tuff, which extends along the east side of northern Sacramento Valley, west and northwest of the Lassen Peak district, thickens eastward, indicating that the source lay in that direction and that the tuff may have been derived from a vent that was active during the earlier stages of volcanism in this district.[74] To the west the Tuscan tuff interfingers with the essentially nonvolcanic Tehama formation of Russell and Vander Hoof, which extends southward along the foot of the Coast Ranges on the west side of Sacramento Valley. A dacitic tuff—the Nomlaki tuff of Anderson and Russell—has been recognized in the lower part of both formations,[75] and

[71] Osmont, V. C., A geological section of the Coast Ranges north of the Bay of San Francisco: California Univ., Dept. Geology, Bull., vol. 4, pp. 58–76, 84–86, 1905. Dickerson, R. E., Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles: California Acad. Sci. Proc., 4th ser., vol. 11, pp. 551–559, 1922. Bailey, T. L., The geology of the Potrero Hills and Vacaville region, Solano County, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 19, pp. 329–330, 1930. Weaver, C. E., Geology of the Coast Ranges immediately north of San Francisco Bay [abstract]: Geol. Soc. America Bull., vol. 41, p. 46, 1930. Weaver, C. E., Geologic cross sections through the Coast Ranges immediately north of San Francisco Bay [abstract]: Geol. Soc. America Bull., vol. 44, p. 155, 1933. Morse, R. R., and Bailey, T. L., Geological observations in the Petaluma district, Calif.: Geol. Soc. America Bull., vol. 46, pp. 1441–1451, 1935.

[72] Idem, pp. 1447–1451.

[73] Williams, Howel, Geology of the Lassen Volcanic National Park, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 21, pp. 195–385, 3 maps, 64 figs., 1932.

[74] Anderson, C. A., The Tuscan formation of northern California with a discussion concerning the origin of volcanic breccias: California Univ., Dept. Geology, Bull., vol. 23, pp. 232–233, 1933.

[75] Idem, pp. 219, 234–235.

Name used in present report	Tulare formation				San Joaquin formation									Etchegoin formation											Names used by Arnold [1]	Names used by Kew [2] for echinoids and by Grant and Gale [3] for mollusks. (Names in brackets not based on records from Coalinga district)
														North Dome							Middle and South Domes					
																					Upper part of formation					
	Above upper Amnicola zone	Upper Amnicola zone	Lower Amnicola zone	Below lower Amnicola zone	Upper Mya zone	Between upper Mya and Acila zones	Acila zone	Between Acila and Pecten zones	Pecten and Trachycardium zones	Between Pecten and Neverita zones	Neverita zone	Between Neverita zone and Cascajo conglomerate member	Cascajo conglomerate member	Above Littorina zone	Littorina zone	Between Littorina and upper Pseudocardium zones	Upper Pseudocardium zone	Siphonalia zone	Macoma zone	Patinopecten zone	Above Pseudocardium-Anadara zone	Pseudocardium-Anadara zone	Below Pseudocardium-Anadara zone	Lower part of formation		
Foraminifera: Elphidium sp																							X	X		
Corals:																										
Astrangia coalingensis Vaughan (pl. 16, fig. 7)									X																Astrangia coalingensis Vaughan	
Coenocyathus ? sp													X													
Worm tubes: Serpula ? sp									X																	
Echinoids:																										
Dendraster gibbsii (Rémond) (pl. 40, figs. 2–4; pl. 42; pl. 43, figs. 1, 2, 4, 5; pl. 44, fig. 6)													cf.					X	X	X					Echinarachnius gibbsii Rémond	Dendraster gibbsii (Rémond).
Dendraster gibbsii humilis Kew (pl. 43, fig. 3)																				X						Dendraster gibbsii humilis Kew.
Dendraster gibbsii mirus Stewart, n. var. (pl. 44, figs. 4, 5)																		X								
Dendraster gibbsii (Rémond), small variety (pl. 20, figs. 10, 11; pl. 21, figs. 3–6)											X															
Dendraster coalingaensis Twitchell (pl. 39, fig. 7 (cf.); pl. 45, figs. 1, 2)							X		X				cf.												Echinarachnius gibbsii Rémond	Dendraster hesperis Kew.
Dendraster coalingaensis macer Stewart, n. var. (pl. 39, fig. 9; pl. 40, figs. 1, 5; pl. 41, figs. 1, 2, 4)													cf.				X									
Dendraster coalingaensis Twitchell, n. var. ? (pl. 44, fig. 3)												X														
Dendraster coalingaensis gibbosus Kew (pl. 45, figs. 5, 6)									X		X	?														Dendraster hesperis gibbosus Kew.
Dendraster coalingaensis Twitchell, small variety with slightly raised petals and deep ambulacral furrows (pl. 10, figs. 6–9; pl. 45, figs. 3, 4).						X	X																			
Dendraster coalingaensis Twitchell, small variety with flat petals (pl. 10, figs. 10–12)						X					X		X													
Dendraster (Merriamaster) perrini (Weaver) (pl. 46, figs. 1, 2, 4, 7, 10, 12)									X																Scutella perrini Weaver; Astrodapsis sp	Dendraster perrini (Weaver).
Dendraster (Merriamaster) arnoldi Twitchell (pl. 39, fig. 5; pl. 41, fig. 3; pl. 46, figs. 3, 5, 6, 8, 9 (cf.), 11, 13 (cf.)).							X [4]		X																	Dendraster coalingaensis Twitchell. Dendraster arnoldi Twitchell.
Bryozoa:																										
Electra monostachys Busk					X																					
Membranipora sp						X					X													X		
Schizoporella sp											X															
Unidentified encrusting Bryozoa									X																	
Brachiopods:																										
Discinisca sp. (pl. 39, figs. 1, 6)													X													
Terebratalia cf. T. smithi Arnold (pl. 16, figs. 5, 6)									X																Terebratalia smithi Arnold	
Gastropods:																										
Tegula? cf. T. dubiosa Grant and Gale													X													
Calliostoma coalingense Arnold (pl. 11, figs. 2, 3; pl. 15, figs. 15, 16)							X		X									X							Calliostoma coalingensis Arnold	Calliostoma coalingense Arnold.
Calliostoma coalingense privum Stewart, n. var. (pl. 32, fig. 5)																		X		X						
Calliostoma kerri Arnold (pl. 15, fig. 21)							X		X																Calliostoma kerri Arnold	Calliostoma kerri Arnold.
Calliostoma cf. C. gemmulatum Carpenter (pl. 15, figs. 22, 23)									X																	
Calliostoma sp													X													
Turcica caffea brevis Stewart, n. var. (pl. 11, figs. 1, 6)							X		X																	
Margarites cf. M. pupillus (Gould)																	X	X							Margarita sp	
Pachypoma cf. P. precursor (Dall)																		X								
Scalez petrolia Hanna and Gaylord										X																
Littorina mariana Arnold (pl. 4, figs. 4–6; pl. 8, figs. 1–6; pl. 29, figs. 8, 9)	X			X	X				X						X		X								Littorina mariana Arnold; Littorina mariana alta Arnold	Littorina mariana Arnold. Littorina mariana alta Arnold.
Littorina sp													X													
Valvata virens platyceps Pilsbry (pl. 4, figs. 1, 2)		X	X																							
Valvata humeralis californica Pilsbry (pl. 4, fig. 3)			X																							
Fluminicola kettlemanensis Pilsbry									X	cf.							?									
Fluminicola cf. F. spiralis Pilsbry (pl. 4, figs. 7–11)		X	X																							
Fluminicola cf. F. yatesiana (Cooper) (pl. 4, fig. 12)			X																							
Fluminicola sp													X													
Pyrgulopsis vincta Pilsbry (pl. 4, figs. 13–16)			X																							
Calipyrgula carinifera Pilsbry (p. 4, figs. 17, 18)			X																							
Calipyrgula ellipsostoma Pilsbry (pl. 4, fig. 19)			X																							
Calipyrgula stewartiana Pilsbry (pl. 4, figs. 20, 21)			X	?																						
Littoridina woodringi Pilsbry (pl. 4, fig. 22)		X	X																							
Amnicola longinqua Gould (pl. 4, figs. 23–27)		X	X	X																						
Amnicola sp														X												
Amnicola? sp															X		?									
Hydrobia andersoni (Arnold) (pl. 4, figs. 28–34)			X																						Amnicola andersoni Arnold	
Hydrobia birkhauseri Pilsbry			X																							
Brannerillus physispira Hannibal (pl. 4, figs. 35–38)			X																							
Brannerillus involutus Pilsbry (pl. 4, figs. 39–50; pl. 5, figs. 1–3)			X																							
Goniobasis kettlemanensis Arnold (pl. 15, figs. 5, 6, 14)					cf.				X	X															Goniobasis kettlemanensis Arnold	
Goniobasis kettlemanensis woodringi Pilsbry (pl. 4, figs. 51, 52)		X	X																							
Goniobasis arnoldiana Pilsbry (pl. 4, figs. 53, 54)		X	X																						Goniobasis nigrina Lea?	
Bittium asperum (Gabb) (pl. 29, fig. 15)							sp.										X									[Bittium (Lirobittium) asperum (Gabb).]
Turritella vanvlecki Arnold (pl. 31, fig. 2)																		X							Turritella vanvlecki Arnold	Turritella vanvlecki Arnold.
Calyptraea cf. C. inornata (Gabb) (pl. 11, fig. 7; pl. 15, fig. 10; pl. 20, fig. 6)					X		X		X		X	X	X		X	sp.	X	sp.							Trochita filosa Gabb	[Calyptraea mamillaris Broderip.]
Calyptraea cf. C. filosa (Gabb) (pl. 8, fig. 7)					X		X										X	X							Trochita filosa Gabb	Calyptraea filosa (Gabb).
Crepidula princeps Conrad							X				X		?							cf.		?	X	X	Crepidula princeps Conrad	Crepidula princeps Conrad.
Crepidula cf. C. onyx Sowerby (pl. 31, fig. 6) (possibly young of C. princeps)									X								X	X								
Ianacus? sp																		X								
Neverita recluziana (Deshayes) (pl. 15, figs. 11, 19, 20; pl. 20, figs. 1–5)							cf.		X		X		?												Neverita recluziana Petit; Neverita recluziana alta Dall	Polinices (Neverita) reclusianus (Deshayes).
Lunatia cf. L. lewisii (Gould) (pl. 15, fig. 8; pl. 31, fig. 5)							X		X		X		?				X	X		sp.				?sp.	Lunatia lewisii Gould	Polinices (Euspira) lewisii (Gould).
Opalia varicostata Stearns (pl. 36, fig. 6)									?		X		X							X					Opalia sp	[Epitonium (Opalia) varicostatum (Stearns).]
Odostomia cf. O. io Dall and Bartsch												X														
"Nassa" moraniana Martin (pl. 34, figs. 5, 6)																		X	sp.	cf.				cf.	Nassa californiana Conrad	Nassarius (Schizopyga) moranianus (Martin).
"Nassa" miser iniqua Stewart, n. var. (pl. 34, fig. 8)																		X		X					Nassa californiana Conrad	Nassarius (Schizopyga) californianus (Conrad)?
"Nassa" cf. "N." waldorfensis Arnold (pl. 39, fig. 4)							X		X																	
"Nassa" coalingensis Arnold (pl. 15, fig. 3)							?		X																Nassa californiana coalingensis Arnold	Nassarius (Schizopyga) californianus coalingensis (Arnold).
Siphonalia kettlemanensis (Arnold) (pl. 31, figs. 1, 7)									cf.									X	cf.	cf.					Thais kettlemanensis Arnold	Kelletia (Kelletia) kettlemanensis (Arnold).
Siphonalia cf. S. humerosa (Gabb) (pl. 11, fig. 9)							X																			
Siphonalia? cf. S.? portolaensis (Arnold)																								X	Chrysodomus portolaensis Arnold	Kelletia (Searlesia) dira portolaensis (Arnold).
Jaton cf. J. festivus (Hinds) (pl. 15, figs. 2, 9)									X																	Purpura (Jaton) festiva (Hinds).
Jaton? sp													X													
Tritonalia cf. T. lurida (Middendorff) (pl. 15, fig. 12)									X																	
Nucella etchegoinensis (Arnold) (pl. 24, figs. 16–18)					?				X	?sp.			X					X							Thais etchegoinensis Arnold; Thais crispatus Chemnitz	Thais (Nucella) lamellosa (Gmelin).
Nucella etchegoinensis (Arnold), ribbed variety (pl. 36, figs. 1, 7)																			X	X						
Forreria coalingensis (Arnold)																								X	Trophon (Forreria) coalingense Arnold	Forreria coalingensis (Arnold).
Forreria magister (Nomland) (pl. 36, figs. 11, 12)																		X	X	X					Trophon (Forreria) ponderosum Gabb	Forreria belcheri avita Nomland.
Forreria magister munda Stewart, n. var. (pl. 15, figs. 17, 18)									X																	
Cancellaria altispira Gabb									X																	[Cancellaria tritonidea altispira Gabb.]
Cancellaria rapa Nomland (pl. 15, figs. 1, 7)									X																	Cancellaria tritonidea rapa Nomland.
Cancellaria cf. C. tritonidea Gabb									X																Cancellaria tritonidea Gabb	Cancellaria tritonidea Gabb.
Progabbia sp. (pl. 15, fig. 4)									X									X								
Mitrella gausapata (Gould) (pl. 11, fig. 5 (cf.); pl. 20, fig. 7)							cf.				X						cf.							sp.	Astyris richthofeni Gabb	Mitrella carinata gausapata (Gould).
Olivella cf. O. pedroana (Conrad) (pl. 20, figs. 8, 9)									sp.		X		X						sp.						Olivella pedroana Conrad	Olivella pedroana (Conrad).
"Pleurotoma" cf. "P." coalingensis Arnold (pl. 11, fig. 4)							X																		Pleurotoma coalingensis Arnold	Clavus (Clathrodrillia) coalingensis (Arnold).
Pseudotoma sp									X											X						
Carinifex sanctaeclarae marshalli Arnold (pl. 5, figs. 4–6)		X	X							?sp.															Carinifex marshalli Arnold	
Parapholyx cf. P. effusa (Lea) (pl. 5, fig. 20)			X																							
Menetus centervillensis (Tryon) (pl. 5, figs. 7–9)			X																							
Menetus vanvlecki (Arnold) (pl. 5, figs. 10–15)			X																						Planorbis vanvlecki Arnold	
Physa wattsi Arnold (pl. 5, figs. 16, 17)		X	X																						Physa wattsi Arnold	
Physa humerosa Gould (pl. 5, figs. 18, 19)			X	X																					Physa humerosa Gould	
Pelecypods:																										
Acila castrensis (Hinds) (pl. 11, figs. 11–17)						X	X																	sp.	Nucula castrensis Hinds	Nucula (Acila) castrensis Hinds.
Anomia sp																				X						
Pododesmus cf. P. macroschisma (Deshayes)													X												Monia macroschisma Deshayes	Pododesmus macroschisma (Deshayes).
Arca cf. A. sisquocensis Reinhart																		X								
Anadara trilineata (Conrad) of Arnold (pl. 11, figs. 10, 19–24; pl. 20, fig. 17)					X	X	X		X		X				sp.							X			Arca trilineata Conrad	Arca (Arca) trilineata Conrad.
Anadara trilineata (Conrad) of Arnold, elongate flat variety (pl. 14, fig. 7; pl. 20, figs. 15, 16)									X		X															
Anadara trilineata (Conrad) of Arnold, short inflated variety (pl. 29, figs. 2, 6)																	X									
Anadara trilineata (Conrad) of Arnold, var. cf. canalis (Conrad) (pl. 24, fig. 7; pl. 31, fig. 9)												X	X					X		X			X	X	Arca trilineata Conrad	Arca (Arca) trilineata Conrad.
Glycymeris grewingki Dall (pl. 29, figs. 10, 11; pl. 33, figs. 7, 8)																	X	X	sp.						Glycymeris coalingensis Arnold; Glycymeris septentrionalis Middendorff	Glycymeris grewingki Dall. Glycymeris septentrionalis (Middendorff).
Mytilus coalingensis Arnold (pl. 32, figs. 3, 4)							X		X	cf.			cf.				sp.	X	X	X				?	Mytilus (Mytiloconcha) coalingensis Arnold	Mytilus (Mytiloconcha) coalingensis Arnold.
Mytilus cf. M. edulis Linné (pl. 8, fig. 8)					X	?																				
Volsella cf. V. modiolus (Linné) (pl. 37, figs. 1, 2)																								X		
Volsella cf. V. recta (Conrad) (pl. 13, fig. 15; pl. 20, figs. 13, 14)									X		X														Modiolus rectus Conrad	Volsella recta (Conrad).
Volsella cf. V. capax (Conrad) (pl. 16, fig. 3)									X																	
Botula? sp. (pl. 13, fig. 14)									X																	
Adula falcata (Gould)?											X									cf.						
Pecten coalingaensis Arnold (pl. 13, figs. 1, 2, 17, 18; pl. 16, fig. 4)							X [5]		X																Pecten coalingaensis Arnold	Pecten (Janira) bellus coalingaensis Arnold.
Aequipecten circularis impostor (Hanna) (pl. 13, figs. 3, 4, 6–9)								sp. [6]	X				cf.												Pecten deserti Conrad	Pecten (Aequipecten) deserti impostor Hanna.
Aequipecten circularis eldridgei (Arnold) (pl. 24, figs. 10–13)									X				X													Pecten (Aequipecten) eldridgei Arnold.
Chlamys etchegoini (Anderson) (pl. 13, fig. 5; pl. 32, fig. 1)									X									X							Pecten wattsi etchegoini Anderson	Pecten (Pallium) swiftii etchegoini Anderson.
Chlamys cf. C. islandicus (Müller)							X																			
Hinnites cf. H. crassa Conrad (pl. 31, figs. 3, 4, 8)									sp.									X		X						
Patinopecten lohri (Hertlein) (pl. 35, figs. 2–5)													?					X	X	X				X	Pecten oweni Arnold	Pecten (Patinopecten) healeyi lohri Hertlein.
Patinopecten cf. P. healeyi (Arnold)									X																	
Lyropecten cf. L. estrellanus (Conrad) (transported by man?)																		X								
Ostrea atwoodi Gabb (pl. 29, figs. 1, 13)																	X	X		X					Ostrea atwoodi Gabb	Ostrea atwoodi Gabb.
Ostrea vespertina Conrad (pl. 14, fig. 9)									X																Ostrea vespertina Conrad	Ostrea vespertina Conrad.
Ostrea vespertina sequens Arnold (pl. 8, figs. 10–14; pl. 10, figs. 1–5)	cf.				X	X																			Ostrea lurida Carpenter; Ostrea vespertina sequens Arnold	Ostrea vespertina sequens Arnold.
Ostrea sp. (small)							X						X													
Lucinoma cf. L. acutilineata (Conrad) (pl. 29, fig. 7)																	X							sp.	Phacoides acutilineatus Conrad	Lucina (Myrtea) acutilineata Conrad.
Taras cf. T. parilis (Conrad) (pl. 35, fig. 6)									sp.				X				X		X	X					Diplodonta parilis Conrad	Taras parilis (Conrad).
Anodonta kettlemanensis Arnold (pl. 6, figs. 1–3)		X	X																						Anodonta kettlemanensis Arnold	
Anodonta sp									X	X				X												
Gonidea coalingensis Arnold (pl. 6, figs. 4–9)		X	X	X																					Gonidea coalingensis Arnold	
Gonidea sp										X																
Sphaerium kettlemanensis Arnold (pl. 5, figs. 21–24)		X	X																						Sphaerium kettlemanensis Arnold	Corbicula kettlemanensis (Arnold).
Sphaerium n. sp.? (pl. 5, figs. 25–28)		X	X																							
Sphaerium cooperi Arnold (pl. 5, figs. 29–34)			X	X																					Sphaerium cooperi Arnold	Sphaerium cooperi Arnold).
Sphaerium sp										X																
Pisidium compressum praecompressum Pilsbry (pl. 5, figs. 35–38)		X	X																							
Pisidium sp. (pl. 5, figs. 39–42)			X																							
Pisidium cf. P. insigne Gabb (pl. 5, figs. 43–46)			X																							
Pisidium cf. P. abortivum exiguum Sterki (pl. 5, figs. 47, 48)			X																							
Tellina? cf. T.? oldroydi Wiedey (pl. 14, fig. 8; pl. 33, fig. 5)									X									X								
Tellina cf. T. bodegensis Hinds (pl. 33, fig. 2)																		X								
Macoma cf. M. vanvlecki Arnold																				X						
Macoma cf. M. indentata Carpenter (pl. 35, fig. 1)																				X						
Macoma affinis Nomland (pl. 9, figs. 1–3; pl. 34, figs. 1–4)					X						cf.	X					X	X	X	X	X		X		Macoma inquinata Deshayes	Macoma inquinata affinis Nomland.
Macoma affinis plena Stewart, n. var. (pl. 15, fig. 13 (cf.); pl. 24, fig. 3; pl. 29, fig. 12; pl. 39, fig. 3)									cf.	cf.		X			X											
Macoma cf. M. nasuta (Conrad) (pl. 14, fig. 5; pl. 20, fig. 12)									X		X													X	Macoma nasuta Conrad	Macoma nasuta (Conrad).
Macoma cf. M. secta (Conrad) (pl. 16, fig. 1)									X																Macoma secta Conrad	Macoma secta (Conrad).
Macoma sp							X		X		?		X			?		X		X			X			
Apolymetis cf. A. dombei (Hanley) (pl. 32, fig. 2)																		X								
Semele n. sp.? (pl. 33, fig. 4)																		X								
Semele flavescens (Gould)?									X																	[Semele flavescens (Gould).]
Semele rubropicta Dall (pl. 11, fig. 18, cf.)							cf.		X																Semele rubropicta Dall	Semele rubropicta Dall.
Mactra? coalingensis Arnold (pl. 33, fig. 1)									cf.									X		cf.					Mactra coalingensis Arnold	Mactra (Spisula?) coalingensis (Arnold).
Pseudocardium densatum (Conrad) of Arnold (pl. 37, figs. 3, 9; pl. 39, fig. 8)																	X	X					X		Mulinia densata Conrad	Mactra (Pseudocardium) densata (Conrad).
Pseudocardium densatum (Conrad) of Arnold var. cf. gabbii Rémond (pl. 37, figs. 7, 8, 10; pl. 29, fig. 16; pl. 30).																	X	X	X	X			X		Mulinia densata Conrad	Mactra (Pseudocardium) densata (Conrad).
Pseudocarium densatum (Conrad) of Arnold vars. (pl. 24, figs. 14, 15, 19, 20; pl. 37, figs. 4–6)								?sp. [6]					X		sp.	sp.						X	X		Mulinia densata Conrad	Mactra (Pseudocardium) densata (Conrad).
Schizothaerus cf. S. nuttallii (Conrad) (pl. 11, fig. 25; pl. 33, fig. 9)							X		X									X	X	X					Schizothaerus nuttalli Conrad; Schizothaerus pajaroanus Conrad	Schizothaerus nuttallii (Conrad). Schizothaerus nuttallii pajaroanus (Conrad).
Saxidomus nuttalli latus Stewart, n. var. (pl. 8, fig. 15; pl. 16, fig. 8; pl. 33, fig. 6)					X		sp.		X		sp.						sp.	X	?sp.	sp.					Saxidomus nuttalli Conrad	Saxidomus nuttalli Conrad.
Compsomyax cf. C. subdiaphana (Carpenter) (pl. 11, fig. 8)							X											X								
Venerupis laciniata hannibali (Howe) (pl. 29, fig. 5)													cf.				X	X	sp.	X				?sp.	Paphia staleyi Gabb	Venerupis (Protothaca) staminea (Conrad).
Venerupis cf. V. tenerrima (Carpenter)																			X						Paphia tenerrima Carpenter	Venerupis (Callithaca) tenerrima (Carpenter).
Venerupis grata tarda Stewart, n. var. (pl. 13, figs. 10–13)									X																Paphia staleyi Gabb?	Venerupis (Protothaca) staminea (Conrad).
Transennella cf. T. tantilla (Gould)					X				X								X								Transennella californica Arnold	Transennella tantilla californica Arnold.
Psephidia n. sp.? (pl. 24, figs. 4–6)												X	X													
Cerastoderma cf. C. meekianum (Gabb) (pl. 24, figs. 8, 9; pl. 29, fig. 14)												X					X								Cardium meekianum Gabb	Laevicardium (Cerastoderma) meekianum (Gabb).
Cerastoderma cf. C. meekianum (Gabb) small variety (pl. 29, fig. 3)															X							X				
Cerastoderma sp									X				X					X	X	X	X			?		
Trachycardium cf. T. quadragenarium (Conrad) (pl. 16, fig. 2)								?sp. [6]	X																	Laevicardium (Trachycardium) quadragenarium (Conrad).
Trachycardium n. sp																		X		X						
Chama pellucida Broderip (pl. 14, figs. 1–4, 10)									X																Chama pellucida Broderip	Chama pellucida Broderip.
Sanguinolaria cf. S. nuttallii Conrad (pl. 36, fig. 10)																		sp.		X				X		Sanguinolaria nuttallii Conrad.
Mya cf. M. dickersoni Clark (pl. 9, figs. 4–9; pl. 24, figs. 2, 21)					X			sp. [6]	X	X	X	X	X	sp.	X	sp.	X	?			X	X	?sp.		Mya japonica Jay	Mya (Mya) arenaria japonica Jay.
Cryptomya cf. C. quadrata Arnold (pl. 39, fig. 2)							X		X																Cryptomya quadrata Arnold	Cryptomya californica (Conrad).
Platyodon colobus Woodring, n. sp. (pl. 21, figs. 1, 2)											X															
Corbula cf. C. gibbiformis Grant and Gale									X																	Corbula (Corbula) gibbiformis Grant and Gale.
Solen perrini Clark (pl. 8, fig. 9; pl. 24, fig. 1)					X	?	sp.		sp.	sp.	?	X	?		sp.		X	X	X						Solen sicarius Gould	Solen sicarius Gould.
Siliqua sp. (pl. 33, fig. 3)																			X	X				X	Siliqua sp	
Panope cf. P. generosa Gould (pl. 14, fig. 11)							X		X		X		?sp.					sp.	sp.	X				sp.	Panopea generosa Gould	Panope (Panope) generosa Gould.
Pholadidea cf. P. penita (Conrad)											X															
Pholadidea ovoidea (Gould) var. (pl. 14, fig. 6)									X																Pholadidea ovoidea Gould	Pholadidea (Pholadidea) ovoidea (Gould)?
Zirfaea gabbi (Tryon) var. (pl. 34, fig. 7)							X		X				cf.						X	sp.					Zirphaea gabbi Tryon	[Pholas (Zirfaea) gabbi (Tryon).]
Pandora cf. P. punctata Conrad (pl. 29, fig. 4)																	X	sp.							Clidiophora punctata Conrad	Pandora punctata Conrad.
Ostracodes:																										
Cytheridea sp												X														
Cytherideis sp												X														
Cytherella sp			X	X																						
Cytherelloidea sp			X																							
Barnacles:																										
Balanus hesperius Pilsbry var.					X								cf.													
Balanus sp							X		X				X					X								
Balanus (Tamiosoma) cf. B. (T.) gregarius (Conrad) (pl. 36, figs. 2–5, 8, 9)																			X	X				X	Tamiosoma gregaria Conrad?	
Decapod crustacean: Cancer antennarius Stimpson																			X							
Undetermined otoliths			X									X														
Undetermined fish remains:																										
"Bulbous growths"			X						X		X		X					X		X					Fish, bulbous growths	
Other remains (plates, spines, vertebrae, teeth?)			X						X				X													
Shark teeth							X		X				X												Carcharodon arnoldi Jordan	
Sting ray (caudal spine) (pl. 13, fig. 16)									X																	
Turtle plates									?										X							
Cormorant ulna									X																	
Land mammals:																										
Beaver teeth (Castor californicus Kellogg)									X																	
Mastodon remains (skull, limb bones, molar fragments, tusk fragments)									X									X					X			
Peccary (cf. Platygonus; distal end of humerus)									X																	
Horse remains: Hoof (ungual phalanx) of small horse, possibly Nannippus or Calippus																			X							
Teeth:																										
Calippus																		X		X						
Pliohippus																		?		X						
Pliohippus or Plesippus												X														
Plesippus	? [7]								X																	
Fragments					X			X					?										X			
Camelid remains (astragulus, calcaneum)									X														X			
Cervid remains (horn fragments, distal end of cannon bone, jaw fragment, tooth)									X											X			?			
Marine mammals:																										
Sea lion?, limb bone																			X							
Eared seal, limb bones											X		X										X			
Porpoise remains:																										
Ear bones											X		X													
Limb bones and vertebrae											X								X	X						
Whalebone whale ear bone											X								X							
Whale vertebrae									X																	
Marine mammal limb bones and vertebrae																		X		?						
Unidentified calcareous algae, cf. Lithomyxa calcigena Howe			X																							
Land plants:																										
Salix coalingensis Dorf										X				X				X								
Alnus merriami Dorf																		X								
Quercus hannibali Dorf																		X								
Umbellaria oregonensis Chaney?										X																
Platanus paucidentata Dorf										X								X								
Garrya masoni Dorf																		X								
Fraxinus caudata Dorf																		X								

[1] Arnold, Ralph, Paleontology of the Coalinga district, Fresno and Kings Counties, Calif.: U. S. Geol. Survey Bull. 396, 1909 [1910]; Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, 1910.

[2] Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ., Dept. Geol., Bull., vol. 12, no. 2, 1920.

[3] Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, 1931.

[4] From sand a few feet below Acila zone.

[5] Probably weathered out of older alluvium.

[6] Observed but not collected.

[7] Float in bottom of arroyo.

vertebrate remains from beds above the dacitic tuff on the west side of the valley are considered of upper Pliocene age.[76] The dacitic tuff in the Kettleman Hills about 125 feet above the base of the *Pecten* zone of the San Joaquin formation may possibly correspond to Anderson and Russell's Nomlaki tuff. If the tuffs in the Kettleman Hills were derived from the Lassen Peak region, they may deserve consideration as a possible aid in establishing correlations between the Coast Ranges, the Sierra Nevada, and the Cascade Range.

PALEONTOLOGY OF EXPOSED FORMATIONS

The table opposite page 78 shows the stratigraphic distribution of fossils from the formations exposed in the Kettleman Hills. In order to correlate the nomenclature of different writers the names used for the fossils by Arnold [77] in his publications on the Coalinga district, by Kew in his echinoid monograph,[78] and by Grant and Gale [79] in their recent catalog of Pliocene and Pleistocene marine mollusks are cited opposite the names used in the present report.

No fossils were collected from Etchegoin strata between the upper *Pseudocardium* and *Siphonalia* zones, and collections from Etchegoin strata underlying the *Patinopecten* zone have not been identified.

For various reasons many of the fossils are indefinitely determined. Most of the indefinitely determined species are represented by inadequate material; the characters of the type material of some species are insufficiently known; and the affinities of other forms have not been worked out. The designation "sp." is used in the species list for undetermined forms—generally incomplete or poorly preserved specimens—that presumably represent some other species than those under the same generic name or that are too imperfect for identification. Some of the "sp.'s" in the species list, however, may be duplications of more completely identified forms. The occurrence of a form identified as "sp." at more than one horizon does not necessarily mean that the same form is represented at the different horizons. The designation "sp." is used in the stratigraphic columns for undetermined forms that probably represent the species or variety cited in the species list.

The affinities of the stratigraphically important species and their distribution are discussed under the systematic headings that follow. This treatment was planned with the expectation that it may aid stratigraphers. The sand dollars are discussed by Ralph Stewart and the barnacles are discussed by W. P. Woodring. The matter dealing with the mollusks was written by both authors. As differentiation of authorship is desirable for future citations, initials are added at the end of paragraphs.

Dimensions of figured specimens, including types, and National Museum catalog numbers for these specimens are cited in the explanation of the plates.

The following new names are proposed in the discussions:

New species and varieties

Echinoids:
- *Dendraster coalingaensis* Twitchell var. *macer* Stewart, p. 81, pl. 39, fig. 9; pl. 40, figs. 1, 5; pl. 41, figs. 1, 2 (type), 4.
- *Dendraster gibbsii* (Rémond) var. *mirus* Stewart, p. 80, pl. 44, figs. 4, 5 (type).

Mollusks:
- *Calliostoma coalingense* Arnold var. *privum* Stewart, p. 84, pl. 32, fig. 5 (type).
- *Forreria magister* (Nomland) var. *munda* Stewart, p. 88, pl. 15, figs. 17, 18 (type).
- *Macoma affinis* Nomland var. *plena* Stewart, p. 93, pl. 24, fig. 3; pl. 29, fig. 12; pl. 39, fig. 3 (type).
- "*Nassa*" *miser* (Dall) var. *iniqua* Stewart, p. 87, pl. 34, fig. 8 (type).
- *Platyodon colobus* Woodring, p. 95, pl. 21, figs. 1 (type), 2.
- *Saxidomus nuttalli* Conrad var. *latus* Stewart, p. 94, pl. 8, fig. 15; pl. 16, fig. 8 (type); pl. 33, fig. 6.
- *Turcica caffea* (Gabb) var. *brevis* Stewart, p. 84, pl. 11, figs. 1, 6 (type).
- *Venerupis grata* (Say) var. *tarda* Stewart, p. 94, pl. 13, figs. 10–13 (type).

ECHINOIDS

Echinoids are represented in the San Joaquin and Etchegoin formations by sand dollars of the genus *Dendraster*. In addition to *Dendraster* in the restricted sense, *Merriamaster*, which is assigned subgeneric rank under *Dendraster*, occurs in the upper part of the San Joaquin formation. Sand dollars are abundant in some sandy strata in both formations in North Dome, are relatively rare in the San Joaquin formation and apparently absent in the Etchegoin in Middle Dome, and were found in South Dome only in the *Pecten* zone of the San Joaquin, and at that horizon they are not abundant. In the following discussion citations for Pacific coast species that may be found in Kew's monograph[80] are omitted, as Kew's work should be available to anyone interested in these fossils.

The Kettleman Hills sand dollars may be classified in three main groups: (1) the *Dendraster gibbsii* group, characterized by a markedly posterior eccentric apical system; (2) the *Dendraster coalingaensis* group, characterized by a less eccentric apical system; and (3) the *Merriamaster* group, characterized by inflated margin of the test, large spine bases, and open petals. The stratigraphic range and probable relations of the different forms of these three groups are shown in figure 11.

Dendraster gibbsii group.—*Dendraster gibbsii* (Rémond) is the oldest sand dollar in the Kettleman Hills and is

[76] Russell, R. D., and Vander Hoof, V. L., A vertebrate fauna from a new Pliocene formation in northern California: California Univ., Dept. Geol. Sci., Bull., vol. 20, pp. 11–21, 7 figs., 1931. Vander Hoof, V. L., Additions to the fauna of the Tehama upper Pliocene of northern California: Am. Jour. Sci., 5th ser., vol. 25, pp. 382–384, 1933.

[77] Arnold, Ralph, op. cit. (Bull. 396), pp. 71–101, 1909 [1910]. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 125–133, 153, 1910.

[78] Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ., Dept. Geology, Bull., vol. 12, pp. 113–130, 1920.

[79] Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, pp. 109–877, 1931.

[80] Kew, W.S.W., op. cit., pp. 23–236, pls. 3–42, 5 figs.

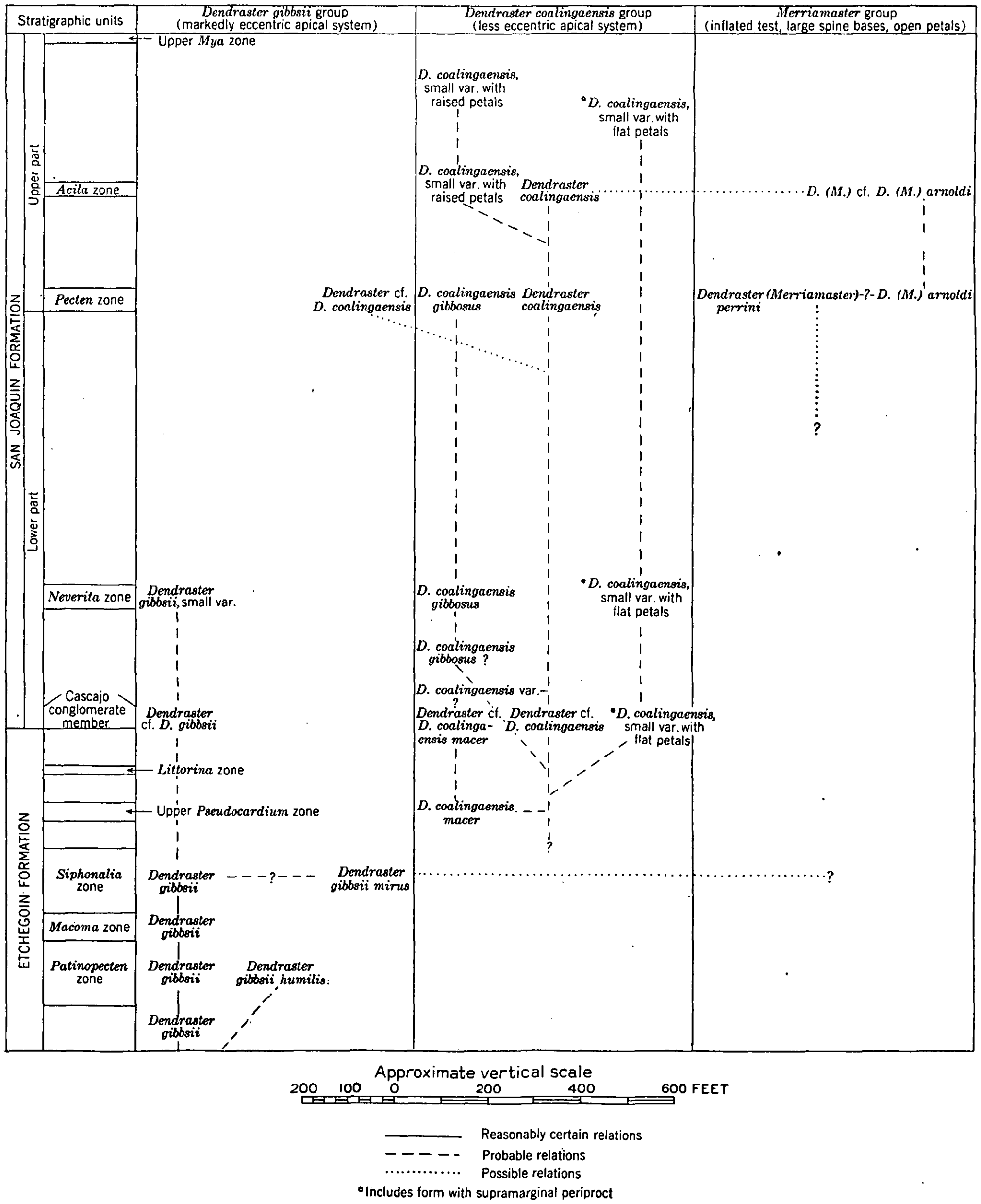


FIGURE 11.—Stratigraphic range and probable relations of sand dollars in San Joaquin and Etchegoin formations.

abundant in strata below the *Patinopecten* zone and in the *Patinopecten* zone (pl. 40, figs. 3, 4; pl. 42, figs 1–5; pl. 43, figs. 1, 2; pl. 44, fig. 6), the *Macoma* zone, and the *Siphonalia* zone (pl. 40, fig. 2). This form has rather inflated margins and a markedly posterior apical system. Specimens that are exceptionally eccentric are assigned to the variety *D. gibbsii humilis* Kew, the type of which was cited from a locality in the Jacalitos Hills west of the Kettleman Hills. The original material of *D. gibbsii* may have been collected in the Kettleman Hills or in the foothills farther west. Rémond's locality, "Kern Lake, Buena Vista County," is clearly erroneous according to current usage; he meant probably Tulare Lake, which is designated Kern Lake on some early maps. Specimen 11050 in the collection of the University of California, labeled "type from C. D. Gibbs, oil region west of Tulare Lake," has been cited as the holotype,[81] but specimen 11328 is also labeled "type." At one locality in the *Siphonalia* zone small specimens of *D. gibbsii* have open petals and large spine bases and are almost as inflated as *Merriamaster.* They are considered abnormal specimens of *D. gibbsii* and are named *D. gibbsii mirus* Stewart, n. var. (pl. 44, figs. 4, 5).

A few specimens similar to *D. gibbsii* were found in the Cascajo conglomerate member at the base of the San Joaquin formation. The small variety that is abundant in the *Neverita* zone of the San Joaquin (pl. 20, figs. 10, 11; pl. 21, figs. 3–6) is generally about half as large as the usual *D. gibbsii.* The *D. gibbsii* group has not been recognized at higher horizons in the San

[81] Kew, W. S. W., op. cit., p. 124.

Joaquin formation, but some specimens in the upper part of the formation, such as the more eccentric forms of *D. coalingaensis*, may possibly be survivors of *D. gibbsii*.

Dendraster coalingaensis group.—The *Dendraster coalingaensis* group, with one exception, was found in the San Joaquin formation, particularly in the upper part of the formation. Aside from a few exceptional specimens, the sand dollars of this group have a less eccentric apical system than those of the *D. gibbsii* group.

D. coalingaensis Twitchell occurs in the *Pecten* zone (pl. 45, figs. 1, 2) and *Acila* zone, and similar specimens were found in the Cascajo conglomerate member. The variety *D. coalingaensis gibbosus* Kew, which has a high center and is usually wider than long, is present in the *Pecten* zone (pl. 45, figs. 5, 6) and at lower horizons in the San Joaquin. Some specimens, identified as *D.* cf. *D. coalingaensis* (pl. 39, fig. 7), from the *Pecten* zone have the general shape and appearance of *D. coalingaensis*, with which they were found, but have the eccentric apical system of *D. gibbsii*.

A small variety of *D. coalingaensis* that has slightly raised petals and deep ambulacral furrows, occurs in the *Acila* zone (pl. 45, figs. 3, 4) and at higher horizons between the *Acila* and upper *Mya* zones (pl. 10, figs. 6–9), including the youngest strata in which sand dollars were observed. Another small variety that has flat petals occurs in the Cascajo conglomerate, in the *Neverita* zone, and at a horizon between the *Acila* and upper *Mya* zones (pl. 10, figs. 10–12). The outline of the test and the position of the periproct are variable in this variety; some specimens have an inframarginal or barely inframarginal periproct (pl. 10, fig. 12), others have a marginal periproct (pl. 10, fig. 10), and others—generally those with an ovate-pentameral outline—have a supramarginal periproct (pl. 10, fig. 11).

The thin sand dollar in the upper *Pseudocardium* zone is the only representative of the *D. coalingaensis* group discovered in the Etchegoin formation. This thin sand dollar is named *D. coalingaensis macer* Stewart n. var. (pl. 39, fig. 9; pl. 40, figs. 1, 5; pl. 41, figs. 1, 2, 4). The opening at the end of the anterior petals is narrower in this variety than in *D. coalingaensis*. A form similar to the variety *macer* occurs in the Cascajo conglomerate. An exceptional specimen (pl. 44, fig. 3), associated with *D. coalingaensis gibbosus* at a horizon immediately above the Cascajo conglomerate, has the narrow petal openings of the variety *macer* but is more inflated, having a profile like that of *D. coalingaensis*. It is classified as a variety of that species.

D. coalingaensis was described from a *Pecten* zone locality in the Kreyenhagen Hills, west of the Kettleman Hills. It is probably closely related to *D. diegoensis* Kew, from the San Diego formation, and, as suggested by Twitchell,[82] may be the ancestor of the living *D. excentricus* (Eschscholtz). *D. hesperis* Kew, from Priest Valley in the Coast Ranges west of the Coalinga district, appears to be a synonym of *D. coalingaensis;* Kew's *D. coalingaensis* Twitchell is *D.* (*Merriamaster*) *arnoldi* Twitchell. *D. hesperis gibbosus* Kew is here given priority over *D.* (*Calaster*) *oregonènsis gibbosus* Kew.[83]

Merriamaster group.—Sand dollars in the *Pecten, Trachycardium*, and *Acila* zones are assigned to *Merriamaster* Lambert,[84] the type of which is *Scutella perrini* Weaver. The open petals, large spine bases, and inflated test are apparently the distinguishing characters of *Merriamaster*. The specimens from the *Pecten* and *Acila* zones appear to be closely related to *D. coalingaensis* and may be abnormal individuals of that species. Inasmuch, however, as sand dollars with the characters of *Merriamaster* have been found at localities from central California to Cedros Island, Lower California, it is convenient to recognize them as distinct, whatever their genetic relations to species of *Dendraster* may be. *Merriamaster* is, therefore, treated as a subgenus of *Dendraster*.

The common sand dollar in the *Pecten* and *Trachycardium* zones, *D.* (*M.*) *perrini* (Weaver) (pl. 46, figs. 1, 2, 4, 7, 10, 12), is a small inflated form with inflated margins and large spine bases. A form with larger spine bases on the petals, *D.* (*M.*) *arnoldi* Twitchell, also occurs in the *Pecten* and *Trachycardium* zones (pl. 46, figs. 3, 5, 6, 8, 11). *D.* (*M.*) *arnoldi* is found in the overlying *Acila* zone (pl. 39, fig. 5; pl. 41, fig. 3), but some specimens are not quite so inflated as the typical form (pl. 46, fig. 9). Some specimens from the *Acila* zone that have poorly defined *Merriamaster* characters are practically indistinguishable from *D. coalingaensis*. The sand dollars from the *Acila* zone classified as *D.* (*M.*) cf. *D.* (*M.*) *arnoldi* might be considered a variety of *D. coalingaensis*, whereas those from the *Pecten* and *Trachycardium* zones classified as *D.* (*M.*) *arnoldi* might be considered a variety of *D.* (*M.*) *perrini*.

The two small imperfect specimens from the Coalinga district described by Twitchell as *Sismondia? arnoldi* and *Sismondia? coalingaensis* are young specimens of *Merriamaster* or *Dendraster;* and, therefore, according to the classification here adopted are homonyms of *D.* (*M.*) *arnoldi* and *D. coalingaensis* respectively. *D.* (*M.*) *arnoldi* Twitchell is given arbitrary priority over *Sismondia? arnoldi* Twitchell, and *D. coalingaensis* Twitchell is likewise given arbitrary priority over

[82] Clark, W. B., and Twitchell, M. W., The Mesozoic and Cenozoic Echinodermata of the United States: U. S. Geol. Survey Mon. 54, p. 196, 1915.

[83] After this account was written *Dendraster* (*Calaster*) *oregonensis gibbosus* was renamed *Anorthoscutum oregonense quaylei* (Grant, U. S., IV, and Hertlein, L. G., The West American Cenozoic Echinoidea: California Univ. at Los Angeles Pub. Math. Phys. Sci., vol. 2, p. 93, 1938).

[84] Lambert, J., Rev. crit. paléozool., 15th year, p. 64, 1911.

Sismondia? coalingaensis Twitchell. *Orchoporus koehleri* Lambert and Thiéry,[85] the type of *Orchoporus* Lambert and Thiéry,[86] was based on the same specimen as *Sismondia? arnoldi* (Arnold's figured *Astrodapsis* sp. undet).[87] This specimen, apparently a young specimen of *D.* (*M.*) *perrini*, is labeled U. S. G. S. locality 4708, a locality in North Dome that probably represents the *Acila* zone. *D.* (*M.*) *perrini* was not found in the *Acila* zone during the field work for the present report. Inasmuch as the collection from locality 4708 has no additional sand dollars agreeing in preservation and morphology with the type specimen and inasmuch as three specimens from locality 4715 (*Pecten* zone at Las Morones in South Dome) are very similar in preservation and morphology to the type specimen, the locality 4708 may be an error. The type of *Sismondia? coalingaensis* is from a locality in the Kreyenhagen Hills not mentioned in Bulletin 398 (U. S. G. S. locality 4779, "little sea urchin bed near top of Etchegoin half a mile east of A. Kreyenhagen's house on Jacalitos Creek"). It is probably a young specimen of the small variety of *D. coalingaensis* that occurs near the top of the San Joaquin formation in the Kettleman Hills.

Relations of Kettleman Hills sand dollars.—The sand dollars of the *D. gibbsii* and *D. coalingaensis* groups may be classified according to the degree of eccentricity of the apical system. As expressed by the ratio $\frac{a}{p}$, in which a is the distance from the anterior margin of the test to the center of the apical system and p is the distance from the posterior margin of the test to the center of the apical system, the degree of eccentricity is as follows:

Degree of eccentricity of sand dollars of D. gibbsii and D. coalingaensis groups

D. coalingaensis	$\frac{a}{p}$ is 2 or is less than 2
D. gibbsii	$\frac{a}{p}$ is greater than 2
D. gibbsii humilis	$\frac{a}{p}$ is greater than 3

This artificial classification corresponds roughly to the stratigraphic position of the forms in the North Dome section. It is, however, of but local significance as *D. jacalitosensis* Kew, which has an apical system similar to that of *D. coalingaensis*, was described from the Jacalitos formation, underlying the Etchegoin formation, in association with *D. gibbsii humilis*. The characters of *D. jacalitosensis* and of specimens from the Jacalitos formation identified as *D. gibbsii* are not well known. In the degree of eccentricity of the apical system the living *D. excentricus* is more like *D. coalingaensis* than like *D. gibbsii*, but some living specimens have an $\frac{a}{p}$ ratio greater than 2.

The periproct of *D. gibbsii* is located at a distance from the margin of the test about equal to the diameter of the periproct and, in general, is a little closer to the margin than on *D. excentricus*. *D. coalingaensis*, however, cannot be separated from *D. excentricus* on this character, because there are too many exceptions, particularly in *D. coalingaensis macer* and in the living species. The position of the peristome as expressed by the ratio $\frac{a}{p}$, in which a is the distance from the anterior margin of the test to the posterior edge of the peristome, and p is the distance from the posterior margin of the test to the posterior edge of the peristome, is as follows:

Position of peristome on sand dollars of D. gibbsii and D. coalingaensis groups and in the living D. excentricus

D. excentricus (75 Recent specimens)	$\frac{a}{p}=1.3$
D. coalingaensis (30 specimens from *Pecten* and *Acila* zones)	$\frac{a}{p}=1.5$
D. coalingaensis gibbosus (50 specimens from *Pecten* zone)	$\frac{a}{p}=1.5$
D. coalingaensis macer (50 specimens from upper *Pseudocardium* zone)	$\frac{a}{p}=1.4$
D. gibbsii (250 specimens from *Siphonalia* zone and *Patinopecten* zone(?))	$\frac{a}{p}=1.6$
D. gibbsii humilis (40 specimens from *Patinopecten* zone)	$\frac{a}{p}=1.7$

The peristome, in general, is less eccentric at successively higher horizons, but the decrease in eccentricity is interrupted in the stratigraphic sequence by *D. coalingaensis macer*. *D. jacalitosensis* may also have a less eccentric peristome than *D. gibbsii*. The ratio expressing the eccentricity is not alone as useful as might appear from the figures, for, although the average ratio for the 75 specimens of *D. excentricus* measured is 1.3, the range is 1.2 to 1.5, thus including the average ratio for *D. coalingaensis*.

On the actinal floor of about 50 specimens of *D. gibbsii* examined the interambulacral ridges connecting the auricles and the pillars are wide and high and are separated by a channel. Thin-test forms of *D. excentricus* usually lack these ridges or show only a trace of them. On 10 specimens of thick-test forms of *D. excentricus* examined the ridges are distinct, but the interambulacral areas between the ridges are also built up, so that there is no deep channel as on *D. gibbsii*. *D. coalingaensis* usually lacks these ridges, thus resembling the thin-test form of *D. excentricus*, but one specimen, probably *D. coalingaensis gibbosus*, from U. S. G. S. locality 4712 (*Pecten* zone in Kreyenhagen

[85] Lambert, J., and Thiéry, P., Essai de nomenclature raisonnée des échinides, pt. 4, p. 293, Chaumont, 1914.
[86] Idem.
[87] Arnold, Ralph, op. cit. (Bull. 396), pl. 28, figs. 5, 5a.

PLATE 39

[Figures natural size unless otherwise designated]

FIGURES 1, 6. *Disciniscа* sp. Locality 185. Cascajo conglomerate member of San Joaquin formation.
1. Length (incomplete) 14.7 mm., height 4.5 mm. U. S. Nat. Mus. 495851.
6. Length 16.8 mm., height 5.9 mm. U. S. Nat. Mus. 495850.

2. *Cryptomya* cf. *C. quadrata* Arnold. Crushed double-valve specimen. Length 37 mm., height 26 mm. Locality 68, *Acila* zone, San Joaquin formation. U. S. Nat. Mus. 495852.

3. *Macoma affinis plena* Stewart, n. var. Type. Length 36.2 mm., thickness 6.5 mm. Locality 238a, *Littorina* zone, Etchegoin formation. U. S. Nat. Mus. 495853.

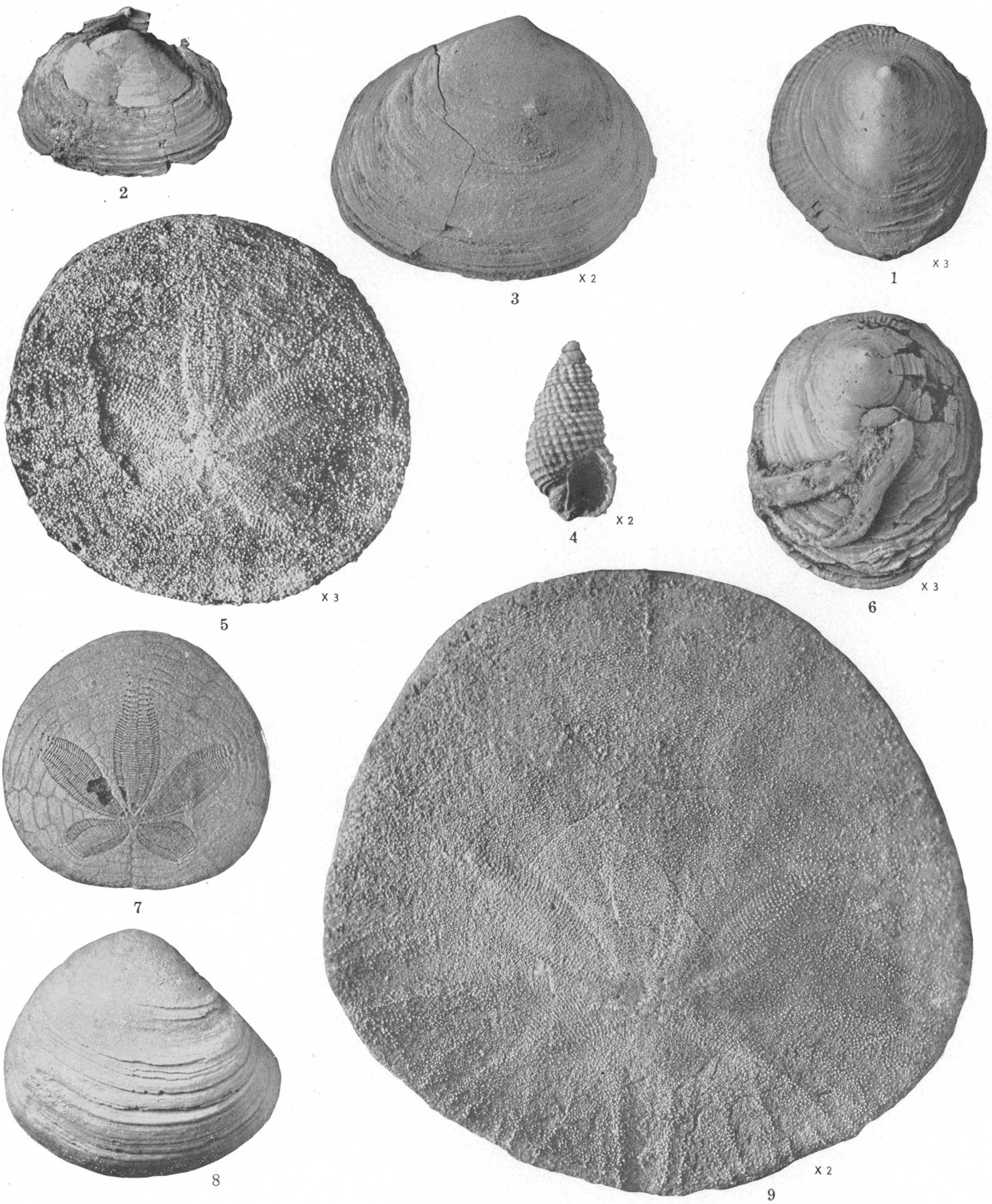
4. "*Nassa*" cf. "*N.*" *waldorfensis* Arnold. Height (incomplete) 16.4 mm., width 8.4 mm. About 100 yards north of locality 63, *Acila* zone, San Joaquin formation. Collected by Richard Bramkamp. U. S. Nat. Mus. 495854.

5. *Dendraster* (*Merriamaster*) *arnoldi* Twitchell. Length 24 mm., width 24.2 mm., height 4.6 mm. Locality 60, sand a few feet below *Acila* zone, San Joaquin formation. U. S. Nat. Mus. 495855.

7. *Dendraster* cf. *D. coalingaensis* Twitchell. Length 48.3 mm., width 50 mm., height 9.5 mm. Locality 76, *Pecten* zone, San Joaquin formation. U. S. Nat. Mus. 495856.

8. *Pseudocardium densatum* (Conrad) of Arnold. Length 50.8 mm., height 45 mm., thickness 20.5 mm. Locality 266a, *Siphonalia* zone, Etchegoin formation. U. S. Nat. Mus. 495857.

9. *Dendraster coalingaensis macer* Stewart, n. var. Length 54 mm., width 58 mm., height 8 to 9 mm. About 400 feet south of locality 238, upper *Pseudocardium* zone, Etchegoin formation. U. S. Nat. Mus. 495858.



SAND DOLLARS AND OTHER FOSSILS FROM SAN JOAQUIN AND ETCHEGOIN FORMATIONS OF NORTH DOME.

PLATE 40

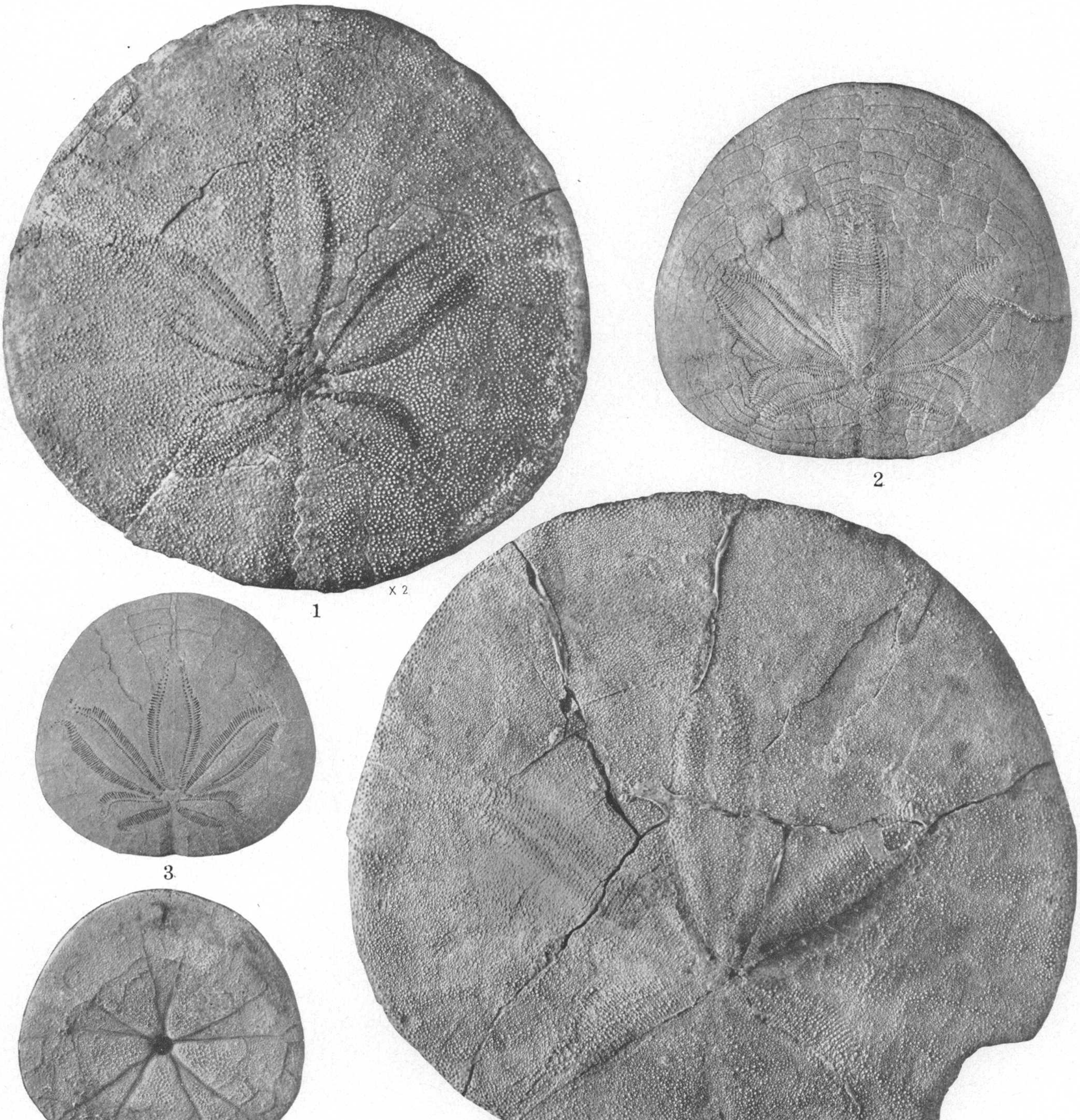
[Figures natural size unless otherwise designated]

FIGURE 1. *Dendraster coalingaensis macer* Stewart, n. var. Length 47 mm., width 47.8 mm., height 7 mm. Locality 242, upper *Pseudocardium* zone. U. S. Nat. Mus. 495859.

2. *Dendraster gibbsii* (Rémond). Length 62.1 mm., width 68 mm., height (slightly crushed) 10 mm. Locality 288, *Siphonalia* zone (?). U. S. Nat. Mus. 495860.

3, 4. *Dendraster gibbsii* (Rémond). Length 45.6 mm., width 48.3 mm., height 11 mm. Locality 343, *Patinopecten* zone. U. S. Nat. Mus. 495861.

5. *Dendraster coalingaensis macer* Stewart, n. var. Length 56.4 mm., width 61 mm., height 7.5 mm. Locality 249, upper *Pseudocardium* zone. U. S. Nat. Mus. 495862a.



SAND DOLLARS FROM ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 41

FIGURES 1, 2. *Dendraster coalingaensis macer* Stewart, n. var. Type. Length 50 mm., width 50.9 mm., height 8 mm. Locality 242, upper *Pseudocardium* zone, Etchegoin formation. U. S. Nat. Mus. 495862.

3. *Dendraster* (*Merriamaster*) *arnoldi* Twitchell. Length 37.3 mm., width 34.3 mm., height (crushed) 7.2 mm. Locality 60, sand a few feet below *Acila* zone, San Joaquin formation. U. S. Nat. Mus. 495863.

4. *Dendraster coalingaensis macer* Stewart, n. var. Length 36 mm., width 34.6 mm., height 5.4 mm. Locality 241, upper *Pseudocardium* zone, Etchegoin formation. U. S. Nat. Mus. 495864.

X 2

1

X 2

3

X 2

4

X 2

2

SAND DOLLARS FROM ETCHEGOIN AND SAN JOAQUIN FORMATIONS OF NORTH DOME.

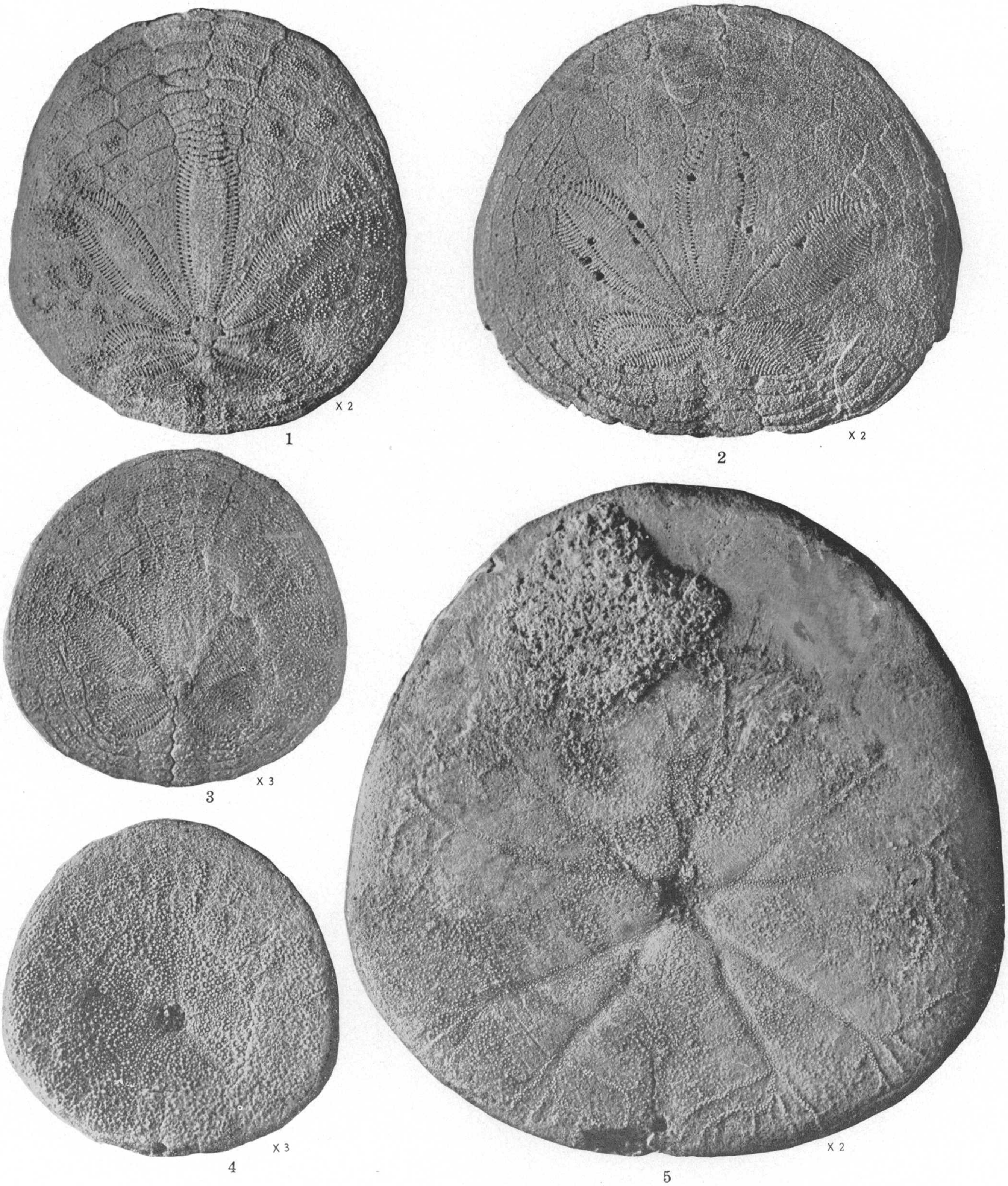
PLATE 42

FIGURES 1–5. *Dendraster gibbsii* (Rémond).

1. Length 37.5 mm., width 34.8 mm., height 8.7 mm. Locality 343, *Patinopecten* zone. U. S. Nat. Mus. 495865.
2. Length (almost complete) 38.3 mm., width 43.8 mm., height 9.6 mm. Locality 343, *Patinopecten* zone. U. S. Nat. Mus. 495866.

3, 4. Length 19.8 mm., width 20.2 mm., height 4.1 mm. Locality 343, *Patinopecten* zone. U. S. Nat. Mus. 495867.

5. Length 59.5 mm., width 57.9 mm., height (incomplete) 15 mm. Locality 332b, *Patinopecten* zone. U. S. Nat. Mus. 495868.



SAND DOLLARS FROM ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 43

FIGURE 1. *Dendraster gibbsii* (Rémond). Length 20 mm., width 19 mm., height 4.6 mm. Locality 340, *Patinopecten* zone. U. S. Nat. Mus. 495869. Young specimen found with very eccentric variety of *D. gibbsii.*

2. *Dendraster gibbsii* (Rémond). Length 56 mm., width 60 mm., height 12 mm. Locality 332b, *Patinopecten* zone. U. S. Nat. Mus. 495870.

3. *Dendraster gibbsii humulis* Kew. Length 32.7 mm., width 28.2 mm., height 7 mm. Locality 307, *Patinopecten* zone. U. S. Nat. Mus. 495871.

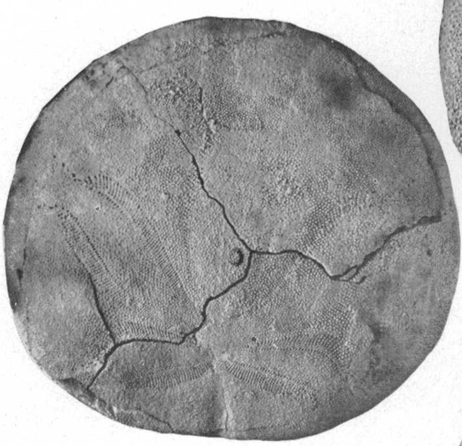
4, 5. *Dendraster gibbsii* (Rémond). Length 60.7 mm., width 59.8 mm., height 11.5 mm. Locality uncertain, *Siphonalia* zone (?). U. S. Nat. Mus. 495872.

X 3

1

X 2

4



2

3 X 2

X 2

5

SAND DOLLARS FROM ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 44

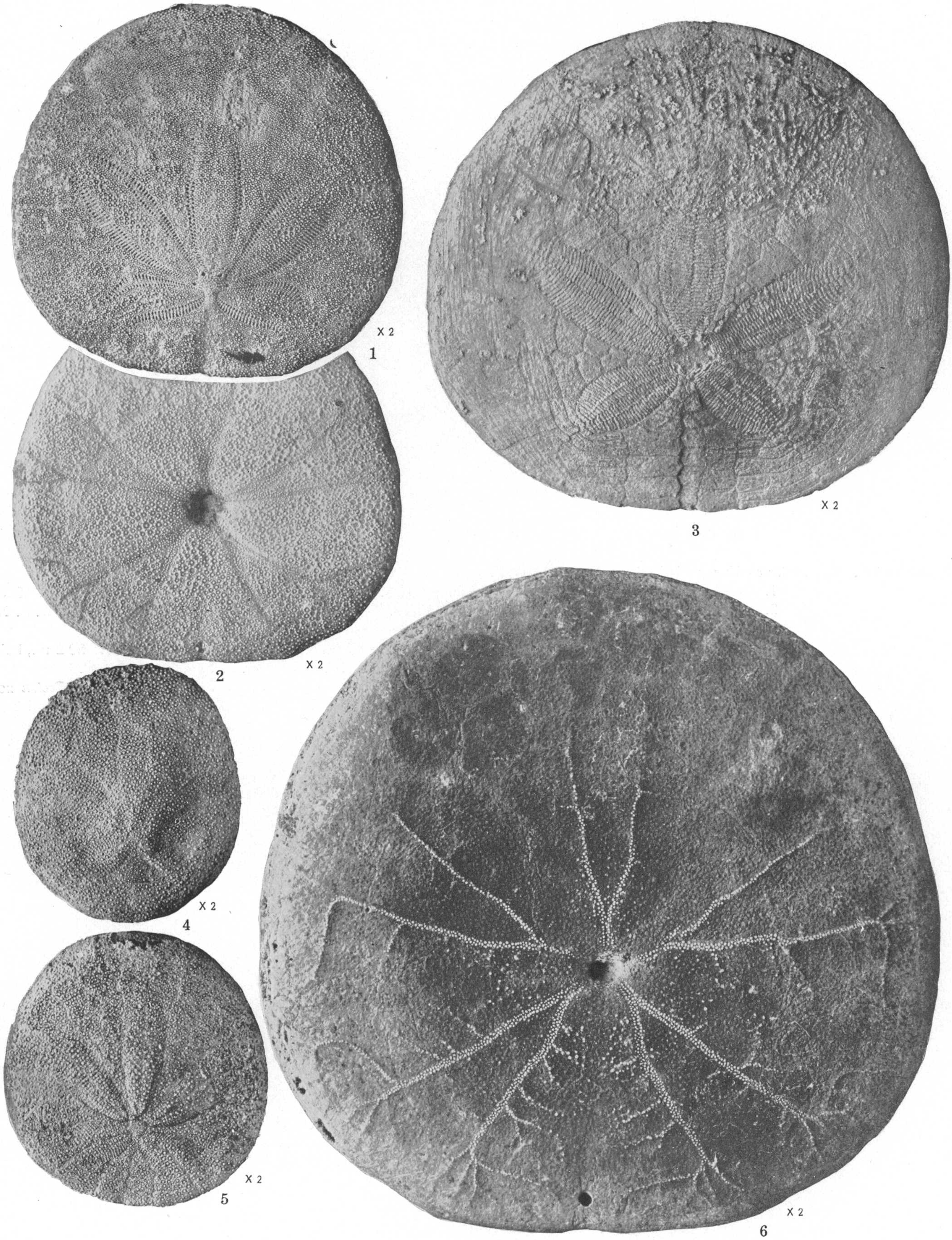
FIGURES 1, 2. *Dendraster gibbsii* (Rémond) var. Length 34.8 mm., width 36.3 mm , height 7.6 mm. Locality uncertain, *Siphonalia* zone (?). U. S. Nat. Mus. 495873.

3. *Dendraster coalingaensis* Twitchell, n. var.? Length 46.5 mm., width 49.4 mm., height 8 mm. Locality 190, near base of San Joaquin formation. U. S. Nat. Mus. 495874.

4. *Dendraster gibbsii mirus* Stewart, n. var. Length 25.1 mm., width 21.8 mm., height (fractured specimen) 5 mm. Locality 275a, *Siphonalia* zone. U. S. Nat. Mus. 495875.

5. *Dendraster gibbsii mirus* Stewart, n. var. Type. Length 26.8 mm., width 27.7 mm., height 5.5 mm. Locality 275a, *Siphonalia* zone. U. S. Nat. Mus. 495876.

6. *Dendraster gibbsii* (Rémond). Length 62 mm., width 62.7 mm., height 16 mm. Locality 332b, *Patinopecten* zone. U. S. Nat. Mus. 485877.



SAND DOLLARS FROM ETCHEGOIN FORMATION OF NORTH DOME.

PLATE 45

FIGURES 1–6. *Dendraster coalingaensis* Twitchell.

1. Length 45.6 mm., width 47.4 mm., height 9.5 mm. Locality 76, *Pecten* zone. U. S. Nat. Mus. 495878.
2. Typical form. Length 36.1 mm., width 37.5 mm., height 7.8 mm. Locality 81, *Pecten* zone. U. S. Nat. Mus. 495879.

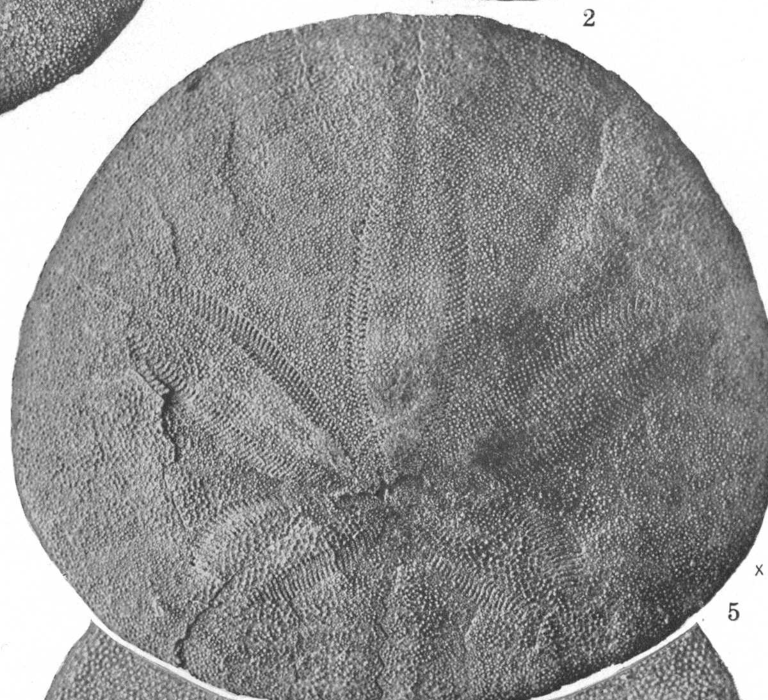
3, 4. Variety with slightly raised petals and deep ambulacral furrows. Length 30.3 mm., width 29 mm., height 7.4 mm. Locality 60, *Acila* zone; just above layer with *Acila*. U. S. Nat. Mus. 495880.

5, 6. Variety *gibbosus* Kew. Length 46.2 mm., width 51.8 mm., height 9.5 mm. Locality 81, *Pecten* zone. U. S. Nat. Mus. 495881.

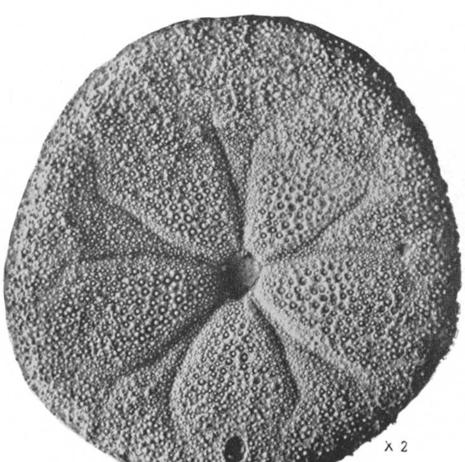
1 X 2

X 2 2

X 2 3



X 2 5



X 2 4

X 2 6

SAND DOLLARS FROM UPPER PART OF SAN JOAQUIN FORMATION OF NORTH DOME.

PLATE 46

[Figures natural size unless otherwise designated]

FIGURE 1. *Dendraster* (*Merriamaster*) *perrini* (Weaver). Pentagonal form. Length 27.1 mm., width 25.5 mm., height 6.2 mm. Locality 81, *Pecten* zone. U. S. Nat. Mus. 495882.

2. *Dendraster* (*Merriamaster*) *perrini* (Weaver). Length 26 mm., width 25.5 mm., height 7.3 mm. Locality 81, *Pecten* zone. U. S. Nat. Mus. 495883.

3. *Dendraster* (*Merriamaster*) *arnoldi* Twitchell. Outline incomplete. Length 21.5 mm., width 21.4 mm., height 5.1 mm. Locality 121, *Trachycardium* zone. U. S. Nat. Mus. 495884.

4. *Dendraster* (*Merriamaster*) *perrini* (Weaver). Length 21.4 mm., width 21.6 mm., height 4.6 mm. Locality 121. *Trachycardium* zone. U. S. Nat. Mus. 495885.

5. *Dendraster* (*Merriamaster*) *arnoldi* Twitchell. Length 28.6 mm., width (almost complete) 28.1 mm., height (crushed) 5.7 mm. Locality 121, *Trachycardium* zone. U. S. Nat. Mus. 495886.

6. *Dendraster* (*Merriamaster*) *arnoldi* Twitchell. Length 22.4 mm., width 22.6 mm., height 4 mm. Locality 94, *Pecten* zone. U. S. Nat. Mus. 495887.

7. *Dendraster* (*Merriamaster*) *perrini* (Weaver). Length 27.8 mm., width 26.7 mm., height 7.4 mm. Locality 81, *Pecten* zone. U. S. Nat. Mus. 495888.

8. *Dendraster* (*Merriamaster*) *arnoldi* Twitchell. Length 17.6 mm., width 17 mm., height 3.7 mm. Locality 121, *Trachycardium* zone. U. S. Nat. Mus. 495889.

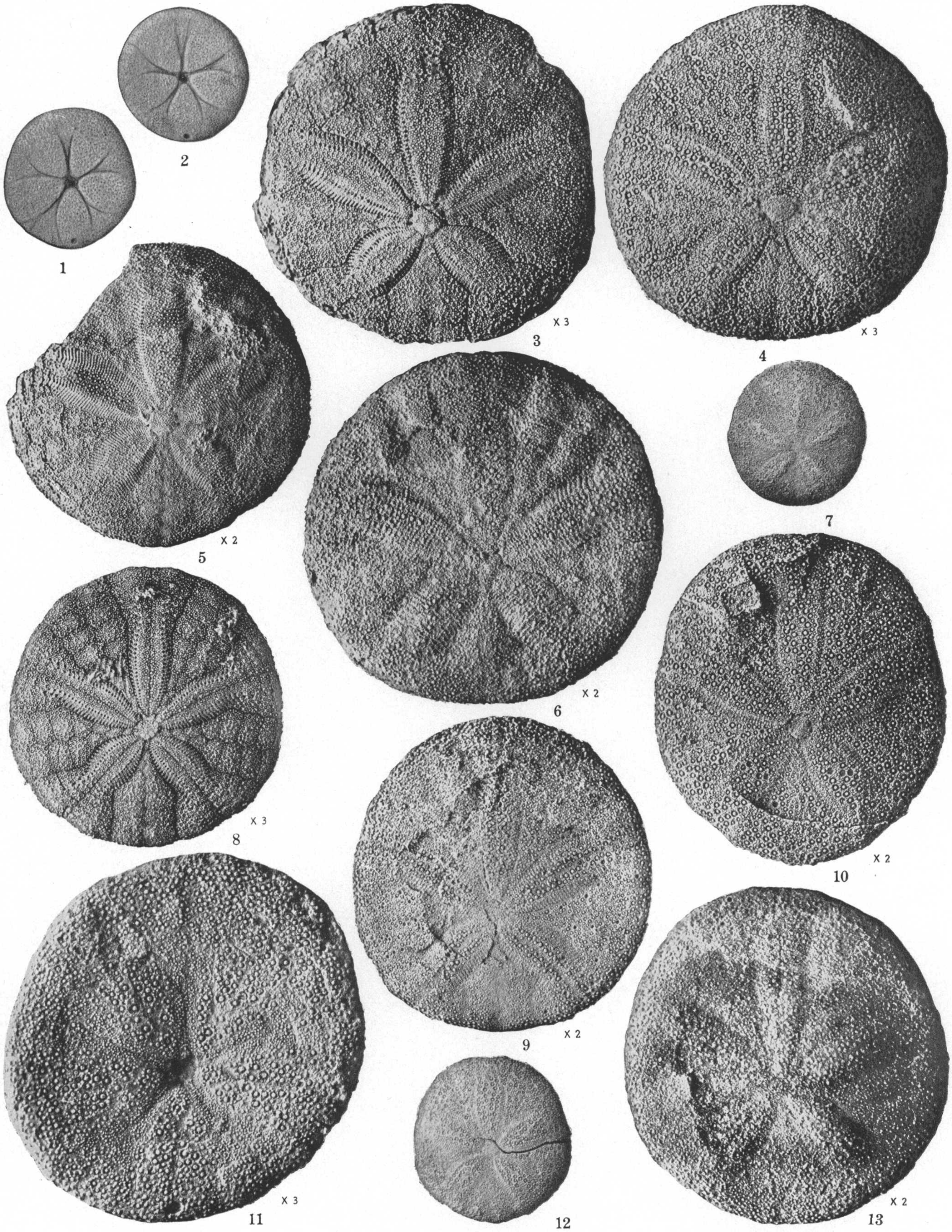
9. *Dendraster* (*Merriamaster*) cf. *D.* (*M.*) *arnoldi* Twitchell. Length 29.3 mm., width 27.4 mm., height 5.3 mm. Locality 60, sand a few feet below *Acila* zone. U. S. Nat. Mus. 495890.

10. *Dendraster* (*Merriamaster*) *perrini* (Weaver). Length 31 mm., width 26.8 mm., height (crushed) 5 mm. Locality 121, *Trachycardium* zone. U. S. Nat. Mus. 495891.

11. *Dendraster* (*Merriamaster*) *arnoldi* Twitchell. Young specimen. Length 22.5 mm., width 22 mm., height (crushed) 4 mm. Locality 121, *Trachycardium* zone. U. S. Nat. Mus. 495892.

12. *Dendraster* (*Merriamaster*) *perrini* (Weaver). Length 32 mm., width 30.5 mm., height 7.6 mm. Locality 81, *Pecten* zone. U. S. Nat. Mus. 495893.

13. *Dendraster* (*Merriamaster*) cf. *D.* (*M.*) *arnoldi* Twitchell. Length 31.2 mm., width 29.3 mm., height 6.4 mm. Locality 121, *Trachycardium* zone. U. S. Nat. Mus. 495894.



SAND DOLLARS FROM UPPER PART OF SAN JOAQUIN FORMATION OF NORTH DOME.

Hills), has ridges and channels resembling those of *D. gibbsii*. The thin *D. coalingaensis macer* has an actinal floor resembling that of *D. excentricus*, though not identical.

The sand dollars of the *D. gibbsii* and *D. coalingaensis* groups have slightly different secondary ambulacral branches from those of *D. exentricus*. Although these minor branches are variable in number and pattern, two main branches can be recognized on the outer (interambulacral) sides of the dichotomus ambulacral furrows. On *D. excentricus* the minor branch closer to the peristome is larger, whereas on *D. gibbsii* and *D. coalingaensis* the minor branch farther from the peristome is larger. The furrows of *D. excentricus* are in general larger and deeper, and therefore more prominent. Some specimens of *D. excentricus*, particularly one from Puget Sound, have minor branches resembling in pattern those of *D. gibbsii*, but the furrows are deeper, as in other specimens of *D. excentricus*.

The minor branches of *D. coalingaensis* are near the periphery of the test, so that for the greater part of their length the furrows lack branches. In this feature the sand dollars from the *Neverita* zone, considered a small variety of *D. gibbsii*, are more like *D. coalingaensis* than like large forms of *D. gibbsii*. Perhaps, however, this feature is to be correlated with the small size of the specimens in the *Neverita* zone, for small specimens of *D. gibbsii* from the Etchegoin formation also appear to lack the minor branches near the peristome.

Despite the exceptions, the pattern of the ambulacral furrows is the most satisfactory basis that has been found for separating *D. gibbsii*, D. *coalingaensis*, and *D. excentricus*, indicating that the two fossil species are distinct and extinct species. Unfortunately the minor branches are not preserved on many specimens that would ordinarily be regarded as well-preserved specimens.

The form of the small flat-petaled sand dollars in the San Joaquin formation characterized by a supramarginal periproct (pl. 10, fig. 11) might be classified with *Anorthoscutum* Lambert and Thiéry,[88] which also has a supramarginal periproct and the type of which is *Scutella interlineata* Stimpson. The ambulacral furrows are not well developed on this form, but the short posterior petals indicate a *Dendraster*, and this form is considered a small variety of *D. coalingaensis*. The classification of this form seems to be important, for if it is related to *Anorthoscutum* it is a northern element in the San Joaquin fauna. *Anorthoscutum* is probably to be regarded as a subgenus of *Phelsumia* Pomel, a genus now represented on the Pacific coast north of Puget Sound by *P. parma* (Lamarck), better known as *Echinarachinus parma*. The ambulacral furrows of *Anorthoscutum* are not well known, but they may be more of less intermediate between the straight furrows of *Phelsumia*, trifurcate near the margin of the test, and the dichotomously branched furrows of *Dendraster*. *Calaster* Kew, proposed as a subgenus of *Dendraster*, is a synonym of *Anorthoscutum*.

[88] Lambert, J., and Thiéry, P., op. cit., pt. 4, p. 319.

The genus *Astrodapsis* Conrad, which occurs in strata on the Pacific coast now assigned to the upper Miocene and lower Pliocene, has the characters that distinguish *Merriamaster* from *Dendraster* proper. *Astrodapsis*, however, has straight ambulacral furrows, short ambulacral plates, and generally has raised petals. Superficially, at least, *Merriamaster* may be thought of as an *Astrodapsis*-like *Dendraster*.

The classification of the Kettleman Hills sand dollars here adopted has been influenced by an examination of the collections of the Recent species *Dendraster excentricus* and *Phelsumia parma* in the National Museum. If it could be shown that at least two living species are included under *D. excentricus*, or that northern and southern subspecies are recognizable, some of the apparent variation of the *Dendraster* living on the Pacific coast might disappear. According to the collection of *Phelsumia parma*, however, sand dollars from one dredging may be very much alike and slightly different from those from another locality. The same impression is gained from a study of the collections from the Kettleman Hills. The collections of living forms indicate that the minor variations, which might be quite useful to geologists in correlating local outcrops, would be of little significance in correlating with other regions. For this reason and also on account of their similar morphology, the locally recognized forms in the Kettleman Hills are treated as varieties rather than as species or subspecies.

MOLLUSKS

In the following discussion of the stratigraphically important mollusks references are omitted for systematic names cited by Grant and Gale[89] in their elaborate catalogue of the Pliocene and Pleistocene marine mollusks of California. This catalogue is indispensable and should be available to anyone who might need the references.

GASTROPODS

Trochidae.—The genus *Calliostoma* is represented in the *Patinopecten* and *Siphonalia* zones of the Etchegoin formation, in the *Pecten* and *Acila* zones of the San Joaquin formation, and by an unidentified fragment in the Cascajo conglomerate member of the San Joaquin. *C. coalingense* Arnold (pl. 11, figs. 2, 3; pl. 15, figs. 15, 16) may be recognized by its blunt rounded spire and beaded collar. It resembles *C. supragranosum* Carpenter, a smaller and more turreted species living in southern California. In size *C. coalingense* is more like another possible relative, a Japanese species in the collections of the National Museum labeled *C. mul-*

[89] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1).

tiliratum Sowerby,[90] which, however, also has a more turreted spire. A variety named *C. coalingense* var. *privum* Stewart, n. var. (pl. 32, fig. 5), which has a lower spire than *C. coalingense*, occurs in the Etchegoin formation. A single specimen of *C. coalingense* from the Pliocene of the Santa Maria district (U. S. G. S. locality 4474) is peculiar in having the spirals outside the columellar area on the base so poorly developed as to be scarcely distinguishable. *C. kerri* Arnold (pl. 15, fig. 21) has a straight-sided acute spire and beaded spirals. It is very similar to *C. "annulatum* (Martyn)" and *C. variegatum* Carpenter, both of which range from Alaska to southern California. A single specimen of *C. kerri* is sufficiently well preserved to show, however, that the spirals on the early whorls are not beaded as they are on its living relatives. *C.* cf. *C. gemmulatum* Carpenter (pl. 15, figs. 22, 23) has a turreted spire and two main spirals. The few incomplete specimens available have a slightly more prominent beaded collar than *C. gemmulatum*, a species living in southern California. (*R. S.*)

The genus *Turcica* was found only in the *Pecten* and *Acila* zones. The fossils are named *Turcica caffea* Gabb var. *brevis* Stewart, n. var. (pl. 11, figs. 1–6). They differ from the Recent California *T. caffea* in the tighter coiling of the later whorls and in the narrower interval between the main spiral band and the next band toward the base. Only one large specimen (length, 30 millimeters) of *T. caffea* is avilable. This living California species is very closely related to *T. imperialis* A. Adams [91] from Japan; in fact, the distinguishing characters of these two species are not known. The fossils from the Kettleman Hills differ also from *T. imperialis*, 25 specimens of which were examined, in the tighter coiling of the later whorls. *T. caffea brevis* occurs with a typical *Pecten* zone fauna at the northwest end of Jacalitos Dome, in the foothills west of the Kettleman Hills (U. S. G. S. localities 4758 and 12323). On the basis of the narrow interval it is also present in the Santa Maria district [92] in strata that are possibly of the same age as the upper part of the San Joaquin; and at Pacific Beach, San Diego, presumably in the San Diego formation. (*R. S.*)

Turbinidae.—The only representative of the family Turbinidae is a large *Pachypoma*, from the *Siphonalia* zone of the Etchegoin formation, comparable to *P. precursor* (Dall) of the Empire formation of Oregon. On *P. precursor* the interval between the basal carina and the next spiral toward the suture is wider than in the living California species *P. "inaequalis* (Martyn)." The presence of two rows of nodes between the basal carina and the diagonal ribs on some Recent specimens suggests that the living species has one more spiral band than *P. precursor*. (*R. S.*)

Viviparidae?—The discovery of molds of the viviparid(?) operculum *Scalez petrolia* Hanna and Gaylord, in association with fresh-water fossils and leaves on the east side of South Dome at a horizon between the *Pecten* zone and the probable equivalent of the *Neverita* zone, is of special interest, as they are the only specimens so far discovered at an outcrop locality. *Scalez petrolia* has been discussed by Woodring, Roundy, and Farnsworth.[93] The horizon at which the Kettleman Hills fossils were found corresponds approximately to the upper *Scalez* zone in the southern San Joaquin Valley subsurface section.[94] *Viviparus* sp.? has been recorded from the upper *Scalez* zone [95] and immediately overlying strata, and it has been suggested that similar shells in the lower *Scalez* zone represent *Vipiparus*.[96] These shells in both zones, however, are probably to be assigned to a relatively large *Fluminicola*, possibly *F. kettlemanensis* Pilsbry. In the subsurface section *Scalez* is more abundant in the lower *Scalez* zone than in the upper *Scalez* zone. No specimens of *Scalez* have been found in the Kettleman Hills in strata that correspond roughly to the lower *Scalez* zone according to the suggested correlations shown in figure 13—strata between the *Littorina* zone and the top of the Etchegoin formation. (*W. P. W.*)

Littorinidae.—*Littorina mariana* Arnold occurs in the Tulare formation (pl. 4, figs. 4–6), in the upper *Mya* zone (pl. 8, figs. 1–6) and *Pecten* zone of the San Joaquin formation, and in the *Littorina* zone (pl. 29, figs. 8, 9) and upper *Pseudocardium* zone of the Etchegoin. The type of *L. mariana* and of the variety *alta* Arnold was collected from the upper *Mya* zone of the Kettleman Hills. Large suites of specimens from a single locality show gradations between the two forms. Arnold considered *L. mariana* to be closely allied to *L. grandis* Middendorff, a northern living species. *L. mariana* differs from Alaskan and Japanese specimens of *L. grandis*, however, in having a smaller aperture, and the early whorls are not carinate as on the living species. The fossils are probably related to *L. scutulata* Gould, a Recent species ranging from Alaska to Lower California, but have a thicker shell and coarser spirals. They also appear to be closely related to *L. remondii* Gabb, an upper Miocene species that is smaller and has flatter whorls and a carinate to subrounded periphery. *L. pittsburgensis* Clark,[97] based on a rounded smooth (worn?) specimen from the type region of *L. remondii*, closely resembles small worn

[90] Pilsbry, H. A., Manual of conchology, vol. 11, p. 342, pl. 15, figs. 45, 46, 1889.

[91] Pilsbry, H. A., Idem, p. 414, pl. 63, figs. 30, 31.

[92] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 322, p. 60, pl. 21, figs. 4, 5 (*Thalotia caffea*), 1907.

[93] Woodring, W. P., Roundy, P. V., and Farnsworth, H. R., Geology and oil resources of the Elk Hills, Calif., including Naval Petroleum Reserve No. 1: U. S. Geol. Survey Bull. 835, pp. 33–36, pl. 10, 1932.

[94] Barbat, W. F., and Galloway, John, San Joaquin clay, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 18, p. 486, fig. 1, 1934.

[95] Idem.

[96] Woodring, W. P., Roundy, P. V., and Farnsworth, H. R., op. cit., pp. 34–35.

[97] Clark, B. L., Fauna of the San Pablo group of middle California: California Univ., Dept. Geol., Bull., vol. 8, p. 484, pl. 65, fig. 22, 1915.

specimens of *L. mariana*. Should *L. remondii* be found to include round-shouldered forms, *L. mariana* may be considered a variety or a synonym of that species. (*W. P. W.*, *R. S.*)

Amnicolidae.—Amnicolids are particularly abundant in the lower part of the Tulare formation. They also occur in fresh-water strata in the San Joaquin formation, in the upper part of the *Littorina* zone of the Etchegoin formation, and in Etchegoin strata overlying the *Littorina* zone.

Fluminicola kettlemanensis Pilsbry,[98] a relatively large species, occurs in the *Pecten* zone, and similar forms occur in the San Joaquin formation below the *Pecten* zone and also in the upper *Pseudocardium* zone. The common *Fluminicola* from the Tulare formation is identified as *F.* cf. *F. spiralis* Pilsbry (pl. 4, figs. 7–11). This form appears to lack the microscopic spiral striae of *F. spiralis*, the type of which is from a well in the San Joaquin Valley. A carinate species from the Tulare formation, *F.* cf. *F. yatesiana* (Cooper) (pl. 4, fig. 12), resembles the larger *F. yatesiana*, described from a locality in Santa Clara County. (*W. P. W.*)

The genus *Pyrgulopsis* is represented in the Tulare formation by a small species, *P. vincta* Pilsbry (pl. 4, figs. 13–16), the body whorl of which is strongly carinate or rounded. (*W. P. W.*)

Three species of the extinct genus *Calipyrgula* are present in the Tulare formation. *C. carinifera* Pilsbry (pl. 4, figs. 17, 18) has a carinate or weakly carinate shoulder; *C. ellipsostoma* Pilsbry (pl. 4, fig. 19) has less convex and less turreted whorls and a rounded or faintly carinate shoulder; and *C. stewartiana* Pilsbry (pl. 4, figs. 20, 21) is a small species. (*W. P. W.*)

Littoridina woodringi Pilsbry (pl. 4, fig. 22) is a Tulare species belonging to a genus now living in South America and Central America and as far north along the Atlantic coast as Delaware but not on the Pacific coast of the United States. (*W. P. W.*)

Amnicola is the most abundant genus in the Tulare formation. The Tulare species is identified as *A. longinqua* Gould (pl. 4, figs. 23–27), which is living in southern California. The form that is most similar to specimens from the type region of *A. longinqua* in the Colorado Desert is abundant at localities 20 and 21, but even in these lots only a few shells have the completely detached peristome (pl. 4, fig. 23) characteristic of most adults from the type region. Many lots include specimens, or consist principally of specimens, that are more slender and have less inflated whorls (pl. 4, figs. 26, 27). The shells at locality 17 are stouter than elsewhere. An unidentified *Amnicola* occurs near the top of the Etchegoin. The small shells from the upper part of the *Littorina* zone identified as *Amnicola?* are poorly preserved, generally due to a calcareous crust. It is reasonably certain, however, that they represent the fresh-water genera *Amnicola* or *Hydrobia* and not the brackish-water genus *Syncera*, also known as *Assiminea*. (*W. P. W.*)

In the collections from the Tulare formation *Hydrobia* is less abundant than *Amnicola*. *Hydrobia* may, however, be more abundant than the collections indicate, for at many localities where collections were not made small smooth amnicolids were assumed to represent *Amnicola*. *Hydrobia andersoni* (Arnold) (pl. 4, figs. 28–34) is recognized by its acute many-whorled turreted spire. As shown by the illustrations, the outline is variable. An exceptionally short, stout form, apparently not represented in the collections of the Geological Survey, has been named *H. andersoni sterea* Pilsbry. The type of *H. andersoni* and three other specimens from the type locality (U. S. G. S. locality 4732) are shown on plate 4, figures 28–31. The type is exceptionally large. *A. birkhauseri* Pilsbry, a small slender form, appears to be rare. (*W. P. W.*)

The extinct genus *Brannerillus* is represented in the Tulare formation by two species. *B. physispira* Hannibal (pl. 4, figs. 35–38), the type of the genus, is carinate, and *B. involutus* Pilsbry (pl. 4, figs. 39–50; pl. 5, figs. 1–3) is rounded. At locality 21, where about 1,500 specimens were collected, *B. involutus* is very variable. Most of the shells from this locality have the sunken perforate apex characteristic of the genus, but some show gradations to a form with a convex imperforate apex (pl. 4, figs. 40, 42, 44, 46, 48). Specimens that have a convex imperforate apex may be confused with stout specimens of *Amnicola longinqua*, with which they are found, but the wider umbilicus and many-whorled minute protoconch of *Brannerillus*, which may be somewhat awry, generally serve to distinguish them. On several specimens of *B. involutus* from locality 21 the apex extends down to the level of the upper edge of the aperture, completely filling the umbilicus. These shells represent a transition to apparently sinistral, actually ultradextal, shells (pl. 5, fig. 1), on one of which the aperture emerges in a plane at right angles to the normal position (pl. 5, figs. 2, 3). The figures of the apparently sinistral shells should be inverted to be oriented like the other figures of this species. (*W. P. W.*)

Pleuroceridae.—*Goniobasis kettlemanensis* Arnold occurs in the *Pecten* zone (pl. 15, figs. 5, 6, 14) of the San Joaquin formation and in strata between the *Pecten* and *Neverita* zones. The Tulare form *G. kettlemanensis woodringi* Pilsbry (pl. 4, figs. 51, 52) is larger and has subdued axial ribs or wrinkles, but lacks the strongly frilled spirals of *G. occata* (Hinds) that lives in the Sacramento River. The smooth Tulare species *G. arnoldiana* Pilsbry (pl. 4, figs. 53, 54) is stouter than the Recent *G. nigrina* Lea, and the outer lip is more sinuous. (*W. P. W.*)

Turritellidae.—*Turritella* is represented by two specimens from the *Siphonalia* zone of the Etchegoin for-

[98] Pilsbry, H. A., Mollusks of the fresh-water Pliocene beds of the Kettleman Hills and neighboring oil fields, Calif.: Acad. Nat. Sci. Philadelphia Proc., vol. 86, p. 549, pl. 19, figs. 1–3, 1935. The Tulare amnicolids also are described in this publication.

mation. Though they are poorly preserved, they are determined as *T. vanvlecki* Arnold (pl. 31, fig. 2) with reasonable certainty. *T. vanvlecki* was described from the *Glycymeris* zone of the Etchegoin on Anticline Ridge, northwest of North Dome. According to Nomland,[99] it occurs in the lowest invertebrate fossil zone in the Pliocene section on Anticline Ridge, where it is associated with a fauna corresponding to the Etchegoin fauna of North Dome with the exception of *Lyropecten "terminus* (Arnold)," [1] recorded by Nomland at his locality 2096. Outside the Coalinga district *T. vanvlecki* has been found 3 miles north of Bradley,[2] in the Salinas Valley, and in the Santa Clara Valley[3] in Ventura County. *T.* cf. *T. vanvlecki* has been reported with a fauna of probable Miocene age from the subsurface section of the Fruitvale oil field[4] near Bakersfield. (*R. S.*)

Calyptraeidae.—Two forms of *Calyptraea*, one smooth and the other ribbed, are recorded from the Etchegoin and San Joaquin formations. The smooth form is listed as *C.* cf. *C. inornata* (Gabb) (pl. 11, fig. 7; pl. 15, fig. 10; pl. 20, fig. 6), the ribbed form as *C.* cf. *C. filosa* (Gabb) (pl. 8, fig. 7). It is possible that only one species is represented and that the smooth specimens are exfoliated or are a smooth variety of the ribbed form. The smooth shells, however, resemble a Recent West Coast species recorded as *C. mamillaris* Broderip or *C. fastigiata* Gould but are generally higher and more slender, whereas no species similar to the ribbed form is living on the Pacific coast. A ribbed *Calyptraea* in the Pliocene of coastal southern California resembles the Recent *C. radians* (Lamarck). Smooth shells from the Kettleman Hills on which the apex is preserved have a large apex. The apex is not preserved on the ribbed fossils. *C. inornata* was described from the Pliocene Purisima formation at Halfmoon Bay; its characters are not well known. The type of *C. filosa* is from the upper Miocene of Contra Costa County. (*W. P. W.*).

Crepidulidae.—Two forms of *Crepidula*, one large and the other small, are present in the Etchegoin and San Joaquin formations, and an undetermined *Ianacus?* was found in the *Siphonalia* zone. The large *Crepidula* is identified as *C. princeps* Conrad, which was described from late Pliocene or early Pleistocene strata at Santa Barbara. It is most abundant in the Etchegoin formation, particularly in South Dome, but occurs at several horizons in the San Joaquin. The small forms, identified as *C.* cf. *C. onyx* Sowerby (pl. 31, fig. 6), may possibly represent young shells of the large form. *C. onyx* is a Recent California species. (*W. P. W.*, *R. S.*)

Naticidae.—The relative abundance of the naticid genera *Neverita* and *Lunatia* is reversed in the Etchegoin and San Joaquin formations. *Lunatia* is relatively abundant in the Etchegoin and rare in the San Joaquin, whereas *Neverita* is perhaps the most abundant gastropod in the San Joaquin but was not found in the Etchegoin.

Neverita reclusiana (Deshayes), a Recent California species, is the most abundant gastropod in the *Neverita* (pl. 20, figs. 1–5), *Pecten*, and *Trachycardium* (pl. 15, figs. 11, 19, 20) zones; and poorly preserved and doubtfully identified specimens occur in the Cascajo conglomerate member and *Acila* zone of the San Joaquin formation. The shells are generally exfoliated (pl. 20, fig. 1) but are locally well preserved. With the exception of rare specimens they are small or of medium size. The outline is variable, ranging from subcylindrical to conical. Subcylindrical specimens (pl. 15, fig. 19; pl. 20, fig. 4) are not represented in collections of Recent shells at the National Museum or the Academy of Natural Sciences of Philadelphia. The Recent shell with a subcylindrical outline figured by Grant and Gale is evidently the Pleistocene and Recent form designated *imperforata*.[5] The Kettleman Hills fossils that are subcylindrical resemble in outline a Miocene form described by Gabb as *Neverita callosa*. *N. reclusiana* is the type of the subgenus *Glossaulax* Pilsbry, which is characterized by the groove on the umbilical callus and is represented throughout the Tertiary on the Pacific coast. (*W. P. W.*, *R. S.*).

The specimens identified as *Lunatia* cf. *L. lewisii* (Gould) (pl. 15, fig. 8) are generally poorly preserved. *L. lewisii* is a Recent species that has a more northern range than *Neverita reclusiana*.

"Nassidae".—Four species of *"Nassa"* are recognized in the Kettleman Hills fauna: a large and a small species in the Etchegoin and a large and a small species in the upper part of the San Joaquin. They are assigned to *"Nassa"* because their more exact generic relationships have not been worked out.

The large Etchegoin species, *"Nassa" moraniana* Martin (pl. 34, figs. 5, 6), occurs in the *Siphonalia* zone, and probably in the *Macoma* and *Patinopecten* zones. It has lirations on the columella and inner lip, thus resembling the Recent California species *"N." fossata* Gould. Apertures are accessible on only three Kettleman Hills specimens from two localities, but the lirations are well shown on many specimens from the Santa Maria district, one of which was figured by Arnold and Anderson as *"Nassa" californiana* (Con-

[99] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geology, Bull., vol. 10, p. 228 (locality 2096), p. 229 (locality 2377), table opp. p. 230, pl. 12, fig. 5, 1917.

[1] It appears to be doubtful whether the Coalinga district *Lyropecten* recorded as *L. terminus* is that form. (See Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif., and their inferred environment: U. S. Geol. Survey Prof. Paper 190, p. 34, 1938.)

[2] Arnold, Ralph, op. cit. (Bull. 396), p. 85, 1909 [1910].

[3] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), pp. 34, 773, pl. 24, fig. 22, 1931.

[4] Gale, H. R., in Preston, H. M., Report on Fruitvale oil field: California Oil Fields (California Dept. Nat. Res. Div. Oil and Gas), vol. 16, no. 4, p. 16, 1931.

[5] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), fig. 14, p. 803.

rad).[6] The large species from the *Pecten* zone and probably from the *Acila* zone of the San Joaquin is "*Nassa*" *coalingensis* Arnold (pl. 15, fig. 3). It has a smooth inner lip and high spire and is typically more slender than "*N.*" *moraniana*. "*N.*" *coalingensis* is probably closely related to a living California species called "*N.*" *californiana* (Conrad). The living species has more axial ribs on the body whorl and large specimens have lirations on the posterior part of the outer lip, which were not observed on the fossils. The distinction between "*N.*" *moraniana* and "*N.*" *coalingensis* may prove useful in separating Etchegoin and San Joaquin faunas in the Coalinga district. Inasmuch, however, as "*N.*" *moraniana* occurs in the Santa Maria district with a fauna of possible San Joaquin age, it is not likely that the two species will prove useful in distinguishing equivalents of the Etchegoin and San Joaquin in other areas. (*R. S.*)

The small "*Nassa*" from the Etchegoin is named "*Nassa*" *miser* (Dall) *iniqua* Stewart, n. var. (pl. 34, fig. 8). It differs from the living "*N.*" *miser*[7] from the Pacific coast of Central America and Mexico in being more slender; some fossil specimens have pseudovarices on the body whorl. "*N.*" *miser iniqua* has seven spirals on the body whorl, only the posterior three of which are completely exposed on the whorls of the spire; young specimens of "*N.*" *moraniana* of the same size have 11 spirals on the body whorl. Arnold[8] figured "*N.*" *miser iniqua* from the Etchegoin of the Jacalitos Hills as "*N.*" *californiana* (Conrad). "*N.*" cf. *N. waldorfensis* Arnold (pl. 39, fig. 4) is the small species that is found in the upper part of the San Joaquin formation. It differs from "*N.*" *miser iniqua* in having nine spirals on the body whorl and four exposed on the whorls of the spire. These four spirals indicate a close relationship to the living California "*N.*" *mendica* Gould. "*N.*" *waldorfensis* was described from the Santa Maria district in association with a fauna resembling that of the upper part of the San Joaquin. About 100 specimens from the Santa Maria district are available. They are very similar to "*N.*" *mendica*. Most of them can, however, be distinguished from the living species by their prominent posterior spiral, but this character is not well defined on the type specimen. "*N.*" *waldorfensis* also lacks the secondary spiral above the suture that is present on some specimens of "*N.*" *mendica*. (*R. S.*)

Neptuneidae.—The genus *Siphonalia* is now living in Japanese waters but has not been found living in the eastern Pacific. Perhaps its nearest relatives in the eastern Pacific are *Solenosteira* and *Kelletia*. *Siphonalia* is represented in the *Siphonalia*, *Macoma*, and *Patinopecten* zones of the Etchegoin and in the *Acila* and *Pecten* zones of the San Joaquin. The Etchegoin *Siphonalia* is a large species sculptured with strong nodes, *S. kettlemanensis* (Arnold) (pl. 31, figs. 1, 7). A form of this species that has practically no nodes occurs in the *Pecten* zone. Arnold's specimens of *S. kettlemanensis* from the Jacalitos formation are at least related to that species, though they are too poorly preserved to be unquestionably identified. An apparently closely related upper Miocene species has been named *Chrysodomus pabloensis* Clark.[8a] As suggested by Grant and Gale,[9] the inadequately known *S. diegoensis* (Dall) from the Pliocene San Diego formation may prove to be conspecific with *S. kettlemanensis*; in that event *S. diegoensis* will be the valid name for the Kettleman Hills species. The *Siphonalia* from the *Acila* zone is a smaller, more slender, and weakly sculptured species identified as *S.* cf. *S. humerosa* (Gabb) (pl. 11, fig. 9). *S. humerosa* was originally described from strata generally assigned to the lower Pliocene, at Elsmere Canyon in Ventura County. It resembles the living Japanese *S. trochulus* (Reeve)[10] in that it lacks axial ribs or nodes on the body whorl. "*Chrysodomus*" *portolaensis* Arnold, from the Etchegoin of the White Creek syncline northwest of Coalinga is probably related to *S. humerosa*. Poorly preserved specimens from the oldest exposed Etchegoin strata in South Dome are similar to "*Chrysodomus*" *portolaensis*. (*R. S.*)

Muricidae.—With the exception of unidentified poorly preserved specimens, muricid gastropods were found only in the *Pecten* zone of the San Joaquin formation. The most abundant species is identified as *Jaton* cf. *J. festivus* (Hinds) (pl. 15, figs. 2, 9). The form shown on plate 15, figure 9, is a variety on which the varices are not curved, but some specimens have the typical curved varices. This variety with straight varices is possibly more abundant in the *Pecten* zone than among living members of *J. festivus*. Although numerous specimens of the fossils are available, none show the development of the ornamentation. *Jaton* is better known in California as *Purpura*, a name used by Martyn. Martyn's "Universal Conchologist" as a source for valid systematic names is, however, very doubtful.[11] Two groups of *Jaton*, probably of at least subgeneric rank, are now living on the California coast. *J. festivus* (Hinds) and *J. carpenteri* (Dall) represent one group; "*Purpura foliata* Martyn" and "*Purpura*" *nuttalli* (Conrad), characterized by a "tooth" on the outer lip, represent the other group, the range of which extends farther north. Just which, if either, of these

[6] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 322, p. 59, pl. 24, fig. 4, 1907.

[7] Dall, W. H., The Mollusca and the Brachiopoda (*Albatross* Repts.): Harvard Coll. Mus. Comp. Zoology Bull., vol. 43, p. 307, pl. 4, fig. 1, 1908.

[8] Arnold, Ralph, op. cit. (Bull. 396), pl. 27, fig. 8, 1909 [1910].

[8a] Clark, B. L., Fauna of the San Pablo group of middle California: California Univ., Dept. Geology, Bull., vol. 8, p. 496, pl. 67, fig. 8, 1915.

[9] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), p. 643.

[10] Reeve, L. A., Conchologia Iconica, *Buccinum*, pl. 2, fig. 7, 1845.

[11] Winckworth, R., Notes on nomenclature: Malacol. Soc. London Proc., vol. 18, pp. 228–229, 1929. Stewart, R. B., Gabb's California Cretaceous and Tertiary type lamellibranchs: Acad. Nat. Sci. Philadelphia Spec. Pub. 3, p. 30, 1930.

two groups is typical *Jaton* is not known, but presumably typical *Jaton* lacks the "tooth." (*R. S.*)

The *Pecten* zone *Tritonalia* cf. *T. lurida* Middendorff (pl. 15, fig. 12) may be specifically distinct from the living California *T. lurida*, because the spirals on the body whorl are more distinctly differentiated as primary and secondary spirals than on Recent specimens. (*R. S.*)

Thaididae.—*Nucella etchegoinensis* (Arnold) is abundant in the Cascajo conglomerate member of the San Joaquin (pl. 24, figs. 16–18) and occurs at other horizons in the San Joaquin and Etchegoin formations. A large variety sculptured with relatively strong spirals is present in the *Macoma* and *Patinopecten* zones of the Etchegoin (pl. 36, figs. 1, 7). *N. etchegoinensis* is closely related to the Recent Pacific coast species called *N. lamellosa* (Gmelin) and perhaps should be cited as a variety or subspecies of the living species. The fossils lack the axial lamellae characteristic of the living species in the northern part of its range. The axial lamellae, however, vary in strength, and they are absent or faintly developed on a form named *N. lamellosa* var. *franciscana* (Dall), ranging from San Francisco Bay [12] to Puget Sound. This Recent form has not been studied, but perhaps it is the same as the Cascajo form. (*W. P. W.*)

The genus *Forreria* occurs in and below the *Siphonalia* zone and at the base of the exposed section in South Dome of the Etchegoin formation and in the *Pecten* zone of the San Joaquin.

Forreria coalingensis (Arnold), characterized by strong widely spaced spirals, was found only in the type region near the south end of South Dome. This species also occurs near the base of the Etchegoin in the Kreyenhagen Hills [13] and in the Jacalitos formation.[14] It is also associated with Jacalitos species in a collection from U. S. G. S. locality 11132, about a mile south of Curry Mountain. Its distribution in the foothills west of the Kettleman Hills suggests that the oldest Etchegoin strata exposed in South Dome are close to the base of the formation. (*W. P. W.*)

The typical form of *Forreria magister* (Nomland) (pl. 36, figs. 11, 12) occurs in the Etchegoin of North Dome. Some specimens have a spine or varix on the lower (anterior) angulation of the later part of the body whorl. No specimens from the *Pecten* zone show this character. It is convenient, therefore, to distinguish the *Pecten* zone variety with the name *F. magister* var. *munda* Stewart, n. var. (pl. 15, figs. 17, 18). The form from Anticline Ridge, apparently from the lower part of the Etchegoin, named *F. belcheri* var. *avita* (Nomland), was described as having a more evident development of nodes on the lower part of the body whorl than *F. magister*. This form, therefore, is probably more closely related to the typical *F. magister* than is the variety *munda*. *F. magister* seems distinct from *F. belcheri* (Hinds), which ranges from San Pedro southward to Lower California and is the only living species along the Pacific coast. The bases of the varixlike spines of large fossil specimens are smaller than those of the living species, and it seems doubtful whether the whorls of the spire had the varixlike spines that are well developed on the living species. (*R. S.*)

Cancellariidae.—Three large Cancellarias are recognized in the *Pecten* zone of the San Joaquin formation: a form that lacks nodes, *Cancellaria rapa* Nomland (pl. 15, figs. 1, 7), and two noded forms, *C. altaspira* Gabb and *C.* cf. *C. tritonidea* Gabb. The occurrence of *C. rapa* in the *Pecten* zone is of interest, because the stratigraphic position of this species in the Coalinga district was not heretofore known. *C. rapa* has been identified in the Santa Maria district,[15] and *C. elodiae* Carson, from the same locality, is probably *C. rapa*. *C. hamlini* Carson, from Elsmere Canyon in Ventura County, is also probably closely related to *C. rapa*. The noded form identified as *C. altaspira* Gabb does not have such a high spire as typical *C. altaspira*, which is from Elsmere Canyon, and may represent the variety *perrin* Carson, described from the Santa Maria district. It seems likely, however, that *C. rapa* itself is a variety of *C. altaspira* that lacks nodes. *C. altaspira* and its allies can be separated from the Pleistocene *C. tritonidea* Gabb, as figured from San Pedro by Arnold,[16] by the absence of a shoulder on the early whorls. Not enough specimens of *C. tritonidea* are available to determine whether this criterion is of specific value. The distinction may, however, be useful and may have a stratigraphic significance. *C. altaspira* is presumably older than *C. tritonidea*, but their ranges possibly overlap. A small imperfect specimen from the *Pecten* zone is identified as *C.* cf. *C. tritonidea* on the basis of the shoulder. The nearest living relative of this group of large Cancellarias seems to be *C. spengleriana* Deshayes from Japan. None of these species represents *Cancellaria* in the restricted sense. Superficially they are similar to *Progabbia* and *Euclia*, but a closer relation with *Merica* and *Crawfordiana* may be evident when the development of their ornamentation is known. (*R. S.*)

A worn specimen referable to *Progabbia* (pl. 15, fig. 4) was found in the *Pecten* zone, and this genus also occurs in the *Siphonalia* zone.

Columbellidae.—A stout *Mitrella* from the *Neverita* zone is identified as *M. gausapata* (Gould) (pl. 20, fig. 7), a Recent species living on the California coast. A more slender form from the *Acila* zone, *M.* cf. *M. gausapata* (pl. 11, fig. 5), may be referable to *M. richthofeni* Gabb,

[12] Packard, E. L., Molluscan fauna from San Francisco Bay: California Univ., Pub. in Zoology, vol. 14, p. 337, pl. 40, figs. 5a, 5b, 1918.

[13] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 133 (locality 4749).

[14] Nomland, J. O., Fauna from the lower Pliocene at Jacalitos Creek and Waltham Canyon, Calif.: California Univ., Dept. Geology, Bull., vol. 9, p. 203, 1916. The Etchegoin Pliocene of middle California: Idem vol. 10, pp. 213, 221, 1917.

[15] Carson, C. M., New molluscan species from the California Pliocene: Southern California Acad. Sci. Bull., vol. 25, p. 51, 1926.

[16] Arnold, Ralph, op. cit. (Bull. 396), pl. 26, fig. 10.

a Pliocene species from Sonoma County, the characters of which are not well known. Unidentified remains of *Mitrella* were found in the Etchegoin of North and Middle Domes. (*W. P. W.*)

Planorbidae.—*Menetus vanvlecki* (Arnold) (pl. 5, figs. 10–15) is the most abundant of the Tulare planorbids. This species is the type of the extinct subgenus *Planorbifex* Pilsbry, characterized by a rounded periphery combined with a weakly or strongly carinate shoulder and base, producing a *Valvata*-like outline. *Carinifex sanctaeclarae marshalli* Arnold (pl. 5, figs. 4–6) also is abundant. This form is smaller and less carinate than typical *C. sanctaeclarae* Hannibal, which is based on fossils from Santa Clara County. It is also smaller than the Recent *C. newberryi* (Lea) and lacks the peripheral carina of the living species. The absence in the Tulare formation of large planorbids of the genus *Helisoma* is noteworthy. The small form described as *Helisoma? kettlemanensis* Pilsbry was not recognized in the collections of the Geological Survey. (*W. P. W.*)

PELECYPODS

Nuculidae.—The genus *Acila*, represented by the living *A. castrensis* (Hinds) (pl. 11, figs. 11–17), is a notable member of the *Acila* zone fauna. Except rare specimens from a horizon above the *Acila* zone and unidentified molds from the lower part of the Etchegoin of Middle Dome, the genus was not found at other horizons. *A. castrensis* is reported from Bering Sea to San Diego. A great deal of information on this species has been recently collected.[17] (*R. S.*)

Arcidae.—An incomplete paired specimen from the *Siphonalia* zone of the Etchegoin formation, *Arca* cf. *A. sisquocensis* Reinhart, is the first representative of the *Arca noae* group discovered in the Coalinga district. It is much larger than *A. sisquocensis*,[18] the type of which is from the Pliocene of the Santa Maria district. The Etchegoin *Arca* is probably more closely related to a Japanese species in the collections of the National Museum labeled *A. krausii* Philippi [19] (123666) than to the living Pacific coast species from Lower California, as the cardinal area has many more ligamental grooves than the living American species. The cardinal area of *A. terminumbonis* Grant and Gale, from the Pliocene of Elsmere Canyon, also has numerous ligamental grooves. When more representatives of the California Miocene [20] and Pliocene Arcas are known they may prove to represent a distinct group. (*R. S.*)

The genus *Anadara* is one of the most abundant fossils in the Etchegoin and San Joaquin formations. All the forms appear to represent one species, which is traditionally identified as *A. trilineata* (Conrad). That identification is accepted and the species is cited as *Anadara trilineata* (Conrad) of Arnold, for the usage in the present report is based on Arnold's identification of specimens from the Coalinga district. *Anadara trilineata* was described by Conrad as having been collected by Newberry at Santa Barbara. According to Newberry's itinerary, however, he was nowhere near Santa Barbara, and no *Anadara* has been found at Santa Barbara. The type specimen appears to be lost and the characters of *A. trilineata* will remain uncertain until it is found at Santa Barbara or until some other type locality is arbitrarily selected. It is possible that Conrad mixed collections from Newberry and Blake received at about the same time and that the original material of *A. trilineata* came from the Kettleman Hills or nearby. Under the locality designation "Tulare Valley?" Conrad described as *Arca microdonta* a fossil received from Blake, who cited the locality as "the hills of the Coast Mountains near the Tulares." The Kettleman Hills fit this description, for Blake approached the foothills from the east. The type of *Arca microdonta*, a well-preserved right valve of an *Anadara*, is in the National Museum. Not only is it unlike any form of *Anadara* known from "the hills of the Coast Mountains near the Tulares," but it is unlike any fossil or living species so far discovered in California; it may have been collected by Blake in Panama during his trip to California.[21] This is a matter of speculation now not subject to verification, but it may be worth consideration should a decision be reached to fix arbitrarily a type locality for *A. trilineata*. (*W. P. W.*)

The typical form of *Anadara trilineata*, as here accepted, occurs at intervals throughout the San Joaquin formation (pl. 11, figs. 10, 19–24; pl. 20, fig. 17), and small specimens also occur near the top of the Etchegoin, at least in the *Pseudocardium-Anadara* zone of Middle and South Domes. It is particularly abundant in the *Acila* zone. It is markedly inequilateral and has an asymmetrical base. A small elongate flat variety that has a more symmetrical base occurs in the *Neverita* zone (pl. 20, figs. 15, 16) and *Pecten* zone (pl. 14, fig. 7). A short inflated variety (pl. 29, figs. 2, 6), many specimens of which are thick-shelled, is characteristic of the upper *Pseudocardium* zone. Aside from this upper *Pseudocardium* zone variety and the small specimens near the top of the Etchegoin, the Anadaras from the Etchegoin have the beaks roughly halfway between the ends of the cardinal area (pl. 31, fig. 9)—that is, the Anadaras are almost equilateral. This more equilateral variety resembles Conrad's figure of *A. canalis*, but inasmuch as the figure is the only

[17] Schenck, H. G., Nuculid bivalves of the genus *Acila*: Geol. Soc. America Spec. Pub. 4, pp. 96–99, 135, pl. 10, 1936.

[18] Reinhart, P. W., Three new species of the pelecypod family Arcidae from the Pliocene of California: Jour. Paleontology, vol. 11, p. 182, pl. 28, figs. 1–3, 1937.

[19] Philippi, R. A., Abbildungen und Beschreibungen neuer oder wenig gekannter Conchylien, vol. 3, p. 88, *Arca*, pl. 5, figs. 8–10, Cassel, Fischer, 1851.

[20] Loel, Wayne, and Corey, W. H., The Vaqueros formation, lower Miocene of California, I, Paleontology: California Univ., Dept. Geol. Sci., Bull., vol. 22, p. 141, 1932. Woodring, W. P., A Miocene *Haliotis* from southern California: Jour. Paleontology, vol. 5, p. 35, 1931.

[21] For a fuller discussion of this matter with literature citations see Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif., and their inferred environment: U. S. Geol. Survey Prof. Paper 190, p. 31, 1938.

basis for identification, it is cited as *A. trilineata* variety cf. *canalis*. *A. canalis*, as well as *A. trilineata*, was claimed to have been collected by Newberry at Santa Barbara. *A. trilineata* variety cf. *canalis* also occurs in the Cascajo conglomerate member and at a higher horizon in the lower part of the San Joaquin between the Cascajo and the *Neverita* zone (pl. 24, fig. 7). Though the ranges of the strongly inequilateral and more equilateral forms overlap, the forms may prove to have stratigraphic significance, at least in the Coalinga district. (*W. P. W., R. S.*)

Anadara trilineata and its allies appear to be extinct, and a close living relative has not been recognized. *Anadara amicula* (Yokoyama),[22] from the Neogene of Japan, is probably a closely related species, but the group is apparently absent from the living fauna of Japan. *A. trilineata* variety cf. *canalis* (Conrad) resembles *A. tatunokutiensis* (Nomuri and Hatai),[23] which is also from the Neogene of Japan. (*R. S.*)

Glycymeridae.—*Glycymeris* was found only in the Etchegoin formation of North Dome. The species represented is identified as *G. grewingki* Dall (pl. 29, figs. 10, 11; pl. 33, figs. 7, 8), the type of which is from the Empire formation of Oregon. The North Dome species is probably conspecific with *G. coalingensis* Arnold, from the Etchegoin at Alcalde Canyon in the Coalinga district, the differences between *G. coalingensis* and *G. grewingki* cited by Arnold being due to differences in the state of preservation of the type specimens. The North Dome species can be separated from the living *G. subobsoleta* (Carpenter) by its greater height. The fossils, therefore, resemble the original figure of *G. septentrionalis* (Middendorff), but only a few beach-worn specimens of *G. septentrionalis* are available for comparison. Unfortunately it is not possible to determine whether the fossils are more closely related to the northern *G. septentrionalis* and *G. subobsoleta* or to the southern *G. migueliana* Dall and *G. corteziana* Dall. The greater height of the North Dome fossils is most evident on large specimens and suggests *G. profunda* (Dall),[24] a San Diego fossil, but North Dome specimens are not so much inflated as the few specimens of *G. profunda* available. If the greater inflation of *G. profunda* is not constant, the North Dome species may be conspecific with *G. profunda*. The name *grewingki* would, however, still be useful for the flat forms, at least as a variety, assuming that they are distinct from *G. septentrionalis*. Arnold's *G. septentrionalis* from the Etchegoin of the Coalinga district apparently represents young shells of his *G. coalingensis*. (*R. S.*)

[22] Yokoyama, M., Tertiary Mollusca from Shinano and Echigo: Tokyo Imp. Univ., Fac. Sci., Jour., sec. 2, vol. 1, p. 19, pl. 7, figs. 2–4 (*Arca*), 1925. Nomura, S., and Hatai, K., On some species of the genus *Arca* from the Neogene of northeast Honsyû, Japan: Japanese Jour. Geology and Geography, Trans. and Abstracts, vol. 13, pp. 63–69, pls. 12, 13, 1936.

[23] Idem.

[24] Dall, W. H., Fossil mollusks from later Tertiaries of California: U. S. Nat. Mus. Proc., vol. 1, p. 13, 1879 (*Axinea*). *Glycymeris profunda* is one of the few names for California Pliocene or Pleistocene mollusks omitted from Grant and Gale's catalog.

Mytilidae.—*Mytilus coalingensis* Arnold occurs in the Etchegoin and San Joaquin formations and is particularly abundant in the *Siphonalia* zone (pl. 32, figs. 3, 4). Shorter and more curved forms from the lower part of the *Patinopecten* zone resemble *M. kewi* Nomland, described from a Coalinga district locality that probably represents the Jacalitos formation. These forms from the *Patinopecten* zone appear to be variations of the typical *M. coalingensis*. Specimens of *M. coalingensis* are as large as the living *M. californianus* Conrad but may be distinguished from the living species by the thicker hinge plate and by the absence of radiating ridges. The nearest living relative of *M. coalingensis* seems to be the large Japanese species *M. crassitesta* Lischke,[25] which, however, does not have so thick a hinge plate and the teeth of large specimens of which are more distinctly formed. Specific criteria distinguishing *M. coalingensis* from the many California Miocene forms that have been named have not yet been worked out. (*R. S.*)

A small *Mytilus* from the upper *Mya* zone, and doubtfully from a horizon between the upper *Mya* and *Acila* zones, is identified as *M.* cf. *M. edulis* Linné (pl. 8, fig. 8). It represents the same species as the living species on the California coast called *M. edulis*. It is not certain, however, that the living California species is the European *M. edulis*. This small *Mytilus* has a thinner hinge plate than young specimens of *M. coalingensis*. (*W. P. W.*)

Volsella cf. *V. modiolus* (Linné) (pl. 37, figs. 1, 2), a relatively short, broad species, occurs near the base of the exposed Etchegoin in South Dome but was not found at other horizons; in fact, the genus was not observed in the Etchegoin of North Dome. The fossils, all of which are paired, appear to be identical with small specimens of the Recent California species called *M. modiolus*, but the California species may not be the same as the European *M. modiolus*. Two species of *Volsella*, both comparable to living California species, occur in the *Pecten* zone: a narrow species, *V.* cf. *V. recta* (Conrad) (pl. 13, fig. 15), and a broad species, *V.* cf. *V. capax* (Conrad) (pl. 16, fig. 3). *V.* cf. *V. recta* is a common fossil in the *Neverita* zone (pl. 20, figs. 13, 14). *V. directa* (Dall), from the Empire formation of Oregon, is probably the same form, but the relations of the Pliocene and Recent forms have not been determined. (*W. P. W., R. S.*)

Pectinidae.—The genus *Pecten*, represented by *P. coalingaensis* Arnold (pl. 13, figs. 1, 2, 17, 18; pl. 16, fig. 4), is characteristic of the *Pecten* zone and was found in place only in that zone. A specimen collected at an *Acila* zone locality may have been derived from older alluvium. On 150 valves of this species the number of ribs ranges from 15 to 23, but three-fourths of the inflated valves have 19 to 21 ribs, and three-

[25] Lischke, C. E., Japanische Meers-Conchylien, vol. 1, p. 151, pl. 11, figs. 1, 2, 1869.

fourths of the flatter valves have 18 to 20 ribs. The nearest living relative of *P. coalingaensis* is *P. cataractes* Dall, from the Gulf of California. The living species may be distinguished from *P. coalingaensis* by the presence of secondary radials in the interspaces on the flatter valve. All of 150 valves of *P. coalingaensis* lack secondary radials except 5, which have a radial in one or two interspaces, but only 1 of 29 left valves of *P. cataractes* lack the radials, and that valve is small (height, 22 millimeters). *P. coalingaensis* and its allies may be distinguished from *P. bellus* Conrad, a fossil species from Santa Barbara, and its allies, by the greater number of ribs, the greater inflation of the inflated valve, and the shorter internal channels—corresponding to the external ribs—on the flatter valve. The cross section of the ribs of the inflated valve also differ in the two groups: *P. bellus* has square-topped ribs, whereas *P. coalingaensis* has round-topped ribs. *P. coalingaensis* was treated as a variety of *P. bellus* by Grant and Gale, but a close relationship seems very doubtful. The two groups are evidently distinct in the living Japanese fauna, *P. bellus* being represented by *P. laqueatus* Lischke [26] and *P. coalingaensis* being represented by *P. puncticulatus* Dunker,[27] which does not have secondary radials on the flat valve. The two specimens of *P. puncticulatus* available differ from *P. coalingaensis* in having fewer large ribs on the flatter valve and small ribs at the dorsal margins of the disc. The inflated right valve of the Japanese species has slightly flatter ribs. *P. vogdesi*, from the Pleistocene at San Pedro, may be a connecting form between *P. coalingaensis* and the living *P. cataractes*. The two specimens of *P. vogdesi* examined lack the secondary radials on the flatter valve, thus resembling *P. coalingaensis*. According to Grant and Gale,[28] however, *P. vogdesi* and *P. cataractes* cannot be consistently distinguished from each other by this character. *Pecten auburyi* Arnold, from the Pliocene of the Puente Hills, near Los Angeles, and *P. lecontei* Arnold, from the Pliocene of Cedros Island, Lower California, apparently lack secondary ribs on the flat valve and according to figures are probably very closely related to *P. coalingaensis*. Two other forms described from Pliocene strata on the Lower California mainland are also probably related to *P. coalingaensis*: *P. heimi* Hertlein, which evidently lacks secondary ribs on the flat valve; and *P. hartmanni* Hertlein, the flat valve of which has not been described. (*R. S.*).

Aequipecten was found only in the San Joaquin formation. *Aequipecten circularis impostor* (Hanna) is locally abundant in the *Pecten* zone (pl. 13, figs. 3, 4, 6–9), and fragmentary remains of a similar form occur in the Cascajo conglomerate member. The *Pecten* zone variety differs from the living California *A. circularis* Sowerby and its allies in having a smaller thinner shell and smaller ears. These fossils were identified by Arnold as *A. deserti* Conrad, the type of which is from the Colorado Desert. They are probably very closely related to that species, which, however, appears to have not quite so many ribs, and at least some specimens have ribs on the lateral areas. On the *Pecten* zone fossils the lateral areas are smooth. *A. circularis eldridgei* (Arnold) (pl. 24, figs. 10–13), found only in the Cascajo conglomerate of South Dome, is smaller than *A. circularis impostor* and has a thicker shell. The Cascajo specimens are smaller and less inflated than specimens from the type locality near McKittrick, where they occur in strata suggested in the present report as representing the equivalent of the Cascajo. This small pecten was heretofore recorded only at the type locality. (*W. P. W.*, *R. S.*)

Chlamys etchegoini (Anderson) is present in the *Siphonalia* zone (pl. 32, fig. 1) of the Etchegoin, and one small specimen (pl. 13, fig. 5) was found in the *Pecten* zone of the San Joaquin. This species is, however, abundant in the *Pecten* zone in the foothills farther west. *C. etchegoini* is closely related to the living Japanese *C. swiftii* (Bernardi). The Kettleman Hills specimens are very similar to *C. swiftii*, but they differ from 20 valves of that species available for comparison in having the ears more distinctly separated from the discs by angles that form furrows on the exterior of the valve. The difference is most marked on large specimens, particularly on left valves. It is not known whether all the American fossil forms can be separated from *C. swiftii* by this character. It is not well marked on the type of *C. parmeleei* (Dall), from the Pliocene at San Diego, possibly because it is a small specimen, but it seems likely that all the American forms will prove to be more closely related to *C. parmeleei* than to *C. swiftii*. *C. parmeleei* has prominent concentric swellings and is probably the same species as *C. wattsi* (Arnold), from the Coalinga district. Although the form with prominent concentric swellings may be a variation of *C. etchegoini*, it has not yet been found with that species in the Kettleman Hills. In the Kreyenhagen Hills this form occurs in the Jacalitos formation [29] as well as in the *Pecten* zone. Another *Chlamys*, *C.* cf. *C. islandicus* (Müller), is represented by fragments in the *Acila* zone. It is the last of the Pectinidae in the Kettleman Hills. (*R. S.*)

The genus *Patinopecten* is abundant in the Etchegoin formation, particularly in the *Patinopecten* zone, and is rare in the San Joaquin. The Etchegoin species is identified as *Patinopecten lohri* (Hertlein) (pl. 35, figs. 2–5). Many of the North Dome specimens have the

[26] Lischke, C. E., op. cit., vol. 2, p. 157, pl. 12, figs. 1–2, 1871. Reeve, L. A., Conchologia Iconica, *Pecten*, pl. 30, fig. 135 (?), 1853.

[27] Pilsbry, H. A., New and hitherto unfigured Japanese mollusks: Acad. Nat. Sci. Philadelphia Proc., vol. 43, p. 473, pl. 19, figs. 1–3, 1892.

[28] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History, Mem., vol. 1, p. 229.

[29] Nomland, J. O., Fauna from the lower Pliocene at Jacalitos Creek and Waltham Canyon, Fresno County, Calif.: California Univ., Dept. Geology Bull., vol. 9, pp. 203, 204, 1936.

primary ribs on the right valve divided at an earlier growth stage than that shown in the figure of the type of *P. lohri*. No specimens from the type locality—Santa Maria district—are available, and it cannot be determined whether or not the type is an abnormal specimen. Two forms of *P. lohri* may, however, eventually be recognized on the basis of the difference in growth stage marked by the division of the primary ribs. A *Patinopecten* fragment from the *Pecten* zone is identified as *P.* cf. *P. healeyi* (Arnold). Although some specimens of *P. healeyi*, originally described from the Pliocene at San Diego, have small secondary ribs in a few of the interspaces of right valves, none of the some 50 specimens available from various localities have so large or so many secondary ribs as are present on right valves of some 30 specimens of *P. lohri*. The specimen from Elsmere Canyon, in Ventura County, figured by Grant and Gale [30] as *P. lohri*, evidently lacks the prominent secondary radials on the right valve and would be identified as *P. healeyi* on the basis of the criteria suggested. (*R. S.*)

Fragments of *Lyropecten* cf. *L. estrellanus* (Conrad), all probably representing one valve, were found on the outcrop of the *Siphonalia* zone. As the locality is near a former habitation, this material may have been transported by man. *Lyropecten*, however, has been collected from the oldest fossiliferous zone in the Etchegoin of Anticline Ridge,[31] northwest of the Kettleman Hills. (*R. S.*)

Ostreidae.—In the Kettleman Hills *Ostrea atwoodii* Gabb (pl. 29, figs. 1, 13), the type of which was collected in the Coast Ranges west of Coalinga, is characteristic of the Etchegoin. It is abundant in the upper *Pseudocardium* zone but was not found at higher horizons. The numerous fine radial ribs on the lower valve and the smooth flat upper valve distinguish this species from other forms in the Kettleman Hills. *O. vespertina* Conrad (pl. 14, fig. 9), characterized by a strongly plicate lower valve and an upper valve that is generally as strongly plicate as the lower valve, occurs in the *Pecten* zone. Arnold considered the Kettleman Hills specimens identical with *O. vespertina* from the Colorado Desert, and no characters have been found to distinguish them.[32] The oyster in the upper *Mya* zone (pl. 8, figs. 10–14) was described by Arnold as *O. vespertina sequens*. It also occurs in strata between the upper *Mya* and *Acila* zones (pl. 10, figs. 1–5). The upper valve of this form is not strongly plicate and is generally undulate or smooth. Small specimens, identified as *O.* cf. *O. vespertina*, are probably dwarfs of this form. These small specimens and also some larger undulate specimens of the variety *sequens* are indistinguishable from the living California *O. lurida* Carpenter. A small unidentified oyster, represented generally by fragments, occurs in the Cascajo conglomerate and *Acila* zone. (*W. P. W.*)

Unionidae.—The two species of fresh-water mussels in the Tulare formation are related to Recent California species. *Anodonta kettlemanensis* Arnold (pl. 6, figs. 1–3) is generally more strongly inflated than *A. nuttalliana* Lea, and the beak sculpture is finer and spread over a larger area. Some of the fossils are elongate and strongly inflated (pl. 6, fig. 3). *Gonidea coalingensis* Arnold (pl. 6, figs. 4–9) is more elongate than *G. angulata* Lea and has a heavier hinge. The beak sculpture of the fossils also is somewhat finer and covers a larger area. The most common form among the fossils is moderately inflated and has a low beak (pl. 6, figs. 5–8). Other specimens are more strongly inflated and have a high beak (pl. 6, fig. 9). Shells that are exceptionally inflated (pl. 6, fig. 4) were collected from a horizon below the upper *Amnicola* zone. Unidentified forms of *Anodonta* and *Gonidea* also occur in the San Joaquin formation, and *Anodonta* was found in Etchegoin strata above the *Littorina* zone. The locality where Nomland collected the *Anodonta* that he described as *A. nitida* [33] represents a horizon in the Etchegoin above the *Littorina* zone, not below the upper *Pseudocardium* zone as Nomland thought. (*W. P. W.*)

Tellinidae.—Specimens of the Miocene *Tellina oldroydi* Wiedey,[34] which is evidently not a typical *Tellina*, have not been examined. The *Pecten* zone (pl. 14, fig. 8) and *Siphonalia* zone (pl. 33, fig. 5) specimens identified as *Tellina?* cf. *T.? oldroydi* are probably closely related to that species. The Kettleman Hills form is probably related to *T. lutea* Gray, living on the Alaskan coast, but is more nearly equilateral. It is also probably closely related to *T. venulosa* Schrenck,[35] a living Japanese species that has the outline of the fossils but has concentric ribs. *T. lutea* lacks concentric ribs, and they are probably absent on *T.?* cf. *T.? oldroydi*. The Kettleman Hills fossils are slightly more inflated than either of the living species. *T.* cf. *T. bodegensis* Hinds (pl. 33, fig. 2), from the *Siphonalia* zone, resembles the living California *T. bodegensis*. (*R. S.*)

A paired specimen from the *Patinopecten* zone is identified as *Macoma* cf. *M. indentata* Carpenter (pl. 35, fig. 1). *M. indentata* is a living species said to range from Puget Sound to Lower California. A poorly preserved specimen also from the *Patinopecten* zone resembles *M. vanvlecki* Arnold, which was described from the Jacalitos formation and may be an inflated form of *M. indentata*. (*R. S.*)

Macoma affinis Nomland ranges through the Etchegoin and San Joaquin formations and is particularly

[30] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), p. 197, pl. 6, figs. 1a, 1b.

[31] Nomland, J. O., op. cit. (California Univ., Dept. Geology, Bull., vol. 10), p. 228 (locality 2096), table opposite p. 230.

[32] Woodring, W. P., op. cit. (Prof. Paper 190), pp. 42–47, 1938.

[33] Nomland, J. O., op. cit. (California Univ., Dept. Geol., Bull., vol. 10), pp. 215–216, 231, pl. 9, fig. 2.

[34] Wiedey, L. W., Notes on the Vaqueros and Temblor formations of the California Miocene with descriptions of new species: San Diego Soc. Nat. History Trans., vol. 5, no. 10, p. 148, pl. 19, fig. 3, 1928.

[35] Schrenck, L. v., Reisen und Forschungen im Amur-Lande, vol. 2, p. 556, pl. 22, figs. 2–5, 1867.

abundant in the *Macoma* zone of the Etchegoin (pl. 34, figs. 1–4) and in the upper *Mya* zone of the San Joaquin (pl. 9, figs. 1–3). This species was described from the upper *Mya* zone at the top of the San Joaquin in the foothills west of the Kettleman Hills. It is similar to the Recent species *M. inquinata* (Deshayes) that ranges from Monterey, Calif., to Alaska and Japan. On the Kettleman Hills fossils that show the pallial sinus the sinus is not so close to the anterior adductor scar as on the living species. The outline of the pallial sinus is variable on about 50 Recent specimens, but in general it is closer to the left anterior adductor scar than to the right; that is, the sinus of the left valve is deeper than the sinus of the right valve, though the difference is not so marked as on *M. nasuta* (Conrad).[36] The deeper sinus of the left valve of *M. nasuta* and the posterior twist of the shell is associated with the animal's habit of lying in the mud on the left side. It is not known whether *M. indentata* also lies on its left side. A left and right valve of *M. affinis* of about the same size do not show a deeper left pallial sinus. Specimens of *M. affinis* were found in the *Macoma* zone normal to the bedding, and their symmetrical pallial sinuses may be associated with this position. The dorsal apex of the pallial sinus of *M. affinis* is angulated (pl. 9, fig. 3; pl. 34, fig. 2) or rounded (pl. 34, fig. 1). Recent specimens of *M. inquinata* show the same variation, but the apex is wider than in the fossils. On some specimens from the upper *Mya* zone a line similar to the sinus, but fainter, extends from the dorsal apex of the sinus toward the umbo (pl. 9, fig. 3). *M. affinis* much resembles an unidentified living Japanese species, represented by one specimen in the National Museum (341099). It has a symmetrical pallial sinus, but the sinus is not so deep as on *M. affinis*, and the outline of the valves is more rounded. (*W. P. W., R S.*)

The small *Macoma* of the *Littorina* zone is named *M. affinis plena* Stewart, n. var. (pl. 29, fig. 12; pl. 39, fig. 3). This form is about half as long as *M. affinis;* it also is more circular, and some specimens are more inflated. The pallial sinus is not well known. This small *Macoma* also occurs in the upper oolite (pl. 24, fig. 3) between the *Neverita* zone and Cascajo conglomerate. A similar form was found in the *Pecten* zone and between the *Pecten* and *Neverita* zones (pl. 15, fig. 13). The *Pecten* zone specimens are not so rounded as specimens from the *Littorina* zone. Their sinuses resemble the sinus of *M. affinis*. (*R. S.*)

Two other species of *Macoma* are comparable to living California species. *M.* cf. *M. nasuta* (Conrad), the interior of which is not known, occurs in the lower part of the Etchegoin of South Dome, in the *Neverita* zone (pl. 20, fig. 12), and in the *Pecten* zone (pl. 14, fig. 5). *M.* cf. *M. secta* (Conrad) (pl. 16, fig. 1) is represented by two worn left valves from the *Pecten* zone.

The genus *Apolymetis* was found only in the *Siphonalia* zone. The fossils are listed as *A.* cf. *A. dombei* (Hanley) (pl. 32, fig. 2). They are larger than the few available specimens of *A. dombei*[37] and have a more prominent posterior sulcus. In view of the range of *A. dombei*—Panama to Peru—it is doubtful whether these fossils from the San Joaquin Valley are related to it. They are, however, more produced anteriorly than the living California *A. biangulata* (Carpenter). (*R. S.*)

Mactridae.—Mactra? coalingensis Arnold, described from the Etchegoin of Alcalde Canyon in the Coalinga district, was found in the *Siphonalia* zone (pl. 33, fig. 1), and similar forms occur in the *Patinopecten* and *Pecten* zones. This species is probably a *Spisula*, but the hinge is not known. (*R. S.*)

Pseudocardium densatum is the most common mactrid. In North Dome it is abundant in and below the upper *Pseudocardium* zone. A few specimens of the genus were found, however, in Etchegoin strata between the upper *Pseudocardium* and *Littorina* zones and in strata that may be the equivalent of the *Littorina* zone. In Middle and South Domes *P. densatum* is abundant in the *Pseudocardium-Anadara* zone, which is considered the essential equivalent of the *Littorina* zone, and also occurs in the Cascajo conglomerate at the base of the San Joaquin formation. The Cascajo specimens may have been transported as fossils. Worn specimens, doubtfully identified as *Pseudocardium*, found in conglomerate between the *Pecten* and *Acila* zones on the west flank of Middle Dome, were doubtless transported as fossils.

Pseudocardium densatum, like *Anadara trilineata*, and *Anadara canalis*, were said to have been collected by Newberry at Santa Barbara, but, like the other two forms, has not been found at or near Santa Barbara. But for Newberry's definite statement to the contrary,[38] it would be reasonable to assume that the fossil Conrad described as *Mulinia densata* came from the San Pablo group, exposed on San Pablo Bay, where Newberry collected. Should a type locality be arbitrarily chosen it may be desirable to ignore Newberry's statement. If, however, the Kettleman Hills are arbitrarily chosen as the type locality of *Anadara trilineata* it may be advantageous to select the same locality for *Mulinia densata*, for specimens similar in outline to Conrad's figure occur there as well as in the San Pablo group. Arnold's identification of Coalinga specimens and Conrad's figure are accepted for the nomenclature used in the present report, and the species is cited as *Pseudocardium densatum* (Conrad) of Arnold. (*W. P. W., R. S.*)

Specimens that are anteriorly produced, like Conrad's figure, were found in the *Siphonalia* (pl. 39, fig. 8)

[36] Weymouth, F. W., The edible clams, mussels, and scallops of California: California Fish and Game Comm. Fish Bull. 4, pp. 13, 43, fig. 12, 1920.

[37] Hanley, Sylvanus, in Sowerby, G. B., Thesaurus conchyliorum, *Tellina*, p. 323, pl. 62, fig. 182, 1847.

[38] Newberry, J. S., Report upon the geology of the route [Williamson's survey in California and Oregon]: U. S., Pacific R. R. Expl., vol. 6, pt. 2, p. 14, 1856.

and upper *Pseudocardium* zones—in the upper *Pseudocardium* zone not at the localities included in the list of fossils—in the *Pseudocardium*-bearing conglomerate (pl. 37, fig. 9) and underlying strata in Middle Dome, and in the *Pseudocardium*-bearing sandstone of South Dome (pl. 37, fig. 3). This form is, however, relatively rare. The most common form in the Etchegoin of North Dome (pl. 29, fig. 16; pl. 30) and in the Etchegoin of Middle Dome below the *Pseudocardium-Anadara* zone (pl. 37, figs. 7, 8, 10) is a large more equilateral variety. This variety is similar in outline to *Pseudocardium gabbii* Rémond, from the San Pablo group. Inasmuch as the relations of the fossils from the two regions have not been determined, the Kettleman Hills form is identified as *P. densatum* variety cf. *gabbii*. A shorter and generally smaller variety (pl. 37, figs. 4–6) is abundant in the *Pseudocardium*-bearing sandstone of South Dome. The form in the *Pseudocardium-Anadara* zone (pl. 24, figs. 19, 20) is a small variety. A similar form (pl. 24, fig. 14), accompanied by an exceptionally elongate form (pl. 24, fig. 15), occurs in the Cascajo conglomerate of South Dome. The different forms of this species are probably the result of different environmental conditions. Nevertheless, the predominance of the variety similar to *P. gabbii* in the lower part of the section and the decrease in size shown by specimens in the *Pseudocardium-Anadara* zone, Cascajo conglomerate, and Etchegoin strata between the upper *Pseudocardium* and *Littorina* zones may be useful in determining stratigraphy at least in the Coalinga district. (*W. P. W., R. S.*)

Pseudocardium appears to be extinct in the eastern Pacific but is known in northern Japan, where it is represented by "*Mactra*" *sachalinensis* Schrenck.[39] This species has the long laterals, inflated valves, and shallow sinus of *Pseudocardium*. The dorsal margins of about 50 available specimens of *P. sachalinensis* are more inflated than those on some 100 specimens from North Dome, and it is possible that this character may serve to distinguish the American and Asiatic forms. In the Asiatic specimens the dorsal side of the left posterior lateral is pitted or striated, or both, and on some specimens the left anterior lateral is similarly ornamented. A few of the best-preserved specimens from the upper *Pseudocardium* zone show similar ornamentation. Some specimens of *Pseudocardium*, both living and fossil, have a small ridge dividing the two parts of the ligament, so that *Pseudocardium* might be cited as a connecting form between *Mactra* and *Spisula*. Some specimens of typical *Spisula*, however, have at least a suggestion of this ridge, and *Pseudocardium* is probably more closely related to *Spisula* than to *Mactra*. In *Mulinia*, to which *P. densatum* was long assigned, the ligament is covered by the shell. "*Mactra*" *orthomorpha*, described by Grant and Gale from a well in the San Joaquin Valley and compared with *P. sachalinensis*, is probably a form of *P. densatum*. The name may prove useful for small specimens such as occur at the upper limit of the range of the genus in the Kettleman Hills. (*R. S.*)

[39] Schrenck, L. v., Reisen und Forschungen im Amur-Lande, vol. 2, p. 575, pl. 23, figs. 3-7, 1867. An earlier name for this species, cited but not accepted by Lamy (Jour. Conchyliologie, vol. 36, p. 314, 1917), is *Mactra sibyllae* Valenciennes (Acad. Sci. Paris Comptes rendus, vol. 46, p. 760, 1858).

Veneridae.—The *Saxidomus* found in the *Siphonalia* (pl. 33, fig. 6), *Pecten* (pl. 16, fig. 8), and upper *Mya* (pl. 8, fig. 15) zones has a wider and longer anterior end than the living California *S. nuttalli* Conrad and is named *S. nuttalli latus* Stewart, n. var. Poorly preserved remains from other horizons in the Etchegoin and San Joaquin formations may represent the same form. Some specimens from the upper *Mya* zone have smaller adductor scars and a shallower pallial sinus than the Recent form, but the figured specimen from that horizon has a deep pallial sinus. (*R. S.*)

Venerupis laciniata hannibali (Howe) occurs in the Etchegoin formation of North Dome (pl. 29, fig. 5). This variety is shorter than Recent specimens from San Diego and San Pedro in the collections of the National Museum labeled *V. staminea laciniata* (Carpenter). These Recent specimens have a more produced posterior ventral margin than *V. staminea* (Conrad) and its allies, and connected forms have not been observed in the collections of the National Museum. *V. hannibali* was described from Lawson's Wildcat series (Pliocene) of the Eel River Basin in northern California and is also known from the Empire formation of Oregon. It is apparently a little shorter than the Recent specimens identified as *V. laciniata*. Two specimens comparable to the living California *V. tenerrima* (Carpenter) were found in the *Macoma* zone. A small circular venerid in the *Pecten* zone of South Dome appears to be a dwarfed *Venerupis*. It has a shallow pallial sinus like that of the Recent *V. grata* (Say), which is reported from Lower California to Chile. The fossil form is more nearly circular than the living *V. grata* and has a thick deposit of callus on the inner side of the valves. It is named *V. grata tarda* Stewart, n. var. (pl. 13, figs. 10–13). The specimen from the *Pecten* zone at Los Morones figured by Arnold [40] as *Paphia staleyi* (Gabb)? represents this form. (*R. S.*)

A small venerid identified as *Transennella* cf. *T. tantilla* (Gould) is recognized in the upper *Pseudocardium*, *Pecten*, and upper *Mya* zones. It is probably the Recent species and is the same as *T. californica* Arnold, which was based on one specimen from the *Pecten* zone. (*R. S.*).

A small trigonal concentrically sculptured venerid from the Cascajo conglomerate member of the San Joaquin and the upper oolite between the Cascajo and the *Neverita* zone is probably a new species of *Psephidia* (pl. 24, figs. 4–6). It is smaller and more trigonal than the Recent *P. lordi* (Baird) and *P. ovalis* Dall, which

[40] Arnold, Ralph, op. cit. (Bull. 396), pl. 26, fig. 8.

also lack sculpture. In outline and sculpture the fossil species resembles the Recent *P. cymata* Dall, which, however, has a short anterior lateral tooth that is absent on the fossils. According to Dall's classification, *Transennella* and *Psephidia* are placed in different subfamilies, *Transennella* being characterized by an anterior lateral and *Psephidia* by the absence of an anterior lateral. Nevertheless, *P. cymata*, which was assigned to *Psephidia* by Dall, has a short anterior lateral lying close to the anterior cardinal. The West coast species assigned to these two genera are apparently closely allied and are perhaps referable to one genus. It is doubtful whether any of them represents *Transennella*. Typical *Transennella* from the Atlantic coast has a deeper pallial sinus, and the right anterior cardinal lies athwart the lateral lamellae instead of almost in line with them as in *T. tantilla*. Moreover, typical *Transennella* is not known to be viviparous,[41] whereas *T. tantilla*,[42] *P. lordi*,[43] and *P. ovalis* [44] are viviparous. (*W. P. W.*)

Cardiidae.—Specimens of *Cerastoderma* from the Etchegoin and San Joaquin formations identified as *Cerastoderma* cf. C. *meekianum* (Gabb) (pl. 24, figs. 8, 9; pl. 29, fig. 14) are poorly preserved. The largest specimens were found in strata between the Cascajo conglomerate member and the *Neverita* zone of the San Joaquin, the largest being almost twice as large as the specimen shown on plate 24, figures 8 and 9. Specimens from this horizon have about 30 ribs as compared with 22 to 24 on *C. meekianum* from the Pliocene of northern California. A small *Cerastoderma* occurs in the *Littorina* zone (pl. 29, fig. 3) and in the *Pseudocardium-Anadara* zone. (*W. P. W., R. S.*)

Trachycardium cf. *T. quadragenarium* (Conrad) is characteristic of the *Pecten* (pl. 16, fig. 2) and *Trachycardium* zones. The ornamentation on the fossils is not sufficiently well preserved to permit a satisfactory comparison with the Recent form. One specimen from locality 71 has spines on both sides of the anterior median ribs, whereas on available specimens of the living form analogous ribs have spines only on their posterior side. It is not likely that the ornamentation of the fossil is due to weathering, but this specimen may be exceptional. Another *Trachycardium*—apparently a new species—not referable to the subgenus *Dallocardia* was found in the *Patinopecten* and *Siphonalia* zones. (*R. S.*)

Myacidae.—*Mya* is one of the most abundant fossils in the San Joaquin formation and in the upper part of the Etchegoin, but it is very rare below the upper *Pseudocardium* zone. Some *Mya* layers contain few if any other fossils. The species is identified as *Mya* cf. *M. dickersoni* Clark. The largest specimens are from the upper *Mya* (pl. 9, figs. 4–9) and *Neverita* zones. At any horizon the outline of the shell is generally variable. An exceptionally equilateral specimen (pl. 24, fig. 2) was collected from the upper oolite between the Cascajo conglomerate and *Neverita* zone, and an exceptionally elongate specimen (pl. 24, fig. 21) came from the *Pseudocardium-Anadara* zone of Middle Dome. The Kettleman Hills *Mya* was identified by Arnold as the living Alaskan and Japanese *M. japonica* Jay. A close relationship with the living species is very doubtful. The fossils that show the pallial sinus and chondrophore have a narrower pallial sinus than the living species and a more prominent deposit of callus on the middle of the chondrophore than that on Recent specimens. The fossils are probably closely related to *Mya dickersoni* Clark, from a horizon near the top of the San Pablo group.[45] Inasmuch as the sinus of *M. dickersoni* has not been described and it is not known whether this species has callus on the middle of the chondrophore, the Kettleman Hills species is identified as *Mya* cf. *M. dickersoni*. *M. dickersoni* has been recorded from the upper Miocene Santa Margarita sandstone north of Coalinga.[46] (*W. P. W., R. S.*)

A new species of *Platyodon*, *P. colobus* Woodring (pl. 21, figs. 1, 2), is represented by four specimens found in their burrows at the base of the *Neverita* zone. It is related to the Miocene *P. piedraensis* Wiedey [47] but has radial sculpture and a shorter, narrower siphonal gape. The elongate Recent species *P. cancellatus* (Conrad), the only living species, has been recorded from strata as old as the upper Miocene. (*W. P. W.*)

The genus *Corbula* is represented by only the worn specimens from the *Pecten* zone. They are comparable to *C. gibbiformis* Grant and Gale, described from San Joaquin Valley subsurface specimens and recorded by Grant and Gale from the *Pecten* zone of the Kettleman Hills. The subsurface bed may be the equivalent of the *Pecten* zone. *C. gibbiformis* may be related to a species living on the Pacific coast of Central America, *C. speciosa* Reeve.[48] (*R. S.*)

Solenidae.—The *Solen* from the San Joaquin (pl. 8, fig. 9; pl. 24, fig. 1) and Etchegoin formations has a straighter dorsal margin than the Recent California *S. sicarius* Gould and is identified as *S. perrini* Clark, described from the San Pablo group. (*W. P. W., R. S.*)

An undetermined species of the genus *Siliqua* occurs in the Etchegoin of North Dome and in and below the *Siphonalia* zone and in the lowest Etchegoin strata exposed in South Dome. It is most abundant in the *Siphonalia* zone (pl. 33, fig. 3). This genus is character-

[41] Dall, W. H., Contributions to the Tertiary fauna of Florida: Wagner Free Inst. Sci. Trans., vol. 3, pt. 6, p. 1240, 1903.

[42] Idem.

[43] Dall, W. H., Synopsis of the family Veneridae and of the North American Recent species: U. S. Nat. Mus. Proc., vol. 26, p. 401, 1902.

[44] Idem, p. 408.

[45] Clark, B. L., Fauna of the San Pablo group of middle California: California Univ., Dept. Geology, Bul., vol. 8, pp. 401, 478, 509 (locality 1617, about 150 feet below the Pinole tuff), pl. 63, figs. 3, 4, 1915.

[46] Nomland, J. O., Fauna of the Santa Margarita beds in the north Coalinga region of California: California Univ., Dept. Geology, Bull., vol. 10, p. 300, 1917.

[47] Wiedey, L. W., New Miocene mollusks from California: Jour. Paleontology, vol. 3, p. 289, pl. 33, fig. 2, 1929.

[48] Reeve, L. A., Conchologia Iconica, *Corbula*, pl. 1, fig. 6, 1843.

ized by an internal ridge extending downward from the beak at about a right angle to the dorsal margin of the shell. Impressions of this ridge are present on internal molds, so that *Siliqua* may be readily identified on the basis of such material. Many of the fossils are preserved with the valves wide open but attached by the ligament. (*R. S.*)

Pholadidae.—The larger borer from the *Macoma* zone identified as *Zirfaea gabbi* (Tryon) var. differs from 20 available Recent specimens of *Z. gabbi* in having more widely spaced concentric lamellae on the anterior umbonal part of the shell beyond the overlapping dorsal margin. Remains from other horizons probably represent the same form. It may prove to be distinct, but its relation to the Miocene *Z. dentata* Gabb is not known. (*R. S.*)

BARNACLES

Large barnacles are abundant in the lower part of the Etchegoin of North Dome and were also found in the lower part of the formation in South Dome. In and below the *Patinopecten* zone and in strata assigned to the *Macoma* zone they form reeflike clusters in which the barnacles stand upright in living position (pl. 27, *A*).

These barnacles are identified as *Balanus* (*Tamiosoma*) cf. *B.* (*T.*) *gregarius* (Conrad). In large specimens the greatly elongated basis is partly filled with blistery horizontal or oblique septa, as in *Tamiosoma*, the type of which is *T. gregaria*. Opercular valves—eight scuta and one broken tergum—were found at the locality shown on plate 27, *A*. They may be present at many other localities, for 77 scuta and 1 tergum were later collected at locality 342a near the base of the *Macoma* zone (?). According to these opercular valves, the large Etchegoin barnacle is a *Balanus* of the group of *B. concavus* Bronn, which was based on fossils from the Italian Pliocene. In terms of the criteria used by Pilsbry,[49] the Etchegoin barnacle might be classified as a subspecies of *B. concavus*. The scutum (pl. 36, figs. 2, 3, 8, 9) is similar to that of *B. concavus proteus* Conrad [50] and *B. concavus chesapeakensis* Pilsbry,[51] Miocene Atlantic coast forms, but the adductor ridge is shorter and the strongly developed ridge bordering the depressor pit is closer to the adductor ridge. The spur on the tergum (pl. 36, figs. 4, 5) is closer to the basi-scutal angle than on these Atlantic coast forms, and the spur furrow is more completely closed by infolding of the sides. The strong radial sculpture on the figured scutum is probably due to corrosion, as it is not so strong on the more complete but smaller scutum from locality 342a. The characters that differentiate the Etchegoin opercular valves from those of the Atlantic coast fossils also differentiate the Kettleman Hills fossils from the form living on the Pacific coast, *B. concavus pacifus* Pilsbry.[52] It, therefore, is improbable that the Kettleman Hills barnacle is directly related to this living form. Opercular valves—seven scuta and four corroded terga—of a *Tamiosoma* similar to *Balanus* (*Tamiosoma*) *gregarius* also are available in a collection from a locality representing a late Miocene or early Pliocene horizon on the east border of Salinas Valley (U. S. G. S. locality 3586, Wildhorse Canyon near Mr. Copley's house, NW¼ sec. 14, T. 20 S., R. 9 E., King City quadrangle.)[53] The opercular valves from this locality, particularly the scuta, are exceptionally thick regardless of size. The scuta are not so strongly sculptured as scuta from the Kettleman Hills; the ridge bordering the depressor pit is wider and cruder; and the articular ridge is longer. The spur on the tergum is wider and apparently closer to the basi-scutal angle. Some of these differences may be due to the thickness of the valves from the Salinas Valley, but according to this material the Kettleman Hills barnacle is distinguishable from the Salinas Valley barnacle. It is not known whether the Salinas Valley barnacle represents *Balanus* (*Tamiosoma*) *gregarius* proper. The data on the original locality of that species,[54] Monterey County, are indefinite, the type material appears to be lost, and opercular valves were not found with the type material. The barnacle from the Salinas Valley is associated with *Astrodapsis salinasensis*, which is considered characteristic of a horizon between the upper Miocene Santa Margarita sandstone and the lower Pliocene Jacalitos formation.[55] *B. gregarius* has been considered a Santa Margarita form, but the horizon from which the type material was collected appears to be indeterminable. Barnacles similar to *B. gregarius* are now known to occur in the Santa Margarita sandstone, in the *Astrodapsis salinasensis* zone, and in the Jacalitos and Etchegoin formations, the Etchegoin form being the last known survivor. Opercular valves of the Santa Margarita and Jacalitos forms have not yet been recorded.

The opercular valves from the Kettleman Hills and Salinas Valley confirm Pilsbry's conclusion that *Tamiosoma gregaria* is a *Balanus*.[56] Nevertheless, the partial filling of the elongate basis with a mass of vesicular calcareous septa is a well-defined character, and it is convenient to emphasize this character in the California

[49] Pilsbry, H. A., The sessile barnacles (Cirripedia) contained in the collections of the U. S. National Museum, including a monograph of the American species: U. S. Nat. Mus. Bull. 93, pp. 100–108, 1907.

[50] Idem. p. 103, pl. 22, figs. 3–3c.

[51] Idem, pp. 103–104, pl. 22, figs. 1–1c.

[52] Idem. pp. 104–108, pl. 23.

[53] This material was collected by Homer Hamlin. According to the field labels, the collection, which includes exceptionally well preserved barnacles, has the same field number and was collected at the same time as the material that for some reason was given a different locality number, 4555. The barnacles that have the locality number 4555 formed the basis for Dall's discussion of *Tamiosoma* (Dall, W. H., On the true nature of *Tamiosoma:* Science, new ser., vol. 15, no. 366, pp. 5–7, 1902) and later were forwarded to Pilsbry. It seems strange that Dall's attention was not called to the opercular valves.

[54] Conrad, T. A., Descriptions of three new genera; twenty-three new species middle Tertiary fossils from California, and one from Texas: Acad. Nat. Sci. Philadelphia Proc., 1856, p. 315, 1857; Description of the Tertiary fossils collected on the survey: U. S., Pacific R. R. Expl., vol. 6, pt. 2, pp. 72–73, pl. 4, fig. 18, 1856.

[55] Richards, G. L., Jr., Revision of some California species of *Astrodapsis:* San Diego Soc. Nat. History Trans., vol. 8, no. 9, pp. 59–66, pl. 7, 1935.

[56] Pilsbry, H. A., op. cit., pp. 125–126.

fossils by retaining the name *Tamiosoma* for a minor subdivision of *Balanus*. This nomenclatorial emphasis appears to be justified, even though the same character was independently acquired by a living Chilean barnacle, *Balanus levis coquimbensis* Sowerby,[57] which belongs to a group of *Balanus* characterized by one to three longitudinal furrows on the exterior of the scutum.

Fragmentary barnacle remains from the *Siphonalia* zone of the Etchegoin may represent *Tamiosoma*, but none that were collected show the elongate basis of *Tamiosoma*. These fossils and others from horizons in the upper part of the Etchegoin and in the San Joaquin are listed as *Balanus* sp.

The very small barnacle *Balanus hesperius* Pilsbry var. from the upper *Mya* zone of the San Joaquin formation is represented by isolated compartments and at locality 35 by six scuta and two terga. Similar compartments occur in the Cascajo conglomerate member. The compartments resemble those of the living Alaskan *B. hesperius*,[58] but the scutum is not so strongly sculptured; the ridges on the callus above the adductor ridge are not so well defined; and the spur on the tergum is shorter.

FISH

The curious fish bones called "bulbous fish growths" by Arnold and Anderson,[59] and colloquially called "fish flippers" by field geologists, are abundant in the fresh-water strata at the base of the Tulare formation. They are also fairly abundant in the *Pecten* zone, *Neverita* zone, and Cascajo conglomerate member of the San Joaquin but are rare in the Etchegoin formation. The specimens from the San Joaquin formation are polished, as though they were transported before burial, whereas those from the Tulare formation and the few specimens from the *Siphonalia* and *Patinopecten* zones of the Etchegoin are not polished. Locally in the Tulare formation these dense bones are accompanied by spines and plates and rarely by vertebrae. A collection of these fossils from the Tulare formation at locality 23 was forwarded to Dr. W. K. Gregory, of the American Museum of Natural History, who kindly prepared the following comments:

The "bulbous fish growths" and related objects have proved to be very difficult to identify. Fairly extensive examination of the literature, as recorded on unpublished cards in our department bibliography, shows that similar swellings occur in several families of marine or estuarine teleosts, notably the sciaenids or weak fishes, the gadids or cods, the angel fishes (Epihippidae), and in *Caranx caringopsis;* the same thing occurs in certain fresh-water siluroids (catfishes). Usually the swellings are limited to median bones, but in a cod skeleton which we have just prepared many of the paired bones are more or less affected. The largest curved bones[60] are undoubtedly opercular bones, which, if allowance is made for inflation, are close to those of Recent hakes (*Merlucius*) of the cod family. The small asymmetrical bones with a median crease are swollen haemal spines that may pertain to the same species. We have failed to identify the other bones even after many attempts. Many somewhat similar bulbous fish growths have been figured from the Crag of Belgium by van Beneden[61] and from the Vienna Basin by Steindachner,[62] but of the numerous figures and plates compared not one agrees satisfactorily with any of the Tulare fossils.

The large curved plate with the sculptured pitted surface in many respects is close to the dermal angular plate of a large *Lepidosteus spatula* but does not correspond closely enough to warrant specific identification. It differs in many details from plates of sturgeon and in other ways from those of catfishes.

The bone that looks something like an elongated oval leaf has been compared with many kinds of fish bones but without success. The same is true of the fine-sculptured small bone with a triangular cross section. We have failed to match this sculpture in our collection of fish skeletons. Dr. R. W. Miner will not admit the sculpture to be the work of any encrusting invertebrate.

The abundance of these bones in the Tulare formation suggests that they represent fresh-water or brackish-water fish. In the San Joaquin and Etchegoin formations they are generally associated with marine fossils, but the same strata also contain remains of land animals. Though the Etchegoin specimens are not polished, they may also represent the remains of fresh-water or brackish-water fish. Similar fish remains have not been recorded elsewhere in California.

LAND MAMMALS

Land mammals, which were examined by Dr. C. L. Gazin, of the National Museum, were found at various horizons in the Etchegoin and San Joaquin formations. The remains are generally fragmentary, usually consisting of isolated bones and teeth. A mastodon skull was discovered, but not collected, in the *Siphonalia* zone of the Etchegoin at locality 299a, and Matthew[63] described a mastodon skull found during excavation in strata a few feet below the *Pecten* zone of the San Joaquin formation.

A greater variety of remains of land mammals was found in the *Pecten* zone than in other strata, and teeth of the extinct beaver *Castor californicus*[64] were not discovered in other strata. Horse teeth, identified as *Plesippus*, are relatively abundant in the *Pecten* zone. A mastodon femur, tibia, and fibula were found at locality 81a a few feet below the base of the *Pecten* zone, but they were doubtless washed out of the *Pecten* zone. These remains are of particular interest, as corals, oysters, bryozoa, and a barnacle were attached to them, showing that they were immersed in sea water before burial. Both the femur and tibia

[57] Pilsbry, H. A., op. cit., pp. 122–123, pl. 28, fig. 4.

[58] Idem, pp. 193–196, pl. 49, figs. 1–1d, 7–8.

[59] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 138, 143–144, pl. 47, figs. 6, 6a, 6b, 8.

[60] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pl. 47, figs. 6, 6a, 6b.

[61] van Beneden, P. J., Sur un poisson fossile nouveau des environs de Bruxelles et sur certain corps énigmatiques du crag d'Anvers: Acad. royale sci. Belgique, 50th year, ser. 3, vol. 1, pp. 116–126, 1 pl., 5 figs., 1881.

[62] Steindachner, Franz, Beiträge zur Kenntniss der fossilen Fisch-Fauna Österreichs: K. Akad. Wiss., Math.-naturwiss. Kl. Sitzungsber., vol. 37, pp. 673–703, 7 pls., 1859.

[63] Matthew, W. D., A Pliocene mastodon skull from California, *Pliomastodon vexillarius*, n. sp.: California Univ., Dept. Geol. Sci., Bull., vol. 19, pp. 335–348, pls. 41–44, 2 figs., 1930.

[64] Stirton, R. A., A review of the Tertiary beavers: Idem, vol. 23, p. 445, figs. 132–140, 1935.

were fractured, but the fractures fit together fairly well. Ordinarily such fractures are due to breaking after fossilization. Corals are attached to the fractured surface of the tibia, however, showing that the fractured surface was exposed as the bone lay on the sea floor. Possibly these bones are the remains of a mastodon whose left hind leg was broken shortly before death or after death in transit. The fractured bones may have been held together by tendons and muscles until they were deposited on the floor of the sea, where they were not buried until the marine animals had become attached to them.

Mastodon remains, mostly tusk fragments but also molar fragments, are more abundant in the upper part of the *Siphonalia* zone of the Etchegoin and near the base of an overlying blue conglomerate than at other horizons. Horse teeth identified as *Pliohippus* occur in the *Patinopecten* zone of the Etchegoin and probably in the *Siphonalia* zone.

Two horse teeth from the Etchegoin formation were recently examined by Professor Chester Stock, of the California Institute of Technology. One tooth is from the *Siphonalia* zone 20 feet northwest of locality 296; the other tooth was collected from the *Patinopecten* zone at locality 319. Professor Stock prepared the following comments on these fossils.

The two horse teeth are referable presumably to the same genus and species. These specimens belong to a small type of *Pliohippus* and show greatest resemblance to teeth of *Calippus martini* Hesse (type specimen, University of California 32814) from Beaver County, Okla. Resemblance is also shown to teeth of a species of *Pliohippus* from Gidley's Clarendon beds of Texas. The teeth from the Kettleman Hills are slightly larger than comparable teeth in the type of *C. martini*, but the occlusal pattern in both shows several points of similarity. Also in both the crowns are distinctly curved. In view of this similarity the teeth from the Kettleman Hills suggest an age comparable to that assigned to the Texas and Oklahoma occurrences, that is, later lower Pliocene.

It is interesting to note that two teeth in the collections of the University of California (29767), collected from the Etchegoin in 1913, represent apparently the Kettleman Hills form. So far as I am aware, no other *Pliohippus* from the California Tertiary has the characters of these specimens.

MARINE MAMMALS

Fragmentary remains of marine mammals were discovered in the Etchegoin and San Joaquin formations. According to identifications by Dr. Remington Kellogg, of the National Museum, sea lion (?), eared seals, whales, and porpoises are represented in this material.

Dr. Kellogg's comments on eared seal limb bones from the sandstone between the *Pseudocardium-Anadara* zone and the *Pseudocardium*-bearing conglomerate in the upper part of the Etchegoin of Middle Dome at locality 350 are as follows:

(a) Left radius broken in three pieces, including complete proximal and distal ends; (b) inner half of proximal end of right radius and a section of distal end of shaft of a right radius; (c) a short section of proximal end of right humerus; (d) external condyle from distal end of right femur, wholly unlike any known extinct and living otarid and may possibly have belonged to some other type of mammal.

The following remarks on eared seal remains from the *Neverita* zone of the San Joaquin formation at locality 166 were prepared by Dr. Kellogg:

Distal end of right humerus, comprising trochlea and internal condyle. This humerus is larger than that of the oldest male of the Recent *Eumetopias jubata* in the National Museum and is likewise larger than that of the Pliocene *Pliopedia pacifica*. The distal trochlea is, however, considerably narrower than in these two forms, and the internal condyle is produced farther distally, the distal margin being almost on a level with the trochlea.

The distal end of a metapodial of an eared seal was collected from the Cascajo congomerate member of the San Joaquin at locality 199.

Dr. Kellogg prepared the following statement concerning the porpoise remains:

A right periotic from strata between the *Neverita* zone and the upper oolite in the lower part of the San Joaquin formation (locality 169) belongs to an extinct porpoise. In general this periotic shows a type of specialization that finds its nearest counterpart in the Recent *Inia geoffrensis*, which inhabits the Amazon River. A left humerus of a small porpoise from the *Neverita* zone (locality 167) is even smaller than that of the smallest Recent porpoise, the South American *Stenodelphis blainvillei*.

A fragment of a right periotic from the Cascajo conglomerate (locality 199) represents, according to Dr. Kellogg, a porpoise that is not related to the form from locality 169. Porpoise vertebrae were found in the *Macoma* and *Patinopecten* zones of the Etchegoin.

Two periotics from the *Macoma* and *Neverita* zones were identified by Dr. Kellogg as representing whalebone whales. Four whole whale vertebrae, apparently articulated, were found in the *Pecten* zone at locality 87.

DIATOMS

Diatoms were found in the three formations exposed in the Kettleman Hills. They are probably present in strata other than those in which they were found. Light-colored clay and silt appear to constitute the most promising type of lithology for diatoms in this region. A search of the Jacalitos formation in the foothills west of the Kettleman Hills and a more exhaustive examination of the Etchegoin and San Joaquin formations in the foothills and in the Kettleman Hills may result in a more complete sequence of Pliocene marine diatom floras in the Coalinga district. Such a sequence might be useful in stratigraphic determinations in subsurface explorations.

Lists of diatoms from the Kettleman Hills, prepared by K. E. Lohman, of the Geological Survey, and brief remarks on the floras may be found under the heading "Stratigraphy of exposed formations." Some of the characteristic species are shown on plates 7, 22, 23, and 38. A consolidated list and a discussion of the floras has been recently published.[65]

[65] Lohman, K. E., Pliocene diatoms from the Kettleman Hills, Calif.: U. S. Geol. Survey Prof. Paper 189, pp. 81-102, pls. 20-23, 1938.

CALCAREOUS ALGAE

A sample of the algal layer in the lower *Amnicola* zone of the Tulare formation at La Salida on the east side of Middle Dome was forwarded to the late Dr. M. A. Howe, of the New York Botanical Garden. He wrote that the alga seems to be allied to *Lithomyxa calcigena*,[66] a Recent form from Furnace Creek, near Harpers Ferry, W. Va.

LAND PLANTS

Land plants were found at several horizons in the San Joaquin and Etchegoin formations. A more thorough search would doubtless increase the number of species. According to identifications by R. W. Brown, of the Geological Survey, the species collected in the Kettleman Hills are recorded from Pliocene formations elsewhere in California.[67]

ENVIRONMENT SUGGESTED BY FOSSILS

In attempts to reconstruct environmental conditions suggested by fossils paleontologists consider generally only a few of the complex and interrelated factors that determine the composition of living communities of animals and plants. Only a few members of fossil communities generally leave a record, if any record is available. Other essential data are unavailable. Moreover, such attempts at reconstruction are necessarily based on information gathered for the most similar living communities. So far as the Pacific coast is concerned, detailed and prolonged studies of particular localities—such as MacGinitie's recent work on the ecologic aspects of Elkhorn Slough,[68] a marine estuary on the coast of Monterey Bay—are urgently needed.

The presence or absence of marine fossils in strata of apparently indistinguishable lithologic composition and depositional features is itself a problem that is immediately apparent to a geologist working in the Kettleman Hills. In that area marine fossils are most abundant in sand, gravel, and silty sand. Some beds of such composition contain numerous fossils, and others are barren or almost barren. Paleontologists assume generally that the presence of marine fossils in marine strata is the normal condition and attempt to explain their absence in strata thought to be marine by invoking special or exceptional conditions. Perhaps, however, the opposite view is to be emphasized—that the hard parts of animals living on the sea floor or in sediments forming the floor are subject to destruction during life by sting rays and other predators, and after death under conditions of nondeposition or slow deposition may be destroyed by erosion and solution without leaving a trace; and that the burial of shells and other hard parts before destruction indicates unusual events or even exceptional events of a minor catastrophic character. In the Kettleman Hills the *Mya* in living position with siphon end upward, and other burrowers and borers found in a similar position, were doubtless overwhelmed by shifting sand or by otherwise exceptionally rapid deposition of sediments. The animals in some of the *Mya* layers and the marine animals in the lower part of the *Littorina* zone may have been killed by relatively abrupt freshening of the water. The conditions determining the presence of fossils in other fossiliferous beds are not known.

The marine formations exposed in the Kettleman Hills were deposited in an inland sea of relatively great extent, as shown on Reed's Pliocene paleogeographic map.[69] Marine Pliocene formations containing the same fossils are found from the south end of the San Joaquin Valley northward to localities a few miles north of Anticline Ridge, in the Coalinga district. The sea did not reach the present foothills of the southern Sierra Nevada, where a nonmarine Pliocene formation is exposed, but in the Bakersfield region a subsurface marine Pliocene tongue almost reaches the present foothills. The ancestral Coast Ranges and the ancestral Sierra Nevada supplied detritus to the inland sea. According to information now available, the inland San Joaquin Valley sea was joined to the open ocean by a strait extending from the Coalinga district northwestward across the present trend of the Coast Ranges to the mouth of the present Salinas Valley. Marine Pliocene formations are found in the Coast Ranges along the trend of this inferred strait. At times the sea may have been connected with the ocean by an arm extending southwestward from the present Salinas Valley to the present site of Santa Barbara.[70] The thick Pliocene section in the Kettleman Hills and adjoining foothills and the absence in these areas of the pre-Tulare unconformity characteristic of the foothills farther north and south indicate that the Kettleman Hills and adjoining foothills lay along, or close to, the trough of the sea and its connecting strait. During late Etchegoin time and during San Joaquin time the sediments were at times deposited in brackish or fresh water. Deposition of the entire Tulare formation, with the apparent exception of brackish-water deposition of brief duration, was in fresh water. The change from saline to brackish and fresh water during late Etchegoin and San Joaquin times was probably due to shallowing of the water through deposition at a rate exceeding the rate of the sinking of the basin. Offshore bars gradually enclosed estuaries that locally were at times filled with fresh water. The final freshening of the water was probably due to blocking of the connection with the ocean by deposition or by deformation in the adjoining Coast Ranges.

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[66] Howe, M. A., The geologic importance of the lime-secreting algae: U. S. Geol. Survey Prof. Paper 170, pp. 63–64, pls. 19–23, 1932.

[67] Dorf, Erling, Pliocene floras of California: Carnegie Inst. Washington Pub. 412, pp. 1–108, 13 pls., 1 fig., 1930.

[68] MacGinitie, G. E., Ecological aspects of a California marine estuary: Am. Midland Naturalist, vol. 16, no. 5, pp. 629–765, 21 figs., 1935.

[69] Reed, R.D., Geology of California, fig. 51 (p. 252), Tulsa, Am. Assoc. Petroleum Geologists, 1933.

[70] Idem.

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In view of the deposition of the Kettleman Hills formations in an inland sea, it is natural to attempt a reconstruction of environmental conditions by comparison with the largest sea extending inland from the present California coast—San Francisco Bay and its continuation, San Pablo Bay, and Suisun Bay. The mollusks of San Francisco Bay and San Pablo Bay and certain of their ecologic aspects have been described by Packard.[71] Suisun Bay, the least saline part of the San Francisco Bay system, where conditions might be similar to those during the deposition of brackish-water Etchegoin and San Joaquin strata, has apparently not been studied.

ETCHEGOIN AND SAN JOAQUIN FORMATIONS

In the marine faunas of the Etchegoin and San Joaquin formations the species of pelecypods outnumber the species of gastropods, the average ratio being about 2:1. The *Acila* zone, in which the same number of both groups are represented, is a notable exception. The living fauna between Alaska and San Diego has about three times as many shell-bearing gastropods as pelecypods,[72] and in general Tertiary faunas have more gastropod than pelecypod species. Doubtless many factors affect this ratio, but the shallow waters of estuaries and bays have generally more species of pelecypods than of gastropods. In San Francisco Bay, where the salinity is lower than in the ocean, the ratio of gastropods to pelecypods is about 1:1.3; in Elkhorn Slough, which has practically the same salinity as the ocean, the ratio of shell-bearing gastropods to pelecypods is about 1:2.6.

The recurrence of certain marine species and genera in Etchegoin and San Joaquin strata and their absence in intervening strata that contain marine fossils suggest that their recurrence is controlled by a recurrence of a combination of environmental conditions and that their apparent local extinction is due to a change in environment. Different conditions at different times are also indicated by a comparison of the marine faunas. The marine fauna of the *Littorina* zone may be considered as an impoverished upper *Pseudocardium* zone fauna; the *Acila* zone fauna as an impoverished *Pecten* zone fauna with the notable addition of *Acila;* and the upper *Mya* zone fauna as an impoverished *Neverita* zone fauna with a preponderance of species, the modern analogs of which thrive in brackish water.

The recurrence of certain forms is shown by the presence in and below the *Siphonalia* zone of the Etchegoin and in the *Pecten* zone or *Acila* zone of the San Joaquin, or generally in both, of the genera *Calliostoma*, "*Nassa*," *Siphonalia*, *Forreria*, *Progabbia*, *Chlamys*, and *Compsomyax*. These genera are absent in intervening marine zones, with the exception of a fragment of *Calliostoma* in the Cascajo conglomerate, and were not found in marine strata above the *Acila* zone. "*Nassa*" is the only one of these genera that was found in both San Francisco Bay and Elkhorn Slough, and a few specimens of *Chlamys* were found among rocks in Elkhorn Slough. *Siphonalia*, however, is no longer living on the Pacific coast; San Francisco Bay is north of the recorded northern limit of *Progabbia;* and both localities are north of the recorded northern limit of *Forreria*. These genera that occur in the lower part of the Etchegoin and recur in the *Pecten* and *Acila* zones may indicate a more open sea and probably deeper water during the deposition of the *Patinopecten*, *Macoma*, *Siphonalia*, *Pecten*, and *Acila* zones than during the deposition of the other zones. *Acila* in particular suggests water of moderate depth. This genus was not found in San Francisco Bay but was dredged outside the bay at depths of 39 to 68 fathoms.[73] The *Acila* zone fauna probably lived in deeper water than any other fauna in the Etchegoin and San Joaquin formations.

The *Pecten* zone was recognized over a larger area than the *Acila* zone and represents less uniform conditions. The relative abundance of *Pecten* and *Aequipecten* in the *Pecten* zone in the south half of the Kettleman Hills is reversed in the north half. The abundance of *Aequipecten* in the south half may indicate shallower and calmer water in that region. The local lagoonal facies, indicated by *Mya*, and the fresh-water facies in the south half also suggest shallow water, possibly controlled by a peninsula extending eastward from the ancestral Coast Ranges.

Mya occurs at many horizons in the upper part of the Etchegoin formation above the upper *Pseudocardium* zone and in the San Joaquin formation, generally in beds that contain no other fossils or few other species. The genus is rare below the upper *Pseudocardium* zone. In Elkhorn Slough *Mya* thrives best where it receives fresh water seepage.[74] It is one of the prevalent genera in San Pablo Bay,[75] the upper part of San Francisco Bay, where the mean annual salinity in round numbers is 15 to 25 parts per thousand,[76] as compared with 34 parts per thousand in the ocean outside the Golden Gate.[77] Live specimens were dredged in Carquinez Strait,[78] where the discharge of the Sacramento and the San Joaquin Rivers reduces the salinity to 15 or 16 parts per thousand, as well as in the more saline waters of San Pablo Bay and San Francisco Bay proper. Along the Oregon coast *Mya* lives generally in mud

[71] Packard, E. L., Molluscan fauna from San Francisco Bay: California Univ., Pub. Zoology, vol. 14, pp. 199–452, pls. 14–60, 1918.

[72] Dall, W. H., Summary of the marine shell-bearing mollusks of the northwest coast of America, from San Diego, Calif., to the Polar Sea * * *: U. S. Nat. Mus. Bull. 112, p. 4, 1921.

[73] Packard, E. L., op. cit., p. 247

[74] MacGinitie, G. E., op. cit., p. 730.

[75] Packard, E. L., op. cit., p. 221.

[76] Sumner, F. B., and others, A report upon the physical conditions in San Francisco Bay, based upon the operations of the United States Fisheries Steamer *Albatross* during the years 1912 and 1913: California Univ., Pub. Zoology, vol. 14, pl. 4, 1914.

[77] Packard, E. L., op. cit., p. 214.

[78] Idem, pl. 52.

flats at river mouths.[79] The *Mya* layers in the San Joaquin and Etchegoin formations appear to represent brackish water. *Mya, Ostrea, Macoma,* and *Littorina,* all of which thrive in brackish water, are the most abundant genera in the upper *Mya* zone, the last of the marine zones. Though *Calyptraea* and *Transennella,* which occur in the upper *Mya* zone, were not found in San Francisco Bay, the upper *Mya* zone represents probably less saline water than any of the other named zones. These two genera, as well as the upper *Mya* zone genus *Nucella,* were not found in Elkhorn Slough, where the salinity is about the same as in the ocean. At least locally the top of the upper *Mya* zone contains only small oysters, probably dwarfs of the larger oyster in the lower part of the zone, and toward the south end of South Dome these small oysters are the only fossils discovered in the zone. They may indicate adverse conditions, possibly reduced salinity marking a transition stage to the freshening of the water at the beginning of the immediately succeeding Tulare time.

Arnold [80] suggested that the abundance of *Arca* [*Anadara*] in the lower part of the Etchegoin indicates an environment somewhat warmer than that now prevailing at the latitude of Coalinga (36° N.). He also pointed out that a cold-water mud flat species *Mya japonica* is abundant in overlying strata, now assigned to the upper part of the Etchegoin; that still younger strata (the *Pecten* zone) contain a fauna having many characteristics in common with the fauna of the Gulf of California; and that the upper *Mya* zone contains species supposed to have been best suited to cold-water and possibly estuarine conditions. As explained under the heading "Age and correlation of exposed formations," these suggestions have been expanded and converted into climatic and age assignments.

The *Anadara* species is extinct, and a closely related living species has not yet been recognized. Moreover, *Anadara* is more abundant in the San Joaquin than in the Etchegoin. *Forreria, Apolymetis,* the new variety of *"Nassa" miser,* and *Trachycardium* might be cited as suggesting warmer water for the lower part of the Etchegoin than now present north of Point Conception. The indicated difference is not great, however, possibly not so great as the probable errors involved in the assumption that the present range of identical or closely related species can be used as a close guide in reconstructions.[81] The difference might be due to a change in the outline of the coast causing a local change in the temperature of the water.

Arnold's identifications of the species "supposed to have been best suited to cold-water and possibly estuarine conditions" are open to question. As explained under the heading "Paleontology of exposed formations," his *Mya japonica* is considered more closely allied to the upper Miocene *Mya dickersoni* than to the living Alaskan species; his *Macoma inquinata* is considered an extinct species, *M. affinis,* probably closely related to *M. inquinata,* which is recorded from Japan and Bering Strait southward to Monterey Bay; and *Littorina mariana* is apparently not closely allied to the Alaskan *L. grandis,* but is probably closely related to the upper Miocene *L. remondii* and to the living *L. scutulata,* which has a reported range from Alaska to Lower California. These forms probably indicate estuarine conditions rather than "cold-water and possibly estuarine conditions."

As was recognized by Arnold, some species in the *Pecten* zone fauna resemble forms now living in the Gulf of California. A striking example is *Pecten coalingaensis,* which is not only related to a species now living in the Gulf of California but is also related to a species now living in Japan. The differences between the *Pecten* zone fauna and the fauna now living in the Gulf of California, however, outweigh the resemblances, which are apparently due to survival in the gulf of relatives of *Pecten coalingaensis* and of *Ostrea vespertina.* Nevertheless, *Calliostoma* cf. *C. gemmulatum, Jaton, Forreria,* and *Corbula* are southern forms, or are related to southern forms, and give a southern cast to the *Pecten* zone fauna. These forms, or their living relatives, are not now found north of Point Conception. The abundance of *Trachycardium* and the poor development of *Cerastoderma* in the *Pecten* zone also suggests warm water. *Trachycardium* is at present a southern genus and *Cerastoderma* a northern genus, but their ranges overlap between Santa Barbara and San Diego. Though other conditions might be considered, it is reasonable to assume that the water of the *Pecten* zone was warmer than the present coastal water north of Point Conception but not necessarily warmer than that at Santa Barbara. The *Neverita* zone fauna suggests the living fauna north of Point Conception. Aside from its smaller size and the absence of the forms of warm-water aspect, the *Neverita* zone fauna closely resembles the fauna of the *Pecten* zone. *Mitrella, Adula,* and *Platyodon* are the only *Neverita* zone molluscan genera not found in the *Pecten* zone, and they have no particular temperature significance. *Neverita,* the most abundant gastropod in both zones, was not found in either San Francisco Bay or Elkhorn Slough. The more northern *Lunatia,* which is rare in the *Neverita* and *Pecten* zones, occurs in both San Francisco Bay and Elkhorn Slough. Possibly *Neverita* is not able to survive winter temperatures in relatively small estuaries and bays but could survive in the large San Joaquin Valley inland sea, where the winter temperature of the water was presumably not as low as in the smaller bays. The fauna of San Francisco Bay was found to have a more northern aspect than the fauna outside the bay, pre-

[79] MacGinitie, G. E., op. cit., p. 730.
[80] Arnold, Ralph, op. cit. (Bull. 396), p. 43, 1909 [1910]. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 137–138, 1910.
[81] For a discussion of this assumption see Woodring, W. P., op. cit. (Prof. Paper 190), p. 12, 1938.

sumably owing to lower winter temperatures in the bay.[82]

Even if the suggestion that the *Pecten* zone fauna indicates warmer water than the other San Joaquin faunas were accepted, it does not necessarily follow that the warm water indicates a general climatic change. During the deposition of the *Pecten* zone the San Joaquin Valley sea may have joined the ocean near the present site of Santa Barbara, whereas during the deposition of the *Neverita* and other San Joaquin zones it may have joined the ocean near the present Monterey Bay. This paleogeographic suggestion is not supported by known occurrences of a fauna similar to the *Pecten* zone fauna; in fact, marine Pliocene strata are not preserved in most of the area between the Salinas Valley and Santa Barbara. Outside of the San Joaquin Valley and its borders the *Pecten* zone fauna has been recognized only in Priest Valley in the Coast Ranges between the Coalinga district and the Salinas Valley. *Pecten coalingaensis* has been recorded from a locality east of Monterey Bay, near Hollister,[83] but it is not known whether a fauna similar to the *Pecten* zone fauna occurs in this region.

Many of the marine fossils of the Etchegoin and San Joaquin formations, including forms that have no close living relatives along the Pacific coast of North America, are closely related to species now living in Japanese waters. The species that have no living relatives along the American coast represent presumably forms that formerly had a more extensive distribution but have become extinct in American waters. The possible environmental significance of their survival in Japanese waters is not known. A comparison of the later Tertiary faunas of Japan with those of the Pacific coast of North America and more data on the later Tertiary faunas of Alaska may yield some information concerning the geologic history of these forms.

TULARE FORMATION

The thin-bedded sediments in the lower part of the Tulare formation suggest lake deposits, and this suggestion is supported by the fauna. According to Pilsbry,[84] it is inferred that the Tulare fresh-water mollusks lived in a large relatively shallow lake that had copious aquatic vegetation and well-aerated water. Some of the fossils may have been carried into the lake by streams, but none of the species is considered distinctly fluviatile by Pilsbry. Land shells, which might be expected if streams contributed a considerable part of the shells, have not been found. The diatoms in the white clay at the base of the formation indicate fresh water and brackish water of varying salinity from place to place. The *Littorina* in the tuff immediately overlying the white clay also indicates brackish water. A brackish-water diatom flora was found near the top of the lower *Amnicola* zone on the east side of Middle Dome. Brackish-water mollusks are not known in the lower *Amnicola* zone, but mollusks were not found with the diatoms. The presence in the Tulare formation of the four genera *Fluminicola*, *Goniobasis*, *Carinifex*, and *Parapholyx* not now found south of the latitude of San Francisco Bay may indicate a cooler climate than at present,[85] but *Fluminicola* and *Goniobasis* occur in fresh-water strata in the *Pecten* zone, the marine fossils of which have a relatively warm-water facies.

The sandstones and conglomerates making up most of the Tulare formation appear to represent stream deposits spread out on a plain extending eastward from the ancestral Coast Ranges. Some of these strata contain oysters and *Littorina*. If these shells were transported into the Tulare sediments as fossils, they were presumably derived from the present Kreyenhagen Hills. In that event other fossils, particularly the thick-shelled durable *Pseudocardium*, the most abundant detrital fossil in the alluvium of the Kettleman Hills, might be expected, unless only a narrow outcrop near the top of the San Joaquin formation was supplying detritus. Both oysters and *Littorina* thrive in brackish water, and their presence in the upper part of the Tulare may indicate temporary connections with the ocean, as Arnold concluded.[86] If they represent a recurrence of brackish water, some indication of ~~brackish-water or~~ marine fossils may be expected in strata of the same age farther west.

AGE AND CORRELATION OF EXPOSED FORMATIONS

AGE

ETCHEGOIN AND SAN JOAQUIN FORMATIONS

Arnold[87] assigned to the upper Miocene the formations in the Coalinga district now considered of Pliocene age. With notable exceptions the marine fossils of these formations closely resemble species from strata in the San Francisco Bay region assigned to the San Pablo formation at the time when Arnold prepared the reports on the Coalinga district. Arnold considered the San Pablo formation, now designated the San Pablo group, of upper Miocene age, and it is still so considered. The most apparent differences between the fauna of the two regions are shown by the echinoids. The San Pablo group, the youngest formation of which is now known as the Neroly formation, contains the echinoid genera *Astrodapsis* and "*Scutella*,"[88] whereas

[82] Packard, E. L., op. cit., p. 233.

[83] Kerr, P. F., and Schenck, H. G., Active thrust faults in San Benito County, Calif.: Geol. Soc. America Bull., vol. 36, p. 475, 1925.

[84] Pilsbry, H. A., Mollusks of the fresh-water Pliocene beds of the Kettleman Hills and neighboring oil fields, Calif.: Acad. Nat. Sci. Philadelphia Proc., vol. 86, pp. 542–544, 1935.

[85] Idem, pp. 542–543.

[86] Arnold, Ralph, op. cit. (Bull. 396), p. 48, 1909 [1910]. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 151, 1910.

[87] Arnold, Ralph, op. cit. (Bull. 396), pp. 28, 44, 1909 [1910]. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 112, 138–139, 1910.

[88] The California Miocene echinoids assigned to *Scutella* are probably closely related to the living Pacific coast genus *Phelsumia*. The generic name *Twitchellia* has been proposed by Lambert and Thiéry for a small Miocene species similar to the species in the San Pablo. (See p. 131.) The relations of these small forms to *Phelsumia* are still undetermined. (*R. S.*)

the Jacalitos formation—the oldest formation in the Coalinga district assigned to the Pliocene—contains *Astrodapsis* and *Dendraster;* the Etchegoin contains *Dendraster;* and the San Joaquin contains *Dendraster* and *Merriamaster*. In addition to the occurrence of *Astrodapsis*, a close relation in age or facies, or both, between the Jacalitos and San Pablo is shown by the presence in these two stratigraphic units of the molluscan genera *Trophosycon*, *Lyropecten*, *Dosinia*, and *Chione*. These genera have not been recognized in the Etchegoin and San Joaquin of the Kettleman Hills with the possible exception of *Lyropecten* in the Etchegoin. *Lyropecten*, however, is recorded from strata on Anticline Ridge assigned by Nomland [89] to the lowest fossiliferous zone in Arnold's Etchegoin of that area.

The Jacalitos and Etchegoin, the latter including the equivalent of the San Joaquin, were assigned to the Pliocene as a result of the discovery of vertebrate remains at scattered localities a few miles north of Anticline Ridge [90] and as a result of further study of the San Pablo invertebrates.[91] *Neohipparion* was found in strata correlated with the Jacalitos formation; *Pliohippus* at the base of the Etchegoin; and an advanced *Pliohippus* or *Equus*, now assigned to *Plesippus*, higher in the section in strata generally considered of late San Joaquin age but more probably representing a lower horizon.

The assignment of the Jacalitos, Etchegoin, and San Joaquin formations to the Pliocene is now generally accepted. The marine faunas of these formations have a Pliocene aspect in terms of the succession of Tertiary faunas on the Pacific coast. The vertebrate evidence now known is not opposed to this assignment. In the Kettleman Hills horse teeth identified as *Calippus* were found in the *Patinopecten* and *Siphonalia* zones of the Etchegoin; *Pliohippus* in the *Patinopecten* zone and probably in the *Siphonalia* zone; *Pliohippus* or *Plesippus* in strata immediately underlying the *Neverita* zone of the San Joaquin; *Plesippus* in the *Pecten* zone of the San Joaquin; and a hoof of a small horse representing possibly *Nannippus* or *Calippus*, was collected from the *Macoma* zone of the Etchegoin. The other vertebrate remains also are not opposed to a Pliocene assignment. A more noncommittal term, such as "late Neogene" might be preferable, but it is doubtful whether much is to be gained by discarding the terms "Miocene" and "Pliocene" after almost a century of usage in the Coast Ranges.

A transitional Pliocene-Pleistocene age has recently been assigned to the *Pecten* zone of the San Joaquin formation and a Pleistocene age to the overlying part of the San Joaquin.[92] This assignment was based on an interpretation of the climatic aspects of the late Etchegoin and San Joaquin faunas.

Arnold's suggestion that the Pliocene faunas of the Coalinga district include cool-water species was emphasized by Gale.[93] Arnold's cool-water species in the *Mya "japonica"* zone (the upper *Mya* zone at the top of the San Joaquin) were considered by Gale as evidence of the approaching cold of the Pleistocene glacial epoch and, therefore, as evidence for assigning this zone to the upper Pliocene—a quite reasonable age assignment on ordinary faunal grounds. Arnold's lower *Mya* zone (probably the *Littorina* zone of the Etchegoin), however, which presumably would have the same climatic and age implication as his upper *Mya* zone, was not considered.

This climatic interpretation was carried to a logical conclusion by Barbat and Galloway. The *Mya*-bearing strata assigned to the *Littorina* zone of the Etchegoin in the present report were interpreted as indicating a "fairly abrupt chilling of the basin" [94] and the Pliocene-Pleistocene boundary was, accordingly, lowered to place these strata in the upper Pliocene and the overlying San Joaquin in the Pleistocene.[95] According to the discussion under the heading "Environment suggested by fossils," it is doubtful whether Arnold's cool-water species are reliable indicators of cool water. Furthermore, if they indicate cool water, the suggestion that they also indicate the oncoming of Pleistocene glaciation is based on the assumption that Pleistocene glaciation is the result of a gradual decrease in the temperature of the earth's atmosphere and hydrosphere. The assignment of the San Joaquin formation to the Pleistocene is not in agreement with the faunal evidence. The few vertebrate remains represent forms generally considered of upper Pliocene age. Many of the marine fossils are similar to species in coastal California formations that are assigned to the Pliocene and underlie strata containing a marine fauna of more modern aspect considered of Pleistocene age.

TULARE FORMATION

The age of the Tulare formation is not satisfactorily known. It is generally considered Pleistocene on stratigraphic grounds. Arnold and Anderson [96] assigned the Tulare to the Pliocene and Pleistocene. This age designation was influenced by the assignment of the underlying marine formations to the Miocene and by the occurrence in the upper part of the Tulare of an oyster identified as the living *Ostrea lurida*. The same

[89] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geology, Bull., vol. 10, pp. 228, table opposite p. 230 (locality 2096), 1917.

[90] Merriam, J. C., Tertiary vertebrate faunas of the north Coalinga region of California: Am. Philos. Soc. Trans., new ser., vol. 22, pp. 191-234, 49 figs., 1915. Relationship of *Equus* to *Pliohippus* suggested by characters of a new species from the Pliocene of California: California Univ., Dept. Geol., Bull., vol. 9, pp. 525-534, 18 figs., 1916.

[91] Clark, B. L., The fauna of the San Pablo group of middle California: Idem, vol. 8, pp. 434-436. 1915.

[92] Barbat, W. F., and Galloway, John, San Joaquin clay, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 495-496, p. 498 (table), 1934. In the table the "C" zone of the San Joaquin—that is the *Pecten* zone—is assigned to the Pleistocene.

[93] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), p. 53, 1931.

[94] Barbat, W. F., and Galloway, John, op. cit., p. 490.

[95] Idem, p. 498 (table).

[96] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 140, 154, 1910.

form of oyster is present in the upper part of the San Joaquin formation, and the Tulare specimens may have been transported as fossils. At all events, they are apparently of no importance so far as age determination is concerned.

The lower part of the Tulare contains the largest fossil fauna of fresh-water mollusks known on the Pacific coast. Of the 31 forms recognized only 4 (*Valvata humeralis*, *Amnicola longinqua*, *Menetus centervillensis*, and *Physa humerosa*) are identified as living forms. In addition, *Valvata virens platyceps* is closely allied to the living *V. virens; Parapholyx* cf. *P. effusa* closely resembles the Recent *P. effusa;* and some of the indefinitely identified species may represent living forms. Nevertheless, this fauna is not a modern fauna. It includes, besides many extinct species, two extinct genera (*Calipyrgula* and *Brannerillus*), an extinct subgenus (*Planorbifex*), and a genus (*Littoridina*) no longer found in the western United States. Though the age relations of the Tulare fauna are uncertain without more data on the succession of Tertiary and Pleistocene fresh-water faunas on the Pacific coast, an assignment to the upper Pliocene is consistent with the character of the fauna. Special conditions might be invoked to account for the relatively rapid extinction of a Pleistocene fresh-water fauna of ancient aspect, as has been implied,[97] but the special conditions should be supported by evidence other than the extinction.

Unfortunately no mammalian remains were found in the Tulare formation of the Kettleman Hills. A horse tooth, identified as *Plesippus?*, was found in the bottom of an arroyo in an area underlain by the Tulare, but it may have been derived from older strata. Fragmentary camelid and rodent remains collected in the Elk Hills,[98] near the south end of the San Joaquin Valley, are the only land mammals so far recorded from strata of undisputed Tulare age. Two carnivores, representing forms generally considered of upper Pliocene age, were found many years ago near McKittrick in strata of uncertain stratigraphic position.[99] The vertebrate-bearing beds at this locality have been assigned to the Tulare formation,[1] but the stratigraphic position still appears to be doubtful.[2] The stratigraphic and age assignments at this locality, however, have no direct bearing on the age of the Tulare in the Kettleman Hills, for the base of the Tulare in the basinward Kettleman Hills may be at a lower horizon than at McKittrick, which lies near the edge of the basin.

Because of the uncertainty concerning the age of the upper part of the Tulare, the formation is considered of upper Pliocene and Pleistocene(?) age.

[97] Barbat, W. F., and Galloway, John, op. cit., pp. 492, 497.

[98] Woodring, W. P., Roundy, P. V., and Farnsworth, H. R., Geology and oil resources of the Elk Hills, Calif., including Naval Petroleum Reserve No. 1: U. S. Geol. Survey Bull. 835, p. 26, 1932.

[99] Merriam, J. C., The Pliocene and Quaternary Canidae of the Great Valley of California: California Univ., Dept. Geol., Bull., vol. 3, pp. 278-283, 1903. A new sabre-tooth cat from California: Idem, vol. 4, pp. 171-175, 1905. Relationships of Pliocene mammalian faunas from the Pacific coast and Great Basin provinces of North America: Idem, vol. 10, p. 425, 1917.

[1] Matthew, W. D., and Stirton, R. A., Osteology and affinities of *Borophagus:* Idem, vol. 19, pp. 179-180, 1930. Russell, R. D., and Vander Hoof, V. L., A vertebrate fauna from a new Pliocene formation in northern California: Idem, vol. 20, p. 20, 1931.

[2] Barbat, W. F., and Galloway, John, op. cit., p. 496.

CORRELATION

In the Coalinga district Pliocene formations containing distinct faunal zones are exposed in direct superposition. The succession and composition of these faunal zones is now fairly well known, though more information is needed for many parts of the district. A comparison of the Coalinga Pliocene faunas with those in Pliocene formations deposited in relatively small embayments extending inland from the present coast, and an attempt to correlate the formations, is difficult owing to the different facies at different localities. Moreover, it is difficult to determine the faunal sequence in coastal California owing to the lack of stratigraphic control at many localities. In the following paragraphs the faunas are briefly compared and correlations are suggested on the basis of the mollusks and echinoids—the most abundant fossils in the Coalinga district. The California and Oregon localities mentioned are shown in figure 12.

Inasmuch as three marine formations are represented in the San Joaquin Valley Pliocene, it is convenient to designate the Jacalitos formation lower Pliocene, the Etchegoin formation middle Pliocene, and the San Joaquin formation upper Pliocene. These age terms have, however, only a relative meaning.

SAN JOAQUIN VALLEY

The Jacalitos fauna was described by Arnold in his reports on the Coalinga district and by Nomland.[3] At a later date Nomland[4] abandoned the name "Jacalitos formation" and assigned the entire marine Pliocene section embracing several faunal zones to the Etchegoin. Nomland's *Chione elsmerensis* zone included most of the Jacalitos. He correlated his overlying *Turritella nova* zone with Arnold's *Glycymeris* zone, defined as representing the basal part of the Etchegoin on Anticline Ridge. The presence of *Trophosycon* in the *Turritella nova* zone suggests, however, a closer relationship with the Jacalitos.

The Jacalitos formation contains *Astrodapsis*, *Trophosycon*, *Lyropecten*, *Dosinia*, and *Chione*. These genera suggest a warm-water facies. Though they may represent a particular facies, their presence in Pliocene strata in the San Joaquin Valley is presumptive evidence for an assignment to the Jacalitos. Outside the foothills west of the Kettleman Hills, marine Jacalitos

[3] Nomland, J. O., Fauna from the lower Pliocene at Jacalitos Creek and Waltham Canyon, Fresno County, Calif.: California Univ., Dept. Geology, Bull., vol. 9, pp. 199-214, pls. 9-11, 1916.

[4] Nomland, J. O., The Etchegoin Pliocene of middle California: Idem, vol. 10, pp. 194-197, 216, 1917.

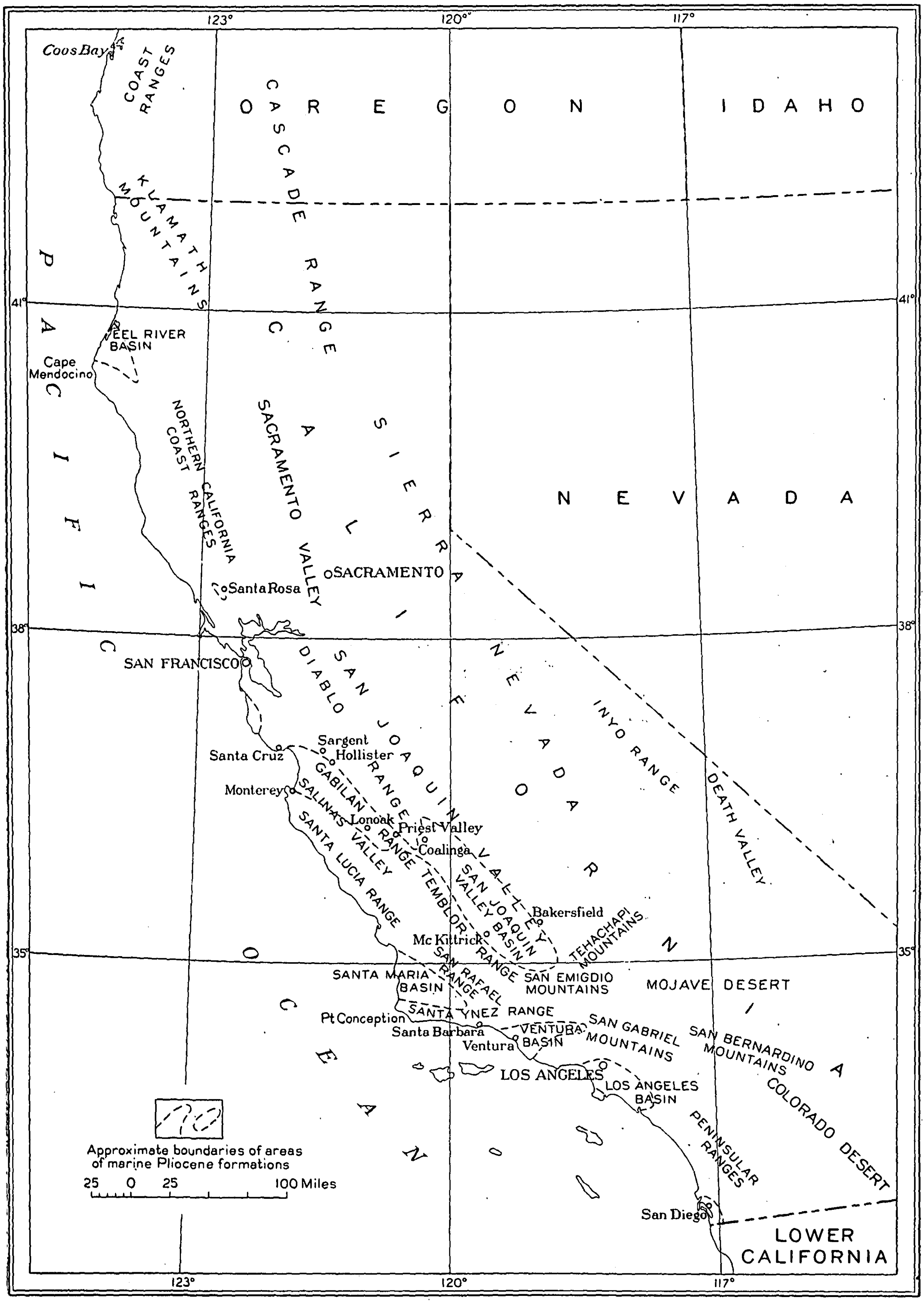

FIGURE 12.—Sketch map of California and southern Oregon showing principal areas of marine Pliocene formations.

invertebrates have been recognized in surface outcrops only in the foothills of the San Emigdio Mountains, at the south end of the San Joaquin Valley, where *Astrodapsis arnoldi crassus* and *Lyropecten "terminus"?* are recorded.[5] A collection from this region in the National Museum (U. S. G. S. locality 12887, north side

[5] Clark, B. L., in Hoots, H. W., Geology and oil resources along the southern border of San Joaquin Valley, Calif.: U. S. Geol. Survey Bull. 812, p. 278, 1930.

of Los Lobos Creek), consisting of fragments of a *Terebratalia*-like brachiopod and poorly preserved large echinoids with strongly raised petals, apparently *Astrodapsis*, suggests the Jacalitos formation, if the strata at this locality are Pliocene.

The *Pseudocardium*-bearing strata that unconformably overlie Miocene shale at the south end of the San Joaquin Valley [6] appear to represent the only recorded outcrop occurrence of Etchegoin fossils outside the Coalinga district. Collections from these strata (U. S. G. S. localities 12879, Muddy Creek; and 12881, first arroyo east of Muddy Creek) contain "*Nassa*" *moraniana*, *Siphonalia*, *Anadara trilineata* variety cf. *canalis*, *Macoma?*, *Pseudocardium densatum*, and *Schizothaerus*. These fossils indicate that in the foothills of the San Emigdio Mountains an undetermined part of the Etchegoin, possibly corresponding to the *Siphonalia* zone or of older age, overlaps onto the Miocene.

Fossiliferous strata of the San Joaquin formation, which like the Jacalitos and Etchegoin is generally overlapped by the Tulare, likewise appear to be recorded at only one locality outside the Coalinga district. The gravel and sand near McKittrick containing *Aequipecten circularis eldridgei* [7] and a small oyster appear to be the equivalent of the Cascajo conglomerate at the base of the San Joaquin. These fossiliferous strata, like the Etchegoin in the San Emigdio foothills, unconformably overlie Miocene shale.

On Anticline Ridge, northwest of the Kettleman Hills, marine Jacalitos strata are absent. The nonmarine formation containing *Neohipparion* in this area has been correlated with the Jacalitos.[8] Although this correlation is quite reasonable on stratigraphic grounds, the relations between the nonmarine formation and the marine Jacalitos is still undetermined. Arnold's *Glycymeris* zone, assigned by him to the base of the Etchegoin, embrace the oldest marine Pliocene strata on Anticline Ridge. Farther north the marine zones of the Etchegoin and San Joaquin gradually disappear. According to Nomland's faunal list,[9] the *Glycymeris* zone corresponds to the *Siphonalia* zone of the Kettleman Hills or older strata. The *Mya "japonica"* zone of this region is evidently not the upper *Mya* zone at the top of the San Joaquin formation, as is implied in Nomland's table.[10] His faunal list,[11] aside from *Glycymeris*, represents forms that occur in the *Littorina* zone of the Etchegoin as well as in the upper *Mya* zone and intervening strata. That this *Mya "japonica"* zone is close to the horizon of the *Littorina* zone is indicated by the occurrence of *Glycymeris*, which in the Kettleman Hills was not found above the upper *Pseudocardium* zone and in the foothills farther west is not known above the *Pecten* zone, and by the occurrence of *Pseudocardium* and *Tamiosoma* in immediately underlying strata.[12] Nomland's identification of the *Pecten* zone in this section was based on the occurrence of "*Pecten nutteri*," [13] a form of *Chlamys etchegoini* that has concentric swellings. Though this form was not found in the Etchegoin of the Kettleman Hills and is not recorded from the Etchegoin of the foothills to the west, it is recorded from the Jacalitos formation. Because of the occurrence of vertebrate remains at localities north of Anticline Ridge the relations between the section there and the marine section farther south are of considerable importance and need further investigation.

Suggested correlations between the Etchegoin and San Joaquin section in the Kettleman Hills and the subsurface section in the San Joaquin Valley, embodying correlations already discussed under the heading "Stratigraphy of exposed formations," are shown in figure 13. The tentative identification of the Jacalitos in a subsurface marine tongue in the Fruitvale oil field [14] near Bakersfield is doubtful. According to the list of mollusks, the marine tongue is probably younger, possibly Etchegoin.

COAST RANGES BETWEEN COALINGA DISTRICT AND SALINAS VALLEY

Marine Pliocene formations are exposed in the Coast Ranges between the Coalinga district and the Salinas Valley,[15] but details of the stratigraphy and paleontology are not available. This is an important region, for it is the first link between the Coalinga district and coastal California. A progressive seaward change in facies might be apparent from a study of the Pliocene faunas of this region. The *Pecten coalingaensis* zone fauna, which has been recognized in Priest Valley,[16] may serve as a useful guide in correlations. The Etchegoin sand dollar *Dendraster gibbsii* is, however, recorded from the *Pecten coalingaensis* zone of this region.[17] The lignitic shale, including beds of low-grade coal, that immediately underlies the *Pecten coalingaensis* zone in Priest Valley [18] indicates fresh-water or lagoonal deposition during early San Joaquin time. Nomland's list of fossils,[19] including *Dendraster gibbsii* and *Pseudocardium* ["*Mulinia*"], from localities about 14 miles southeast of Priest Valley suggests the

[6] Pack, R. W., The Sunset-Midway oil field, Calif., pt. 1, Geology and oil resources: U. S. Geol. Survey Prof. Paper 116, p. 45, pl. 11, 1920. Hoots, H. W., op. cit. (Bull. 812), pp. 276–279, pl. 35, *A*, 1930.

[7] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, Calif.: U. S. Geol. Survey Bull. 406, p. 80, 1910. Pack, R. W., op. cit. (Prof. Paper 116), p. 46.

[8] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 107–108. Nomland, J. O., op. cit. (California Univ., Dept. Geol., Bull., vol. 9), pp. 79, 83, 1916.

[9] Idem, pp. 81–82.

[10] Idem, p. 85.

[11] Idem, p. 83.

[12] Idem.

[13] Idem, p. 82.

[14] Gale, H. R., in Preston, H. M., Report on Fruitvale oil field: California Oil Fields (California Dept. Nat. Res. Div. Oil and Gas), vol. 16, no. 4, p. 16, 1931.

[15] Pack, R. W., and English, W. A., Geology and oil prospects in Waltham, Priest, Bitterwater, and Peachtree Valleys, Calif.: U. S. Geol. Survey Bull. 581, pp. 132–135, 1914.

[16] Idem, pp. 135, 158.

[17] Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ., Dept. Geology, Bull., vol. 12, p. 126, 1920. Univ. California locality 3004 is in Priest Valley.

[18] Pack, R. W., and English, W. A., op. cit., pp. 134, 158.

[19] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geology, Bull., vol. 10, p. 215, 1917.

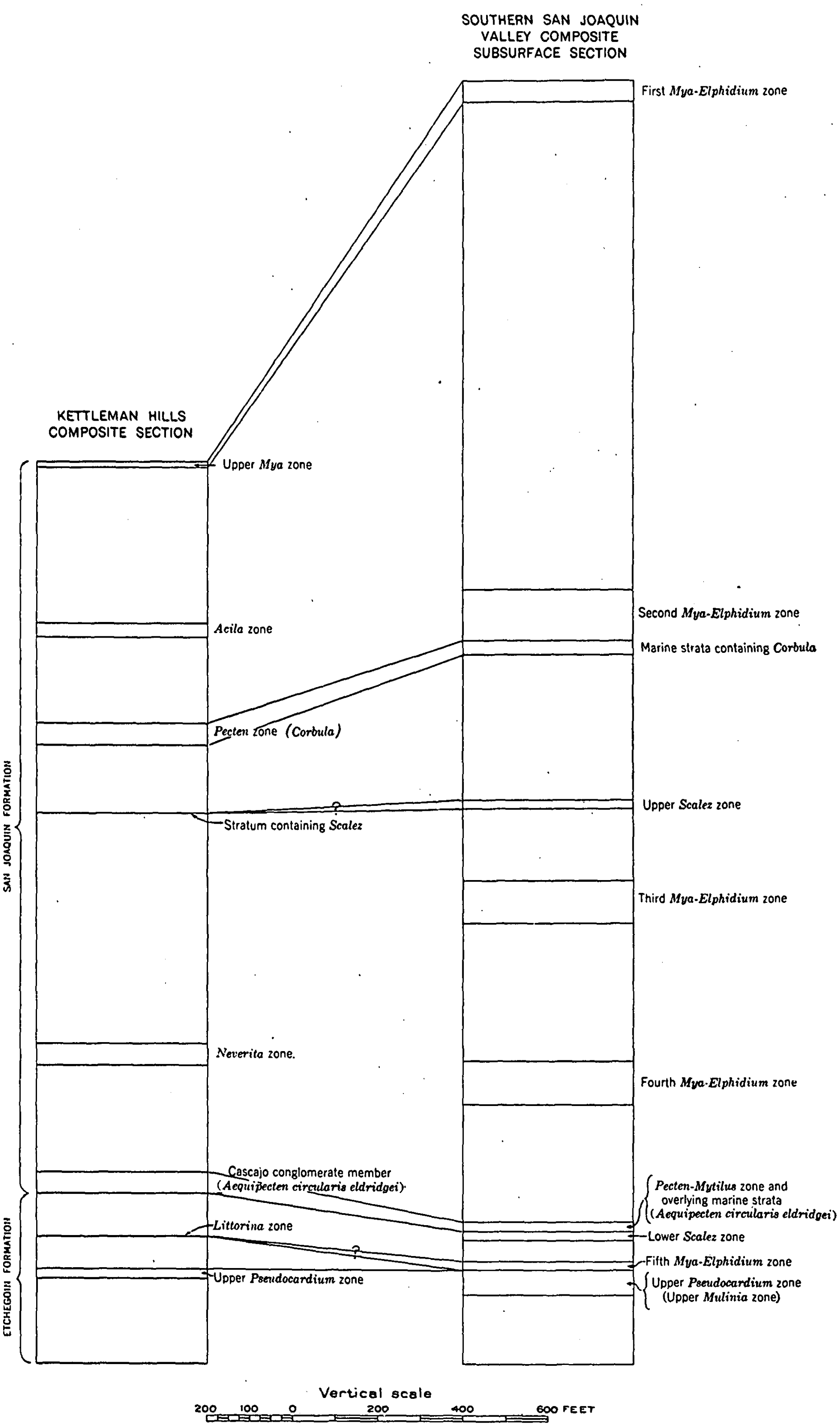

FIGURE 13.—Suggested correlation of upper part of Etchegoin formation and San Joaquin formation in Kettleman Hills with subsurface section in southern San Joaquin Valley. San Joaquin Valley subsurface section after Barbat and Galloway (Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 486–488, fig. 1, 1934).

Etchegoin, but *Lyropecten* [*"Pecten" estrellanus catalinae*] presumably indicates older strata than those exposed in the Kettleman Hills, possibly corresponding to the *Glycymeris* zone of Anticline Ridge. Pliocene formations, identified as the Jacalitos and Etchegoin,[20] also are exposed in the hills bordering the east side of

[20] English, W. A., Geology and oil prospects of the Salinas Valley-Parkfield area, Calif.: U. S. Geol. Survey Bull. 691, p. 231, 1918.

southern Salinas Valley, but no lists of fossils are available.

The few Pliocene fossils, including *Ostrea atwoodii* and *Lyropecten* [*"Pecten" estrellanus* var.] listed by Nomland [21] from a locality near Lonoak again suggest the Etchegoin, possibly the *Glycymeris* zone. This region is the type locality of *Ostrea atwoodii*, which in the Kettleman Hills was not found above the upper *Pseudocardium* zone of the Etchegoin.

The U. S. National Museum has recently received a collection of Pliocene fossils, strongly suggestive of the lower part of the Etchegoin, from localities on the east side of the San Benito River, southeast of San Benito. The fossils include *Dendraster gibbsii, Siphonalia kettlemanensis, "Chrysodomus" portolaensis, Forreria magister, Glycymeris grewingki, Ostrea atwoodii,* and *Pseudocardium densatum.*

SALINAS VALLEY

Most of the Salinas Valley is underlain by the nonmarine Paso Robles formation. On the grounds of stratigraphic position and origin the Paso Robles is generally correlated with the nonmarine Tulare formation, though in the Salinas Valley proper the Paso Robles overlies Miocene strata. According to Robert Anderson,[22] the lower part of the Paso Robles is marine and is the equivalent of part of the marine Pliocene section in the Coalinga district. The fossils, however, have not been described or listed.

SARGENT DISTRICT

Two marine faunas have been listed from the Sargent oil field,[23] in the Coast Ranges east of the mouth of Salinas Valley, the lower one designated Etchegoin and the upper one Merced (p. 109). The lower fauna includes the Jacalitos and Recent genus *Chione,* and the upper fauna includes the Jacalitos and Recent genus *Dosinia.* As neither fauna includes *Astrodapsis, Trophosycon,* and *Lyropecten*—extinct Jacalitos genera—they are considered later than the Jacalitos. In this region and doubtless elsewhere in coastal California *Chione* and *Dosinia* evidently do not have the stratigraphic significance that they have in the Coalinga district. The lower faunal list includes *Dendraster gibbsii* [*"Echinarachnius"*], *Siphonalia kettlemanensis* [*"Thais"*], *"Chrysodomus" portolaensis, Glycymeris, Chlamys etchegoini* [*"Pecten"*], *Patinopecten lohri* [*"Pecten oweni"*], *Ostrea atwoodii,* and *Macoma indentata.* The upper faunal list includes *Acila castrensis* and *Cancellaria tritonidea.* These fossils suggest that the lower fauna is Etchegoin and the upper fauna is San Joaquin. Other forms listed from the upper fauna—*"Nassa" moraniana, "Arca" canalis, Venerupis tenerrima* [*"Paphia"*], and *Pandora*—however, do not confirm this correlation, for these forms occur in the Etchegoin of the Coalinga district and are unknown in the San Joaquin. *Dendraster* (*Merriamaster*) *arnoldi,* a sand dollar characteristic of the upper part of the San Joaquin formation, is recorded from the "upper Etchegoin formation" near the Sargent oil field.[24] Kew used the designation "upper Etchegoin formation" for the San Joaquin formation, but it is not known with which of Martin's faunas this sand dollar is associated. *Dendraster ashleyi,* possibly Martin's *Echinarachnius gibbsii,* is also recorded from Sargent.[25] An earlier record of *Pseudocardium* [*"Mulinia"*] in the Sargent oil field [26] was not mentioned by Martin. Possibly this genus is rare or absent at Sargent owing to a more open sea than in the San Joaquin Valley. At all events it is not recorded at any other locality in coastal California but is known in coastal Oregon—a distribution suggesting that *Pseudocardium* is essentially a northern genus. This suggestion is supported by the occurrence of the genus, called *Mulinia* by Dall and Mertie, in late Tertiary strata in Alaska.[27] The presence of two Pliocene faunas in the Sargent district invites not only a more detailed study of the stratigraphy and paleontology but also a more detailed comparison with the Pliocene faunas of the Coalinga district. Such work may make more profitable a comparison between the Coalinga Pliocene faunas and Pliocene faunas from localities north of Sargent.

Marine Pliocene fossils are recorded from a locality near Hollister, southeast of Sargent.[28] The few species listed suggest the Etchegoin rather than the San Joaquin, with the exception of *Pecten coalingaensis* and *Patinopecten healeyi* [*"Pecten healyi"*]. Confirmation of the occurrence of *Pecten coalingaensis* in this region and data on the associated fauna are desirable.

SANTA CRUZ QUADRANGLE AND SAN FRANCISCO PENINSULA

Martin's list [29] is the most recent faunal list for the Purisima formation of the Santa Cruz quadrangle. According to this list the Purisima might represent either the Etchegoin or San Joaquin; in fact, it suggests both. *Dendraster gibbsii* [*"Echinarachnius"*], *"Nassa" moraniana, "Chrysodomus" portolaensis, "Arca" canalis, Patinopecten lohri* [*"Pecten oweni"*], *Lucinoma* [*"Phacoides"*], *Venerupis tenerrima* [*"Paphia"*], and *Pandora* [*"Clidiophora"*] suggest the Etchegoin, whereas *Dendraster* (*Merriamaster*) *perrini* [*"Scutella"*], *Acila castrensis, "Arca" trilineata,* and *Patinopecten healeyi* [*"Pecten"*] suggest the San Joaquin. A more northern aspect than shown by the faunas of the Coalinga district is indicated by *Neptunea* [*"Chrysodomus"*], *Fusitriton* [*"Argobuccinum"*], *Miopleiona,* and *Thracia.* Perhaps,

[21] Nomland, J. O., op. cit. (California Univ., Dept. Geol., Bull., vol. 10), p. 215.

[22] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 142.

[23] Martin, Bruce, The Pliocene of middle and northern California: California Univ., Dept. Geology, Bull., vol. 9, pp. 233, 245, 1916.

[24] Kew, W. S. W., op. cit. (California Univ., Dept. Geol., Bull., vol. 12), p. 115, pl. 28, figs. 2a, 2c, 1920.

[25] Idem, p. 116.

[26] Jones, W. F., The geology of the Sargent oil field: Idem, vol. 6, p. 68, 1911.

[27] Dall, W. H., in Mertie, J. B., Jr., Notes on the geography and geology of Lituya Bay, Alaska: U. S. Geol. Survey Bull. 836, p. 130, 1931. Woodring, W. P., in Capps, S. R., Kodiak and vicinity, Alaska: U. S. Geol. Survey Bull. 868, p. 118, 1937.

[28] Kerr, P. F., and Schenck, H. G., Active thrust faults in San Benito County, Calif.: Geol. Soc. America Bull., vol. 36, p. 475, 1925.

[29] Martin, op. cit. (California Univ., Dept. Geol., Bull., vol. 9), p. 243.

however, these forms indicate deeper water. The southern genus *Dosinia* also is recorded. The northern sand dollar *Anorthoscutum*, which is Kew's *Calaster* and is probably a subgenus of the Recent *Phelsumia*, is represented by *A. interlineatum* ["*Scutella*"]. According to Kew,[30] *Anorthoscutum oregonensis* ["*Dendraster* (*Calaster*)"] occurs in the Purisima formation in association with *Dendraster gibbsii humilis* and *Dendraster* (*Merriamaster*) *perrini*.

Martin's faunal lists[31] also are the latest for the fauna of the Merced formation of the San Francisco Peninsula and adjoining parts of the Santa Cruz quadrangle. Martin considered the Merced younger than the Purisima. The Merced formation is generally divided into two parts. The only sand dollars in the lower part of the Merced represent the northern *Anorthoscutum* ["*Scutella*"], and an undetermined form is the only representative of the Pectinidae. The mollusks listed from the lower part of the Merced are not strongly suggestive of the San Joaquin formation as opposed to the Etchegoin formation. Perhaps *Dendraster gibbsii* and *Merriamaster*, both of which are recorded from the Purisima, became extinct before the deposition of the Merced, and perhaps the lower part of the Merced is younger than the San Joaquin. Inasmuch, however, as neither *Dendraster* nor *Merriamaster* are recorded at localities farther north, with the exception of an Alaskan record of *D. gibbsii* ["*Echinarachnius*"],[32] perhaps the absence of these sand dollars in the Merced is due to a faunal barrier that did not exclude the northern *Anorthoscutum*, and perhaps the lower part of the Merced is the equivalent of some part of the San Joaquin. The upper part of the Merced, which contains the living *Dendraster excentricus* and living species of mollusks, has long been considered of probable Pleistocene age.

SANTA ROSA DISTRICT

Pliocene marine strata at localities near Santa Rosa, in Sonoma County, have been correlated with the Merced. They interfinger with the volcanics of the Sonoma andesite. Dickerson's indirect correlation of the marine strata with the Jacalitos formation[33] is not justified, as *Neohipparion*, on which the correlation was based, occurs in the Petaluma formation, which unconformably underlies the Sonoma.[34] Dickerson's lists of marine fossils[35] include "*Chrysodomus*" *imperialis*, which occurs in the Jacalitos formation but is not certainly known in younger formations in the Coalinga district. A more profitable comparison of the Pliocene fauna from this region with the Coalinga faunas may be possible when the relations between the Merced of the San Francisco Peninsula and the Coalinga formations are more satisfactorily known.

EEL RIVER BASIN

Martin divided Lawson's Wildcat series of the Eel River Basin, in Humboldt County, into two parts and listed fossils from each part.[36] No sand dollars are included in the list for the lower part. *Neptunea* ["*Chrysodomus*"], *Liomesus*, *Fusitriton* ["*Argobuccinum*"], and *Thyasira* suggest a cool-water (deep-water(?)) facies for the lower part. The deep-water genus *Solemya* was also recognized in the lower part. The northern sand dollar *Anorthoscutum* ["*Scutella*"] is the only echinoid listed from the upper part. In this respect the upper part of Lawson's Wildcat resembles the lower part of the Merced. A cool-water (deep-water(?)) facies for the upper part of the Eel River Basin Pliocene is suggested by the occurrence of *Neptunea* ["*Chrysodomus*"], *Fusitriton* ["*Argobuccinum*"], *Admete*, *Bela*, *Taranis*, and *Thracia;* but *Chione* also is recorded. Though *Chione* is now a warm-water genus, species assigned to *Chione* are found in late Tertiary faunas from Central America to Alaska. The absence of *Anadara* in the Eel River Basin is probably due to some unknown environmental condition, as it is present farther north in Oregon. The upper part of Lawson's Wildcat may be the equivalent of the lower part of the Merced.

COOS BAY, OREG.

The late Tertiary fauna in the Empire formation of the Coos Bay district has been described by Dall[37] and Howe.[38] The Empire formation was assigned to the Miocene by Dall and to the Pliocene by Howe. *Anorthoscutum* ["*Dendraster*" or "*Scutella*"] is the only echinoid recorded from the Empire, as well as from the lower part of the Merced and the upper part of Lawson's Wildcat. "*Chrysodomus*" *imperialis*, *Glycymeris grewingki*, *Lucinoma* ["*Phacoides*"], *Macoma indentata*, *Pseudocardium* ["*Mulinia*"], and *Venerupis laciniata hannibali* ["*Paphia*"] suggest the Jacalitos or Etchegoin faunas. "*Chrysodomus*" *imperialis* is the only one of these forms that is not certainly found above the Jacalitos in the Coalinga district, according to Nomland.[39] The Empire formation was assigned to the

[30] Kew, W. S. W., op. cit. (California Univ., Dept. Geology, Bull., vol. 12), p. 134.

[31] Martin, Bruce, op. cit. (California Univ., Dept. Geology, Bull., vol. 9), pp. 229-232.

[32] Dall, W. H., in Mertie, J. B., Jr., op. cit. (Bull. 836), p. 130. The single specimen from locality 7032, erroneously cited as 17932, is not *Dendraster gibbsii*. The oral surface is inaccessible, but the relatively long posterior petals indicate that this sand dollar is related to *Phelsumia;* the periproct is not supramarginal. Five poorly preserved specimens from locality 4414, recorded as *Echinarachnius* sp. (idem, p. 129, locality "613"), represent apparently the same form. The eccentricity of the apical system and the relative length of the posterior petals are variable.

[33] Dickerson, R. E., Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles: California Acad. Sci. Proc., 4th ser., vol. 11, p. 559, 1922.

[34] Morse, R. R., and Bailey, T. L., Geological observations in the Petaluma district, Calif.: Geol. Soc. America Bull., vol. 46, pp. 1447-1449, 1935.

[35] Dickerson, R. E., op. cit., pp. 544-545, 550.

[36] Martin, Bruce, op. cit. (California Univ., Dept. Geology, Bull., vol. 9), pp. 238-239.

[37] Dall, W. H., The Miocene of Astoria and Coos Bay, Oreg.: U. S. Geol. Survey Prof. Paper 59, 1909.

[38] Howe, H. V., Faunal and stratigraphic relationships of the Empire formation, Coos Bay, Oreg.: California Univ., Dept. Geol. Sci., Bull., vol. 14, pp. 85-114, pls. 7-12, 1922.

[39] Nomland, J. O., op. cit. (California Univ., Dept. Geology, Bull., vol. 10), p. 220. This species is recorded by Arnold and Anderson (Bull. 398, p. 132) from an Etchegoin locality in the Kreyenhagen Hills (locality 4750). The only specimen in the collection from this locality is an apical fragment too poorly preserved for certain identification.

Pliocene by Howe principally on account of the presence of *Anorthoscutum* ["*Calaster*"], which was considered a subgenus of *Dendraster*. If *Anorthoscutum* is more closely related to *Phelsumia* than to *Dendraster*, however, it is not necessarily indicative of the Pliocene. Though the sand dollars and Pectinidae characteristic of the upper Miocene San Pablo group of California have not been found as far north as Oregon, the Empire fauna is more probably Pliocene than Miocene. If it is Pliocene, it is probably more nearly the equivalent of the Etchegoin than of the Jacalitos or San Joaquin.

SANTA MARIA BASIN

Numerous well-preserved Pliocene fossils are found in the Santa Maria Basin. This area is important as offering the most promising possibility for a comparison and correlation of the Pliocene faunas of the Coalinga district with those of localities farther south in coastal California, but details of the stratigraphy and paleontology have not been published. L. M. Clark [40] correlated the lower part of Porter's Foxen formation, as interpreted by himself, with the Jacalitos and the middle and upper parts with Arnold's Etchegoin, which included the San Joaquin formation. Clark's record of *Astrodapsis* and *Lyropecten estrellanus terminus* ["*Pecten*"] from the lower part of Porter's Foxen formation strongly suggests the Jacalitos. Clark's faunal subdivisions have not been recognized in Arnold and Anderson's list of fossils from this area.[41] "*Nassa*" *moraniana* ["*Nassa californiana*"] (U. S. G. S. locality 4477) occurs in the Etchegoin formation, and a form similar to "*Nassa*" *waldorfensis* (localities 4473 and 4474) occurs in the upper part of the San Joaquin. *Turcica caffea brevis* ["*Thalotia*" *caffea*], another fossil from the upper part of the San Joaquin, is in the collection from locality 4475. This form and "*Nassa*" *waldorfensis* suggest the upper part of the San Joaquin, but in the Santa Maria Basin "*Nassa*" *waldorfensis* is recorded in association with "*Nassa*" *moraniana*. The occurrence of *Patinopecten lohri* ["*Pecten oweni*"] suggests the Etchegoin. The sand dollar *Dendraster ashleyi* ["*Echinarachnius*"] is recorded in association with "*Nassa*" *moraniana*, but a sand dollar that appears to be *D. ashleyi* ["*Echinarachnius excentricus* var."] [42] and a *Calliostoma*, probably related to the Etchegoin form *C. coalingense privum* are, however, in the collection from locality 4474 in association with species of San Joaquin aspect. Unfortunately the details of the ambulacral furrows on the sand dollars available from the Santa Maria Basin are not sufficiently well preserved to permit comparison with the extinct Coalinga forms and the living species. According to Kew's illustration of *D. ashleyi*,[43] the branches of the ambulacral furrows are more like those of *D. gibbsii* than like those of the living *D. excentricus*. *D. ashleyi* is probably a flat thin form of *D. gibbsii*. *D. ashleyi ynezensis* [44] should be compared with *D. coalingaensis*.

SANTA BARBARA

The name "Santa Barbara formation" is adopted for the marine formation exposed in the southwestern part of Santa Barbara. This formation was assigned to the Fernando formation by Arnold.[45] The name "Santa Barbara" was first used in a zonal sense by Smith.[46] The Santa Barbara formation is considered of Pleistocene age and is correlated with the San Pedro sand, including a marl member and a silt member, of the San Pedro district in the Los Angeles Basin.[47]

The Santa Barbara formation contains a well-preserved fauna listed and partly illustrated by Arnold.[48] No faunal basis for comparison with the Pliocene formations in the Coalinga district is apparent. The fauna is essentially modern. Assignment to the upper Pliocene, aside from a climatic interpretation by Gale,[49] is based on the occurrence in the lower part of the formation of extinct species generally considered characteristic of the Pliocene—particularly *Crepidula princeps* and *Pecten bellus*. *Anadara* and *Lyropecten* are not known to occur in the Santa Barbara formation. The upper part of the formation represents probably water too deep for these genera, but the lower part appears to have been deposited in shallow water. The Santa Barbara formation may have been deposited after the extinction of *Anadara* and *Lyropecten* along this part of the California coast. No discontinuity is apparent in this formation, which is strongly transgressive and rests unconformably on strata as old as the Sespe formation, locally of upper Eocene to lower Miocene age. Inasmuch as the Pliocene-Pleistocene boundary cannot be rigidly drawn in marine strata on faunal grounds, a combination of faunal and diastrophic criteria is preferable so long as the faunal evidence is not strongly opposed to the diastrophic evidence. In view of the essentially modern character of the fauna in the Santa Barbara formation, the entire formation is considered of Pleistocene age, and the extinct species are considered Pleistocene survivals. Other extinct species are present in the upper part of the formation at Santa

[40] Clark, L. M., in Reed, R. D., Geology of California, pp. 231, 232, Tulsa, Am. Assoc. Petroleum Geologists, 1933.

[41] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 322, pp. 58–60, 1907.

[42] Idem, pl. 24, fig. 8.

[43] Kew, W. S. W., op. cit. (California Univ., Dept. Geology, Bull., vol. 12.) pl. 27 fig. 1c.

[44] Idem, p. 116, pl. 36, figs. 2a, 2b.

[45] Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 321, pp. 31–32, 1907.

[46] Smith, J. P., Geologic range of Miocene invertebrate fossils of California: California Acad. Sci. Proc., 4th ser., vol. 3, p. 169, 1912; Climatic relations of the Tertiary and Quaternary faunas of the California region: Idem, vol. 9, pp. 150–151, 1919.

[47] Arnold assigned the Santa Barbara formation to the Pliocene and Pleistocene in The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, pp. 50–53, 1903; op. cit. (Bull. 321), p. 31 [assignment qualified]. J. P. Smith assigned it to the upper Pliocene (op. cit., vol. 9). Bailey assigned the lower part to the upper Pliocene and the upper part tentatively to the lower Pleistocene in Lateral change of fauna in the lower Pleistocene: Geol. Soc. America Bull., vol. 46, p. 494, 1935.

[48] Arnold, Ralph, op. cit. (Bull. 321), p. 32, pls. 11–16.

[49] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), pp. 35–36.

Barbara and at localities elsewhere in formations assigned to the Pleistocene.

The same faunal succession is found at Rincon Point, about 12 miles southeast of Santa Barbara, where the Santa Barbara formation lies unconformably on vertical beds of Miocene shale. A coarse-grained sand at the base contains *Crepidula princeps* and *Pecten bellus*. Overlying calcareous sand and marl contain a fauna that in the San Pedro district is assigned to the Pleistocene.

VENTURA BASIN

In a 20,000-foot Pliocene and Pleistocene section exposed in the Ventura Basin no evidence for major discontinuities is apparent. In the western part of the basin the lower part of the Pliocene is assigned to the Repetto formation and the upper part to the Pico formation, the subdivision being based on differentiation of the foraminiferal faunas. The Pliocene in the eastern part of the basin is assigned to the Pico formation, the type region of which is in this area. The eastern part of the basin has been mapped by Kew,[50] whose report includes a list of Pliocene fossils. The stratigraphy and paleontology, particularly of the eastern part of the basin, have been discussed by Gale.[51]

The strata at Elsmere Canyon in the eastern part of the basin resting directly on the granitic rocks of the San Gabriel Range contain *Astrodapsis*, *Trophosycon*, *Dosinia*, and *Chione*. The fauna at this locality is strongly suggestive of the Jacalitos formation, and a correlation with the Jacalitos is generally accepted. Kew,[52] however, called attention to the presence in this fauna of the living species of sand dollar *Dendraster excentricus*. Whether this record indicates an exceptionally long range for this species or a misidentification is not known. The possibility that it indicates an age as young as Pleistocene, in conformity with other records of *D. excentricus*, is too remote for serious consideration.

Faunas from localities in the eastern part of the basin west and northwest of Elsmere Canyon are similar in most respects to the fauna at Elsmere Canyon, but *Astrodapsis* and *Trophosycon* have not been found. Despite the absence of these genera English[53] considered the faunas at the different localities of the same age. Gale, however, considered the faunas at localities other than Elsmere Canyon of middle Pliocene age and designated the beds the San Diego zone on account of the resemblance of the fauna to that of the San Diego formation. (See p. 112.) Gale correlated his San Diego zone with the *Pecten coalingaensis* zone. *Lyropecten*, *Dosinia*, and *Chione*, recorded by Gale in his San Diego zone, suggest the Jacalitos formation in terms of the faunal succession in the Coalinga district, though these genera are quite certainly younger than Jacalitos in coastal California, the last two surviving until the present time; *Turritella vanvlecki* suggests the Etchegoin; and *Siphonalia humerosa* ["*Cantharus*"], which also is present at Elsmere Canyon, a variety of *Anadara trilineata* ["*Arca*"], *Pecten coalingaensis*, *Chlamys* of the *C. etchegoini* group ["*Pecten* (*Pallium*) *swiftii* var."], *Aequipecten* of the *A. deserti* group, *Ostrea vespertina*, and *Patinopecten healeyi* suggest the upper part of the San Joaquin formation. In the correlation of his San Diego zone with the *Pecten coalingaensis* zone Gale emphasized the occurrence in the Ventura Basin of *Pecten coalingaensis*, a form of *Chlamys etchegoini* with concentric swellings, *Aequipecten* of the *A. deserti* group, and *Ostrea vespertina*. The identification of *Pecten coalingaensis* should be confirmed by an examination of the inner side of the flat valves. According to the figure,[54] the form identified as *P. coalingaensis* might rather be associated with *P. hemphilli*. The *Chlamys* figured as *Pecten* (*Pallium*) *swiftii* form *parmeleei*[55] resembles specimens of *Chlamys etchegoini* from the *Siphonalia* zone of the Etchegoin, whereas the form with concentric swellings figured as *Pecten* (*Pallium*) *swiftii* form *wattsi*[56] resembles specimens in the *Pecten coalingaensis* zone of the foothills west of the Kettleman Hills. Though this form was not found in the Etchegoin of the Kettleman Hills, it is present in the Jacalitos.[57] The significance of the identification of *Aequipecten circularis impostor* is doubtful, as unequivocal criteria permitting the recognition of this form have not yet been worked out. *Ostrea vespertina* is unknown in the Jacalitos and Etchegoin but is recorded from the upper Miocene Santa Margarita sandstone north of Anticline Ridge,[58] and its value as a guide fossil is doubtful. The correlation of Gale's San Diego zone in the Ventura Basin with the *Pecten* zone cannot be regarded as established. These strata may be of Jacalitos, Etchegoin, or San Joaquin age. They are probably the equivalent of the Etchegoin, if the strata at Elsmere Canyon are the equivalent of the Jacalitos. They doubtless represent a facies similar to that of the San Joaquin.

Mollusks appear to be rare in the thick Pliocene section in the western part of the Ventura Basin, and the stratigraphic position of Gale's San Diego zone in this thick section is not known. Waterfall[59] listed a small

50 Kew, W. S. W., Geology and oil resources of a part of Los Angeles and Ventura Counties, Calif.: U. S. Geol. Survey Bull. 753, pp. 69-75, 77-79, pl. 1, 1924.

51 Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), pp. 26-39, 46-49. Faunal lists for the localities discussed may be assembled from the records in the systematic part of the memoir.

52 Kew, W. S. W., op. cit. (Bull. 753), p. 79.

53 English, W. A., The Fernando group near Newhall, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 8, p. 211, 1914.

54 Grant, U. S., IV and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1.), p. 227, pl. 2, fig. 2.

55 Idem, pl. 10, fig. 2.

56 Idem, pl. 10, fig. 3.

57 Nomland, J. O., op. cit. (California Univ., Dept. Geology, Bull., vol. 9), pp. 203, 204. The absence of a record of this form in the equivalent of the Jacalitos in Nomland's final consolidated list (idem, vol. 10, p. 219) is evidently an error that might have misled Gale.

58 Nomland, J. O., Fauna of the Santa Margarita beds in the north Coalinga region of California: California Univ., Dept. Geology, Bull., vol. 10, p. 300, 1917.

59 Waterfall, L. N., A contribution to the paleontology of the Fernando group, Ventura County, Calif.: Idem, vol. 18, pp. 82-83, table opposite p. 78, 1929.

fauna from the lower part of the Pico formation of this region. The list includes *Siphonalia humerosa* ["*Cantharus*"], suggestive of the San Joaquin but also found at Elsmere Canyon, and *Glycymeris grewingki*, an Etchegoin species. A fauna from the upper part of the Pico formation in the western part of the Ventura Basin also was recorded by Waterfall.[60] This fauna resembles the fauna of the Santa Barbara formation and like it includes northern species, indicating cool water and probably water of moderate depth. The strata in the Ventura Basin containing this fauna were designated the Santa Barbara zone by Gale. Bailey[61] found that the mudstones containing this fauna interfinger with normally overlying marine sand and gravel containing a modern fauna considered Pleistocene by all geologists familiar with this region. The Pleistocene marine sand and gravel constitute the marine Saugus of Kew and Waterfall, the San Pedro of Bailey, and the Las Posas formation of Pressler. An assignment to the Pleistocene of the strata containing the fauna similar to that at Santa Barbara is preferable to an assignment to the upper Pliocene. A satisfactory Pliocene-Pleistocene lithologic boundary in the western part of the Ventura Basin has not yet been recorded.

On the south slope of the Santa Susana Mountains, forming the southern boundary of the Ventura Basin, Pliocene fossils occur in sandstone, formerly assigned to the Saugus formation by Kew,[62] that rests unconformably on strata as old as Upper Cretaceous. The fauna includes *Merriamaster* [*Dendraster pacificus*, *D. cedrosensis*], *Dendraster*, *Lyropecten* ["*Pecten*" *cerrosensis*], and a *Chlamys* with concentric swellings recorded as *C. swiftii parmeleei*. These forms, aside from *Lyropecten*, suggest the *Pecten* zone of the San Joaquin formation more strongly than any fauna in the Ventura Basin owing to the occurrence of *Merriamaster*.

LOS ANGELES BASIN

The Pliocene of the Los Angeles Basin is divided into a lower part, the Repetto formation, and an upper part, the Pico formation. The subdivision, as in the western part of the Ventura Basin, is based on the differentiation of the foraminiferal faunas. The type locality of the Repetto formation is in this area.

The Repetto formation contains mollusks and echinoids of deep-water facies and mollusks of shallow-water and also of intermediate-depth facies.[63] The fossils of shallow-water facies include *Lyropecten cerrosensis*, *Ostrea vespertina*, *Trachycardium* cf. *T. quadragenarium*, and *Corbula gibbiformis*. These forms suggest Gale's San Diego zone and also, aside from *Lyropecten*, the *Pecten* zone of the San Joaquin formation. That the resemblance to the *Pecten* zone is a facies resemblance rather than an age resemblance is suggested by the stratigraphic position of these fossils in the Los Angeles Basin section.

In sandstone resting unconformably on Miocene shale near Santa Monica, near the northwest border of the Los Angeles Basin, is a small Pliocene fauna characterized by the abundance of Pectinidae and brachiopods.[64] The stratigraphic position of this fauna in the Los Angeles Basin section is not recorded, but it presumably represents a sandy facies of a part of the Pico formation. Aside from its smaller size and the absence of *Merriamaster*, this fauna is closely similar to that occurring on the south slope of the Santa Susana Mountains, mentioned under the heading "Ventura Basin" above, and ever since it was discovered has been considered of San Diego age.

A large fauna from the upper Pico formation as exposed in the city of Los Angeles has been listed by Moody[65] and Grant.[66] It is not comparable with any fauna in the Coalinga district. *Siphonalia gilberti*, described from this locality, is considered a variety or subspecies of *S. fortis*, which occurs in the Santa Barbara formation and in Pleistocene strata at San Pedro. The absence of sand dollars, *Anadara*, *Lyropecten*, and *Ostrea* in this fauna from Los Angeles and the presence of the living northern *Patinopecten caurinus*, *Propeamussium*, and other forms suggests water of moderate depth. *Anadara* and *Lyropecten* may have become locally extinct by the time this fauna lived, but their absence is more probably due to deposition at depths too great for those genera. The fauna is not modern enough to be of Pleistocene age. A similar fauna, but one including *Lyropecten cerrosensis*, is recorded from a locality representing the Pico formation near Santa Monica.[67]

Pliocene fossils from the Puente Hills, on the northeast border of the Los Angeles Basin, have been listed by Arnold.[68] They represent probably one or more horizons in the Pico formation. These fossils are of particular interest as they include *Pecten auburyi*, which may be very closely related to *P. coalingaensis* or may be identical with that species.

SAN DIEGO

The fauna of the San Diego formation, which plays an important role in discussions of California Pliocene fossils, is in need of revision. Arnold's list,[69] represent-

[60] Waterfall, L. N., op. cit., pp. 77–83, table opposite p. 78.

[61] Bailey, T. L., Lateral change of fauna in the lower Pleistocene: Geol. Soc. America Bull., vol. 46, pp. 489–502, pl. 44, fig. 1, 1935.

[62] Kew, W. S. W., op. cit. (Bull. 753), pp. 84–85, 88 (localities 8139, 8144, 8145, 8151, 8153, 8154, 8157, 8159). Woodring, W. P., Pliocene deposits north of Simi Valley, Calif.: California Acad. Sci. Proc., 4th ser., vol. 19, pp. 57–64, 1930.

[63] Woodring, W. P., op. cit. (Prof. Paper 190), pp. 13–15, 1938.

[64] For the most recent list see Woodring, W. P., in Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, p. 119, 1931.

[65] Moody, C. L., Fauna of the Fernando of Los Angeles: California Univ., Dept. Geology, Bull., vol. 10, pp. 39–62, pls. 1–2, 1916.

[66] Soper, E. K., and Grant, U. S., IV, Geology and paleontology of a portion of Los Angeles, Calif.: Geol. Soc. America Bull., vol. 43, pp. 1058–1067, 1932 [1933].

[67] Woodring, W. P., in Hoots, H. W., op. cit. (Prof. Paper 165), p. 116.

[68] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, p. 107, 1907.

[69] Arnold, Ralph, The Tertiary and Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, p. 28, 1907.

Suggested correlation of marine Pliocene and lower Pleistocene formations in California, Oregon, and Lower California

	Coalinga district	Coast Ranges between Coalinga district and Salinas Valley	Sargent district	Santa Cruz quadrangle	San Francisco Peninsula	Santa Rosa district	Eel River Basin	Coos Bay, Oreg.	Santa Maria Basin		Santa Barbara	Ventura Basin: Western part	Ventura Basin: Eastern part	South slope of Santa Susana Mountains	Los Angeles Basin	San Diego	Cedros Island, Lower California
Lower Pleistocene(?).	Tulare formation. (Nonmarine.)	Nonmarine strata assigned to Tulare or Paso Robles formations. (In the Salinas Valley the Paso Robles formation rests on Miocene strata.)			Upper part of Merced formation. (*Dentraster excentricus.*)				Nonmarine strata.	Lower Pleistocene.	Santa Barbara formation. (*Dendraster excentricus Crepidula princeps, siphonalia fortis, Pecten bellus, Chlamys opuntia, Patinopecten caurinus, Mercemaria perlaminosa.*)	Kew's and Waterfall's marine Saugus formation; Pressler's Las Posas formation; Bailey's San Pedro formation. (*Dendraster diegoensis, Crepidula princeps, Chlamys opuntia, Patinopecten caurinus, Mercenaria perlaminosa, Chione simillima, C. fernandoensis*). Waterfall's upper Pico fauna; Gale's Santa Barbara zone; Bailey's Santa Barbara formation (*Dendraster diegoensis, D. d. venturaensis, Crepidula princeps, "Nassa" moraniana*[2]*, Siphonalia fortis, Acila castrensis, Chlamys opuntia, Patinopecten caurinus, Mercenaria perlaminosa, Chione succincta, C. fernandoensis.*)	Saugus formation.[1] (Nonmarine.)		San Pedro sand, including a marl member and a silt member. (*Dendraster excentricus, Siphonalia fortis, Acila castrensis, Pecten bellus, Chlamys opuntia, Patinopecten caurinus, Mercenaria perlaminosa, Chione succincta.*)		
Pliocene. Upper.	San Joaquin formation. (*Dendraster coalingaensis, D. gibbsii* small var., *Merriamaster, "Nassa"* cf. *"N." waldorfensis, Siphonalia* cf. *S. humerosa, Acila castrensis, Pecten coalingaensis, Aequipecten circularis impostor, Chlamys etchegoini wattsi, Patinopecten* cf. *P. healeyi, Ostrea vespertina, Corbula* cf. *C. gibbiformis.*)	Equivalent of San Joaquin formation. (*Pecten coalingaensis* zone reported in Priest Valley.)	Martin's Merced fauna. (*"Nassa" moraniana, Acila castrensis, Dosinia.*)	Purisima formation. (*Dendraster gibbsii, Merriamaster, Anorthoscutum, "Nassa" moraniana, "Chrysodomus" portolaensis, Acila castrensis, Patinopecten healeyi, P. lohri, P. purisimaensis, Chlamys etchegoini wattsi, Dosinia.*)	Lower part of Merced formation. (*Anorthoscutum, "Nassa" moraniana, Siphonalia fortis, S. "fortis" angulata, "Chrysodomus" portolaensis?, Acila castrensis, Chione succincta.*)		Martin's upper fauna. (*Anorthoscutum, Acila castrensis, Patinopecten caurinus, Chione securis.*)		(*Dendraster ashleyi, Turcica caffea brevis, "Nassa" waldorfensis, "Nassa" moraniana, Patinopecten healeyi, Lyropecten* cf. *L. cerrosensis, Ostrea vespertina, Dosinia, Chione.*)	Upper Pliocene.		Pico formation. Waterfall's lower Pico fauna. (*Siphonalia fortis gilberti, S. humerosa angulata, Pecten bellus, Patinopecten healeyi?.*)		Strata formerly assigned to Saugus formation by Kew. (*Dendraster diegoensis, D. d. venturaensis, Merriamaster, Pecten bellus hemphilli, Chlamys opuntia, C. etchegoini parmeleei, Patinopecten healeyi, Lyropecten cerrosensis, L. veatchii, Ostrea vespertina.*)	Pico formation. Strata in Los Angeles and near Santa Monica. (*Crepidula princeps, Siphonalia fortis gilberti, Pecten bellus, Chlamys opuntia, Patinopecten caurinus, P. healeyi, Lycropecten cerrosensis, Chione simillima.*) Strata in Puente Hills and near Santa Monica. (*Anadara* cf. *A. camuloensis, Pecten auburyi, Chlamys opuntia, C. etchegoini parmeleei, Patinopecten healeyi, Lyropecten cerrosensis, Ostrea vespertina.*)	Strata at Pacific Beach. (*Dendraster diegoensis, Merriamaster, Turcica caffea brevis, Crepidula princeps, Anadara trilineata* var., *Pecten bellus hemphilli, Aequipecten circularis invalidus, Chlamys opuntia, C. etchegoini parmeleei, Patinopecten healeyi, Lyropecten cerrosensis, Ostrea vespertina.*)	Pliocene strata. (*Dendraster diegoensis, Dendraster gibbsii humilis,*[2] *Merriamaster Pecten lecontei, P. bellus, Aequipecten circularis invalidus, Chlamys opuntia, Patinopecten healeyi, Lyropecten cerrosensis, L. veatchii, Ostrea vespertina.*)
Pliocene. Middle.	Etchegoin formation. (*Dentraster gibbsii, Turritella vanvlecki, "Nassa" moraniana, Siphonalia kettlemanensis, "Chrysodomus" portolaensis, Chlamys etchegoini, Patinopecten lohri, Lyropecten "terminus," Ostrea atwoodii, Pseudocardium, Tamiosoma.*)	Equivalent of Etchegoin formation reported near Lonoak and in southeastern part of Priest Valley quadrangle. (*Dendraster gibbsii, "Nassa" moraniana, Patinopecten healeyi, Patinopecten lohri, Lyropecten estrellanus* var., *Ostrea atwoodii, Pseudocardium, Tamiosoma.*)	Martin's Etchegoin fauna. (*Dendraster gibbsii, Siphonalia kettlemanensis, "Chrysodomus" portolaensis, Patinopecten lohri, Ostrea atwoodii, Chione securis.*)			Strata assigned to Merced formation by Dickerson. (*"Nassa" moraniana, "Chrysodomus" portolaensis "Chrysodomus" imperialis, Patinopecten turneri.*)	Lawson's Wildcat series. Martin's lower fauna. (*Patinopecten dilleri.*)	Empire formation. (*"Chrysodomus" imperialis, Acila blancoensis, A. empirensis, Patinopecten coosensis, Pseudocardium, Chione securis.*)	(*Patinopecten lohri.*)	Middle Pliocene.			Gale's San Diego zone. (*Turritella vanvlecki, Siphonalia humerosa, Acila castrensis, A. semirostrata, Anadara camuloensis, Pecten coalingaensis,*[2] *Aequipecten circularis impostor, Chlamys etchegoini parmeleei, Patinopecten healeyi, Lyropecten cerrosensis, Ostrea vespertina, Dosinia, Chione fernandoensis, Corbula gibbiformis.*) Pico formation.		Strata in Los Angeles and penetrated by wells. (*Acila?* cf. *A. castrensis, Acila semirostrata, Anadara camuloensis, Lyropecten cerrosensis, Ostrea vespertina, Corbula gibbiformis.*)	San Diego formation. ?Strata penetrated by well in San Diego. (*Siphonalia diegoensis, Acila castrensis.*)	
Pliocene. Lower.	Jacalitos formation. (*Astrodapsis, Dendraster gibbsii, "Nassa" moraniana, Trophosycon, "Chrysodomus" portolaensis, "Chrysodomus" imperialis, Chlamys etchegoini wattsi, Patinopecten lohri, Lyropecten "terminus," Pseudocardium, Dosinia, Chione elsmerensis, Tamiosoma.*)	Equivalent of Jacalitos formation. (Fossils not recorded.)							(*Astrodapsis, Forreria magister, Lyropecten "terminus"* (fide L. M. Clark).)	Lower Pliocene.		Repetto formation.	Strata at Elsmere Canyon. (*Astrodapsis, Dendraster excentricus,*[2] *Trophosycon, Siphonalia humerosa* and var. *angulata, Patinopecten lohri, Lyropecten* cf. *L. cerrosensis, Dosinia, Chione fernandoensis, C. elsmerensis.*)		Repetto formation	Strata in San Diego. (*"Nassa" moraniana, Trophosycon, Dosinia.*)	

[1] Not certainly known whether the base of the Saugus formation represents an overlap or a facies change of varying chronologic value in different parts of the basin.
[2] Confirmation of identification appears desirable.

ing only fossils from Pacific Beach, is the latest list available, but many records for Pacific Beach and other localities are included in the systematic part of Grant and Gale's catalog.

If all the late Tertiary strata at and near San Diego are to be included in the San Diego formation, three faunal zones are probably represented. The lower zone containing *Trophosycon*, a large form of "*Nassa*" *moraniana*, and *Dosinia* is present in the city of San Diego. This zone is suggestive of the Jacalitos formation. A middle zone may be present in strata penetrated by a well in San Diego. *Siphonalia diegoensis*, which was collected from the well, may be the same form as *S. kettlemanensis* from the Etchegoin formation. The upper zone, which is exposed in the sea cliff at Pacific Beach, contains *Dendraster diegoensis*, *Dendraster* (*Merriamaster*) *pacificus*, a variety of *Anadara trilineata*, an *Aequipecten* of the *A. circularis* group, a form of *Chlamys etchegoini* with concentric swellings, *Lyropecten cerrosensis*, and *Ostrea vespertina*, all of which, with the exception of *Lyropecten*, are suggestive of the *Pecten* zone of the San Joaquin formation. *Turcica caffea brevis*, another fossil from the upper part of the San Joaquin, is in a collection from Pacific Beach. *Dendraster* (*Merriamaster*) *pacificus*, which resembles *D.* (*M.*) *arnoldi*, is particularly suggestive of the upper part of the San Joaquin. According to Kew's figure of the type of *Dendraster diegoensis*,[70] the ambulacral furrows are more or less intermediate between those of the Coalinga Dendrasters and the living *D. excentricus*. The pattern of the minor branches is like that of *D. gibbsii*, but the degree of eccentricity is more like that of *D. coalingaensis*.

CEDROS ISLAND, LOWER CALIFORNIA

A fauna from Cedros Island, about 300 miles south of San Diego, has been described by Jordan and Hertlein [71] and correlated with that of the San Diego formation at Pacific Beach. The fossils include *Dendraster gibbsii humilis*, *D. diegoensis*, *Merriamaster* [*Dendraster pacificus*, *D. cedrosensis*, *Astrodapsis kewi*, *A. israelskyi*], and *Pecten lecontei*, which may be identical with *P. caolingaensis*. Aside from *Dendraster gibbsii humilis*, these forms are suggestive of the *Pecten* zone of the San Joaquin formation. Cedros Island is the type locality of *Lyropecten cerrosensis*, which occurs at many localities in coastal southern California in strata that have been correlated with the part of the San Diego formation exposed at Pacific Beach.

SUMMARY

The correlations suggested in the preceding discussion are summarized in the table opposite page 112. Many of these suggested correlations are unsatisfactory, as they are based on echinoids and on selected genera and species of mollusks and for the most part on second-hand information in the form of faunal lists. Evidence from other groups of fossils should be in agreement if the correlations are substantiated. Foraminifera have proved particularly useful in correlations covering areas where depositional conditions were essentially uniform, as in the Los Angeles Basin and the western part of the Ventura Basin. They have even been used for refined correlations of minor faunal units between regions as far distant as the Los Angeles Basin and the Eel River Basin in northern California,[72] regions in which the depositional environment was presumably similar. Foraminifera should be particularly useful in correlation of formations, such as the Repetto and much of the Pico, in which other fossils are rare or absent; in fact, the stratigraphic subdivisions in the Pliocene of the Los Angeles Basin and the western part of the Ventura Basin are based solely on them. In the Pliocene formations of the Coalinga district Foramanifera are relatively rare.

Difficulties in the proposed faunal correlations resulting from changes in facies are hard to overcome at present. It is expected, however, that more satisfactory correlations between the Coalinga district and coastal California may be made when the Pliocene formations and fossils of the area northwest of the Coalinga district and those of the Santa Maria Basin are better known.

The genetic relations of the sand dollars assigned to *Merriamaster* are uncertain; they may possibly be variations of the species of *Dendraster* with which they are associated. Nevertheless, the occurrence of *Merriamaster* appears to be the most useful ground now available for the correlation of the San Joaquin formation with coastal formations. The correlation of *Merriamaster*-bearing strata at localities in southern coastal California is supported by other faunal evidence and by diastrophic evidence. For example, wherever *Merriamaster* occurs in southern coastal California and Lower California it is associated with *Lyropecten cerrosensis*. In southern coastal California *Merriamaster*-bearing strata are strongly transgressive and rest unconformably on formations ranging in age from Miocene to Upper Cretaceous. In the absence of faunal evidence to the contrary, an assumption that this transgression is essentially synchronous at different localities may be justified, but more data on the stratigraphic position of *Merriamaster* and the associated fauna with reference to the sequence of Pliocene faunas in coastal California are needed.

The assignment of the part of the San Diego formation exposed at Pacific Beach to the upper Pliocene is a corollary of its proposed correlation with the upper part of the San Joaquin. The assignment of strata at Elsmere Canyon and in San Diego to the lower Pliocene

[70] Kew, W. S. W., op. cit. (California Univ., Dept. Geology, Bull., vol. 12), pl. 30, fig. 2b.

[71] Jordan, E. K., and Hertlein, L. G., Contribution to the geology and paleontology of the Tertiary of Cedros Island and adjacent parts of Lower California: California Acad. Sci. Proc., 4th ser., vol. 15, pp. 409–464, 27–34, 1926.

[72] Reed, R. D., Southern California as a structural type: Am. Assoc. Petroleum Geologists Bull., vol. 21, pp. 552–553, fig. 2, 1937

is based principally on the occurrence of the extinct *Trophosycon*. *Trophosycon* may, of course, have survived later in the Ventura Basin than in the San Joaquin Valley and may have survived still later at San Diego. At Elsmere Canyon, however, it is accompanied by the extinct echinoid *Astrodapsis*, and at San Diego it is associated with a large form of *"Nassa" moraniana* also found in the lower part of the Etchegoin and in the Jacalitos. The assignment of the Santa Barbara formation and strata in the Ventura Basin containing a similar fauna to the Pleistocene results from combining faunal and diastrophic criteria in an attempt to determine the Pliocene-Pleistocene boundary in the marine formations. The transgression of the Santa Barbara formation at Santa Barbara and nearby localities is comparable with the early Pleistocene transgression in the San Pedro region, and with few exceptions the faunas in the two regions are similar. The faunal criteria minimize the survival of species formerly considered characteristic of the Pliocene—particularly *Crepidula princeps* and *Pecten bellus*—and emphasize the local extinction of *Anadara* and *Lyropecten*.

STRATIGRAPHY AND PALEONTOLOGY OF FORMATIONS PENETRATED BY WELLS AND EXPOSED NEARBY

The formations penetrated by wells in the Kettleman Hills range in age from Pliocene to Eocene. Those penetrated depend, of course, on the location. Wells at the north end of North Dome start at or near the top of the exposed Tulare formation and pass through the entire section so far described. The exposed formations are, however, not included under the present heading with the exception of the Etchegoin formation, only a small part of which is exposed in North and Middle Domes. In South Dome a greater thickness of Etchegoin, but apparently not the entire formation, is exposed. The subsurface formations crop out at nearby localities along the foot of the Coast Ranges, and brief descriptions of outcrop sections are included in the following discussion.

The subsurface formations are shown in the generalized stratigraphic section on plate 51. Their thickness and character are summarized in the following table:

Subsurface section in Kettleman Hills

Series	Formation	Approximate thickness (feet)	Lithology	Remarks
Pliocene.	Undifferentiated Etchegoin and Jacalitos formations.	3,600 to 4,300	Sandy shale, clay shale, sand.	
Miocene.	Reef Ridge shale.	175 to 600	Heaving shale, tough shale, sticky shale, hard shale, sandy shale, tuffaceous sand.	Caving shale of drillers.
	McLure shale member of Monterey shale.	1,000 to 2,500	Brown shale, generally hard, flakey, gray shale; sand; bentonite near base.	Brown shale of drillers.
	Temblor sandstone.	2,000	Sand, sandy shale, shale, siltstone.	Includes six oil zones composed of sand and sandy shale, and five barren zones composed of sandy shale, shale, siltstone, and sand.
Oligocene (?) and Eocene.	Kreyenhagen shale.	1,000 to 1,150	Shale, siltstone, sand.	Completely penetrated so far by only a few wells.
Eocene.	McAdams sand.	[1] 650	Sand, siltstone.	Reached so far by only a few wells.

[1] Base not reached at time report was completed (October 1, 1937).

The term "sand" is used throughout the description of the subsurface section for sandy strata regardless of the degree of consolidation.

PLIOCENE SERIES

UNDIFFERENTIATED ETCHEGOIN AND JACALITOS FORMATIONS

The Pliocene subsurface section is treated as representing undifferentiated Etchegoin and Jacalitos formations. There is no economic incentive to distinguish these two formations—if, indeed, their differentiation is practicable in subsurface work.

The Jacalitos formation, which, as shown in the table on page 27, is included in the Etchegoin by some geologists, was named by Arnold and Anderson.[73] The type region is in the Jacalitos Hills and Kreyenhagen Hills adjoining Jacalitos Creek in the foothills west of the Kettleman Hills. On the advance edition

[73] Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga oil district: U. S. Geol. Survey Bull. 357, p. 40, 1908. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 96.

of the Kettleman Hills geologic map, issued in 1934, the designation "Jacalitos sandstone" was used to contrast this part of the section with underlying units, but the lithology appears to be too diverse for the term "sandstone."

STRATIGRAPHY, LITHOLOGY, AND FOSSILS

OUTCROP SECTIONS OF JACALITOS FORMATION

Kreyenhagen Hills and Jacalitos Hills.—In the Kreyenhagen Hills and Jacalitos Hills the Jacalitos formation, as described by Arnold and Anderson, consists of sandstone, conglomerate, silty shale, and tuff and has a thickness of 3,000 to 3,300 feet,[74] excluding the silty shale and silty sandstone now referred to the underlying Reef Ridge shale. Marine fossils occur at various horizons; some beds in the lower part of the formation contain silicified wood, carbonaceous material, and leaf imprints. According to Nomland,[75] a scour discontinuity is apparent at the base of the formation near the west end of Reef Ridge. Throughout much of the Kreyenhagen and Jacalitos Hills the base of the overlying Etchegoin formation was drawn by Arnold and Anderson at the base of the zone of blue sandstone, but southeast of Canoas Creek the zone of blue sandstone was said to extend progressively farther down into the Jacalitos, reaching a horizon more than 1,000 feet below the top of the Jacalitos southeast of Big Tar Canyon.[76] A collection of fossils from the upper part of the Jacalitos at Arnold and Anderson's locality 4642, 2 miles southeast of Big Tar Canyon, appears to support this claim, as it includes *Lyropecten* and *Chione*. In view, however, of the statement that near Zapata Creek the zone of blue sandstone in the Etchegoin has a thickness of more than 2,500 feet, whereas southeast of Big Tar Canyon the thickness is less than 800 feet,[77] the possibility that this apparent downward extension of blue sandstone into the Jacalitos represents an overlap of Etchegoin may need investigation.

Northwest of Jacalitos Creek the Jacalitos overlaps onto Cretaceous rocks.[78] This overlap was recognized by Arnold and Anderson, but on the geologic map accompanying Bulletin 398 the overlapping strata are shown as Vaqueros (Temblor of present terminology) with the explanation in the legend that in the Alcalde Hills the Vaqueros possibly includes some Jacalitos.

Sandstones in the lower part of the Jacalitos along Canoas Canyon and Big Tar Canyon were reported by Bramlette [79] to contain an abundance of fresh zoned andesine, more or less altered volcanic glass, and ferromagnesian minerals. Hornblende is the most abundant ferromagnesian mineral in the lower part of the section, but at higher horizons augite is progressively more abundant. A large part of these sandstones consists of pyroclastic material, with which ordinary clastic debris is mixed. Most of the original glass has been altered to minute zeolitic crystals that appear to be clinoptilolite.

Anticline Ridge.—On the north slope of Anticline Ridge conglomerate, sandstone, and reddish and greenish clay, constituting a thickness of about 1,600 feet, underlie the Etchegoin formation and rest on upper Miocene sandstone—the Santa Margarita sandstone.[80] The absence of marine fossils, the abundance of petrified wood, the presence of leaf imprints and remains of land mammals, and the character of the rocks indicate that these strata are nonmarine. The reddish clay has a considerable amount of iron oxide and farther north, on the Domengine ranch, has been mined to make up heavy drilling mud for operations in the Kettleman Hills. On the south slope of Anticline Ridge the nonmarine formation overlaps the Santa Margarita sandstone and rests on the Temblor sandstone (Vaqueros of Arnold and Anderson). Two miles farther southwest the nonmarine formation in turn overlaps the Temblor sandstone and rests on Kreyenhagen shale.[81] The nonmarine formation was referred to the Jacalitos by Arnold and Anderson.[82] Though it may be the essential equivalent of the marine Jacalitos, the relations of the marine formation in the one area to the nonmarine formation in the other area are not known.

SUBSURFACE SECTION

The subsurface undifferentiated Etchegoin and Jacalitos formations in the Kettleman Hills are similar lithologically to the outcrop section in the Kreyenhagen and Jacalitos Hills. Blue sands are conspicuous in unweathered well samples apparently representing the Etchegoin formation. Tar sands have been encountered in the lower part of the section.

Goudkoff [83] differentiated the Jacalitos and Etchegoin formations in the Kettleman Hills subsurface section on faunal and lithologic grounds and recognized nine zones in these formations. Sufficient samples are not now available to attempt recognition of more than generalized subdivisions.

The thickness of subsurface undifferentiated Etchegoin and Jacalitos formations is shown in the second table following. The total approximate thickness of the two formations in outcrop and subsurface sections is shown below.

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[74] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 98–104.

[75] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geol. Bull., vol. 10, pp. 201–202, 1917.

[76] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 103–104.

[77] Idem, p. 119.

[78] Idem, p. 106. Pack, R. W., and English, W. A., Geology and oil prospects in Waltham, Priest, Bitterwater, and Peachtree Valleys, Calif.: U. S. Geol. Survey Bull. 581, pl. 5, 1914. Henry, Gerard, McLure shale of the Coalinga region, Fresno and Kings Counties, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 408, 1930.

[79] Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 18, p. 1570, 1934.

[80] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 107–108.

[81] The representation of this overlap precisely along an east-west land section line on plate 1 of Bulletin 398 is probably a drafting error, as it does not agree with the preliminary geologic map (Bull. 357, pl. 1).

[82] Arnold, Ralph, and Anderson, Robert, idem.

[83] Goudkoff, P. P., Subsurface stratigraphy of Kettleman Hills oil field, Calif. Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 438–443, 1934.

Approximate thickness, in feet, of undifferentiated Etchegoin and Jacalitos formations in outcrop and subsurface sections

	Feet
Outcrop section in Kreyenhagen Hills	6,000
Outcrop section on Anticline Ridge	3,300
Outcrop and subsurface sections in Kettleman Hills:	
North end of North Dome (Lillis-Welch No. 1, sec. 24, T. 21 S., R. 16 E.)	3,700
Central part of North Dome	4,800
Central part of Middle Dome	5,100
South Dome (Ohio Smith No. 1, sec. 35, T. 24 S., R. 19 E.)	5,300

The undifferentiated Etchegoin and Jacalitos consist chiefly of sandy shale, clay shale, and sand. The following table, compiled from well logs, shows the percentage of these constituents in nine wells spaced at average intervals of 2.4 miles from the north end of North Dome to South Dome.

The southward increase in thickness appears to be due mainly to a general southward increase in the percentage of sand. The records of the Huffman and Burbank wells, however, show marked exceptions to this general trend. Possibly the exceptions are partly due to logging of the same type of lithology as sand or as sandy shale in different wells. The sands presumably contain much tuffaceous material, as in the outcrop sections, and such material might be recorded as sand or sandy shale depending on individual preference.

Principal lithologic constituents in subsurface undifferentiated Etchegoin and Jacalitos formations in Kettleman Hills

Well	Sand	Sandy shale	Clay shale	Thickness of formations
North Dome:	*Percent*	*Percent*	*Percent*	*Feet*
Lillis-Welch No. 1, sec. 24, T. 21, S., R. 16 E	20	26	54	3,670
Superior Huffman, No. 1, sec. 29, T. 21 S., R. 17 E	6	77	17	4,480
Kenda 38-34-J [1]	34	43	23	4,500
Kenda 47-2-P	20	53	27	4,445
Kenda 88-2-P	21	63	16	4,500
Kenda 61-20-Q	27	59	14	4,500
Kenda 7-26-Q	51	23	26	4,275
Middle Dome:				
Petroleum Securities Burbank No. 1, sec. 30, T. 23 S., R. 19 E	6	60	34	4,350
South Dome:				
Ohio Smith No. 1, sec. 35, T. 24 S., R. 19 E	49	18	33	3,780
Average	26	47	27	4,280

[1] The term "Kenda" is an acrostic abbreviation for Kettleman North Dome Association. This association and the Standard Oil Co. of California have adopted for their wells a system of notation in which the first number represents the location of the well in a section, the second number represents the section, and the letter represents the township. For outline maps showing the system of well location and township designations see plate 51.

According to well logs, the undifferentiated Etchegoin is made up of thick sand zones separated by relatively thin shale zones. The lower, or Jacalitos, part of the section is marked by a slight increase in the percentage of shale. The following generalized subdivisions may be recognized in descending order: (1) *Pseudocardium* zone, (2) upper sand zone, (3) lower sand and shale zone.

Pseudocardium zone.—Fragments of *Pseudocardium* ["*Mulinia*"] shells recognized in ditch samples indicate a zone near the top of the subsurface section that may be designated the *Pseudocardium* zone. This zone doubtless includes a greater thickness than the upper *Pseudocardium* zone (upper *Mulinia* zone) of the outcrop section in North Dome. Wells in the central part of North Dome start at a horizon below the subsurface *Pseudocardium* zone. Goudkoff [84] recorded an *Anadara* ["*Arca*"]-*Mya-Pseudocardium* ["*Mulinia*"] association, strongly suggestive of the outcrop *Pseudocardium-Anadara* zone, from Chanslor-Canfield-Midway McGlashan No. 1 well, sec. 17, T. 24 S., R. 19 E., at a depth between 720 and 970 feet. If these fossils represent the *Pseudocardium-Anadara* zone that was used in Middle Dome as the datum for the structure contours shown on plate 51 the contours are in error at this locality by a margin of 150 to 400 feet.

Upper sand zone.—A thick zone consisting of about 2,500 feet of sand interbedded with minor beds of sandy shale and light-colored clay immediately underlies the *Pseudocardium* zone. Wells in the central part of North and Middle Domes and in the southern part of South Dome start in this zone. The sand is recorded generally as fine-grained gray sand, but some of it is logged as green or bluish-green sand, and the recorded texture ranges from fine-grained to fairly coarse grained.

Lower sand and shale zone.—The lower half of the undifferentiated Etchegoin and Jacalitos consists in descending order of (1) 200 to 400 feet of greenish clay shale, (2) about 500 feet of fine-grained gray sand, (3) 200 to 400 feet of dark-gray clay and sandy clay, (4) about 1,000 feet of fine-grained gray and greenish-gray sand, and (5) 200 to 400 feet of dark bluish-gray claystone and siltstone. Sand dollars and mollusks occur in some beds of sand, and Foraminifera and diatoms in some beds of shale and clay. Carbonized plant fragments are common in both sand and shale. Goudkoff [85] recorded Foraminifera and the characteristic Jacalitos mollusks *Lyropecten "terminus"* ["*Pecten*

[84] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 439, 442.

[85] Idem, p. 442.

estrellanus terminus"] and *Dosinia jacalitosana* from this part of the section.

AGE AND CORRELATION OF JACALITOS FORMATION

The age and correlation of outcrop sections of the Jacalitos formation are discussed under the heading "Age and correlation of exposed formation." Approximately the lower two-thirds of the subsurface undifferentiated Etchegoin and Jacalitos in North and Middle Domes and most of the section in South Dome correspond presumably to the Jacalitos of the Kreyenhagen and Jacalitos Hills. Goudkoff [86] correlated diatomite at the top of the section exposed on Chico Martinez Creek, in the Coast Range foothills 40 miles southeast of the Kettleman Hills, and diatomaceous silt and siltstone in the subsurface section in the nearby Lost Hills, North Belridge, and Belridge fields (fig. 15) with the Jacalitos of the Coalinga district. Diatoms are the most abundant fossils in the strata involved in the proposed correlation, and so far as known the diatom floras have not been compared with the sequence of floras in the Coalinga district.

MIOCENE SERIES

CLASSIFICATION AND NOMENCLATURE

The present confusion in the classification and nomenclature of Miocene strata in the Coalinga and nearby districts illustrates the difficulties encountered in attempting to establish a satisfactory classification and stratigraphic terminology for formations that change rapidly in thickness, lithology, and fossil content and that show virtually complete sections at one locality and discontinuities and overlaps at adjoining localities. This confusion has become so acute that, instead of affording a ready means for transferring concepts, the stratigraphic names are so heavily loaded with qualifications that they really lose the primary usefulness of names. Consideration of the history of the classification and terminology of Miocene formations in the Coast Ranges and of the principles involved is beyond the scope of this report. Nevertheless, certain aspects of these matters need consideration in justification of the system adopted.

The principle that lithologic constitution is the controlling basis for the subdivisions designated formations was long ago adopted by the Geological Survey,[87] and this principle has recently been restated and recommended by several organizations.[88] The advantages of this basis in the economic application of geology and in the requirements of the layman as shown by Powell [89] are evident. Moreover, this basis has an underlying genetic significance; a change, for example, from sandstone to shale denotes an environmental change controlled by events that are generally significant in the geologic history of a region. If lithologic constitution is accepted as the basis for subdivision, it follows that a formation need not be of the same age in different localities; in fact, the age may differ markedly from place to place,[90] for the environmental conditions that control the genetic unity of a formation may extend over larger or smaller areas from time to time.

Stratigraphic subdivisions based on criteria of chronologic value are essential in any geologic investigation—particularly so perhaps in the Coast Ranges, where striking facies changes occur within short distances—for the geologic history of a region cannot be deciphered without the correlations that are based on them. Paleontologic subdivisions, called zones,[91] generally constitute the most readily available basis for attempting to establish chronologic relations over extensive areas. Among some paleontologists the simple term "zone" has fallen into disrepute on account of its lack of precision, but it is still a useful term and its indefiniteness is an advantage, as it does not imply precise knowledge as to the absolute range of species and faunas.[92]

Yet it is essential to keep in mind that formations consisting of a lithologic unit, or of subordinate units, that have a genetic unity are not to be confused with faunal zones. The two systems of subdivisions are more or less incompatible and should be treated as wholly independent, a matter that was emphasized many years ago by H. S. Williams.[93] Chronologic subdivisions based on fossils or other criteria of chronologic value may be independently superimposed on lithologic subdivisions.

The classification and terminology of Coast Range Miocene strata have suffered from the misconception that the formations, originally based on lithologic subdivisions, represent essential time units each characterized by a distinct fauna—a misconception against which Louderback protested.[94] Detailed mapping and work in micropaleontology confirm Louderback's contention that similar lithologic units in different regions overlap chronologically, and that contemporaneous sandstone and shale faunas are quite different, as might be expected. The recent development of micropaleontology, particularly the study of Foraminifera, on which the

[86] Goudkoff, P. P., op. cit., pp. 443-447.

[87] Powell, J. W., Conference on map publication: U. S. Geol. Survey 10th Ann. Rept., pt. 1, p. 64, 1890. Walcott, C. D., Nomenclature and classification for the geologic atlas of the United States: U. S. Geol. Survey 24th Ann. Report., pp. 21-27, 1903.

[88] Ashley, G. H., and others, Classification and nomenclature of rock units: Geol. Soc. America Bull., vol. 44, p. 431, article 5 (b), 1933; Am. Assoc. Petroleum Geologists Bull., vol. 17, p. 850, 1933.

[89] Powell, J. W., Methods of geologic cartography in use by the United States Geological Survey: 3d Internat. Geol. Cong. Compte rendu, p. 232, 1888.

[90] Ashley, G. H., and others, op. cit. (Geol. Soc. America Bull., vol. 44), p. 432, article 6.

[91] Idem, p. 430, article 2 (d); p. 440, article 16 (d).

[92] For a discussion of the terms that have been proposed see Arkell, W. J., The Jurassic system in Great Britain, pp. 14-37, Oxford, 1933.

[93] Williams, H. S., Dual nomenclature in geological classification: Jour. Geology, vol. 2, pp. 145-160, 1894.

[94] Louderback, G. D., The Monterey series in California: California Univ., Dept. Geology, Bull., vol. 7, pp. 177-241, 1913.

greatest amount of work has been done so far, is of special significance, for at many places a large part of these Miocene beds consist of fine-grained rocks in which other fossils are rare or absent. In the light of new data on chronology, some geologists claim that the formations should be defined in terms of the time interval represented in the type region, or in more complete sections should the section in the type region be found to be incomplete, as is often the case in the Coast Ranges. But this method attempts to combine two essentially incompatible systems of subdivision and results in a nomenclature that needs extensive qualifications and is subject to violent changes. And the defining of formations in terms of faunal zones leads to the position of recognizing a formation on a lithologic basis in the type region but perhaps in no other region. It would, of course, be advantageous to have maps on which both lithologic and chronologic subdivisions, based on faunal zones, are shown, but inasmuch as lithologic units are the units dealt with in most engineering and industrial applications of geology and inasmuch as even reconnaissance lithologic maps are available for only a small part of the Coast Ranges, the time when lithologic-chronologic maps may be made appears to be rather distant.

Recognizing the difficulty of expressing the strictly chronologic aspects of geologic events in terms of lithologic units that have a changing chronologic value, R. M. Kleinpell [95] has proposed a chronologic subdivision of the Coast Range Miocene based principally on zoning by means of Foraminifera. It is expected that this proposed chronologic subdivision will provide an impetus in clarifying the Miocene history of the Coast Ranges and in stimulating attempts to refine the chronology. In view of the desirability of distinguishing more sharply between lithologic and chronologic subdivisions and in view of current American practice of giving geographic names to lithologic subdivisions, there appears to be some doubt as to the advisability of applying geographic names in adjective form to the larger chronologic subdivisions designated stages by Kleinpell, for faunal designations seem particularly appropriate for faunal units. The need for distinguishing by formal terms faunal units of different rank is hardly urgent in view of the elastic concept involved in the term "zone." That there is danger of confusing lithologic and faunal systems of subdivisions is apparent from the tentative proposal to introduce the name "Reliz formation," [96] which is likely to be confused with Kleinpell's Relizian stage. Kleinpell's designations have, however, the advantage of avoidance of awkward terms such as "lower upper Miocene."

[95] Kleinpell, R. M., Difficulty of using cartographic terminology: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 374-379, 1934: Proposed biostratigraphic classification of California Miocene [abstract]: Geol. Soc. America Proc., 1934, pp. 390-391: Miocene stratigraphy of California, pp. 87-135, Tulsa, Am. Assoc. Petroleum Geologists, 1938.

[96] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 451 (footnote).

The subsurface Miocene section in the Kettleman Hills consists of the following three main lithologic units in descending order: (1) soft silty shale, (2) hard porcelaneous mudstone, (3) sandstone with minor shale units. The names that are used for these major units, the corresponding units recognized by drillers and oil operators, and the names used in Bulletin 398 for the outcrop section on Reef Ridge are shown in the following table.

Miocene formations in Kettleman Hills subsurface section

Name used in this report	Corresponding major unit recognized by drillers and oil operators	Name used in Bulletin 398 for outcrop section on Reef Ridge
Reef Ridge shale.	Caving shale.	Transition zone included in Jacalitos formation or Santa Margarita (?) formation.
McLure member of Monterey shale.	Brown shale.	Santa Margarita (?) formation.
Temblor sandstone.	Temblor sand.	Vaqueros sandstone.

This classification is the same as the classification proposed by Gester and Galloway,[97] and aside from a minor difference in formal nomenclature, the terminology also is the same. The correspondence of the formally named units to the informal units of drillers and oil operators is an indication that this classification is based on lithologic features. Details of the lithology, stratigraphy, paleontology, and mineralogy are lacking, or are not available, in many parts of the section, not only in the Kettleman Hills but also in nearby outcrop sections. It is by no means certain that the classification here adopted adequately reflects the principal events in the Miocene history of the region. Many discontinuities may be hidden within the principal lithologic units; indeed, according to Goudkoff,[98] such discontinuities are recognizable, and the discontinuities and faunal zones are adequate grounds for a different classification.

Plate 47 shows the relations of the Kettleman Hills Miocene section to nearby outcrop sections, based on fossil and heavy-mineral data; and figure 14 is a generalized representation of the inferred chronologic relations. Regardless of the interpretation of the chronologic relations of the Miocene formations in the areas covered, the sections on plate 47 show several features: (1) The regional southward thickening from Anticline Ridge to Chico Martinez Creek, where the Miocene section is almost seven times as thick as on Anticline Ridge, 65 miles distant; (2) the southward decrease in the proportion of coarse detrital constituents, and conversely the southward increase in the proportion of

[97] Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 1174-1182, 1933.

[98] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 438-469.

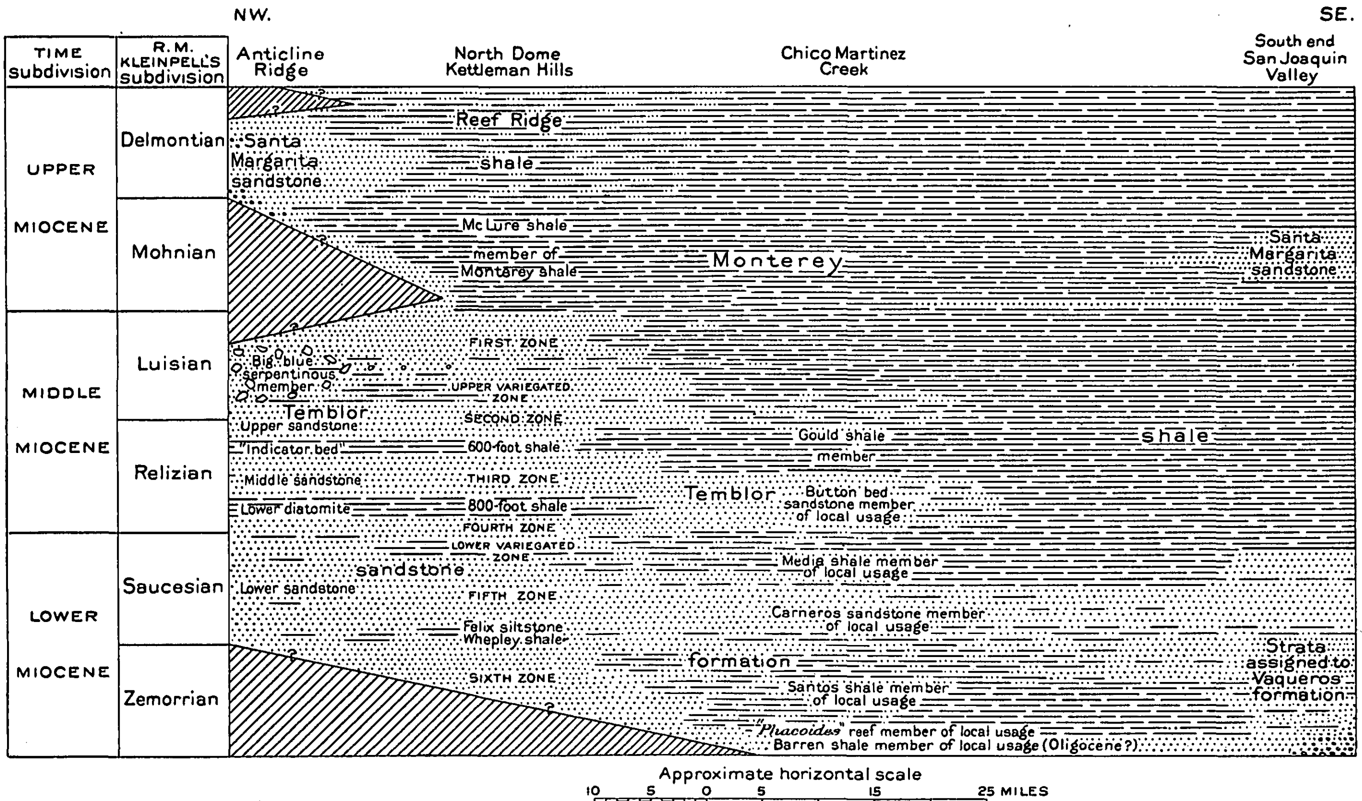


FIGURE 14.—Inferred chronologic relations of Miocene formations on west side of southern San Joaquin Valley. Diagonal ruling represents hiatus. Drillers' names used for subdivisions of Temblor sandstone in Kettleman Hills subsurface section.

siliceous shale of Monterey type; (3) the eastward thickening from Reef Ridge to the Kettleman Hills.

REEF RIDGE SHALE

Underlying the Jacalitos formation is a relatively thin lithologic unit consisting chiefly of soft silty shale with subordinate beds of silty sandstone. This unit is the caving shale of drillers and has recently been named the Reef Ridge shale.[99] The type region is along the foot of Reef Ridge. Arnold and Anderson considered the Reef Ridge shale as a transition zone between the Santa Margarita (?) formation (McLure shale member of Monterey shale) and the Jacalitos formation. Along the greater part of Reef Ridge they mapped the transition zone with the Jacalitos,[1] but near the southeast end of Reef Ridge [2] most of the transition zone—perhaps all—and in McLure Valley [3] the entire transition zone was mapped as part of the Santa Margarita (?) formation.

STRATIGRAPHY, LITHOLOGY, AND FOSSILS

OUTCROP SECTION ALONG REEF RIDGE

Along the foot of Reef Ridge are sharp-crested spurs, which are formed by hard beds in the McLure shale member of the Monterey shale. A narrow depression between these spurs and low rounded hills formed by sandstone in the lower part of the Jacalitos formation is occupied by the Reef Ridge shale (pl. 48). Exposures of the shale and interbedded sandstone are found along stream banks, as along Zapata Canyon and Jasper Canyon, but for the most part these rocks are poorly exposed. They form a narrow belt of characteristic clayey soil that is deeply cracked during the long dry season, indicating, as Bramlette suggests, that they contain much bentonitic material. Foraminifera from a locality in this region are considered in the discussion of fossils from wells in the Kettleman Hills.

As recorded by Barbat and Johnson, the thickness of the Reef Ridge shale along the foot of Reef Ridge ranges from 182 to 855 feet. The range in thickness was doubtfully attributed to erosion before the deposition of the Jacalitos formation, but it was recognized that the apparent variation may be due to inadequate exposures and to uncertainty as to the limits of the formation. Arnold and Anderson recorded a thickness of 400 to 600 feet for the transition zone corresponding to the Reef Ridge shale.[4] In a section measured by M. N. Bramlette, K. E. Lohman, and R. M. Kleinpell along a ravine about 200 yards north of Big Tar Canyon the thickness of the Reef Ridge shale appears to be about 280 feet, but the base and top are indefinite.

Details of the stratigraphy of the Reef Ridge shale and of its relations to the Jacalitos formation and the

[99] Gester, G. C., and Galloway, John, op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 17), pp. 1174-1176, 1933. Barbat, W. F., and Johnson, F. L., Stratigraphy and Foraminifera of the Reef Ridge shale, upper Miocene, Calif.: Jour. Paleontology, vol. 8, pp. 3-17, pl. 1, 1934.

[1] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 92, 93, 98, 99, 100, 101, 103, fig. 4.

[2] Idem, p. 92 (uppermost member of section).

[3] Idem, p. 104.

[4] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 92 (uppermost member of section), 99, 101, 102 (lowest member of section).

McLure shale are not available and are apparently not well known.[5] Near Jasper Canyon the Jacalitos was described as resting on an irregular surface of shale now referred to the Reef Ridge,[6] a relation that may be the result of submarine scouring. In Zapata Canyon a basal sandstone of the Reef Ridge shale is described as indicating discontinuity, and north of the west end of Reef Ridge the Reef Ridge shale is said to overlap onto Cretaceous rocks,[7] as does the Jacalitos formation. It seems probable that the Reef Ridge shale represents a transition from the siliceous shale of the McLure to the sandstone of the Jacalitos formation.

SUBSURFACE SECTION

The strata immediately underlying the Jacalitos formation in the Kettleman Hills subsurface section are similiar lithologically and faunally to the Reef Ridge shale and are assigned to that formation. With few exceptions the top of the Reef Ridge shale is recorded from ditch samples and is placed at a horizon where shale predominates over sand. Inasmuch as the lower part of the Jacalitos consists of alternating beds of sand and shale and inasmuch as the Reef Ridge shale contains some sand, the top of the formation is generally uncertain. The base of the formation is perhaps more satisfactorily determined by the occurrence of hard shale in the underlying McLure shale, but soft shale in the upper part of the McLure may be included in the Reef Ridge shale. Strata assigned to the Reef Ridge shale range in thickness from about 175 feet to about 750 feet in North Dome. In Middle Dome the thickness is about 725 feet and in South Dome about 675 feet. The average thickness in the entire area is about 500 feet. Owing to the presence of tough, sticky blue shale, which tends to slough off from the walls of wells, the Reef Ridge shale is generally called by drillers the caving shale or heaving shale.

As recorded in logs and as represented by cores that were examined, the subsurface Reef Ridge shale consists of various types of shale, sandy shale, and sand. The percentage of principal lithologic constituents in nine wells is shown in the following table, compiled from logs.

[5] For a recent discussion of these features published after the present report was prepared see Seigfus, S. S., Stratigraphic features of Reef Ridge shale in southern California: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 24–44, 5 figs., 1939.

[6] Nomland, J. O., The Etchegoin Pliocene of middle California: California Univ., Dept. Geology, Bull. vol. 10, pp. 201–202, 1917.

[7] Barbat, W. F., and Johnson, F. L., op. cit., p. 6.

Principal lithologic constituents in subsurface Reef Ridge shale in Kettleman Hills

Well	Heaving shale	Tough shale	Sticky shale	Sandy shale	Hard shale	Sand	Thickness of formation
North Dome:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Feet*
Lillis-Welch No. 1, sec. 24, T. 21 S., R. 16 E	17	3	--------	6	74	--------	175+
Superior Huffman No. 1, sec. 29, T. 21 S., R. 17 E	--------	--------	--------	74	26	--------	200+
Kenda 38-34-J	--------	60	--------	--------	19	21	600±
Kenda 47-2-P	--------	17	--------	39	20	24	750±
Kenda 88-2-P	--------	50	10	13	13	14	425±
Kenda 61-20-Q	--------	--------	--------	81	8	11	385
Kenda 7-26-Q	--------	46	31	--------	21	2	455
Middle Dome:							
Petroleum Securities Burbank No. 1, sec. 30, T. 23 S., R. 19 E	--------		--------	60	35	5	725
South Dome:							
Ohio Smith No. 1, sec. 35, T. 24 S., R. 19 E	11	27	11	40	--------	11	675±
Average	3	22	6	35	25	9	485±

The upper part of the Reef Ridge shale in the northwestern part of North Dome consists of sandy shale, generally grayish rather than bluish. Sands of varying thickness are recorded in wells southeast of Kenda well 38–34–J but appear to be absent farther northwest.

Goudkoff[8] reported that the upper part of the Reef Ridge shale—his I zone, tentatively assigned to the Jacalitos, and the upper part of his J zone, assigned to the McLure—is missing in wells on the crest of North Dome. The discontinuity advocated by Goudkoff is not recognizable on the basis of available data.

According to Bramlette,[9] sands in the lower part of the subsurface Reef Ridge shale have a distinct mineralogical composition. They contain a bentonitic matrix or groundmass that shows characteristic swelling in water. The sand grains include very abundant andesine phenocrysts, much biotite, spherules of barite, and rhombs of secondary dolomite. At higher horizons in the Reef Ridge shale the pyroclastic material has a hornblende andesite composition, grading upward into the andesitic sands of the Jacalitos formation.

Foraminifera from the Reef Ridge shale of wells in the Kettleman Hills and in the North Belridge field have been described by Barbat and Johnson,[10] who also listed a few mollusks recovered from cores.[11] Foraminifera from the lower part of the Reef Ridge shale of the Kettleman Hills were also recorded by Goudkoff,[12]

[8] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 442–443, 451–452.

[9] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1570.

[10] Barbat, W. F., and Johnson, F. L., op. cit.

[11] Idem, p. 8.

[12] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 452.

who placed this part of the caving shale in the McLure shale. R. M. Kleinpell has identified the following Foraminifera in core material from the Kettleman Hills and in an outcrop sample from the foot of Reef Ridge. Some of the characteristic species are shown on plate 49.

Foraminifera from Reef Ridge shale of wells in Kettleman Hills and of outcrop at foot of Reef Ridge

[Identifications by R. M. Kleinpell. R, rare; F, few; C, common; A, abundant]

Species	Localities																	
	Outcrop	Subsurface																
	Reef Ridge	North Dome													South Dome			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Indeterminate arenaceous forms															F			
Trochammina ? sp															R			
Lagena cf. *L. hispida* Reuss	F																	
Lagena cf. *L. scalariformis* (Williamson)	R																	
Nonion belridgensis Barbat and Johnson										R		R						
Nonionella miocenica Cushman (pl. 49, figs. 13–15)	R			C	F	A		R		A	R	A	F	C				R
Nonionella miocenica Cushman var. (pl. 49, figs. 1–4)		A																
Plectofronidcularia ? sp											R							
Buliminella elegantissima (d'Orbigny) (pl. 49, fig. 5)		F																
Buliminella curta Cushman (pl. 49, fig. 16)							F			F	F							
Buliminella subfusiformis Cushman											R	?					?	
"*Buliminella*" *dubia* Barbat and Johnson (pl. 49, figs. 27, 28)	R	?	?			F				F	R	?						
Bulimina cf. *B. ovata* d'Orbigny (pl. 49, figs. 33, 34)	R									R		F		R				
Bulimina montereyana Kleinpell (pl. 49, figs. 17, 18)	R					F				R				C				
Bulimina montereyana Kleinpell ? (smashed)							F	A	C	C	A		C	A				
Bulimina montereyana delmonteensis Kleinpell (pl. 49, figs. 19. 20)	?			R		A				?		A	F	F				
Bulimina sp																	R	
Globobulimina cf. *G. pacifica* Cushman		F		C	C					F		R		F				
Virgulina californiensis grandis Cushman and Kleinpell (pl. 49, figs. 23, 24)	A			F		A		?		F		A	F					F
Virgulina bramlettei Galloway and Morrey (pl. 49, figs. 25, 26)										F		?						
Virgulina subplana Barbat and Johnson (pl. 49, figs. 6, 7)		C										R						
Virgulina aff. *V. nodosa* R. E. and K. C. Stewart (pl. 49, figs. 8–10)		R																
Bolivina brevior Cushman (pl. 49, fig. 29)	?											R						
Bolivina cf. *B. seminuda foraminata* R. E. and K. C. Stewart (pl. 49, figs. 21, 22)										F								
Bolivina obliqua Barbat and Johnson (pl. 49, figs. 30–32)	A			F		A	F			A	A	F	A	F	F			R
Bolivina obliqua Barbat and Johnson ? (smashed)						A				A	A	C	C		F			
Bolivina obliqua Barbat and Johnson (var. or immature specimens)						C												
Bolivina vaughani Natland (pl. 49, figs. 11, 12)	R	R																
Bolivina sp. (distorted form)										F								
"*Bolivina* sp." Barbat and Johnson (pl. 49, figs. 35, 36)																		A
Uvigerina ? sp																R	R	
Globigerina bulloides d'Orbigny						R										R		
Cibicides sp																R	R	

1. Reef Ridge, first prominent ravine northwest of Big Tar Canyon, 140 feet below lowermost sandstone of Jacalitos formation. R. M. Kleinpell, collector.
2. Kenda well 27–34–J, depth 5,198 feet.
3. Same well, depth 5,204 feet.
4. Standard well 8–1–P, depth 4,875 to 4,891 feet.
5. Same well, depth 4,881 feet.
6. Petroleum Securities Robinson well No. 1, sec. 14, T. 22 S., R. 17 E., depth 8,296 to 8,300 feet.
7. Bolsa Chica Ferguson well No. 1, sec. 24, T. 22 S., R. 17 E., depth 6,929 to 6,939, feet.
8. Same well, depth 7,038 to 7,045 feet.
9. Same well, depth 7,107 to 7,119 feet.
10. Same well, depth 7,385 to 7,394 feet.
11. Same well, depth 7,429 to 7,430 feet.
12. Standard well 87–27–Q, depth 5,100 to 5,107 feet.
13. Same well, depth 5,107 to 5,126 feet.
14. Same well, depth 5,126 to 5,144 feet.
15. Same well, depth 5,187 feet.
16. Chanslor-Canfield-Midway Sahlen well No. 1, sec. 28, T. 24 S., R. 19 E., depth 5,511 feet.
17. Same well, depth 5,623 feet.
18. Same well, depth 5,775 feet.

Kleinpell's comments on these Foraminifera are as follows:

The fauna of the Reef Ridge shale is a well-defined local unit, characterized by the abundance of *Nonionella miocenica* (pl. 49, figs. 13–15), *Bulimina montereyana* (pl. 49, figs. 17, 18), *Bulimina montereyana delmonteensis* (pl. 49, figs. 19, 20), *Virgulina californiensis grandis* (pl. 49, figs. 23, 24), and the presence of *Bolivina obliqua* (pl. 49, figs. 30–32). The strata containing this fauna may be referred to the *Bolivina obliqua* zone,[13] but the upper limit of the zone in this region is uncertain. A similar fauna has been recorded from a well in Salinas Valley, where it occurs immediately above a fauna representing the "middle *Nonicn* fauna" of the Monterey shale in the type region.[14] The species of the family *Buliminidae*, and particularly the presence of *Bolivina obliqua*, suggest correlation of the Reef Ridge shale fauna with the fauna of Hoots' lithologic unit 18[15] in the upper part of the Modelo formation of the Santa Monica Mountains. *Buliminella curta* (pl. 49, fig. 16), *Buliminella dubia* (pl. 49, figs. 27, 28), *Bulimina montereyana*, *Virgulina californiensis grandis*, and *Bolivina brevior* (pl. 49, fig. 29) indicate a Miocene age rather than Pliocene, but it would not be surprising to find that some of these species occur higher than is now apparent. *Buliminella curta* is recorded from strata in the Los Angeles Basin referred to the lower Pliocene,[16] but these strata may be slightly older than the lower Pliocene of other localities in the Los Angeles and Ventura Basins.

The collections from Kenda well 27–34–J and from the Sahlen well at depths of 5,511 and 5,623 feet represent a dwarf fauna. These collections differ from others assigned to the Reef Ridge shale in the absence of *Bolivina obliqua* and in the presence of *Virgulina* aff. *V. nodosa* and *Cibicides* sp. They may be of lower Pliocene age, but this appears improbable.

AGE AND CORRELATION

The Reef Ridge shale is considered of upper Miocene age. According to Kleinpell, its Foraminifera have Miocene affinities. He considers that the formation

[13] Kleinpell, R. M., Miocene stratigraphy of California, pp. 134–135, Tulsa, Am. Assoc. Petroleum Geologists, 1938.

[14] Idem, fig. 14 (pocket).

[15] Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, pp. 103, 112–114, 1931.

[16] Stewart, R. E., and Stewart, K. C., "Lower Pliocene" in eastern end of Puente Hills, San Bernardino County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, no. 11, pp. 1445–1450, 1930.

corresponds closely to his Delmontian stage [17] and that the formation is probably the equivalent of the upper diatomite member in the type region of the Monterey shale (Galliher's lithologic member 1)[18]. On faunal and lithologic grounds the Reef Ridge-Jacalitos boundary is a convenient Miocene-Pliocene boundary.

Barbat and Johnson [19] recorded Reef Ridge Foraminifera from the upper part of the subsurface Miocene section in the Belridge field (Ohio Bear State No. 23), 45 miles southeast of the Kettleman Hills, and suggested that these strata are to be correlated with the unnamed diatomaceous shale member at the top of the Miocene section along the nearby mountain front on Chico Martinez Creek. (See section, p. 125.)

On general lithologic grounds assignment of the entire shale unit between the Jacalitos formation and the Temblor sandstone to one formation rather than assignment of formation rank to the Reef Ridge shale may be justified. In outcrop sections, however, the Reef Ridge shale does not include shale of Monterey type, whereas the underlying McLure shale does.

McLURE SHALE MEMBER OF MONTEREY SHALE

The most characteristic and widespread Miocene formation in the Coast Ranges consists of a considerable thickness, generally several thousand feet, of rocks characterized by the preponderance of various kinds of hard siliceous shale and soft shale containing microscopic siliceous fossils. These strata include varying proportions of ordinary sedimentary rocks and of the unusual siliceous rocks, but the siliceous rocks, diverse as they are, give the formation a characteristic unity. The pioneer workers in the Coast Ranges realized this unity,[20] and so has every geologist since, but the unity has become lost in the involved stratigraphic nomenclature that has come into usage.

Monterey shale, or Monterey formation, is the earliest name for Coast Range Miocene rocks characterized by this lithology. The name "Monterey formation" was first used by Blake in 1855.[21] It is quite improbable, as Louderback [22] maintained, that Blake intended to introduce a formal stratigraphic name; he did not use the name in two accounts of the geology at Monterey.[23] Nevertheless his description is quite adequate. The type region of the Monterey shale is in the vicinity of Monterey, where it has a thickness of about 3,000 feet and rests on granitic rocks.[24] The basal part, which ranges in thickness from a few inches to 200 feet, consists of sandstone and calcareous shale.

[17] Klenpell, R. M., op. cit., p. 165.

[18] Galliher, E. W., Geology and physical properties of building stone from Carmel Valley, Calif.: Mining in California (Division of Mines), vol. 28, no. 1, p. 24, fig. 3, 1932.

[19] Barbat, W. F., and Johnson, F. L., op. cit., pp. 8-9.

[20] Trask, J. B., Report on the geology of the Coast mountains [Calif.], pp. 28-29 [Sacramento], 1855. Blake, W. P., Geological report: U. S., Pacific R. R. Expl., vol. 5, pt. 2, p. 189, 1857. Whitney, J. D., Geological survey of California, Geology, vol. 1, Report of progress and synopsis of the field work from 1860 to 1864, pp. 74, 153-154, 1865.

[21] Blake, W. P., Notice of remarkable strata containing the remains of Infusoria and Polythalmia in the Tertiary formation of Monterey, Calif.: Acad. Nat. Sci. Philadelphia Proc., vol. 7, p. 331, 1855.

[22] Louderback, G. D., The Monterey series in California: California Univ., Dept. Geology, Bull., vol. 7, pp. 193-195, 1913.

[23] Blake, W. P., Observations on the physical geography and geology of the coast of California from Bodega Bay to San Diego: U. S. Coast Survey Rept. Superintendent 1855, app. 65, pp. 390-392, 1856; Geological report: U. S., Pacific R. R. Expl., vol. 5, pp. 180-182, 1857.

Until 1913 Monterey was used as the name for a unit of formation rank in publications of the Geological Survey dealing with the Coast Ranges, but in that year Monterey was raised to group rank to include the Vaqueros sandstone, which underlies the shale in some districts. Inasmuch as the use of the same name for a group and for a formation within the group is ambiguous and confusing, this action seemed to demand the introduction of a new name—†Salinas shale [25]—for the shale formerly called Monterey in an area adjoining the type region of the Monterey.[26] A further complication was introduced by the proposal of another name—†Maricopa shale—for the shale along the south and west sides of the San Joaquin Valley also formerly referred, wholly or in part, to the Monterey shale. When the name Maricopa was introduced [27] it apparently was intended simply as a replacement of the former name Monterey shale, a replacement made necessary by the raising of Monterey to group rank, but later it was retained on the grounds that whatever its lithologic character it embraces the chronologic equivalent not only of part of the original Monterey shale but also of the overlying Santa Margarita formation,[28] grounds that are not now considered sufficient for a new name.

The raising of Monterey to group rank was based on the view, then entirely reasonable, that the Vaqueros sandstone and Monterey shale together constitute a stratigraphic unit of varying lithologic facies separated from the overlying Santa Margarita sandstone by a widespread unconformity, or from the overlying San Pablo formation by an unconformity, or marked faunal change.[29] The occurrence of a widespread unconformity between Monterey and Santa Margarita is no longer accepted.[30] It also is now recognized that the Santa Margarita consists of sandstone that in different regions is at dif-

[24] Galliher, E. W., Geology and physical properties of building stone from Carmel Valley, Calif.: Mining in California (Division of Mines), vol. 28, no. 1, pp. 14-41, 25 figs., map, 1932. The basal part of the section, referred by Galliher to the Temblor (?), is here included in the Monterey shale.

[25] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey.

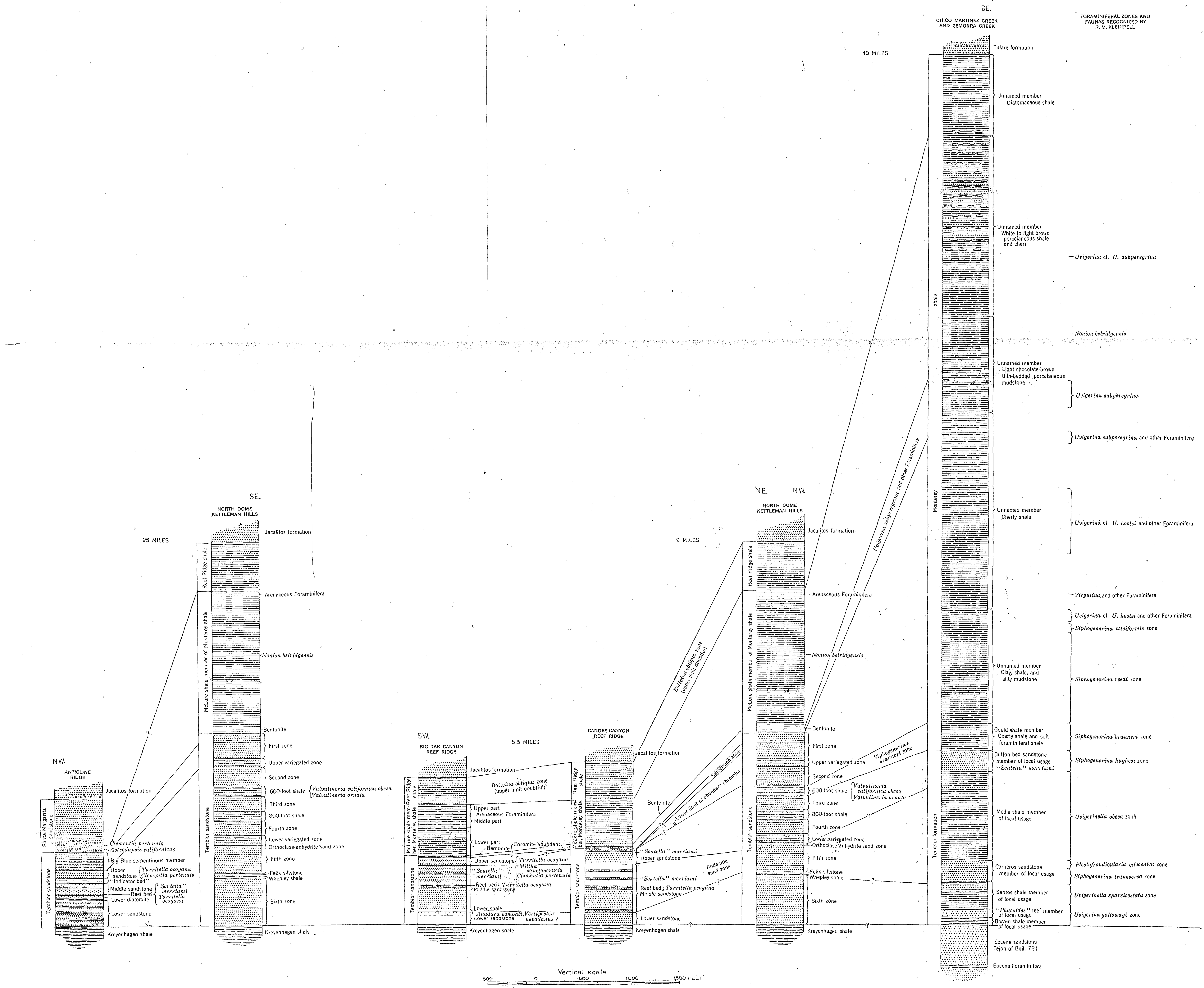
[26] English, W. A., Geology and oil prospects of the Salinas Valley-Parkfield area, Calif.: U. S. Geol. Survey Bull. 691, pp. 227-229, 1918.

[27] English, W. A., Geology and oil prospects of Cuyama Valley, Calif.: U. S. Geol. Survey Bull. 621, pp. 198-200, 1916.

[28] English, W. A., Geology and oil prospects of the Salinas Valley-Parkfield area, Calif.: U. S. Geol. Survey Bull. 691, p. 228, 1918. Pack, R. W., The Sunset-Midway oil field, Calif., pt. 1, Geology and oil resources: U. S. Geol. Survey Prof. Paper 116, pp. 27-28, 1920.

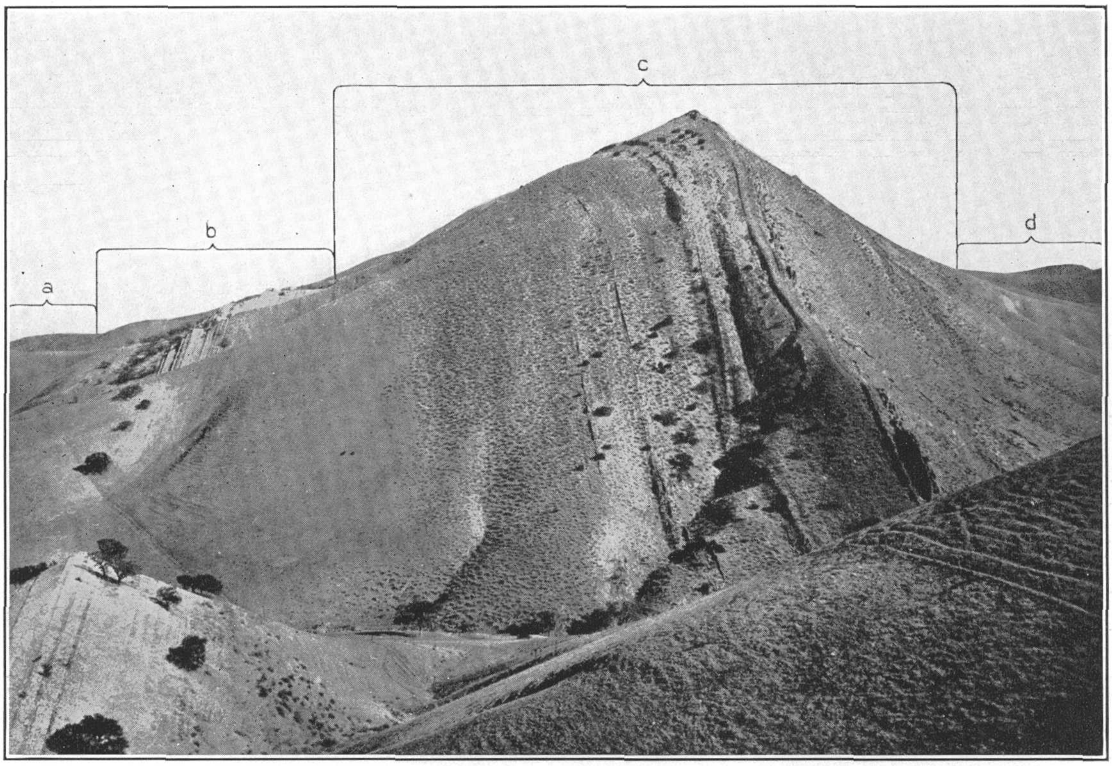
[29] Louderback, G. D., The Monterey series in California: California Univ., Dept. Geology, Bull., vol. 7, pp. 177-241, 1913. Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), pp. 9-11, 1914.

[30] Reed, R. D., The post-Monterey disturbance in the Salinas Valley, Calif.: Jour. Geology, vol. 33, pp. 588-607, 3 figs., 1925; Geology of California, pp. 206-207, Tulsa, Am. Assoc. Petroleum Geologists, 1933.



MIOCENE FORMATIONS OF NORTH DOME SUBSURFACE SECTION AND NEARBY OUTCROP SECTIONS AND THEIR CHRONOLOGIC RELATIONS AS INFERRED FROM FAUNAL AND MINERALOGICAL DATA.

Anticline Ridge: Temblor sandstone below Big Blue serpentinous member measured by K. E. Lohman on south slope of Anticline Ridge, on first spur southeast of Phoenix Canyon, which enters Oil Canyon in southern part of sec. 20, T. 19 S., R. 15 E.; remainder of section after Geological Survey Bulletin 398. Big Tar Canyon, Reef Ridge: McLure shale member of Monterey shale and Reef Ridge shale measured by M. N. Bramlette, K. E. Lohman, and R. M. Kleinpell. Canoas Canyon, Reef Ridge: McLure shale member of Monterey shale and Reef Ridge shale after Geological Survey Bulletin 398. Chico Martinez Creek and Zemorra Creek: Measured by M. N. Bramlette, K. E. Lohman, and R. M. Kleinpell. The foraminiferal assemblage characterized by *Uvigerina subperegrina* was recognized on Reef Ridge but not in Kettleman Hills.



A. VIEW LOOKING SOUTHEASTWARD ACROSS TAR CANYON.

B. VIEW LOOKING SOUTHEASTWARD FROM FIRST SPUR SOUTHEAST OF TAR CANYON.

MIOCENE FORMATIONS ON REEF RIDGE, 8 MILES SOUTHWEST OF KETTLEMAN HILLS.

a. Reef Ridge shale.
b. McLure shale member of Monterey shale.
c. Temblor sandstone.
d. Kreyenhagen shale (Eocene).

Photographs by K. E. Lohman.

PLATE 49

FIGURES 1–4. *Nonionella miocenica* Cushman var. Kenda well No. 27, sec. 34, T. 21 S., R. 17 E., depth 5,198 feet. U. S. Nat. Mus. 373089.

5. *Buliminella elegantissima* (d'Orbigny). Same locality as preceding. U. S. Nat. Mus. 373088.

6, 7. *Virgulina subplana* Barbat and Johnson. Same locality as preceding. U. S. Nat. Mus. 373091.

8–10. *Virgulina* aff. *V. nodosa* R. E. and K. C. Stewart. Same locality as preceding. U. S. Nat. Mus. 373092.

11, 12. *Bolivina vaughani* Natland. Same locality as preceding. U. S. Nat. Mus. 373090.

13–15. *Nonionella miocenica* Cushman. Petroleum Securities Co. well No. 1, sec. 14, T. 22 S., R. 17 E., depth 8,296–8,300 feet. U. S. Nat. Mus. 373086.

16. *Buliminella curta* Cushman. Bolsa Chica Oil Co. well No. 1, sec. 24, T. 22 S., R. 17 E., depth 6,929–6,939 feet. U. S. Nat. Mus. 373084.

17, 18. *Bulimina montereyana* Kleinpell. Standard Oil Co. well No. 87, sec. 27, T. 22 S., R. 18 E., depth 5,126–5,144 feet. U. S. Nat. Mus. 483781.

19, 20. *Bulimina montereyana delmonteensis* Kleinpell. Petroleum Securities Co. well No. 1, sec. 14, T. 22 S., R. 17 E., depth 8,296–8,300 feet. U. S. Nat. Mus. 373082.

21, 22. *Bolivina* cf. *B. seminuda foraminata* R. E. and K. C. Stewart. Bolsa Chica Oil Co. well No. 1, sec. 24, T. 22 S., R. 17E., depth 7,385–7,394 feet. U. S. Nat. Mus. 373105.

23, 24. *Virgulina californiensis grandis* Cushman and Kleinpell. Standard Oil Co. well No. 87, sec. 27, T. 22 S., R. 18 E., depth 5,100–5,107 feet. U. S. Nat. Mus. 373079.

25, 26. *Virgulina bramlettei* Galloway and Morey. Bolsa Chica Oil Co. well No. 1, sec. 24, T. 22 S., R. 17 E., depth 7,385–7,394 feet. U. S. Nat. Mus. 373081.

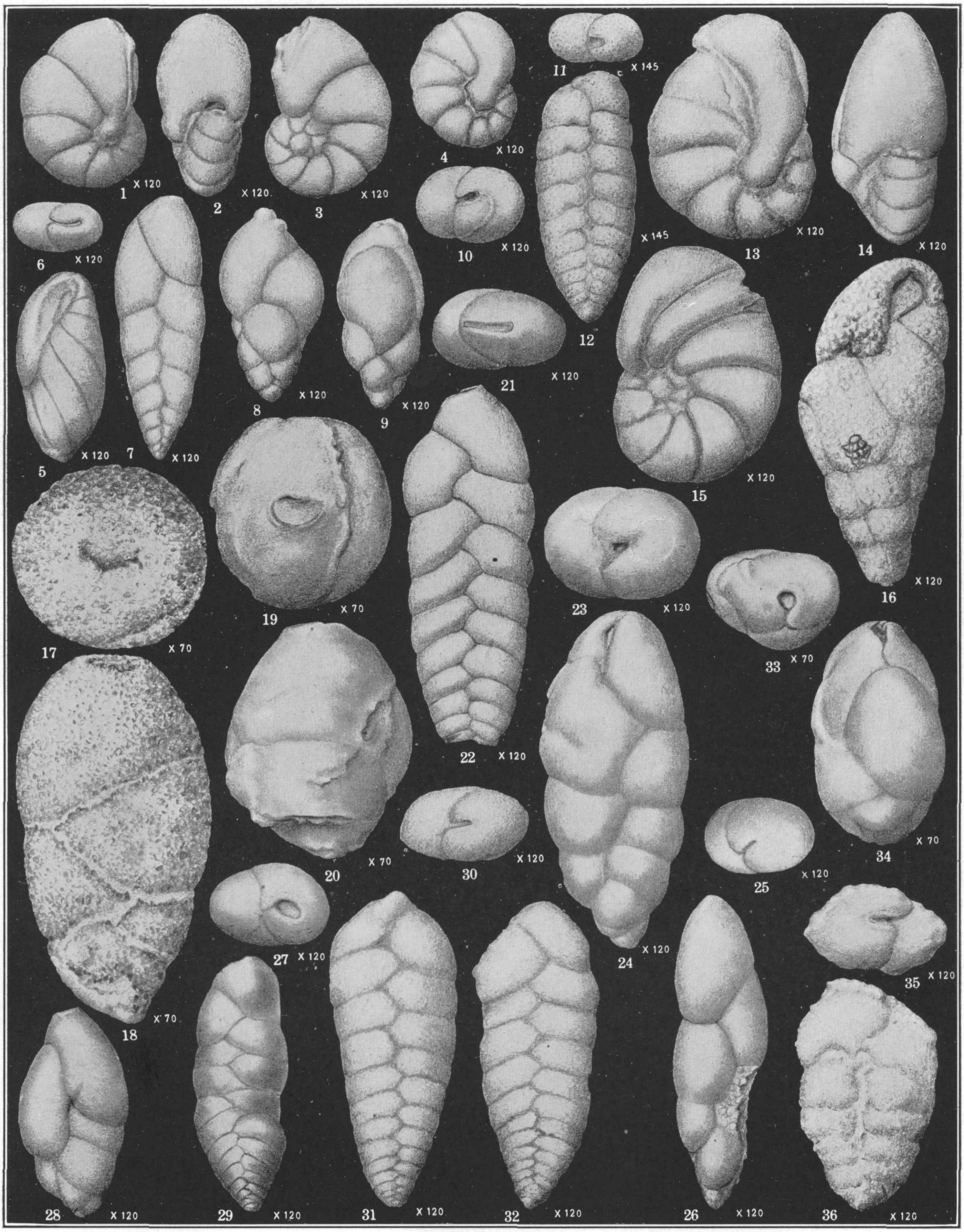
27, 28. "*Buliminella*" *dubia* Barbat and Johnson. Same locality as preceding. U. S. Nat. Mus. 373085.

29. *Bolivina brevior* Cushman. Standard Oil Co. well No. 87, sec. 27, T. 22 S., R. 18 E., depth 5,100–5,107 feet. U. S. Nat. Mus. 373103.

30–32. *Bolivina obliqua* Barbat and Johnson. Petroleum Securities Co. well No. 1, sec. 14, T. 22 S., R. 17 E., depth 8,296–8,300 feet. U. S. Nat. Mus. 373087.

33, 34. *Bulimina* cf. *B. ovata* d'Orbigny. Standard Oil Co. well No. 87, sec. 27, T. 22 S., R. 18 E., depth 5,100–5,107 feet. U. S. Nat. Mus. 373083.

35, 36. "*Bolivina* sp." Barbat and Johnson. Chancellor-Canfield-Midway Oil Co. Sahlen well No. 1, sec. 28, T. 24 S., R. 19 E. depth 5,775 feet. U. S. Nat. Mus. 373106.



FORAMINIFERA FROM REEF RIDGE SHALE OF WELLS IN KETTLEMAN HILLS AND OF OUTCROP ALONG FOOT OF REEF RIDGE.

PLATE 50

FIGURES 1, 2. *Robulus* aff. *R. nikobarensis* (Schwager). McLure shale, Reef Ridge, ⅜ mile north of Sulphur Spring Gap. U. S. Nat. Mus. 373093.

3, 4, 7. *Cancris brongniartii* d'Orbigny. McLure shale, same locality as preceding. U. S. Nat. Mus. 373094.

5, 6. *Uvigerina subperegrina* Cushman and Kleinpell. McLure shale, same locality as preceding. U. S. Nat. Mus 373098.

8–10. *Cibicides* cf. *C. illingi* (Nuttall). McLure shale, same locality as preceding. U. S. Nat. Mus. 373095.

11, 12. *Bolivina cuneiformis* Kleinpell. McLure shale, same locality as preceding. U. S. Nat. Mus. 373096.

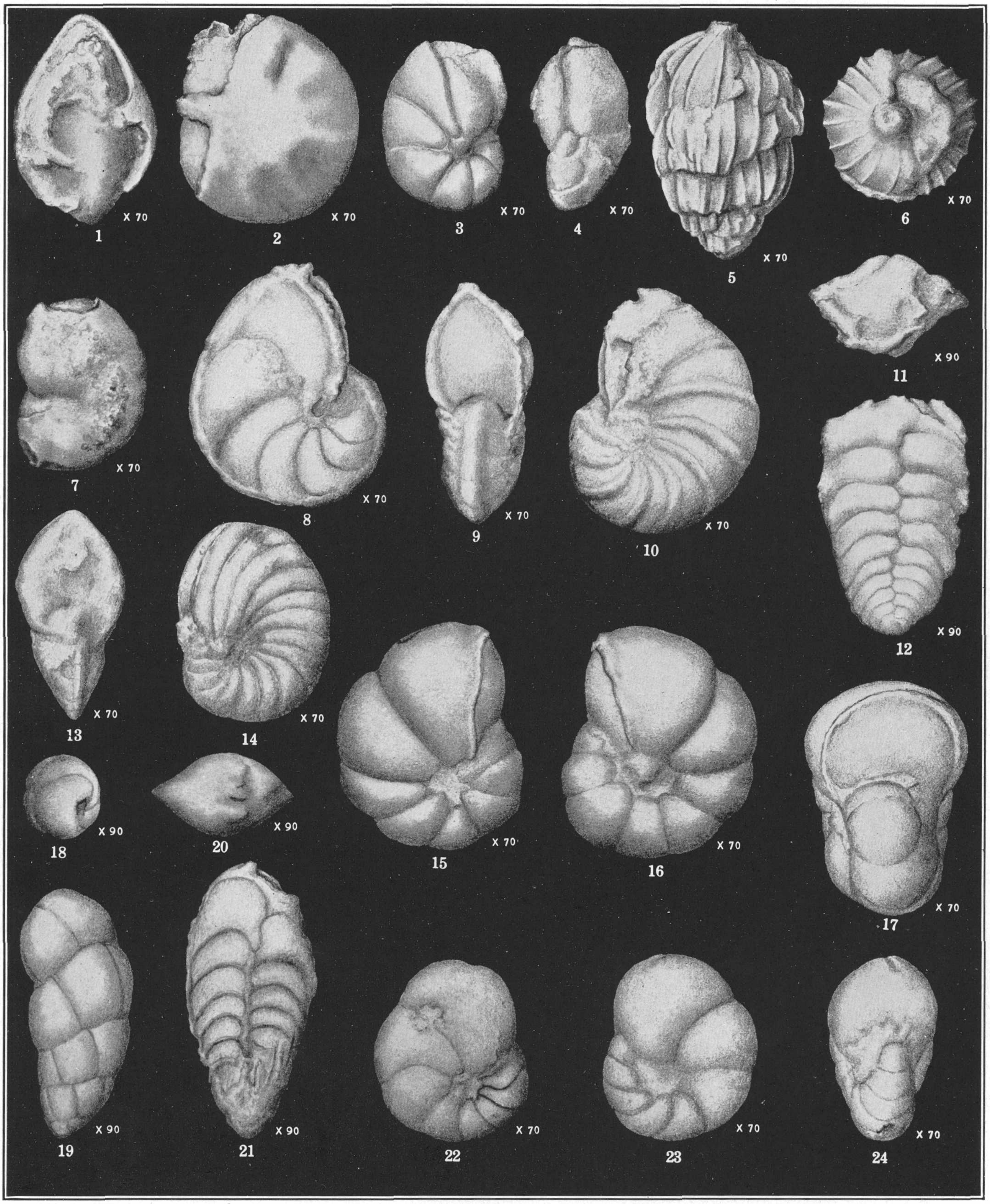
13, 14. *Nonion costiferum* (Cushman). Base of Gould shale, Zemorra Creek. U. S. Nat. Mus. 373102.

15–17. *Valvulineria californica obesa* Cushman. Gould shale, same locality as preceding. U. S. Nat. Mus. 373099.

18, 19. *Buliminella subfusiformis* Cushman. Gould shale, same locality as preceding. U. S. Nat. Mus. 373097.

20, 21. *Bolivina imbricata* Cushman. Gould shale, same locality as preceding. U. S. Nat. Mus. 373101.

22–24. *Valvulineria ornata* Cushman. Gould shale, same locality as preceding. U. S. Nat. Mus. 373100.



FORAMINIFERA FROM BASAL PART OF McLURE SHALE MEMBER OF MONTEREY SHALE ON REEF RIDGE AND FROM GOULD SHALE MEMBER OF MONTEREY SHALE ON ZEMORRA CREEK.

ferent horizons in the upper part of the Monterey shale,[31] and that the San Pablo consists principally of sandstone that is of the same age as the upper part of Monterey shale elsewhere.[32] These views are generally accepted by geologists working in the Coast Ranges. Therefore, the grounds for using Monterey as a group name including the Vaqueros are no longer tenable, and if Monterey is extended to embrace the entire Coast Range section referred to the Miocene, as it logically should be if the name is applied to Coast Range Miocene strata below a widespread unconformity, it loses its utility.[33] Many California geologists have continued to use Monterey as a formation name, but the usage is not uniform. Some geologists use it for a type of shale, which is the usage here recommended; others give it a chronologic implication either in terms of the section in the type region or of more complete sections.

From this brief history of the name "Monterey" as affecting the Coalinga and nearby regions it is apparent that it has been used: (1) as a formation name for a particular type of lithology without any definite chronologic implication other than Miocene; (2) as a formation name based on a chronologic implication of varying value; and (3) as a group name. It is proposed to abandon Monterey as a group name including the Vaqueros sandstone and to treat Monterey shale as a formation name for Miocene strata in the Coast Ranges characterized by hard siliceous shale and soft shale containing microscopic siliceous fossils, regardless of varying chronologic relations of these strata within the Miocene, in accordance with the principle that a formation need not be of the same age from place to place. In areas where units of formation rank are recognized within the Monterey, group usage is still retained. This proposal results in the abandonment of Salinas shale and Maricopa shale as synonyms of Monterey shale. Geologists who favor giving formations a sharply defined and invariable chronologic value may urge that all three names are useful, as they have different age connotations, but unless the names are used in a very narrow sense only for the time equivalent represented in the type region, they need qualifications as to locality and faunal zones as much as the general name "Monterey"; and, furthermore, if the names are used in this narrow sense, a great many more names are needed.

The proposed usage of Monterey shale has the merits of calling attention to a widespread distinctive type of lithology and of simplifying the nomenclature, but its practical application at places may be difficult on account of the varying proportions of ordinary kinds of rock interbedded with shale of Monterey type. In areas where rocks other than siliceous shale form a considerable part of the section, Monterey formation rather than Monterey shale is preferable. As mapping progresses member names may be proposed for lithologic units within the Monterey; or formations may be recognized, as has been done in the San Francisco Bay region.[34] In areas where sandstone or ordinary shale greatly predominate over siliceous shale a different nomenclature may be advantageous. It is not the purpose of this account to attempt to consider Miocene stratigraphic nomenclature in different parts of the Coast Ranges, for in many areas much work remains to be done; the purpose is to attempt to clarify the basis for the nomenclature adopted for the Coalinga and nearby districts.

The usage of Monterey shale here advocated was adopted by the Geological Survey in 1935 for the Miocene strata of the Palos Verdes Hills [35] (San Pedro Hills), which adjoin the Los Angeles Basin; but, as stated in the account dealing with the Palos Verdes Hills, this action was based on the arguments now presented.

The unit here designated the McLure shale member of the Monterey shale is the only Miocene shale of Monterey type in the Reef Ridge and Kettleman Hills sections. According to the principles followed in this report, it would be proper to call it simply Monterey shale, as was done 30 years ago. The name McLure, however, has come into such wide usage that it appears undesirable to urge its abandonment. The McLure is considered a member of the Monterey on the grounds that it represents a particular type of Monterey lithology—porcelaneous mudstone. This type of lithology is present but is apparently not recognizable as a mappable unit in the thick section of Monterey shale on Chico Martinez Creek, which includes the chronologic equivalent of the McLure. (See p. 125.)

STRATIGRAPHY, LITHOLOGY, AND FOSSILS

OUTCROP SECTIONS

Reef Ridge.—The McLure shale is the Miocene shale of Monterey type cropping out along Reef Ridge. In this region it was called the Monterey shale by F. M. Anderson,[36] the Santa Margarita (?) formation by Arnold and Anderson,[37] and the McLure shale by Henny.[38] The type region is on the south side of

[31] Barbat, W. F., and Weymouth, A. A., Stratigraphy of the *Borophagus littoralis* locality, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 21, pp. 30–31, 1931. Reed, R. D., op. cit. (Geology of California), p. 190. Richards, G. L., Jr., Revision of some California species of *Astrodapsis:* San Diego Soc. Nat. History Trans., vol. 8, no. 9, p. 63, 1935.

[32] Kleinpell, R. M., Miocene Foraminifera from Contra Costa County, Calif. [abstract]: Geol. Soc. America Proc., 1933, p. 390, 1934; Miocene stratigraphy of California, pp. 166–167, Tulsa, Am. Assoc. Petroleum Geologists, 1938.

[33] Reed, R. D., op. cit. (Geology of California), p. 163

[34] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), pp. 9–11, 1914.

[35] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., Miocene stratigraphy and paleontology of Palos Verdes Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 125–149, 3 figs., 1936.

[36] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 171, pl. 34, section 1, 1905.

[37] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 90–94.

[38] Henny, Gerard, McLure shale of the Coalinga region, Fresno and Kings Counties, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 403–410, 3 figs., 1930.

McLure Valley, south of the southeast end of Reef Ridge. Along the part of Reef Ridge opposite the Kettleman Hills and in the Pyramid Hills the thickness of the McLure increases southward from 200 feet to 1,200 feet.[39] Henny [40] cited 800 feet as the average thickness in this area. It consists principally of chocolate-brown porcelaneous mudstone that breaks with a conchoidal fracture and may be divided into three main parts, the middle part containing the hardest beds. The hard middle part forms the crest of spurs, on which the hardest beds crop out in little ridges (pl. 48). At the base of the formation are sandy beds containing glauconite grains and phosphatic pellets. The following section, which was kindly supplied by M. N. Bramlette, was measured by M. N. Bramlette, K. E. Lohman, and R. M. Kleinpell in a ravine about 200 yards northwest of Big Tar Canyon.

Section of McLure shale member of Monterey shale on north slope of Reef Ridge about 200 yards northwest of Big Tar Canyon

[Measured by M. N. Bramlette]

	Feet
Reef Ridge shale:	
Poorly exposed soft silty shale; weathered surface suggests bentonitic soil; increasingly sandy toward top, apparently grading upward into sandstone of Jacalitos formation	280
McLure shale member of Monterey shale:	
Upper part:	
Soft chocolate-brown mudstone containing *Cyclammina* and other arenaceous Foraminifera and a few calcareous concretions	100
Middle part:	
Reef-forming hard brown porcelaneous mudstone containing *Cyclammina*, *Gaudryina?* and other undeterminable arenaceous Formaminifera (identifications by R. M. Kleinpell); calcareous concretions absent. The hardest beds have a thickness of 1 to 2 feet and alternate with softer beds	55
Chocolate-brown porcelaneous mudstone, harder than underlying beds; progressively more porcelaneous and harder upward; contains a few arenaceous Foraminifera	80
Lower part:	
Chocolate-brown porcelaneous mudstone; diatom impressions more numerous than in underlying mudstone; zones of calcareous concretions at intervals of 5 to 10 feet	66
Chocolate-brown porcelaneous mudstone containing a few arenaceous Foraminifera and a few impressions of diatoms; zones of diatom-bearing 1- to 2-foot ovoid calcareous concretions at intervals of about 20 feet	56
Green sand with abundant glauconite grains and phosphatic pellets, and numerous sponge spicules	3

[39] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 93.

[40] Henny, Gerard, op. cit., p. 404.

Section of McLure shale member of Monterey shale on north slope of Reef Ridge about 200 yards northwest of Big Tar Canyon—Con.

	Feet
McLure shale member of Monterey shale—Continued.	
Lower part—Continued.	
Soft clayey sand with glauconite grains and sponge spicules, and a few ovoid calcareous concretions	55
Hard clayey fine-grained sandstone with glauconite grains and a few phosphatic pellets	48
Soft clayey fine-grained sand and sandy clay, poorly exposed	72
Greenish-gray bentonite, poorly exposed	2
Soft clayey siltstone or silty clay, poorly exposed	15
Thickness of McLure shale	552
Temblor sandstone:	
Reef-forming sandstone with a 1-foot oyster-bearing conglomerate at top. Columns belonging to a cheek tooth crown of the marine mammal *Desmostylus*, probably representing *D. hesperus* (identification by Remington Kellogg), were found in sandstone immediately underlying the conglomerate.	

The 2-foot bed of bentonite 15 feet above the base of the McLure is a noteworthy feature of this section. A bed of bentonite in the same part of the section has been recognized in Canoas Canyon 5½ miles northwest of Big Tar Canyon. Foraminifera from a horizon near the base of the McLure on Reef Ridge are considered in the discussion of fossils from Kettleman Hills wells.

Along Reef Ridge the McLure rests with apparent conformity on the Temblor sandstone. At the south end of Reef Ridge, however, the McLure extends across the edges of the Temblor and underlying Tertiary formations and, along the borders of McLure Valley, overlaps onto Cretaceous rocks.[41]

Chico Martinez Creek.—Shale of Monterey type increases in thickness southward in the Temblor Range to the region near Chico Martinez Creek, 40 miles southeast of the Kettleman Hills, where the greatest thickness is exposed. At this locality the Monterey shale overlies the Temblor formation. The shale was called the Monterey shale by F. M. Anderson,[42] the Monterey shale and Santa Margarita (?) formation by Arnold and Johnson,[43] and the Maricopa shale by English.[44] The following section, measured on Chico Martinez Creek by M. N. Bramlette, K. E. Lohman, and R. M. Kleinpell, and made available by M. N. Bramlette, shows a thickness of 7,235 feet. The top of the section is marked by an unconformable overlap.

[41] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 91.

[42] Anderson, F. M., op. cit., p. 169.

[43] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, Calif.: U. S. Geol. Survey Bull. 406, pp. 58-59, 65-66, 1910.

[44] English, W. A., Geology and petroleum resources of northwestern Kern County, Calif.: U. S. Geol. Survey Bull. 721, pp. 13-25, 1921.

Section of Monterey shale on Chico Martinez Creek in Temblor Range, 40 miles southeast of Kettleman Hills

[Measured by M. N. Bramlette]

	Feet
Tulare formation:	
Conglomerate and sandstone resting with angular discordance on the Monterey shale.	
Monterey shale:	
Unnamed member:	
11. White to dove-colored diatomaceous shale	750
10. Diatomaceous shale with thin chert beds and zones of calcareous concretions	80
Unnamed member (?):	
9. White to light-brown porcelaneous shale with abundant diatom impressions; thin chert beds numerous; zones of calcareous concretions at intervals of 10 to 20 feet. Thin beds of fine-grained sandstone, some of which are impregnated with tar, in about the middle part of this unit	1, 885
Unnamed member (?):	
8. Light chocolate-brown, thin-bedded porcelaneous mudstone with diatom impressions becoming less distinct downward; zones of calcareous concretions at intervals of 10 to 20 feet	1, 015
Unnamed member (?):	
7. White-weathering, dove-colored cherty shale with vague diatom impressions; zones of calcareous concretions at intervals of 10 to 20 feet	480
6. Brown-weathering, buff to dove-colored cherty shale with vague diatom impressions; few zones of calcareous concretions	445
5. Thinly laminated shale, less siliceous than overlying shale; no diatom impressions; zones of calcareous concretions at intervals of 10 to 20 feet	400
4. Alternating zones of hard and soft slightly calcareous, cherty shale; numerous zones of calcareous concretions	705
Unnamed member:	
3. Soft foraminiferal clayey shale with phosphatic nodules and stringers; zones of calcareous concretions at intervals of 10 to 20 feet	250
2. Silty mudstone; zones of calcareous concretions at intervals of 10 to 20 feet	940
Gould shale member:	
1. Hard cherty shale interbedded with soft foraminiferal shale; few zones of calcareous concretions	285
Thickness of Monterey shale	7, 235
Temblor formation (Button bed sandstone member of local usage).	

This section and the foraminiferal zones recognized by R. M. Kleinpell are shown on plate 47. The subdivision of this thick section of Monterey shale into members is tentative. The light chocolate-brown porcelaneous mudstone, which has a thickness of 1,015 feet and constitutes the third member from the top, is lithologically comparable to the McLure shale of McLure Valley and Reef Ridge but is more thinly bedded. The lowest member has been formally named the Gould shale by Barbat,[45] who referred it to the Temblor formation. On a lithologic basis it is part of the Monterey shale—a classification that agrees with the classification first proposed for this region.[46]

Anticline Ridge.—The McLure shale and the Reef Ridge shale are missing on Anticline Ridge and on the west side of San Joaquin Valley north of Anticline Ridge. Their absence constitutes one of the contrasts in the geology of different parts of the Coalinga district. On Anticline Ridge and father north sandstone and conglomerate that have a maximum thickness of 600 to 850 feet [47] are in the corresponding part of the section. These strata represent part of the Coalinga beds of F. M. Anderson [48] and the Santa Margarita (?) formation of Arnold and Anderson [49] and of Anderson and Pack.[50] If a local name is desired for the sandstone and conglomerate, the term "Coalinga" is available with suitable restriction imposed on F. M. Anderson's restriction.[51] Santa Margarita formation, or preferably Santa Margarita sandstone, however, may be an appropriate name for this formation, as for sandstone in the upper part of the Miocene section in other districts in the Coast Ranges.

The Ladd well of the Petroleum Securities Co. in the Guijarral Hills, between Anticline Ridge and the Kettleman Hills, encountered a thickness of 895 feet of brown shale. The correlation of this brown shale with the McLure is supported by the occurrence of a bed of bentonite 38 feet above the base of the shale. According to this correlation, Miocene shale of Monterey type is represented in a subsurface section 10 miles southeast of the outcrop of coarse detrital Miocene strata on Anticline Ridge.

SUBSURFACE SECTION

In the Kettleman Hills subsurface section the Reef Ridge shale is underlain by hard shale that is similar lithologically to the McLure shale and is, therefore, assigned to the McLure. The hard shale is designated the brown shale by drillers—a somewhat misleading designation, as much of the shale is gray, though it has a brownish color when wet. During the drilling of a few early wells a larger proportion of the McLure shale was cored than of any unit so far considered. One to

[45] Barbat, W. F., Age of producing horizon at Kettleman Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 16, pp. 611-612, 1932.

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

[47] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 90. 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, p. 93, 1915.

[48] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 174-178, 1905.

[49] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 89-90.

[50] Anderson, Robert, and Pack, R. W., op. cit., pp. 91-93.

[51] Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 17-23, 1908.

three thin beds of bentonite occur near the base of the McLure, 100 feet or less above the top of the oil-bearing Temblor sandstone in North Dome. The bentonite is readily recognized in core or ditch samples and is an important horizon marker. Until recently, when electrical logging [52] came into general use, cores were generally taken near the base of the McLure to locate the bentonite. In wells in which the First zone of the Temblor was open to production a water string was set about 25 feet below the bentonite. A strong flow of salt water is encountered about 300 feet below the top of the McLure.

The top of the brown shale is logged where hard shale that markedly slows down the rate of drilling is encountered.[53] Structure contours drawn on the top of the brown shale in North Dome show an anticline surface resembling in general that shown by contours drawn on the top of the underlying Temblor sandstone but showing minor irregularities that appear to be arranged in channel-like patterns suggestive of an eroded surface. Whether this apparently irregular surface represents a discontinuity between the Reef Ridge shale and McLure shale, as has been advocated,[54] appears to be doubtful. It is likely that the top of the brown shale represents different horizons in a continuous section, for if the upper part of the subsurface McLure includes soft shale, as in the outcrop section on Reef Ridge, the soft shale is doubtless included in the overlying Reef Ridge shale. Goudkoff's interpretation [55] of the subsurface stratigraphy is different from the interpretation adopted in the present report, as he divided the McLure shale of the present report into two main parts separated by a discontinuity.

As shown in the table below, the thickness of the McLure shale, as logged, ranges from 930 to 1,500 feet in North Dome, the average being about 1,300 feet. In Middle Dome the thickness is about 2,100 feet, and in South Dome about 2,500 feet. The thickness is greater than in the outcrop section on Reef Ridge, and in the three anticlines of the Kettleman Hills it is progressively greater southward, as in the outcrop sections southward from Reef Ridge.

The subsurface McLure appears to include two main parts. The upper part consists chiefly of massive hard brown or gray shale interbedded with streaks of darker brown shale, some of which contains pyritized diatoms. The lower part is made up mainly of grayish-brown shale and zones of brittle and flaky brown to brownish-black shale. The lithologic constituents in nine wells, disregarding a few minor constituents, are shown in the following table. This table was compiled from logs, but some of the logs are based on a considerable percentage of cores.

[52] The term "electrical log" is used for logs showing the results of surveys made by the Schlumberger method. For descriptions of this method see Schlumberger, Conrad, Schlumberger, Marcel, and Leonardon, E. G., Electrical coring, a method of determining bottom-hole data by electrical measurements: Am. Inst. Min. Met. Eng. Trans., vol. 110, Geophysical prospecting, pp. 237–272, 22 figs., 1934; A new contribution to subsurface studies by means of electrical measurements in drill holes: Idem, pp. 273–288, 9 figs.

[53] Schenck, H. G., Miocene brown shale of the Kettleman Hills wells, Calif. [abstract]: Geol. Soc. America Bull., vol. 42, p. 300, 1931.

[54] Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 17, p. 1177, 1933.

[55] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 451–454, 457–458.

Principal lithologic constituents in subsurface McLure shale member of Monterey shale in Kettleman Hills

Well	Brown shale	Hard shale	Clay shale	Black shale	Sandy shale	Sand	Thickness of formation
North Dome:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Feet*
Lillis-Welch No. 1, sec. 24, T. 21 S., R. 16 E	10	75	6	------	8	1	1, 340
Superior Huffman No. 1, sec. 29, T. 21 S., R. 17 E	35	36	25	------	4	------	1, 215
Kenda 38–34–J	5	38	18	------	25	14	1, 250
Kenda 47–2–P	29	67	------	------	4	------	930
Kenda 88–2–P	10	52	19	------	17	2	1, 300
Kenda 61–20–Q	10	83	------	------	2	5	1, 400
Kenda 7–26–Q	53	47	------	------	------	------	1, 500
Middle Dome:							
Petroleum Securities Burbank No. 1, sec. 30, T. 23 S., R. 19 E	25	40	4	16	6	9	2, 125
South Dome:							
Ohio Smith No. 1, sec. 35, T. 24, S., R. 19 E	4	47	31	------	10	8	2, 500
Average	19	53	13	2	8	5	1, 500

A few thin hard beds, logged as limestone or shell, correspond probably to the calcareous concretions in the outcrop sections. If the base of the McLure is marked by conglomerate or sandstone, these strata are probably assigned to the underlying Temblor. An 8- to 10-inch bed of hard coarse-grained sandstone containing limestone pebbles as much as half an inch in diameter is recorded in Kenda well 8-8-Q at a horizon 4 feet above the top of the Temblor.

Small dark-colored phosphatic pellets, composed of impure collophane, are found at several horizons in the lower 600 to 750 feet of the McLure. These pellets have been described by Galliher [56] as fecal pellets of unknown origin. They are locally given the acrostic name "sporbo" (smooth, polished, round,

[56] Galliher, E. W., Collophane from Miocene brown shale of California: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 257–269, 1931; Organic structure in sediments: Jour. Sedimentary Petrology, vol. 2, pp. 46–47, 2 figs., 1932.

black objects). Similar pellets are found in the lower part of the McLure in the outcrop section on Reef Ridge.

One to three thin beds of bentonite ranging in thickness from a few inches to 2 feet are present in most North Dome wells at a horizon 30 to almost 100 feet above the base of the McLure. Bentonite was found 286 feet above the base of the McLure in Petroleum Securities Burbank well No. 1 in Middle Dome and 340 feet above the base in Continental Gatchell well No. 28-7 in South Dome. The beds of bentonite are particularly useful horizon markers, as they are readily identified and are found at fairly uniform intervals above the productive sands. The bentonite recovered from cores is white when dry and somewhat waxy. In water it swells slightly, sloughs in characteristic flakes, and changes in color to light gray or dark gray, or may show a slight greenish to bluish tint. Glass shards in varying proportions indicate that this material is altered volcanic ash. Core samples examined by P. G. Nutting, of the Geological Survey, have a high silica content, indicating that they are only partly altered. Samples collected from the lower part of the McLure exposed on Reef Ridge and from shallow wells near the outcrop show a more complete alteration to bentonite. Moreover, the degree of alteration varies indirectly with distance from the outcrop and depth from the surface. This relation is so constant that the bentonite in the Kettleman Hills and on Reef Ridge is likely to represent products of the same ash fall. At least one bed of bentonite 1 to 2 feet thick may extend over the entire area of North and Middle Domes. The bentonite has been cored or logged in nearly all North Dome wells drilled since it was discovered in August 1929.[57] It was not, however, recorded in 13 early wells drilled close to the crest of the anticline but has subsequently been found in nearby wells, including wells located in structurally higher positions. Practically all wells that encounter the top of the Temblor sand below the −5,500-foot structure contour drawn on the top of the Temblor show at least one bed of bentonite and some show two. Three beds of bentonite are reported only in wells in which the top of the Temblor is encountered at the −6,000-foot structure contour or lower. These relations suggest that North Dome may have been the site of a submarine ridge during the early part of McLure time and that deposition of sediments was more rapid on the slopes of the ridge than on the crest. Should future drilling show that bentonite is missing along much of the crest, this suggestion will be supported by that evidence. In Middle Dome bentonite has been found in three of the five wells drilled to December 1936.

The thickness of strata between the bentonite and the top of the Temblor increases southeastward from 40 feet in the Guijarral Hills (between North Dome and Anticline Ridge) to 275 feet in Middle Dome, a rate of 10 feet to the mile. Farther west the thickening of this stratigraphic interval in the same direction from Canoas Creek to the Devils Den district is at a rate of 12 feet to the mile.

Fish scales are abundant in the subsurface McLure shale as well as at the outcrop. Pyritized diatoms, which may be accompanied by pyritized sponge spicules, occur at various horizons. Poorly preserved arenaceous Foraminifera are found in the upper part of the shale. Despite their poor preservation, these Foraminifera played an important role in the drilling of the discovery well. D. D. Hughes recognized their similarity to arenaceous forms in the upper part of the McLure exposed on Reef Ridge. The occurrence of these fossils and the similar lithology furnished grounds for correlation with the outcrop section and led to deeper drilling in the expectation of finding oil in sand that was expected to underlie the McLure.

A few Foraminifera from the middle part of the McLure of Kenda well 81–34–Q were identified by R. M. Kleinpell, whose list of species and comments are as follows:

Foraminifera from middle part of McLure shale member of Monterey shale of Kettleman North Dome Association well No. 81, sec. 34, T. 22 S., R. 18 E., depth 5,805–5,818 feet

[Identifications by R. M. Kleinpell]

Nonion belridgensis Barbat and Johnson, abundant.
Nonionella miocenica Cushman, abundant.
Bulimina cf. *B. ovata* d'Orbigny, abundant.
Virgulina sp. (poorly preserved specimens), few.

The occurrence of *Nonion belridgensis* in the well material and as molds or impressions in the part of the Monterey shale on Chico Martinez Creek lying between strata containing *Uvigerina* cf. *U. subperegrina* and strata containing *Uvigerina subperegrina* suggests an approximate correlation. (See pl. 47.) The core specimens show a slight tendency toward the development of limbate sutures that is not apparent on the molds from Chico Martinez Creek. The range of *Nonion belridgensis* and the other species in the preceding list is so great, however, that the correlation is doubtful.

No fossils are available from the base of the McLure shale of Kettleman Hills wells, and fossils are rare at this horizon at the outcrop along Reef Ridge. R. M. Kleinpell identified the following Foraminifera in samples collected near Sulphur Spring Gap, about 3 miles southeast of Big Tar Canyon. The characteristic species of this fauna, which is of considerable stratigraphic importance, are shown on plate 50.

The following remarks on these fossils were prepared by Kleinpell, who assigns the fossiliferous basal part of the McLure to his *Bulimina uvigerinaformis* zone.[58]

This small fauna is characterized by *Robulus* aff. *R. nikobarensis* (pl. 50, figs. 1, 2), *Bolivina cuneiformis* (pl. 50, figs. 11, 12), *Uvigerina subperegrina* (pl. 50, figs. 5, 6), which is the most abundant and most characteristic species, *Cancris brongni-*

[57] Dodd, H. V., Recent developments in the Kettleman Hills field: California Oil Fields (California, Div. Oil and Gas), vol. 17, no. 1, p. 12, 1931 [1932].

[58] Kleinpell, R. M., Miocene stratigraphy of California, p. 129, Tulsa, Am. Assoc. Petroleum Geologists, 1938.

artii (pl. 50, figs. 3, 4, 7), and *Cibicides* cf. *C. illingi* (pl. 50, figs. 8–10). In the Monterey shale on Chico Martinez Creek molds and impressions of *Uvigerina subperegrina* are numerous in the lower part of the light chocolate-brown porcelaneous mudstone, constituting lithologic unit 8 of the section on page 125, and in the upper part of the underlying white-weathering dove-colored cherty shale of lithologic unit 7. This part of the Monterey on Chico Martinez Creek is considered the chronologic equivalent of the strata containing the fauna in the basal part of the McLure on Reef Ridge. In the section on Chico Martinez Creek *Uvigerina subperegrina* appears to be associated with molds of *Uvigerina carmeloensis*, which is a characteristic species in Galliher's "lower *Nonion* fauna" in the type Monterey section.[59]

The small fauna from the basal part of the McLure shale may be more satisfactorily compared with the fauna from a horizon 250 feet above the base of the Modelo formation in Topanga Canyon in the Santa Monica Mountains. *Uvigerina subperegrina* and *Robulus* aff. *R. nikobarensis* characterize both assemblages; *Uvigerina hootsi*, a characteristic species in the Modelo, is doubtfully represented in the McLure; and *Bolivina cuneiformis* and *Cibicides* cf. *C. illingi*, two other forms from the basal McLure, are also present in the basal Modelo of the Santa Monica Mountains and occur at the same or closely related horizons elsewhere in southern California.

Bolivina cuneiformis, which occurs at the base of the McLure, was recognized in a sample from Ohio Smith well No. 1, in South Dome, at a depth of 5,120–5,125 feet, or 1,750 feet above the base of the McLure. Its stratigraphic significance in the well material is uncertain.

Foraminifera from basal part of McLure shale member of Monterey shale at outcrop on Reef Ridge near Sulphur Spring Gap

[Identifications by R. M. Kleinpell. R, rare; F, few; C, common; A, abundant]

Species	Localities		
	1	2	3
Reophax? sp	------	R	------
Textularia cf. *T. subplana* Reuss	------	------	F
Robulus aff. *R. nikobarensis* Schwager (pl. 50, figs. 1, 2)	C	------	------
Bolivina cuneiformis Kleinpell (pl. 50, figs. 11, 12)	C	------	F
Uvigerina hootsi Rankin?	C	------	A
Uvigerina subperegrina Cushman and Kleinpell (pl. 50, figs 5, 6)	A	A	A
Discorbis? sp	------	R	------
Cancris brongniartii d'Orbigny (pl. 50, figs. 3, 4, 7)	F	------	R
Cassidulina pulchella d'Orbigny	F	------	C
Globigerina bulloides d'Orbigny	------	R	------
Planulina? sp	R	------	F
Cibicides cf. *C. illingi* (Nuttall) (pl. 50, figs. 8–10)	F	------	------

1. Three-eighths of a mile north of Sulphur Spring Gap, on Reef Ridge between Big Tar Canyon and Little Tar Canyon, about 12 feet above base of basal conglomerate of McLure shale. M. N. Bramlette, R. M. Kleinpell, and K. E. Lohman, collectors.
2. Same locality, shale bed 3 feet higher stratigraphically. M. N. Bramlette, R. M. Kleinpell, and K. E. Lohman, collectors.
3. A quarter of a mile north of Sulphur Spring Gap, about 12 feet above base of basal conglomerate of McLure shale. R. D. Reed and C. Cassel, collectors.

AGE AND CORRELATION

Though the brown shale of the North Dome subsurface section is three times as thick as the McLure shale of the Big Tar Canyon outcrop section, it appears to be the essential chronological equivalent of the McLure exposed at Big Tar Canyon and nearby. In both sections bentonite occurs near the base and arenaceous Foraminifera in the upper part. In both sections the McLure is overlain by the Reef Ridge shale that contains Foraminifera of the *Bolivina obliqua* zone. Moreover, the basal sandy strata containing phosphatic pellets in the outcrop section are in about the same stratigraphic position as the shale containing similar pellets in the subsurface section. The glauconite accompanying the pellets at the outcrop has not been recognized, however, in the subsurface section. The increased thickness in North Dome, as compared with the outcrop section on Reef Ridge, and the southward increase in thickness from North Dome to Middle Dome and South Dome are attributed to basinward thickening. The thick section of Monterey in the Temblor Range on and near Chico Martinez Creek represents not only a continuation and maximum development of the southward thickening but also a southward gradation of the upper part of the Temblor sandstone of the Coalinga district into shale.

According to Kleinpell's age determination of the Foraminifera in the basal part of the McLure shale and in the Reef Ridge shale, the McLure shale of the Coalinga district is in the lower part of the upper Miocene of current Coast Range chronology and corresponds approximately to his Mohnian stage.[60] In terms of the succession of foraminiferal zones the McLure is the chronologic equivalent of about the middle part of the Monterey shale of the type region.

When Arnold and Anderson referred the shale of Monterey type cropping out on Reef Ridge to the Santa Margarita (?) formation, the Santa Margarita was regarded as occupying a definite place in the Miocene time scale above the Monterey. Northwest of Reef Ridge the shale of Monterey type overlies sandstone containing fossils that are considered of Santa Margarita age.[61] Henny later claimed that the shale unconformably overlies sandstone containing Santa Margarita fossils.[62] There still appears to be some doubt concerning these fossils, which may have come from the basal sandy part of the McLure shale. One of them was cited as an *Astrodapsis* with "prominent raised petals." If the age assignment of the McLure as based on Foraminifera is accepted, the occurrence of an *Astrodapsis* of this character either in sandstone unconformably underlying the McLure or in the basal part of the McLure itself is apparently not in agreement with Kew's evolutionary scheme for *Astrodapsis*,[63] in which the large species with strongly raised petals are later than small species with flat or weakly raised petals. According to this scheme, the earliest and most primitive described species of *Astrodapsis* is *A.*

[59] Galliher, E. W., Stratigraphic position of the Monterey formation: Micropaleontology Bull., vol. 2, no. 4, pp. 71–74, 1931.

[60] Kleinpell, R. M., op. cit., p. 165.

[61] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 89, 95.

[62] Henny, Gerard, McLure shale of the Coalinga region, Fresno and Kings Counties, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 406, 1930.

[63] Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ., Dept. Geology, Bull., vol. 12, pp. 41–45, 1920.

brewerianus from the Briones sandstone, which according to Kleinpell[64] is a little younger than the base of the McLure. Astrodapses from the base of the Modelo formation in the Santa Monica Mountains are considered more primitive than *A. brewerianus* in terms of Kew's scheme,[65] a conclusion that is in apparent agreement with the age assignment of the foraminiferal zones in the Modelo formation of the Santa Monica Mountains, the base of which constitutes the base of Kleinpell's Mohnian stage and represents the base of the upper Miocene of the Coast Ranges, as now generally accepted.

The chronologic relations of the McLure shale to the Santa Margarita sandstone exposed on Anticline Ridge are uncertain. The occurrence of large Astrodapses with strongly raised petals in the Santa Margarita sandstone suggests a horizon high in the upper Miocene, but the *Astrodapsis* of Santa Margarita aspect at the base of the McLure northwest of Reef Ridge, or in sandstone underlying the McLure, throws doubt on this assignment. That there may be discontinuities at both the bottom and the top of the Santa Margarita sandstone of Anticline Ridge is indicated by the occurrence at these horizons of nonmarine strata—the Big Blue member of the Temblor below it and the nonmarine formation referred to the Jacalitos by Arnold and Anderson above it. The Santa Margarita sandstone of this region may be the chronologic equivalent of the Reef Ridge shale. (See fig. 14.)

TEMBLOR SANDSTONE

The age and nomenclature of the oil-bearing sands underlying the McLure shale in the Kettleman Hills have been treated in different ways by different geologists. They have been referred to the Temblor, partly to the Vaqueros and Temblor, and partly to the Vaqueros, Temblor, and Monterey. The diverse and confusing stratigraphic nomenclature is due principally to attempts to assign essentially invariable age designations to the formations, Vaqueros, Temblor, and Monterey. The oil-bearing sands and interbedded relatively thin shales constitute a major lithologic unit between the McLure shale and Kreyenhagen shale, and this unity is recognized in the proposal to apply one formation name to them—Temblor sandstone.

Formation names were first given to the Miocene strata in this part of the Coast Ranges by F. M. Anderson in 1905. On the northeast slope of the Temblor Range 40 miles southeast of the Kettleman Hills the Miocene section consists of the great thickness of shale, mostly of Monterey type, already described, below which lie alternating units of sandstone and shale. It is natural to divide this section at the top of the uppermost sandstone, as was done by F. M. Anderson, who appropriately designated the overlying shale Monterey and proposed the new name "Temblor" for the alternating sandstone and shale.[66] The sandstone on Reef Ridge underlying the Monterey shale (McLure shale member of Monterey shale, according to the terminology adopted in the present report) and forming the crest of the ridge also was assigned to the Temblor.[67] Due to a misidentification of older siliceous shale (Kreyenhagen shale) as Monterey, sandstone in the same part of the section on Anticline Ridge, including the "reef bed," was not recognized as Temblor and was grouped with overlying strata to constitute the Coalinga beds,[68] an interpretation that was corrected in a later account.[69] Arnold and Anderson regarded the sandstone at these localities as of the same age as the previously described Vaqueros sandstone of the outer Coast Ranges. Consequently, they used the name Vaqueros sandstone and considered Temblor a synonym of Vaqueros.[70]

Discussion concerning the stratigraphic and chronologic relations of the Vaqueros and Temblor have been summarized by several writers.[71] It is generally recognized that the current usage of these two formation names is unsatisfactory. The term "Vaqueros sandstone" is currently used for sandstone throughout the Coast Ranges containing the *Turritella inezana* fauna; and the term "Temblor sandstone," or "Temblor formation," for sandstone containing the *Turritella ocoyana* fauna;[72] that is, they are generally used for faunal zones.[73] A typical Vaqueros fauna is readily distinguished from a typical Temblor fauna. At many localities only the one or the other is represented. Where they are found in the same section, the Vaqueros fauna underlies the Temblor fauna, as was suggested many years ago,[74] but in many regions a transition zone containing fossils of intermediate aspect is recognized.[75] The ranges of the index species after which the *Turritella inezana* zone and the *Turritella ocoyana* zone were named, and of other species, are now known to overlap.

The usage of formation names for faunal zones is improper. Such usage for the terms "Vaqueros" and

[64] Kleinpell, R. M., Miocene stratigraphy of California, fig. 14 (in pocket), Tulsa, Am. Assoc. Petroleum Geologists, 1938.

[65] Woodring, W. P., in Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, pp. 110-111, 1931.

[66] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 169-170, 1905.

[67] Idem, p. 171, pl. 34, section 1.

[68] Idem, pp. 172-173, 174-176, pl. 34, section 3.

[69] Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, pp. 16, 19-20, 1908.

[70] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 87.

[71] Louderback, G. D., The Monterey series in California: California Univ., Dept. Geology, Bull., vol. 7, pp. 177-241, 1913. Wiedey, L. W., Notes on the Vaqueros and Temblor formations of the California Miocene with descriptions of new species: San Diego Soc. Nat. History Trans., vol. 5, no. 10, pp. 98-107, 1928. Loel, Wayne, and Corey, W. H., The Vaqueros formation, lower Miocene of California, pt. 1, Paleontology: California Univ., Dept. Geol. Sci., Bull., vol. 22, pp. 45-50, 1932. Kleinpell, R. M., Miocene stratigraphy of California, pp. 161-163, Tulsa, Am. Assoc. Petroleum Geologists, 1938.

[72] Wilmarth, M. G., Names and definitions of the geologic units of California: U. S. Geol. Survey Bull. 826, pp. 88-89, 94, 1931.

[73] Louderback, G. D., op. cit., pp. 230-231.

[74] Merriam, J. C., A note on the fauna of the lower Miocene in California: California Univ., Dept. Geology, Bull., vol. 3, p. 380, 1904.

[75] Loel, Wayne, and Corey, W. H., op. cit., pp. 125-127.

"Temblor" is of long standing, however, and in a general way has proved useful. An attempt to put into general effect logical usage is likely to be more confusing than helpful. Nevertheless for the purpose of the present report these terms are not used for faunal zones.

STRATIGRAPHY, LITHOLOGY, AND FOSSILS

OUTCROP SECTIONS

Zemorra Creek.—The type region of the Temblor formation is in the Temblor Range near Carneros Creek.[76] The following section shows the principal subordinate units on Zemorra Creek, the south fork of Chico Martinez Creek, which is 2½ miles southeast of Carneros Creek. This section, measured by M. N. Bramlette, K. E. Lohman, and R. M. Kleinpell, is a continuation of the Chico Martinez Creek section on page 125.

Section of Temblor formation in type region on Zemorra Creek in Temblor Range, 40 miles southeast of Kettleman Hills

[Measured by M. N. Bramlette]

	Feet
Gould shale member of Monterey shale.	
Temblor formation:	
Button bed sandstone member of local usage:	
Moderately coarse grained sandstone with some glauconite and phosphate pellets; uppermost 10 feet harder and more calcareous, and containing abundant "buttons" ("*Scutella*" *merriami*); cross-bedding 25 feet below top	195
Sandstone, softer and finer grained than overlying sandstone; some glauconite	45
Media shale member of local usage:	
Dark silty shale, in part foraminiferal; few zones of calcareous concretions. A hard sandstone about 5 feet thick is 160 feet below the top; and the top of a 50-foot zone of cherty shale is 40 feet lower	920
Carneros sandstone member of local usage:	
Coarse-to-medium grained sandstone with many zones of hard limy concretions; a thin foraminiferal shale 80 feet below the top	215
Santos shale member of local usage:	
Dark silty shale, some beds containing Foraminifera. A hard reef-forming calcareous sandstone is 60 feet below the top; 120 feet below the top the shale is phosphatic and includes some thin beds of soft glauconitic sandstone; a bed at the base a foot thick contains phosphatic pellets	295
"*Phacoides*" reef member of local usage:	
Medium-grained glauconitic sandstone with hard fossiliferous reef at base	85
Barren shale member of local usage:	
Hard purplish-brown highly fractured sandy to silty shale; few Foraminifera	75
Thickness of Temblor formation	1, 830
Massive, "cavernous," poorly sorted sandstone (Tejon formation of Bulletins 406 and 721).	

[76] For geologic maps of this region see Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, Calif.: U. S. Geol. Survey Bull. 406, pl. 1, 1910; English, W. A., Geology and petroleum resources of northwestern Kern County, Calif.: U. S. Geol. Survey Bull. 721, pl. 1, 1921.

According to a section measured by K. E. Lohman, the Temblor formation on Carneros Creek has a thickness of 1,500 feet and consists of the same main units as on Zemorra Creek. With the exception of the Santos shale member of local usage, the main units are considerably thinner on Carneros Creek than on Zemorra Creek. Also on Carneros Creek a hard fossiliferous reef lies at the top of the "*Phacoides*" reef member of local usage instead of at the base.

The names for the members cited in the preceding section have come into general use among geologists working in this region.[77] They are not considered in the present report, for some still have informal status; and so far only one of the formally named members, the Carneros sandstone member, has been defined.[78]

The foraminiferal zones recognized by Kleinpell in the Temblor formation of the type region have recently been described.[79] Their stratigraphic positions are shown on plate 47. A published account of the mollusks in the "*Phacoides*" reef member of local usage is not available, other than F. M. Anderson's list,[80] which is assumed to include fossils from this horizon. The informal name for the member is derived from the abundance of "*Phacoides*" *acutilineatus* [*Lucinoma acutilineata*]. There also is no published list for the mollusks in the Carneros sandstone member of local usage. The button bed sandstone member of local usage at the top of the Temblor formation is characterized by the abundance of little sand dollars ("buttons"). These sand dollars were described by Anderson as *Astrodapsis merriami*[81] and are generally known as *Scutella merriami*.[82] Stefanini[83] and Lambert and Thiery[84] have pointed out that at least some of the Pacific coast Miocene sand dollars assigned to *Scutella* are allied to the genus *Phelsumia*, formerly known as *Echinarachnius*, which is now represented on the Pacific coast as far south as Puget Sound by *P. parma* (Lamarck).[85] In *Phelsumia* the ambulacral furrows tri-

[77] Gester, G. C., and Galloway, John, op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 17), fig. 3 (p. 1169).

[78] Cushman, J. A., and Barbat, W. F., Notes on some arenaceous Foraminifera from the Temblor formation of California: Cushman Lab. Foram. Research Contr., vol. 8, p. 31, 1932. Packard, E. L., and Kellogg, Remington, A new cetothere from the Miocene Astoria formation of Newport, Oregon: Carnegie Inst. Washington Pub. 447, p. 17, 1934.

[79] Kleinpell, R. M., Miocene stratigraphy of California, pp. 103–117, Tulsa, Am. Assoc. Petroleum Geologists, 1938. Kleinpell gives lists of species on pp. 40–45, 54–55.

[80] Anderson, F. M., op. cit., p. 170. A few species are mentioned in Kleinpell, R. M., op. cit., p. 39.

[81] Anderson, F. M., op. cit., pp. 193–194, pl. 14, figs. 33, 34. Recorded from Tar Springs [Big Tar Canyon], Kreyenhagen's [Canoas Canyon], and Temblor. According to Kew (op. cit., p. 73), the cotypes are from the east side of the Temblor Range [presumably near Carneros Creek].

[82] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pl. 28, fig. 4 (incorrectly oriented; posterior end is on right side). Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ., Dept. Geology, Bull., vol. 12, pp. 72–73, pl. 12, figs. 3a–f, 1920.

[83] Stefanini, G., Sugli echini terziari dell'America del Nord: Soc. geol. italiana Bol., vol. 30, p. 703, 1912; Relations between American and European Tertiary echinoid faunas: Geol. Soc. America Bull., vol. 35, p. 845, 1924.

[84] Lambert, J., and Thiéry, P., Essais de nomenclature raisonnée des échinides, pt 8–9, p. 583, 1925.

[85] Lambert, J., and Thiéry, P. (op. cit., pt. 4, p. 316, 1914) proposed the generic name *Phelsumaster* for this species on the grounds that *Phelsumia* was invalidated by an earlier name *Phelsuma*.

furcate near the margin of the test. The ambulacral furrows are not clearly discernible on specimens of "*Scutella*" *merriami* and allied species that are available. The generic name *Twitchellia* has been proposed for "*Scutella*" *merriami*.[86] This species is here assigned to "*Scutella*," as its generic relations are still uncertain.[87] A group of "Scutellas" consisting of species much larger than "*S.*" *merriami* occurs in the California Miocene but has not been discovered along the west side of the San Joaquin Valley.

According to the foraminiferal zones represented, the greater part of the Temblor in the type region represents the lower Miocene of the Coast Range section as generally accepted, and the barren shale member of local usage is probably of Oligocene age. In view of the age relations some geologists assign the lower part of the section to the Vaqueros. This assignment has received further support by the recent announcement that *Lyropecten magnolia* and *Ostrea vaquerosensis* have been found in a sandstone in the upper part of the Santos shale of local usage.[88] *Lyropecten magnolia* has long been considered one of the most characteristic of typical Vaqueros fossils. Its discovery in the Santos shale of local usage indicates how little reliance can be placed on the absence of typical Vaqueros species, which are not known in the "*Phacoides*" reef of local usage or in the Carneros sandstone of local usage, though according to the horizon and facies they might be expected in these strata. Vaqueros fossils were recorded from the northeast slope of the Temblor Range by Arnold and Anderson,[89] who cited *Turritella inezana*, "*Pecten*" *magnolia*, and "*Pecten*" *bowersi* from a locality in sec. 36, T. 26 S., R. 17 E., south of Antelope Valley. It is assumed that this citation refers to the collection that has the locality number 4941 (three-quarters of a mile north of Miller Brothers' house, along their grade road; 6 miles east of Annette, Kern County). This collection includes three specimens of *Turritella inezana* that are most similar to *T. inezana* in the restricted sense, as interpreted by Loel and Corey.[90] The only pectens now in the collection are *Lyropecten miguelensis* and *Vertipecten nevadanus* (cited as "*Pecten*" *bowersi*). The stratigraphic position of the strata containing these fossils is not known. The claim that the lower part of the Temblor is of the age of Vaqueros elsewhere has ample paleontologic support. Instead of dividing this section into Vaqueros and Temblor parts it appears to be more satisfactory to refer the alternating sandstone and shale to one formation; to separate and name as many members as is compatible with the degree of refinement in mapping; and to express the chronologic relations of the formation and its members in terms of faunal zones.

Reef Ridge.—The sandstone that forms the crest of the greater part of Reef Ridge (pl. 48), west of the Kettleman Hills, is referred to the Temblor sandstone. This sandstone was not adequately examined during the field work for the present report, but it appears to be divisible into several parts.

The following section was measured along Big Tar Canyon:

Section of Temblor sandstone in Big Tar Canyon, Reef Ridge

	Feet
Temblor sandstone (top not exposed):	
Upper sandstone:	
14. Soft dirty sandstone, iron-stained at base, lighter in color toward top; few beds of harder and cleaner sandstone 1 to 2 feet thick; some layers oil-stained. Upper part contains *Turritella ocoyana*, *Miltha sanctaecrucis*, *Clementia pertenuis* and other fossils (see p. 142)	67
Middle sandstone:	
13. Limy sandstone and medium-grained sandstone. Basal layer, 1½ feet thick, forms uppermost virtually continuous reef (the uppermost reef extending for a short distance on the east side of the canyon, as shown on plate 48, *A*, is in the overlying sandstone); contains *Oliva*, *Aequipecten andersoni*, *Dosinia*, and barnacles	17
12. Dirty sandstone, poorly exposed	78
11. Coarse-grained, limy, reef-forming sandstone containing "buttons" ("*Scutella*" *merriami*) and *Aequipecten andersoni*	4
10. Clean medium-grained sandstone and thinner layers of poorly exposed dirty sandstone	101
9. Main reef forming crest of Reef Ridge:	
h. Limy sandstone containing many specimens of *Turritella ocoyana*	1½
g. Medium-grained sandstone	11
f. Sandy limestone, molds of shells; forms crest of reef	2
e. Medium-grained sandstone	4½
d. Sandy limestone, indeterminable fossils	2
c. Medium-grained sandstone	1
b. Sandy limestone, molds of shells	4½
a. Coarse-grained limy sandstone, molds of shell	8
8. Dirty sandstone resembling unit 6	87
7. Cleaner and harder sandstone, with ferruginous concretionary nodules and layers	38

[86] Lambert, J., Rev. Crit. Paléozoologie, 20th year, p. 171, 1915. *Twitchellia* was proposed for *Twitchellia merriami* (Anderson) as figured by Twitchell under the name *Scutella? merriami* (Anderson) (U. S. Geol. Survey Mon. 54, pl. 85, figs. 7a–c, 1915; specimen from locality 4772, *Scutella merriami* bed in Canoas Canyon). Lambert considered the other specimen figured by Twitchell (figs. 8 a–b; specimen from locality 4775, Garza Creek gorge in Reef Ridge, hard sandstone "button bed") as a different species, for which he proposed the name *Twitchellia packi*. These two specimens are poorly preserved and appear to be immature; the petals on the figures are greatly retouched. They are regarded as representing the same species—"*Astrodapsis*" *merriami* Anderson. Later Lambert and Thiéry claimed that *Twitchellia packi* is the type of *Twitchellia*; that the specimen represented by Twitchell's fig. 7 should be referred to *Orchoporus merriami* (Twitchell); and that the "true" *Scutella merriami* is an *Astrodapsis* (Lambert and Thiéry, op. cit., pt. 8–9, p. 577, 1925).

[87] *Astrodapsis merriami* has recently been assigned to *Echinarachnius* (Grant, U. S., IV, and Hertlein, L. G., The West American Cenozoic Echinoidea: California Univ. at Los Angeles Pub. Math. Phys. Sci., vol. 2, p. 60, 1938), and the specimen from Canoas Canyon figured by Twitchell as *Scutella? merriami* has been named *Orchoporus lamberti* (idem, p. 52). *Orchoporus* was based on an immature *Merriamaster* (see p. 82 of present report).

[88] Clark, L. M., and Clark, Alex, The Vaqueros in the Temblor Range [abstract]: Am. Assoc. Petroleum Geologists Bull., vol. 19, p. 137, 1935.

[89] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 87.

[90] Loel, Wayne, and Corey, W. H., The Vaqueros formation, lower Miocene of California, pt. 1, Paleontology: California Univ., Dept. Geol. Sci., Bull., vol 22, pp. 254–255. 1932.

Section of Temblor sandstone in Big Tar Canyon, Reef Ridge—Continued

	Feet
Temblor sandstone (top not exposed)—Continued.	
Middle sandstone—Continued.	
6. Dirty sandstone weathering into small blocks or spheroidal masses	47
5. Medium-grained sandstone; some layers oil-stained. Upper part forms low reef on southwest slope of Reef Ridge	9
4. Dirty iron-stained sandstone and cleaner oil-stained sandstone; layers half a foot to several feet thick	63
Lower shale:	
3. Light chocolate-brown shale containing coarse sand grains	11
Lower sandstone:	
2. Iron-stained soft dirty sandstone	22
1. Sandstone:	
e. Medium-grained sandstone weathering into spheroidal masses	1
d. Dirty thin-bedded sandstone	1½
c. Iron-stained concretionary sandstone containing *Anadara osmonti* and *Vertipecten* cf. *V. nevadanus*	1
b. Sandstone similar to unit a, with lenses of pebbly sandstone, in which small black chert pebbles are most conspicuous; contains *Vertipecten* cf. *V. nevadanus*	5
a. Medium-grained, poorly cemented sandstone with small pebbles, grades upward into unit b	9
Thickness of measured section	596

Base of formation not exposed.

The base and top of the formation are not exposed in the region where this section was measured. The highest exposures appear to be close to the top of the formation, but a considerable thickness may be missing at the base. It is estimated that the total thickness is about 700 feet. The base of the sandstone is well exposed in a canyon on the southwest slope of Reef Ridge about a mile southeast of Big Tar Canyon, where the sandstone rests on Kreyenhagen shale. At the base is a conglomerate, 2 or 3 inches thick, that is heavily impregnated with gypsum and contains small rounded pebbles of black chert and flat pebbles of Kreyenhagen shale. The strata overlying the basal conglomerate consist of dirty gray sandstone and harder cleaner buff sandstone.

Bramlette [91] reported that the lower sandstone of the preceding section has a mineral composition of rather nondescript character. The middle sandstone constitutes a sharply differentiated andesite sand zone characterized by the abundance of andesine and andesitic rock grains of finer texture, varying amounts of more or less altered shards of volcanic glass, and considerable green and basaltic (brown) hornblende, augite, and actinolite. The upper sandstone has a rather nondescript mineral assemblage but contains abundant chromite, and the uppermost sample contains a small amount of serpentine and uvarovite.[92] Fossils from the upper sandstone are discussed under the heading "Age and correlation."

A section measured in Canoas Canyon 5½ miles northwest of Big Tar Canyon is as follows:

Section of Temblor sandstone in Canoas Canyon, Reef Ridge

	Feet
McLure shale member of Monterey shale.	
Temblor sandstone:	
Upper sandstone:	
Soft grayish sandstone with lenses of cross-bedded sandy limestone. Sandstone contains abundant "buttons" ("*Scutella*" *merriami*)	11
Sandy limestone containing abundant "buttons" ("*Scutella*" *merriami*) and some *Aequipecten andersoni*	13
Soft buff-gray sandstone, some harder layers; oil seeps	136
Middle sandstone:	
Medium-grained buff-gray sandstone; poorly preserved fossils	4
Unexposed (on east side of canyon a bed of sandstone, 2 to 3 feet thick, lying 3 feet below base of overlying sandstone contains abundant *Aequipecten andersoni*)	68
Medium-grained buff-gray sandstone. An 8-inch bed containing poorly preserved fossils is present 5 feet above base and another fossiliferous bed a foot thick occurs at top	15
Unexposed	70
Thin-bedded dirty sandstone, containing "buttons" ("*Scutella*" *merriami*), *Aequipecten andersoni*, and *Neverita?*, capped by a 5-inch layer of harder, cleaner sandstone	5
Massive cavernous buff-gray sandstone with harder concretionary layers and partings of dirty sandstone. A few layers 1 to 2 inches thick contain small pebbles. Much of the sandstone is oil-stained	71
Sandstone	3
Thin-bedded dirty sandstone	11
Main reef forming crest of Reef Ridge:	
Sandy limestone. Some layers contain specimens of *Turritella ocoyana* and consist of almost pure limestone, others are more sandy, and some contain small chert pebbles. Fossils throughout entire thickness, mostly molds. Forms crest of reef	12½
Medium-grained sandstone	1
Sandy limestone; poorly preserved fossils	1
Medium-grained sandstone	7½
Coarse-grained pebbly sandstone, grading upward into limy sandstone; pebbles mostly chert and quartz	8
Soft medium-grained massive sandstone; few hard concretionary layers and thin-bedded layers of dirtier sandstone	158
Coarse-grained pebbly sandstone forming low reef on southwest slope of Reef Ridge	18
Iron-stained and oil-stained dirty sandstone	70
Thickness of measured section	683

Lowest part of formation, presumably including equivalent of lower sandstone in Big Tar Canyon, not exposed.

[91] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), table 4 (p. 1564), p. 1567, fig. opposite p. 1567.

[92] Idem, table 4 (p. 1564), p. 1572, fig. opposite p. 1567.

The lowermost part of the formation is not exposed along Canoas Canyon. Exposures on a spur on the southwest slope of Reef Ridge about half a mile northwest of the canyon indicate that a thickness of about 125 feet, mainly soft gray dirty sandstone, underlies the lowest exposures in the canyon, making a total thickness of about 800 feet. This sandstone corresponds presumably to the lower sandstone in Big Tar Canyon. A bed of conglomerate, consisting of chert pebbles and some serpentine pebbles overlies the upper sandstone. The conglomerate has a thickness of an inch to a foot and fills channels in the sandstone. The conglomerate is overlain by 60 feet of glauconitic clayey sand, 10 feet above the base of which is a bed of bentonite. The clayey sand represents the basal part of the McLure shale member of the Monterey, and the conglomerate is also assigned to the McLure.

According to Bramlette,[93] a sample from the lowest part of the formation exposed on a spur northwest of Canoas Canyon is similar in mineral composition to the lower sandstone of the Big Tar Canyon section. The middle sandstone represents the well-defined andesitic sand zone. The upper sandstone, however, has a smaller proportion of chromite than the upper sandstone in Big Tar Canyon.

Fossils from various localities on Reef Ridge were listed and described by F. M. Anderson [94] and Arnold.[95] The specimen of "*Scutella?*" *merriami* figured by Twitchell,[96] on which the genus *Twitchellia* was based (see p. 131), is from locality 4772, which apparently represents the sandstone at the top of the Temblor in Canoas Canyon.[97]

Anticline Ridge.—The following section of the Temblor sandstone on the south slope of Anticline Ridge, northwest of the Kettleman Hills, near Phoenix Canyon, which enters Oil Canyon in the southern part of sec. 20, T. 19 S., R. 15 E., was measured by K. E. Lohman.

Section of Temblor sandstone on first ridge southeast of Phoenix Canyon on south slope of Anticline Ridge

[Measured by K. E. Lohman]

	Feet
Nonmarine formation assigned to Jacalitos by Arnold and Anderson.	
Temblor sandstone:	
Big Blue serpentinous member: Greenish silt and sandstone with lenses of pebbles, including serpentine; thickness approximate	60
Upper sandstone: Gray poorly bedded fine-grained to moderately coarse grained generally soft sandstone; a few harder beds form small ledges; upper part fossiliferous; lowermost part iron-stained and fossiliferous	90
Temblor sandstone—Continued.	
"Indicator bed": Pale chocolate brown to white laminated punky diatomite. Northeastward along strike changes to hard porcelaneous and cherty shale	39
Middle sandstone:	
Soft, poorly exposed medium-grained to coarse-grained sandstone; near top grades into finer-grained sandstone and siltstone	43
Discontinuous light buff to gray reef-forming moderately coarse grained calcareous sandstone	10
Soft poorly exposed medium to coarse-grained sandstone	64
Hard light buff to gray medium- to coarse-grained fossiliferous, calcareous sandstone; forms main reef	10
Soft medium- to coarse-grained sandstone; lower part poorly exposed	33
Lower diatomite: Massive conchoidally fracturing white clayey (?) diatomite	14
Lower sandstone:	
Chocolate-brown to buff, white weathering sandy siltstone containing poorly sorted angular sand grains and a few diatoms; lower 40 feet poorly exposed	93
Massive coarse-grained chocolate-brown oil-stained sandstone, grading near top into sandy shale and sandy siltstone	22
Chocolate-brown to buff white weathering hackly fracturing siltstone containing diatoms	36
Massive chocolate-brown to buff oil-stained sandstone; upper part forms ledge, lower part softer; few pebbles at base	53
Chocolate-brown fractured mudstone with silty partings	10
Reddish-brown moderately coarse grained poorly cemented sandstone; grains subrounded and poorly sorted; coarser towards base	39
Conglomerate consisting of well-rounded pebbles having an average length of about 1½ inches but ranging in length from 1 to 4 inches. Granite, quartzite, and a basic rock are the most abundant constituents	30
Thickness of Temblor sandstone	646
Kreyenhagen shale.	

Bramlette [98] reported that the Temblor of this area shows a marked difference in mineral content from that of Reef Ridge. Sandstones underlying the Big Blue serpentinous member contain abundant hypersthene, which is very rare or absent in sandstones on Reef Ridge, and also some andalusite and kyanite, which are not present in the strata on Reef Ridge. The Big Blue serpentinous member forms the most distinct mineral zone in the Temblor of the Coalinga district.

Fossils from the Temblor sandstone on Anticline Ridge were listed and described by F. M. Anderson [99]

[93] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., Vol. 18), table 4 (p. 1564), pp. 1567, 1572, fig. opposite p. 1567.

[94] Anderson, F. M., op. cit., pp. 171-172, 205.

[95] Arnold, Ralph, op. cit. (Bull. 396), pp. 16-20, 54-63, pls. 5-9, 1909 [1910]. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 84-88, pls. 27-31, 1910.

[96] Clark, W. B., and Twitchell, M. W., The Mesozoic and Cenozoic Echinodermata of the United States: U. S. Geol. Survey Mon. 54, pp. 185-186, pl. 85, figs. 7a-c, 1915.

[97] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 84, 86. According to the section on p. 84, locality 4772 represents the base of the uppermost 180 feet of Vaqueros sandstone in Canoas Canyon, but the type of preservation suggests that the fossils were collected at the top of the sandstone.

[98] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1573.

[99] Anderson, F. M., op. cit., pp. 176 (first two lists and probably also the third), 177, 196, 197, 200, 203.

and Arnold.[1] Fossils from the upper sandstone are discussed under the heading "Age and correlation."

SUBSURFACE SECTION

The subsurface Kettleman Hills section assigned to the Temblor sandstone is about 2,000 feet thick. It is more than twice as thick as the Temblor sandstone on Reef Ridge and on Anticline Ridge but is not much thicker than the Temblor formation in the type region farther south. As in the outcrop section in the type region, the formation in the subsurface section consists of alternating units made up chiefly of sand and shale, but the proportion of sand is greater in the subsurface section. With regard to the proportion of sand and shale the subsurface section is intermediate between the Reef Ridge and type region outcrop sections. Mineral zones represented in the Temblor on Reef Ridge are recognized in the subsurface section, and a distinctive mineral zone in the upper part of the subsurface section is clearly the equivalent of at least part of the Big Blue serpentinous member on Anticline Ridge. Though the subsurface Temblor is in general comparable to the Temblor in the type region, it is inferred that the upper part of the subsurface Temblor is younger, for a shale in the upper part of the subsurface section contains a foraminiferal fauna similar to that in the Gould shale member of the Monterey shale overlying the Temblor in the type region. (See fig. 14 and discussion under heading "Age and correlation," p. 141.)

[1] Arnold, Ralph, op. cit. (Bull. 396), pp. 16–20, 54–63, pls. 5–9, 1909 [1910]. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 84–88, pls. 27–31, 1910.

Lillis-Welch well No. 1, sec. 24, T. 21 S., R. 17 E., at the north end of North Dome, penetrated the entire Temblor sandstone. The thickness of the formation in this well is about 1,900 feet, or about 1,500 feet if the lowermost 365 feet of sandy strata are assigned to the "*Leda*" zone of the Kreyenhagen shale. In Standard well 46–13–H the Temblor is reported to be 1,670 feet thick. In another deep well, Kenda well 4–18–J, at the north end of North Dome, the Temblor is reported to be 1,700 feet thick. In Kenda well 38–34–J, which also penetrated the entire formation, the thickness is about 2,200 or 2,000 feet, depending on the assignment of the lowermost 200 feet of hard siltstone, silty shale, and sand. Continental Gatchell well No. 28–7, sec. 7, T. 25 S., R. 20 E., drilled in South Dome during 1935, is reported to have penetrated a thickness of 1,833 feet of strata referred to the Temblor, disregarding dip and possible deviation of the well from vertical.

Much of the subsurface Temblor is, of course, more completely represented by core material than overlying subsurface formations. Since electrical logging has come into general usage, however, much less coring is done than formerly. Inasmuch as only six wells have so far reached the Temblor sandstone in Middle Dome and only three in South Dome, the formation is not so well known in those areas as in North Dome.

The percentage of the principal lithologic constituents in the subsurface Temblor is as follows:

Principal lithologic constituents in subsurface Temblor sandstone in Kettleman Hills

Well	Sand	Sandy shale	Hard shale	Clay shale	Thickness of formation
	Percent	*Percent*	*Percent*	*Percent*	*Feet*
North Dome:					
Lillis-Welch No. 1, sec. 24, T. 21 S., R. 16 E.	90	------	------	10	[1] 1,500–1,900
Superior Huffman No. 1, sec. 29, T. 21 S., R. 17 E.	56	------	------	44	[2] 1,258
Kenda 38–34–J	66	------	------	34	[1] 2,000–2,200
Kenda 47–2–P	73	------	2	25	[2] 950
Kenda 88–2–P	36	32	27	5	[2] 986
Kenda 61–20–Q	49	40	9	2	[2] 1,396
Kenda 7–26–Q	50	30	17	3	[2] 551
Middle Dome:					
Petroleum Securities Burbank No. 1, sec. 30, T. 23 S., R. 19 E.	81	9	------	10	[2] 1,770
South Dome:					
Ohio Smith No. 1, sec. 35, T. 24 S., R. 19 E.	63	20	10	7	[2] 1,164
Average	52	27	14	7	[1] 1,750–2,050

[1] Thickness depends on interpretation of contact between Temblor and Kreyenhagen.
[2] Base not reached.

The subdivisions adopted for the Temblor of North Dome are essentially the same as the subdivisions used by Dodd [2] and by Gester and Galloway.[3] Six zones of oil-bearing sand and sandy shale and five barren zones, consisting chiefly of shale or siltstone and sandy shale, are now recognized. The lowest barren zone is divided into two parts. The zones of oil-bearing strata are numbered in consecutive order downward in the section, and drillers' terms are used for the barren zones. Drillers' names have also been used for some of the oil zones. Owing to lateral changes in lithology and to incomplete data some of the subordinate units are not clearly recognizable throughout North Dome. These units and their principal features are as follows:

[2] Dodd, H. V., Recent developments in the Kettleman Hills field: California Oil Fields (California, Div. Oil and Gas), vol. 17, no. 1, pp. 5–44, 13 pls., 1931 [1932]. Dodd, H. V., and Kaplow, E. J., Kettleman North Dome and Kettleman Middle Dome fields, progress in development: Idem, vol. 18, no. 4, pp. 5–20, 3 pls., 1933 [1934].

[3] Gester, G. C., and Galloway, John, op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 17), pp. 1180–1182.

Subsurface Temblor sandstone of North Dome

Unit (drillers' terms)	Approximate thickness (feet)	Character
First zone (Milham zone).	200–300	Hard fine-grained sand and shaly sand alternating with sandy shale. Oil and gas produced in discovery well (now Kenda well 88–2–P) came mainly from this zone.
Upper variegated zone.	100–200	Mottled greenish, reddish, and purplish shale; sand. Thins and disappears southward. This zone and the lower 100 feet of the First zone, which contains abundant serpentine and uvarovite, are correlated with the Big Blue serpentinous member of the Temblor sandstone exposed on Anticline Ridge, northwest of the Kettleman Hills.
Second zone (Elsinore zone).	100–300	Medium- to coarse-grained sand with minor beds of fine-grained shaly sand and shale. Productive over a large area.
600-foot shale.	50–150	Hard somewhat sandy shale and interbedded fine-grained shaly sand. Thins southward. On basis of foraminiferal fauna correlated with Gould shale member of Monterey shale.
Third zone.	100–300	Medium- to moderately coarse-grained sand, interbedded with sand of finer grain and minor beds of shale. A few thin hard calcareous streaks logged as reef beds. Productive over almost same area as Second zone.
800-foot shale.	50–175	Flaky black and dark-gray shale interbedded with sandy shale and minor beds of fine-grained sand.
Fourth zone.	60–170	Fine- to coarse-grained sand and interbedded sandy shale.
Lower variegated zone.	125–245	Greenish muddy sand; mottled greenish, reddish, and purplish shale. Apparently thins southward. Foraminifera suggest correlation with upper part of Media shale of local usage.
Fifth zone.	200–400	Somewhat poorly sorted mostly medium- and coarse-grained poorly consolidated sand and interbedded shale. Proportion of shale increases southward. Upper part characterized by abundance of orthoclase and anhydrite; lower part characterized by abundance of andesine. With few exceptions lowest productive Temblor zone. Principal source of so-called brown or black oil. May prove to be more extensive than any other productive Temblor zone.
Felix siltstone.	20–40	Hard dark-gray siltstone and silty shale; fine-grained poorly sorted silty sand.
Whepley shale.	15–40	Hard dark-brown to brownish-gray shale. Foraminifera suggest correlation with lower part of Carneros sandstone of local usage and upper part of Santos shale of local usage.
Sixth zone (Beal zone).	355–640	Fine-grained silty sand and coarse-grained cleaner sand; thin beds of hard calcareous sand. Has been designated "mollusk boring sandstone" and Vaqueros sandstone.

First zone (*Milham zone*).—The First zone, which is the first productive zone, is designated by drillers the Milham zone or Elliott zone. These terms are derived from the discovery well of the Milham Exploration Co., on the Elliott lease in sec. 2, T. 22 S., R. 17 E., now Kenda well 88–2–P. The oil and gas produced by this well came mainly from this zone.

The thickness of the First zone ranges from about 200 feet at the north end of North Dome to a maximum of about 300 feet on the crest of the central part of the anticline. According to Goudkoff's identification [4] of the underlying upper variegated zone in Petroleum Securities Burbank well No. 1, in Middle Dome, a thickness of a little more than 100 feet of hard fine- to medium-grained sand may be assigned to the First zone in Middle Dome. In South Dome an undetermined thickness of sand and sandy shale, including the sand 150 feet below the top of the Temblor that yielded the strong flow of salt water encountered in Ohio Smith well No. 1, may be tentatively regarded as representing the First zone.

In North Dome the First zone consists of hard fine-grained gray sand and shaly sand alternating with dark-brown sandy shale. In wells that were cored or electrically logged seven to eight sands and at least seven shales are present in this zone. In the north half of the anticline about 80 percent of the First zone consists of sand and in the south half about 50 percent.

Bramlette [5] reported that about the upper 100 feet of the First zone in North Dome has a rather uniform mineral assemblage of nondescript character. The underlying 150 feet extending down almost to the base of the First zone constitute the serpentine zone—the most distinctive mineral zone in the subsurface section.[6] It is characterized by the abundance of serpentine and the green garnet, uvarovite, and by the common occurrence of glaucophane. These minerals were clearly derived from the area of Franciscan (Jurassic?) rocks on Joaquin Ridge, northwest of Anticline Ridge. On the basis of this sharply differentiated and readily recognized mineral zone, the lower part of the First zone is correlated with at least part of the Big Blue serpentinous member of the Temblor sandstone exposed

[4] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 456.

[5] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1569.

[6] Idem, pp. 1568–1569.

on Anticline Ridge and farther north.[7] The Big Blue has the same suite of minerals and occurs in about the same part of the section.

Mollusks are reported from the First zone in the logs of many wells. According to these records, fragments of oysters and of a small pecten, some of which are identified as *Aequipecten andersoni* ["*Pecten*"], appear to be most abundant.

Upper variegated zone.—The upper variegated zone, which includes variegated shale, has a thickness of 100 to 200 feet in North Dome. Toward the south it thins and disappears. Inasmuch as the marked change in color from the grayish and brownish rocks of the First zone to greenish, reddish, and purplish rocks is readily recognized, the upper variegated zone is a useful key zone. During the early development of the oil field cores were taken to locate the zone, which serves as a guide for landing casing to shut off the First zone.

The upper variegated zone thins rapidly southward and in the southern half of North Dome shows only traces. Goudkoff,[8] however, identified the zone in Petroleum Securities Burbank well No. 1, in Middle Dome. The zone has not been found in South Dome.

Mottled greenish, reddish, and purplish shale are the most conspicuous constituents of the upper variegated zone, particularly in the upper 20 to 25 feet. The underlying 75 to 175 feet consists chiefly of gray sand with thin beds of shale. Some of the sand and shale in the lower part of the zone are also variegated. A brittle crumbly greenish-purple shale, logged in a few wells, may be considered the base of the zone. Rounded pebbles of green, red, and black chert are common in the sands. Stringers of small pyrite crystals are recorded in sands and sandy shales.

Goudkoff [9] pointed out that the thickness of strata between the bentonite near the base of the McLure and the top of the upper variegated zone increases from 268 feet at the north end of North Dome to 328 feet in the central part of the anticline and that the thickness increases at a more uniform rate than the thickness of strata between the bentonite and the top of the Temblor sandstone.

The upper variegated zone is doubtless the equivalent of part of the Big Blue serpentinous member, or more probably is the equivalent of nonmarine strata immediately underlying the Big Blue and generally considered part of that member.

Second zone (*Elsinore zone*).—Underlying the upper variegated zone is the Second zone. It is also designated by drillers the Elsinore zone, a name derived from North American Elsinore well No. 1, sec. 36, T. 21. S., R. 17 E. This zone is the source of the oil produced from that well. As pointed out by Gester and Galloway,[10] the Second zone was at one time thought to extend over a larger area than any other productive zone in North Dome. The thickness of the Second zone in North Dome ranges from 100 to 300 feet, depending on the shale that is selected as representing the top of the underlying 600-foot shale. A zone about 150 feet thick overlying shale correlated with the 600-foot shale may be regarded as the equivalent of the Second zone in Middle Dome. About 80 feet of medium- to fine-grained sand, with a few thin beds of hard shell and shale and a 2-foot reef bed, were recorded in the 110-foot interval above shale correlated with the 600-foot shale in Continental Gatchell well No. 28–7, in South Dome.

The Second zone in North Dome consists of medium- to coarse-grained sand interbedded with fine-grained shaly sand and a few thin beds of shale. The porosity of some of the sands is as high as 16 to 20 percent. Some marginal wells in which less than 100 feet of this zone is open to production are highly productive. Strata in Middle Dome that may correspond to the Second zone consist of fine-grained sand, shaly sand, and a few beds of brittle black shale.

In mineral content the Second zone, as well as the First zone, differs from that of underlying zones in the abundance of chromite, which is less common lower in the section.[11]

According to well records, oysters and pectens, some of the latter of which are identified as *Aequipecten andersoni* ["*Pecten*"], are the most abundant fossils in the Second zone, as in the First zone. Goudkoff [12] grouped the First and Second zones under the designation "*Pecten andersoni* sand." He recorded *Turritella ocoyana* from his *Pecten andersoni* sand and listed Foraminifera from shale near the base. *Chlamys branneri* ["*Pecten*"] and *Chione temblorensis* are recorded in the Gatchell well in South Dome from strata corresponding to the Second zone.

600-foot shale.—The barren zone underlying the Second zone has been named the 600-foot shale, as it occurs about 600 feet below the top of the Temblor in the northern part of North Dome. It is an important zone in establishing correlations within the Kettleman Hills and with the outcrop section farther south in the type region of the Temblor. The 600-foot shale is identified in the three anticlines in the Kettleman Hills and has been recognized in wells near the foot of Reef Ridge [13] but apparently not in the Reef Ridge outcrop section.

The 600-foot shale has a minimum thickness of about 50 feet in the northern part of North Dome, a maximum

[7] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 89–90. 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. 83–84, 1915.

[8] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 456.

[9] Idem, pp. 455–456.

[10] Gester, G. C., and Galloway, John, op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 17), p. 1181.

[11] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1568.

[12] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 455–456.

[13] Siegfus, Stanley, personal communication.

of about 150 feet in the central part, and thins farther south. It consists chiefly of hard dark-brown somewhat sandy shale interbedded with fine-grained shaly sand. The beds of shale are generally not more than 15 feet thick. In many of the early wells the 600-foot shale was left open, but in later wells that produce from underlying zones it is generally cased off.

Goudkoff [14] reported that the thickness of strata between the bentonite near the base of the McLure shale and the top of the 600-foot shale ranges within limits of 584 and 650 feet from the north end of North Dome to South Dome, whereas the thickness of strata between the top of the Temblor sandstone (his *Pecten andersoni* sand) and the top of the 600-foot shale is quite irregular, indicating that sand near the top of the Temblor grades laterally into shale. The thickness of strata between the bentonite and the 600-foot shale and other units in the Temblor in seven wells between the north end of North Dome and South Dome is shown in the following table.

Thickness, in feet, of strata between bentonite near base of McLure shale member of Monterey shale and 600-foot shale and other units in Temblor sandstone in Kettleman Hills

Well	Top of Temblor sandstone	Upper variegated zone	600-foot shale
North Dome:			
Lillis-Welch No. 1, sec. 24, T. 21 S., R. 16 E.	45	270	600
Standard 8-27-J	40	330	520
Kenda 21-1-P	60	340	585
Standard 21-17-Q	70	----------	575
Kenda 81-34-Q	100	----------	568
Middle Dome:			
Standard 6-29-V	260	----------	620
South Dome:			
Continental Gatchell No. 28-7, sec. 7, T. 25 S., R. 20 E.	340	----------	690

The preceding table indicates that, in general, the section thickens southward, and that the top of the Temblor sandstone is a less reliable stratigraphic guide than the upper variegated zone or the 600-foot shale. Nevertheless, the top of the sandstone is important economically, and it is not known whether the variation in thickness between the bentonite and the top of the sandstone is due to lateral gradation of sand into shale, which is a reasonable inference, to the grouping of sand of varying thickness at the base of the McLure with the Temblor, or to erosional discontinuity between these formations.

Poorly preserved Foraminifera from the 600-foot shale of Kenda well 27-34-J, and of Standard well 87-27-Q, were submitted to R. M. Kleinpell. Samples from Superior Huffman well No. 1 and Petroleum Securities well No. 1 were made available to Mr. Kleinpell through the kindness of Mr. D. D. Hughes. The Foraminifera from the 600-foot shale and from the Gould shale member of the Monterey shale, with which Kleinpell correlates the 600-foot shale, are listed in the table on page 138. Some of the characteristic species of the Gould shale are shown on plate 50. Mr. Kleinpell has prepared the following remarks on these fossils:

> The fauna of the Gould shale, representing the *Siphogenerina branneri* zone, is characteristic and widespread. It is marked by the earliest appearance of several species, including typical *Bolivina imbricata* (pl. 50, figs. 20, 21), *Valvulineria californica obesa* (pl. 50, figs. 15–17), and *Pullenia miocenica*, and by the extensive development of other species, including *Nonion costiferum* in the restricted sense (pl. 50, figs. 13, 14), *Buliminella subfusiformis* (pl. 50, figs. 18, 19), *Siphogenerina branneri*, *Valvulineria miocenica depressa*, *Valvulineria ornata* (pl. 50, figs. 22–24), and *Baggina robusta*. The abundance of *Nonion costiferum*, *Bolivina imbricata*, *Valvulineria californica obesa*, and *Valvulineria ornata*, and the doubtful occurrence of *Baggina robusta*, afford grounds for correlating the 600-foot shale with the Gould shale.

Foraminifera from the 600-foot shale of Kettleman Hills wells were listed by Goudkoff,[15] who correlated the 600-foot shale with the Gould shale. Other geologists have correlated the basal part of the McLure shale or the upper part of the Temblor sandstone (upper part of First zone) with the Gould shale.[16]

Third zone.—The Third zone is recognized in the developed parts of North Dome as well as in Middle and South Domes. In North Dome it is productive over almost the same area as the Second zone, but in Middle and South Domes it has not yet been found to be productive. The thickness of the Third zone in North Dome is 100 to 300 feet and averages about 180 feet.

Medium- to moderately coarse-grained sand is the principal constituent of the Third zone. Sand of finer grain, shale, generally recorded as sandy shale, and a few thin hard calcareous streaks, logged as reef beds are also present. According to tests by P. G. Nutting, the porosity of the sand ranges from about 12 to 20 percent and the permeability from 5 to 12.5 cubic centimeters per minute.

Bramlette [17] reported that chromite is less abundant in sands assigned to the Third zone than in sands in the Second and First zones. Largely on the basis of this distinction the 600-foot shale was tentatively located in Petroleum Securities Burbank well No. 1, in Middle Dome, before it was known that the shale contains Foraminifera characteristic of the 600-foot shale.

Fossils recorded from the Third zone, principally fragments of oysters and pectens, are apparently similar to those in the overlying productive zones.

800-foot shale.—The third barren zone is encountered about 800 feet below the top of the Temblor in wells

[14] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 457.

[15] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 456–457.

[16] Cunningham, G. M., and Barbat, W. F., Age of producing horizon at Kettleman Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 16, pp. 417–421, 1932. Barbat, W. F., Age of producing horizon at Kettleman Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 16, pp. 611–612, 1932. Gester, G. C., and Galloway, John, op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 17), pp. 1179–1181, fig. 3.

[17] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1568.

Foraminifera from Gould shale member of Monterey shale at outcrop on Zemorra Creek and from 600-foot shale of wells in Kettleman Hills

[Identifications by R. M. Kleinpell. R, rare; F, few; C, common; A, abundant]

Species	Localities										
	Outcrop, Zemorra Creek				North dome				Middle dome		
	1	2	3	4	5	6	7	8	9	10	11
Indeterminate arenaceous forms						F				F	R
Robulus branneri Cushman and Kleinpell			R								
Robulus reedi Kleinpell	?R			R							
Robulus smileyi Kleinpell	C										
Robulus cf. *R. smileyi* Kleinpell						R					
Robulus? cf. *R. miocenicus* (Chapman)						R					
Lenticulina relizensis Kleinpell			F								
Planularia luciana Kleinpell			C	?							
Hemicristellaria beali (Cushman)	A		R	R							
Hemicristellaria? cf. *H. beali* (Cushman)									R		
Dentalina pauperata d'Orbigny			R	F							
Dentalina sp				F							
Dentalina roemeri Neugeborgen	F			?							
Dentalina obliqua (Linné) (of Cushman)	R			C							
Dentalina? sp											R
Nodosaria tornata Schwager				F							
Nonion costiferum (Cushman) (pl. 50, figs. 13, 14)	C	R	R		C	C			F	F	F
Nodogenerina advena Cushman and Laiming			C	C							
Buliminella curta Cushman						C			C	A	C
Buliminella subfusiformis Cushman (pl. 50, figs. 18, 19)	C	C			F	R				?R	?R
Bulimina ovata d'Orbigny			F				?				
Bulimina pseudotorta Cushman	A		R								
Bulimina? sp					F				F	F	F
Virgulina? cf. *V. californiensis* Cushman					R				R	R	R
Bolivina imbricata Cushman (pl. 50, figs. 20, 21)	C	A	A	F		?F			C	C	C
Bolivina brevior Cushman			R								
Bolivina advena advena Cushman			C	F							
Bolivina advena ornata Cushman			?								
Bolivina advena striatella Cushman?					C	R					
Bolivina cf. *B. marginata* Cushman									R	R	
Bolivina salinasensis Kleinpell?				R							
Bolivina cuneiformis Kleinpell?			R								
Uvigerinella californica Cushman	C		C	R							
Uvigerina proboscidea Schwager?			F	F							
Siphogenerina branneri (Bagg) (not of Cushman)	F		A	A							
Siphogenerina kleinpelli Cushman			R	F							
Siphogenerina cf. *S. kleinpelli* Cushman					R	R					
Valvulineria williami Kleinpell	F										
Valvulineria miocenica depressa Cushman	R		F	?							
Valvulineria californica obesa Cushman (pl. 50, figs. 15–17)	A	R	R	F		C		C	?R		F
Valvulineria? cf. *V. californica appressa* Cushman						R					
Valvulineria ornata Cushman (pl. 50, figs. 22–24)	F					F	F			F	R
Eponides keenani Cushman and Kleinpell			R								
Baggina robusta Kleinpell	A	C	R	A				?			
Pulvinulinella? cf. *P. subperuviana* Cushman					C	F			C	C	C
Cassidulina crassa d'Orbigny				F							
Pullenia miocenica Kleinpell			R	F							
Sphaeroidina bulloides d'Orbigny				R							
Globigerina bulloides d'Orbigny			A		R					R	
Globigerina conglomerata Schwager			F								
Anomalina salinasensis Kleinpell			F	C				?			
Planulina depressa d'Orbigny				R							
Cibicides americanus (Cushman) n. var	R										

1. Zemorra Creek, 2 feet above base of Gould shale.
2. Same locality, 75 feet above base of Gould shale.
3. Same locality, 215 feet above base of Gould shale.
4. Same locality 245 feet above base of Gould shale.
5. Superior Huffman well No. 1, sec. 29, T. 21 S., R. 17 E., depth 7,656 feet.
6. Same well, depth 7,666 feet.
7. Kenda well 27-34-J, depth 7,361 to 7,372 feet.
8. Standard well 87-27-Q, depth 7,354 to 7,358 feet.
9. Petroleum Securities Burbank well No. 1, sec. 30, T. 23 S., R. 19 E., depth 7,937 to 7,944 feet.
10. Same well, depth 7,959 feet.
11. Same well, depth 7,970 feet.

along or close to the crest of northern North Dome, and is, consequently, known as the 800-foot shale. Its thickness in North Dome appears to range from 50 to 175 feet. It has not been completely cored in any well and has been partly cored in only a few wells. The results of electrical logging show, however, that it extends throughout the developed area. This barren zone is now generally cased off in wells on the flanks or plunging ends of North Dome.

Black flaky shale and dark-gray shale, interbedded with sandy shale and thin beds of fine-grained sand, are the principal constituents of the 800-foot shale in North Dome. Some of the sands contain "*Scutella*," *Turritella*, and pectens. In Middle Dome only thin beds of shale are reported at the approximate stratigraphic position of the 800-foot shale. In South Dome about 130 feet of shale encountered in Continental Gatchell well No. 28–7 appears to be the equivalent of the 800-foot shale. These strata consist of hard massive black shale to fissile grayish-brown shale with several beds, each about a foot thick, made up almost entirely of phosphatic pellets.

Fourth zone.—Underlying the 800-foot shale is the Fourth zone, the thickness of which in North Dome is about 60 to 170 feet, and the average is about 120 feet. About 300 feet of sand, in Middle and South Domes, which has not yet been found to be productive, may tentatively be regarded as the equivalent of this zone.

In North Dome the Fourth zone consists of fine- to medium-grained sand interbedded with sandy shale. In the northeastern part of the anticline electrical logs indicate an average thickness of about 20 feet of very porous rock, presumably coarse-grained sand. The thickness of rock of this type rather than the thickness of the zone itself is an important factor in the productiveness of the zone. A thickness of almost 60 feet of rock of this type is indicated in and near the King lease in sec. 29, T. 21 S., R. 17 E., about 80 feet in part of the Felix area in sec. 35, T. 21 S., R. 17 E., and adjoining sections, and considerably less on the crest of the northern part and in the southern part of North Dome.

Samples from sands assigned to the Fourth zone were examined by Bramlette.[18] They appear to show no distinctive minerals except possibly a relative abundance of feldspars.

According to logs, a small pecten, generally identified as *Aequipecten andersoni* ["*Pecten*"], is the most abundant fossil in the Fourth zone. Several occurrences of "*Scutella*" are recorded. Goudkoff[19] recorded "*Scutella*" only from the Third and Fourth zones and grouped these strata under the term "button bed sandstone."

Lower variegated zone.—The fourth barren zone is designated the lower variegated zone because in part of North Dome the zone, generally the lower part, includes variegated shale. The lower variegated zone is apparently persistent as a generally unproductive zone throughout the Kettleman Hills, though it is not reported in the logs of many wells, even in wells that are only about 900 feet distant from wells in which it was identified either in cores or in ditch samples. Fragments of reddish, greenish, and purplish shales are conspicuous in ditch samples at localities where this zone includes variegated shale, and its stratigraphic position has been determined by such cuttings more frequently than by coring. The lower variegated zone has been reported in wells here and there in the northern three-fourths of North Dome and is traceable by means of electrical logs. It is apparently recognizable as a zone including shale in Middle and South Domes. By means of an epidote-augite-hornblende assemblage and a *Nonion-Nonionella* foraminiferal fauna Goudkoff[20] has traced the lower variegated zone from North Dome to South Dome and farther south.

In North Dome the thickness of the lower variegated zone appears to range from 125 to 245 feet. Toward the south it thins and loses the variegated shale. In wells in which the zone has been most completely cored it consists mainly of muddy greenish sand with streaks of variegated shale. Beds of shale more than a foot thick are rare. Sands containing black, red, and green chert pebbles and shale pebbles are as characteristic of the zone as variegated shale. Goudkoff[21] identified the lower variegated zone in Petroleum Securities Burbank well No. 1, in Middle Dome, on the basis of the mineral content and foraminiferal fauna. Variegated shale, however, is not recorded in this well, and sandy shale and sand containing small pebbles at a horizon 250 feet lower is suggestive of the zone. About 120 feet of black, brown, or gray sandy shale encountered in Ohio Smith well No. 1, in South Dome, may be the equivalent of the lower variegated zone. A 155-foot shale zone, logged under the name "Media shale" in the Continental Gatchell well No. 28–7, in South Dome, may also be the equivalent of the lower variegated zone. The shale zone in the Gatchell well consists of hard shale. Cores representing hard dark-brown shale and hard dark-gray silty carbonaceous shale were recovered. According to these tentative identifications, the lower variegated zone loses the variegated shale and chert pebbles southward, and the proportion of shale increases in the same direction.

A few species of Foraminifera, among which *Nonion incisum*, *Nonionella*, and *Virgulina* are most abundant, are recorded from the upper part of the lower variegated zone by Goudkoff.[22] He has recognized a similar assemblage in the type region of the Temblor formation immediately underlying the button bed sandstone of local usage—that is, in the upper part of the Media shale of local usage—and in a shale streak about 400 feet below the top of the Temblor sandstone at Big Tar Canyon.[23]

Fifth zone.—The Fifth zone is with few exceptions the lowest productive zone penetrated by wells in North Dome. It is the principal source of the so-called brown or black oil. It is not only productive in a large area in North Dome, where it may prove to be more extensive than any other productive zone, but is also tentatively recognized in Middle and South Domes. The Fifth zone is 200 to 400 feet thick in North Dome.

[18] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), table 2 (p. 1562); depth 6975 to 7073 feet, inclusive.

[19] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 458–459, fig. 7.

[20] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 459, figs. 4, 5.

[21] Idem, p. 459.

[22] Idem.

[23] Idem, p. 464.

According to data now available, its average thickness is about 300 feet.

According to logs and cores, the Fifth zone in North Dome consists chiefly of somewhat poorly sorted and poorly consolidated greenish sand. The sand shows a considerable variation in grain size, but medium- and coarse-grained sand is more abundant than fine-grained sand, except near the top and bottom of the zone where the grains are so small that some of the rock would be properly classified as siltstone. Clay shale of variable thickness is interbedded with the sand and may be correlated by means of electrical logs in at least the northern two-thirds of North Dome. It may eventually be possible and even desirable to subdivide this zone into smaller units separated by the more persistent shales. This possibility is indicated by casing perforation records of wells recently completed in this zone. The relative proportion of sand and shale appears to vary irregularly from well to well, but in general the percentage of shale increases southward from about 10 percent in northern North Dome to 25 percent in southern North Dome. In Middle and South Domes, however, the proportion of sand is as high as in northern North Dome.

At the top of the Fifth zone and apparently extending upward into the lower variegated zone, is a thin distinctive mineral zone that is designated the orthoclase-anhydrite zone by Bramlette.[24] As its name implies, this mineral zone is characterized by the abundance of orthoclase, much of which is fresh, and anhydrite. The zone may represent alkalic pyroclastic debris, but no bentonitic material was recognized. Most of the Fifth zone represents Bramlette's andesitic sand zone,[25] which is characterized in the well material by the abundance of green hornblende and basaltic hornblende.

A few fossils, including *Aequipecten andersoni* [*"Pecten"*] and oysters, are recorded from sands in the Fifth zone.

Felix siltstone.—The fifth or lowermost barren zone, which has a thickness of 35 to 80 feet, is divided into two parts. The upper part is designated by drillers the Felix siltstone, as it was first recognized in wells drilled on the Felix lease of the Petroleum Securities Co. in sec. 35, T. 21 S., R. 17 E., and adjoining areas.

The Felix siltstone has been identified in a little more than the northern half of North Dome, but has not been recognized in Middle Dome or South Dome. It has a thickness of 20 to 40 feet and consists of hard gray siltstone, silty sand, and silty shale. In some wells sand containing phosphatic pellets was encountered. Near the north end of North Dome a few poorly preserved fossils, including *Macoma* and *Mactra*, are recorded.

[24] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1568.

[25] Idem, pp. 1567-1568.

Whepley shale.—The lower part of the fifth barren zone is designated by drillers the Whepley shale. It was first penetrated by a well on the Whepley lease of the Associated Oil Co. in sec. 35, T. 21 S., R. 17 E. When first encountered it was called the *"Leda"* zone, as it was thought to represent the *"Leda"* zone of the underlying Kreyenhagen shale, but it is now assigned to the Temblor. In North Dome the Whepley shale is recognized in about the same area as the Felix siltstone, except near the north end of the anticline. It has also been identified near the south end of North Dome and may be presented in Petroleum Securities Burbank well No. 1, in Middle Dome, about 925 feet below the 600-foot shale. The probable equivalent of the Whepley in this well includes hard, sandy, black and gray shale. A shale about 50 feet thick encountered in Continental Gatchell well No. 28–7, in South Dome, was logged under the name "Santos shale." It may be the equivalent of the Whepley. The absence of the Whepley shale near the north end of North Dome is attributed by some geologists to an erosional discontinuity.

In North Dome the Whepley shale ranges from 15 to 40 feet in thickness and averages probably 30 feet. It consists of brittle, hard, dark-brown or brownish-gray shale of rather uniform character wherever recognized. Small pyritized pectens are abundant in some wells, and other mollusks and Foraminifera are present. The following mollusks are represented in core material from two wells.

Mollusks from Whepley shale

[Identifications by W. P. Woodring]

Species	1	2
Nuculana sp.	X	X
Hyalopecten cf. *H. peckhami* (Gabb)	X	X
Cyclocardia? cf. *C. montereyana* (Arnold)	------	X

1. Petroleum Securities Felix well No. 3, sec. 35, T. 21 S., R. 17 E., depth 8,495 to 8,516 feet.
2. Kenda well 61-2-P, depth 8,312 to 8,328 feet.

The Whepley shale was first designated the *"Leda"* zone from the occurrence of *Nuculana* [*"Leda"*] and other fossils similar to those in the *"Leda"* zone of the Kreyenhagen shale. The *Nuculana* in the Whepley shale resembles the species from the Monterey shale of the Santa Cruz Mountains recorded under the name *Yoldia impressa* (Conrad)[26] but is smaller and more inequilateral. The posterior dorsal margin is less excavated than in the *Nuculana* from the *"Leda"* zone of the Kreyenhagen shale. The little pecten is represented by many impressions and molds of crushed speci-

[26] Arnold, Ralph, Descriptions of new Cretaceous and Tertiary fossils from the Santa Cruz Mountains, Calif.: U. S. Nat. Mus. Proc., vol. 34, p. 351, pl. 35, fig. 3, 1908. Branner, J. C., Newsom, J. F., and Arnold, Ralph, U. S. Geol. Survey Geol. Atlas, Santa Cruz folio (no. 163), pl. 2, fig. 49, 1909. *Nucula impressa* Conrad (U. S. Expl. Exped., Geology, p. 726, pl. 18, figs. 7 a-e, 1849) [not *Nucula impressa* Sowerby 1825], from the Miocene of Astoria, Oreg., has been named *Yoldia (Portlandia) astoriana* by J. Henderson (Nautilus, vol. 33, p. 122, 1920). It is considered a relatively elongate *Saccella*.

mens, which retain some shell material replaced by pyrite that shows the microscopic camptonectes sculpture. These specimens resemble *Hyalopecten peckhami* (Gabb), the type material of which is from the Monterey shale of the Ventura Basin.[27] Similar pectens are found in the Kreyenhagen shale. The small *Cyclocardia?* is similar to "*Venericardia*" *montereyana* Arnold [28] from the Monterey shale of the Santa Cruz Mountains but lacks nodes on the ribs. In addition to these mollusks, *Odostomia*, "*Nassa*", *Acila*, "*Phacoides*", *Macrocallista*, and fish scales are recorded from the Whepley shale in well logs.

According to Goudkoff,[29] Foraminifera from the Whepley shale indicate that it is the equivalent of strata in the lower part of the Temblor formation in the type region. R. M. Kleinpell considers the Whepley shale fauna to represent approximately his *Siphogenerina transversa* zone, which embraces strata in the Carneros sandstone of local usage and the Santos shale of local usage. (See pl. 47.)

Sixth zone (*Beal zone*).—The Sixth zone is the lowest productive zone in the Temblor and also the lowest subdivision. This zone is designated by drillers the Beal zone, a name derived from the lease in sec. 34, T. 21 S., R. 17 E., where it was first encountered. It has been designated Vaqueros (?)[30] and has been described under the name "mollusk boring sand." [31] It is doubtful whether the irregular borings that characterize much of the sand in this zone were made by mollusks.

So far the Sixth zone has been completely penetrated by only a few wells. In North Dome the thickness of the zone increases from 355 feet at the north end of the anticline to 640 feet in sec. 34, T. 21 S., R. 17 E. It consists of fine-grained somewhat silty sand, fine- to coarse-grained cleaner sand, silty shale, and a few thin beds of hard calcareous sand. The electrical log of Kenda well 38–34–J indicates a more or less regular alternation of porous and less porous strata, corresponding approximately to the distribution of barren and oil-bearing core samples.

The lowest 300 feet of strata penetrated by Petroleum Securities Burbank well No. 1, in Middle Dome, may represent the Sixth zone. These strata consist of sandy shale and fine-grained sand grading downward into medium- and coarse-grained sand. A considerable thickness of sand underlying the probable equivalent of the Whepley shale in Continental Gatchell well No. 28–7, in South Dome, may be the equivalent of the Sixth zone.

Samples from the Sixth zone show a mineral content corresponding to that of the lower sandstone in the Temblor at Big Tar Canyon.[32]

AGE AND CORRELATION

The Kettleman Hills Temblor section is not closely similar to the outcrop sections on Carneros Creek, Reef Ridge, and Anticline Ridge, and yet it combines features of the outcrop sections in these three regions. The foraminiferal faunas from the 600-foot shale, lower variegated zone, and Whepley shale are rather meager, but they offer a basis for comparison with the section in the type region of the Temblor formation. An andesitic sand zone and a zone characterized by abundant chromite are recognized in the subsurface section and on Reef Ridge. The serpentine zone of the subsurface section affords a datum plane for comparison with the section on Anticline Ridge. Correlations based on these and other data are shown on plate 47 and figure 14.

The lower part of the Temblor in the Kettleman Hills appears to be of the same age as the lower part of the Temblor in the type region and, therefore, is to be correlated with part of the Vaqueros sandstone of many regions; in fact, the Sixth zone has been provisionally referred to the Vaqueros.[33] An undetermined additional part of the Kettleman Hills section, probably up to or including the Fifth zone, may also be the equivalent of Vaqueros elsewhere. The 600-foot shale is considered the chronologic equivalent of the Gould shale member of the Monterey. From this correlation and the correlation of the McLure shale it follows that the Kettleman Hills section from the base of the 600-foot shale upward to the top of the Temblor sandstone is of the same age as most of the lower half of the Monterey shale in the type region of the Temblor. Geologists who define Monterey in terms of the age of Monterey shale in the Chico Martinez Creek section assign this part of the Kettleman Hills section to the Monterey.[34] If, however, Monterey is used for the time interval represented in the type region in Monterey Peninsula, as indicated by foraminiferal zones, the base of the Monterey in the Kettleman Hills section is to be shifted to an undetermined higher horizon, probably near the base of the upper variegated zone.

The lower sandstone in the sections examined on Reef Ridge appears to be the equivalent of an undetermined division of the lower part of the Temblor of the Kettleman Hills and of the type region and doubtless is Vaqueros according to the terminology of some

[27] For a discussion of this group of pectens, see Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif., and their inferred environment: U. S. Geol. Survey Prof. Paper 190, pp. 35–41, 1938.

[28] Arnold, Ralph, op. cit., pp. 380–381, pl. 35, fig. 4. Branner, J. C., Newsom, J. F., and Arnold, Ralph, op. cit., pl. 2, fig. 48.

[29] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 459–460.

[30] Idem, p. 460, fig. 4.

[31] Dodd, H. V., and Kaplow, E. J., Kettleman North Dome and Kettleman Middle Dome fields, progress in development: California Oil Fields (California, Dept. Nat. Res., Div. Oil and Geol.), vol. 18, no. 4, p. 12, 1933 [1934].

[32] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1567, table 1 (p. 1562), depth, 7,876 to 7,916 feet, inclusive.

[33] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 460.

[34] Goudkoff, P. P., Age of producing horizon at Kettleman Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 839–842, 1931; Subsurface stratigraphy of Kettleman Hills oil field, Calif.: Idem, vol. 18, pp. 454–458, 1934.

geologists. The middle sandstone exposed on Reef Ridge constitutes the andesitic sand zone, which includes most of the Fifth zone.[35] The upper sandstone exposed in Canoas Canyon may represent the Fourth and Third zones. In the abundance of chromite the upper sandstone exposed in Big Tar Canyon is similar to sands in the Second and First zones overlying the 600-foot shale.[36] Bramlette, therefore, suggested that the part of the subsurface section above the 600-foot shale is not represented in Canoas Canyon, whereas the part between the 600-foot shale and the base of the serpentine zone, near the base of the First zone, is represented in Big Tar Canyon—features pointing to discontinuities at different horizons in the Temblor exposed on Reef Ridge, probably due to nondeposition.

The meager paleontologic evidence is not opposed to Bramlette's suggestion. In Big Tar Canyon "*Scutella*" occurs in the middle sandstone and in Canoas Canyon it occurs in both the middle and the upper sandstones. In the subsurface section "*Scutella*" is recorded from the Third and Fourth zones, but if the andesitic sand zone is at the same horizon as on Reef Ridge, "*Scutella*" may be expected to occur also in the Fifth zone. In the type region of the Temblor, "*Scutella*" occurs in the button bed sandstone of local usage. Though "*Scutella*"-bearing sandstones at other localities may not be the chronologic equivalent of the button bed sandstone, the mineral zones suggest that these little sand dollars are not found either in the subsurface section or on Reef Ridge in the part of the section that some geologists refer to the Monterey. The following fossils were collected from the upper part of the upper sandstone on the slope on the east side of Big Tar Canyon:

Fossils from upper division of upper sandstone of Temblor sandstone on east side of Big Tar Canyon (U. S. G. S. locality 13138)

[Identifications by W. P. Woodring.]

Gastropods:
- *Turritella ocoyana* Conrad.
- *Neverita* sp.
- *Forreria* sp.
- 2 undetermined species.

Pelecypods:
- *Anadara* sp.
- *Aequipecten andersoni* (Arnold)?
- *Ostrea* cf. *O. titan* Conrad.
- *Miltha sanctaecrucis* (Arnold).

Pelecypods—Continued.
- *Lucinoma* cf. *L. acutilineata* (Conrad).
- *Macoma pierci* Arnold.
- *Apolymetis* n. sp.?
- *Dosinia* cf. *D. mathewsonii* Gabb.
- *Clementia pertenuis* (Gabb).
- *Trachycardium* cf. *T. vaquerosensis* (Arnold).

This faunal zone is not represented in the "*Scutella*"-bearing upper sandstone exposed in Canoas Canyon. *Miltha sanctaecrucis* (Bull. 398, pl. 28, fig. 6) and *Clementia pertenuis* (Bull. 398, pl. 30, fig. 3) are not recorded from the middle and lower sandstones exposed on Reef Ridge. Inasmuch as these two species occur in the Vaqueros sandstone,[37] they cannot be accepted as dependable chronologic guides for a particular part of the Temblor in the Coalinga district unless long-continued collecting and independent evidence indicates that the unknown environmental control that determined their presence or absence in this region has a chronologic significance. The type of *Miltha sanctaecrucis* is from "*Scutella*"-bearing Temblor sandstone in the Devils Den district, south of the Kettleman Hills (locality 4861, reef bed in sec. 23, T. 25 S., R. 18 E., a quarter of a mile southeast of Barton's cabin).[38] It should be pointed out that the type of "*Scutella*" *andersoni* Twitchell [39] is from this locality. As compared with 50 other specimens from this locality, mostly poorly preserved, the type of "*S.*" *andersoni* is exceptionally domed; and the periproct is slightly supramarginal, whereas it is marginal on some specimens. These sand dollars have petals resembling those of "*Scutella*" *merriami* from the button bed sandstone of local usage in the type region of the Temblor, the largest specimens of which have notches in the posterior ambulacral areas, as in "*S.*" *andersoni*. Large suites of specimens from different localities are needed to determine the relations of these forms. "*Scutella*" *andersoni* is recorded from the Vaqueros.[40] It is not known whether the "*Scutella*"-bearing sandstone in the Devils Den district is older or younger than the Gould shale member of the Monterey. West of the Devils Den district [41] and also at the northwest end of Reef Ridge [42] Temblor sandstone overlaps onto Cretaceous rocks.

The serpentine zone of the Kettleman Hills section represents at least part of the Big Blue serpentinous member of the Temblor on the Coalinga anticline;[43] perhaps the upper variegated zone, which underlies the serpentine zone, also is to be correlated with the Big Blue or with nonmarine strata immediately underlying the Big Blue. The southward thinning and disappearance of the serpentine zone and upper variegated zone conform to their inferred derivation from a source to the northwest. The lower variegated zone, which includes strata similar to those in the upper variegated zone, also loses these characteristic strata southward. Nonmarine strata corresponding to the lower variegated zone have not been recognized on Anticline Ridge.

[35] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 1567–1568.

[36] Idem, p. 1572.

[37] Loel, Wayne, and Corey, W. H., The Vaqueros formation, lower Miocene of California, pt. 1, Paleontology: California Univ., Dept. Geol. Sci., Bull., vol. 22, pp. 211, 218, 1932.

[38] Arnold, Ralph, op. cit. (Bull. 396), pp. 58–59, 1909 [1910].

[39] Clark, W. B., and Twitchell, M. W., The Mesozoic and Cenozoic Echinodermata of the United States: U. S. Geol. Survey Mon. 54, pp. 183–184, pl. 85, figs. 3a–d, 1915.

[40] Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ., Dept. Geology, Bull., vol. 12, pp. 62–64, 1920 (the figured specimen from the Tejon Hills on the east side of northern San Joaquin Valley appears to represent "*Scutella*" *tejonensis* Kew). Loel, Wayne, and Corey, W. H., op. cit., p. 177.

[41] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, Calif.: U. S. Geol. Survey Bull. 406, p. 45, 1910. English, W. A., Geology and petroleum resources of northwestern Kern County, Calif.: U. S. Geol. Survey Bull. 721, pl. 1, 1921. Reed, R. D., Geology of California, pp. 176–177, Tulsa, Am. Assoc. Petroleum Geologists, 1933.

[42] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 67, 80.

[43] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), pp. 1568–1569, 1573.

Perhaps, however, some of the sandstone included in the lower sandstone of that area is the equivalent of the lower variegated zone.

The serpentine zone is thin or absent at the two localities examined on Reef Ridge. As the serpentine zone is several hundred feet above the 600-foot shale, the Big Blue is considered younger than any sandstone in the type region of the Temblor; that is, it is Monterey in the nomenclature of some geologists.[44]

[44] See discussion by Reed, R. D., op. cit., pp. 217-220; Kleinpell, R. M., Miocene stratigraphy of California, pp. 70-71, Tulsa, Am. Assoc. Petroleum Geologists, 1938.

It has long been recognized that the Big Blue has the stratigraphic position of Monterey shale and that it may be the chronological equivalent of part of the Monterey.[45] The upper sandstone exposed on Anticline Ridge between the Big Blue and the "indicator bed" may also be younger than strata at the top of the type Temblor. The following fossils occur in the upper sandstone:

[45] Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, p. 21, 1908. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 76, 88, 1910.

Fossils from upper sandstone of Temblor sandstone exposed on Anticline Ridge and farther north

[Identifications by W. P. Woodring]

Name used in this report	Localities						Name used by Arnold in Bulletins 396 and 398
	4631	4633	13362	13358	13359	13120	
Gastropods:							
Turritella ocoyana Conrad (Bull. 398, pl. 30, figs. 1, 2)	X	X	----	X	X	----	*Turritella ocoyana* Conrad.
Calyptraea sp	X	----	----	----	X	----	*Trochita* sp. indet.
Crepidula cf. *C. rostralis* (Conrad)	X	----	----	----	----	----	*Crepidula* sp.
Neverita reclusiana callosa Gabb	X	----	----	?	?	----	*Neverita callosa* Gabb.
Ficus cf. *F. modesta* (Conrad)	----	X	----	----	----	----	*Ficus pyriformis* Gabb.
Trophosycon oregonense (Conrad)	X	X	----	X	----	----	*Agasoma kernianum* Cooper.
Bruclarkia barkeriana (Cooper) (Bull. 398, pl. 30, fig. 5).	X	----	----	----	----	----	*Agasoma santacruzana* Arnold.
"*Murithais*" *wilkesanus* (Anderson)? (Bull. 398, pl. 31, fig. 4).	X	----	----	----	----	X	*Ocinebra topangensis* Arnold.
Cancellaria cf. *C. simplex* Anderson (Bull. 398, pl. 31, fig. 6).	X	----	----	----	----	----	*Cancellaria vetusta* Gabb.
Cancellaria andersoni Arnold (Bull. 398, pl. 31, fig. 5)	X	----	----	----	----	----	*Cancellaria andersoni* Arnold.
Oliva californica Anderson	----	----	----	?	X	----	
"*Bathytoma*" *pierci* Arnold (Bull. 398, pl. 31, fig. 7)	X	----	----	----	----	----	*Bathytoma pierci* Arnold.
Terebra sp	X	----	----	----	----	----	Not recorded.
Conus owenianus Anderson (Bull. 398, pl. 31, fig. 3)	X	----	----	?	X	----	*Conus owenianus* Anderson.
Pelecypods:							
Anadara cf. *A. osmonti* (Dall)	X	----	----	----	----	----	Not recorded.
Glycymeris cf. *G. branneri* Arnold	----	----	----	X	----	----	
Aequipecten andersoni (Arnold)	X	----	X	----	----	----	*Pecten andersoni* Arnold.
Lyropecten sp	----	----	X	----	----	----	
Lucina cf. *L. excavata* Carpenter	----	----	----	----	X	----	
Lucinoma acutilineata (Conrad)	X	----	----	----	----	----	*Phacoides acutilineatus* Conrad.
Macoma pierci Arnold (Bull. 398, pl. 29, fig. 6)	X	----	----	----	----	----	*Macoma pierci* Arnold.
Macoma sp	----	X	----	----	----	----	*Macoma* aff. *secta* Conrad.
Apolymetis cf. *A. biangulata* (Carpenter)	----	----	----	X	----	----	
Dosinia cf. *D. ponderosa* (Gray) (Bull. 398, pl. 31, fig. 1).	X	----	----	----	----	----	*Dosinia ponderosa* Gray.
Amiantis diabloensis (Anderson)	----	----	----	----	----	X	
Saxidomus vaquerosensis Arnold (Bull. 398, pl. 29, fig. 7).	X	----	----	----	----	----	*Saxidomus vaquerosensis* Arnold.
Chione temblorensis (Anderson) (Bull. 398, pl. 30, fig. 7).	X	----	----	----	----	X	*Chione temblorensis* Anderson.
Clementia pertenuis (Gabb) (Bull. 398, pl. 30, fig. 3)	X	X	----	----	----	----	*Venus pertenuis* Gabb. *Chione conradiana* Anderson.
Trachycardium vaquerosensis (Arnold) (Bull. 398, pl. 31, fig. 2).	X	----	----	----	----	----	*Cardium vaquerosensis* Arnold.
Zirfaea cf. *Z. dentata* Gabb	----	X	----	----	----	----	*Zirphaea dentata* Gabb.

4631. *Turritella* bed on east flank of high hill northeast of Oil City, in SE¼NE¼ sec. 10, T. 19 S., R. 15 E.; collected by Ralph Arnold and J. H. Pierce, 1907.
4633. *Turritella* bed about 11 miles NNE. of Coalinga, just below Big Blue on ridge in sec. 10, T. 19 S., R. 15 E.; collected by Ralph Arnold, 1907.
13362. West side of first long canyon east of Oil Canyon, 1,800 feet west of the southeast corner of sec. 20, T. 19 S., R. 15 E., 4 feet above top of "indicator bed"; collected by K. E. Lohman, 1934.
13358. First ridge east of Oil Canyon, 2,400 feet N. 81° W. from the southeast corner of sec. 20, T. 19 S., R. 15 E., 84 feet above top of "indicator bed"; collected by K. E. Lohman, 1934.
13359. Same locality as preceding, but float within 5 feet of outcrop and apparently from same bed; collected by K. E. Lohman, 1934.
13120. Second spur southeast of mouth of Phoenix Canyon, float about 20 feet above "indicator bed"; collected by W. P. Woodring, 1933.

Many of the species in the preceding list are not recorded from the "*Scutella*"-bearing parts of the Temblor in the Coalinga district. It was apparently this feature that led Arnold to consider that the fossils from the upper part of the Temblor on Anticline Ridge represent a "unique" fauna.[46] Additional collecting and more work on the fossils are needed to determine the chronological significance of this faunal zone. It would ordinarily be considered indicative of "Temblor age," as it includes *Turritella ocoyana*, which is the most abundant species, *Bruclarkia barkeriana*, *Aequipecten andersoni*, *Chione temblorensis*, and other species that have been regarded as characteristic Temblor

[46] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), p. 87, 1910.

fossils. Some of the species that, so far as the Coalinga district is concerned, have been found only in the part of the Temblor overlying the "*Scutella*"-bearing sandstone are known from the Vaqueros sandstone. It is inferred that their absence in the "*Scutella*"-bearing sandstone is due to unknown environmental conditions and that they may appear at any horizon in the Temblor provided the environment was suitable. *Miltha sanctaecrucis* has been found in the upper sandstone exposed in Big Tar Canyon but not in the upper sandstone on Anticline Ridge. *Clementia pertenuis*, which occurs in the upper sandstone in both areas, is more abundant in the Santa Margarita sandstone overlying the Big Blue.[47] A list of fossils from a horizon said to be in the Santa Margarita sandstone north of Coalinga [48] includes many species that occur in the upper sandstone of the Temblor on Anticline Ridge. "*Scutella*" has not been found in the upper sandstone exposed on Anticline Ridge and in Big Tar Canyon, but the significance of its apparent local extinction is uncertain. Though it has not been found in the Santa Margarita sandstone of the Coalinga district, "*Scutella*" *gabbi* (Rémond),[49] which apparently is related to the small "*Scutella*" of the Coalinga district, occurs in the upper Miocene San Pablo group.

According to the correlations that now appear to be reasonable, the Big Blue is of late middle Miocene age, according to current Coast Range chronology. Moreover, it appears probable that the upper sandstone on Anticline Ridge and in Big Tar Canyon is probably assignable to the middle part of the middle Miocene, that is, it is probably the age equivalent of the Gould shale member of the Monterey shale or a little younger.

The age of the sandstone underlying the Big Blue in terms of the marine section is of particular interest, as on the Domengine ranch 6 miles north of Anticline Ridge the land mammals of the *Merychippus* zone occur a few feet below the base of the Big Blue. [50] This fauna is assigned to a stratigraphic position between the Mascall of Oregon and the Barstow of California, that is, it is considered of late middle Miocene age. [51]

The chronologic relations of the remainder of the section on Anticline Ridge are uncertain. The diatom-bearing "indicator bed" has the same relative stratigraphic position as the 600-foot shale and Gould shale. The middle sandstone, which includes the main reef bed containing "*Scutella*", would be expected to correspond to the andesitic sand zone of the Kettleman Hills and Reef Ridge or to overlying sandstone, but it is characterized by an abundance of hypersthene, which is rare in the other two areas, and by the presence of andalusite and kyanite, which were not found in the other areas.[52] A comparison of the diatoms in the "indicator bed" and lower diatomite with those in the shales of the Temblor formation and the lower part of the Monterey on Carneros Creek and Chico Martinez Creek may afford data for a determination of the chronologic relations of this part of the Temblor. This matter is now being investigated by K. E. Lohman.

OLIGOCENE (?) AND EOCENE SERIES

KREYENHAGEN SHALE

The major shale unit underlying the Temblor sandstone in the Kettleman Hills subsurface section is assigned to the Kreyenhagen shale. A discussion of the Kreyenhagen shale is likely to be confusing to readers unfamiliar with the geology of the Coalinga and nearby districts, for the term "Kreyenhagen" has been used with different meanings, and the name for a faunal zone in the Kreyenhagen has also been used with different meanings. The term "Kreyenhagen shale" is used in the present report for the entire shale unit and interbedded sandstone, regardless of whether the strata in this unit are of Oligocene and Eocene age or only of Eocene age.

The name "Kreyenhagen shales" was introduced by F. M. Anderson at the time when the other formations in this region were named.[53] The principal features of the Kreyenhagen and the long-continued controversy concerning the usage of the name have been reviewed by Jenkins.[54] Much of the controversy is traceable to the citation of two localities in the original description—one on Anticline Ridge and the other at the Kreyenhagen wells on Reef Ridge (Canoas Canyon). The formation exposed on Anticline Ridge assigned to the Kreyenhagen by F. M. Anderson is not similar lithologically to the formation exposed in Canoas Canyon, and it is now generally agreed that the formation exposed on Anticline Ridge is considerably older. In his first account of the geology of this region F. M. Anderson referred the shale exposed on Anticline Ridge, now generally considered the equivalent of the Kreyenhagen in Canoas Canyon, to the Monterey. This error is readily understandable, for the shale identified by F. M. Anderson as Monterey is remarkably similar lithologically to the Monterey. It might have been avoided, however, for on Anticline Ridge the Temblor sandstone containing characteristic fossils overlies the

[47] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), Idem, p. 94 (cited as *Chione conradiana*). Woodring, W. P., American Tertiary mollusks of the genus *Clementia:* U. S. Geol. Survey Prof. Paper 147, pp. 40–42, 1926.

[48] Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, p. 23, 1908.

[49] Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ., Dept. Geology, Bull., vol. 12, pp. 69–71, pl. 12, figs. 4a, b; pl. 13, figs. 1, 2a, b, 3, 1920.

[50] Merriam, J. C., Tertiary vertebrate faunas of the north Coalinga region of California: Am. Philos. Soc. Trans., new ser., vol. 22, pp. 194–196, 1915. Bode, F. D., The fauna of the *Merychippus* zone, north Coalinga district, Calif.: Carnegie Inst. Washington Pub. 453, pp. 65–96, 2 pls., 10 figs. 1935.

[51] Bode, F. D., idem, pp. 84–86.

[52] Bramlette, M. N., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 1573.

[53] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 163, 1905.

[54] Jenkins, O. P., Stratigraphic significance of the Kreyenhagen shale of California: Mining in California, vol. 27, no. 2, pp. 141–186, 11 figs., 1931.

shale identified by F. M. Anderson as Monterey, whereas on Reef Ridge the Temblor sandstone underlies the Monterey. In view of the name itself and of long-established usage, Canoas Canyon and adjoining parts of Reef Ridge are considered the type region of the Kreyenhagen shale. F. M. Anderson still objects to the generally accepted usage of the name "Kreyenhagen shale" for the formation exposed on Anticline Ridge.[55] Part of the controversy also is attributable to failure to recognize that at different localities the Kreyenhagen includes strata of different age.

The Kreyenhagen shale is a shale of Monterey type. It consists chiefly of porcelaneous mudstone and diatomaceous shale, and parts of the formation show abundant siliceous micro-organisms—diatoms, radiolaria, and silicoflagellates. This remarkable duplication of lithologic, floral, and faunal facies is one of the striking features in the geology of this region. It is quite natural that early workers[56] identified this siliceous shale on Anticline Ridge as Monterey, for at that locality the younger siliceous shale exposed on Reef Ridge (McLure shale member of Monterey shale), only 20 miles distant, is absent. Moreover, on Reef Ridge where both siliceous shale formations are present, the Kreyenhagen is generally poorly exposed, whereas the McLure stands out in bold relief.

[55] Anderson, F. M., Kreyenhagen shales and the Lillis shale [abstract]: Geol. Soc. America Bull., vol. 42, pp. 302-303, 1931.

[56] Watts, W. L., The gas and petroleum yielding formations of the central valley of California: California State Min. Bur. Bull. 3, pp. 61-63, 65, 1894. Eldridge, G. H., The petroleum fields of California: U. S. Geol. Survey Bull. 213, p. 307, 1903. Anderson, F. M., op. cit., pp. 172-173, 174-176, pl. 34, sec. 3.

STRATIGRAPHY, LITHOLOGY, AND FOSSILS

OUTCROP SECTIONS

Region north of Anticline Ridge.—The shale of Monterey type north of Anticline Ridge (the Kreyenhagen shale of the present report) underlies Miocene sandstone (Temblor sandstone) and overlies Eocene sandstone (Domengine sandstone). It has been treated in different ways, as shown in the following table.

Classification and nomenclature of shale of Monterey type (Kreyenhagen shale) north of Anticline Ridge

F. M. Anderson, 1905 [1]		Anderson and Pack, 1915 [2]		Condit, 1903 [3]			Jenkins, 1931 [4]		F. M. Anderson, 1931 [5]		Atwill, 1935 [6]		
Miocene.	Monterey shales.	Oligocene (?).	Kreyenhagen shale (sandstone considered down-faulted Vaqueros).	Oligocene (?).	Kreyenhagen shale.	A horizon.	Oligocene (?).	*Leda* zone.	Miocene.	Lillis shale.	Oligocene.	Tumey formation.	Tumey shale.
						B horizon.		Intermediate sandstone and shale.					Tumey sandstone.
						C horizon.							
						D horizon.	Eocene(?).	Kreyenhagen shale proper.			Eocene.	Kreyenhagen shale.	

[1] Anderson, F. M., Astratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 172-173, 1905.
[2] 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. 74-78., 1915.
[3] Condit, D. D., Age of the Kreyenhagen shale in the Cantua Creek-Panoche Creek district, Calif.: Jour. Paleontology, vol. 4, pp. 259-262, 1930.
[4] Jenkins, O. P., op. cit.
[5] Anderson, F. M., Kreyenhagen shales and the Lillis shale [abstract]: Geol. Soc. America Bull., vol. 42, pp. 302-303, 1931.
[6] Atwill, E. R., Oligocene Tumey formation of California: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 1192-1204, 3 figs., 1935.

The "*Leda*" zone at the top of the Kreyenhagen consists of white diatomaceous silty shale. Calcareous concretions in this zone contain a few mollusks, first recorded by F. M. Anderson,[57] on the basis of which this zone has been correlated with the Weaver's Lincoln formation of Washington, which is considered of Oliogocene age.[58] The "*Leda*" zone has a maximum thickness of about 150 feet and is known to occur only in the region extending across Arroyo Ciervo [59] and 13 miles farther southeast on the Domengine ranch.[60] The contact between the "*Leda*" zone and the underlying shale is described as representing a discontinuity.[61]

The part of the Kreyenhagen constituting Atwill's Tumey shale (Condit's B horizon) has a thickness of about 700 feet [62] and is made up principally of light chocolate-brown diatomaceous shale, which on weathered surfaces has generally a whitish or purplish-brown stain. This shale has been designated as part of the *Uvigerina cocoaensis* zone, which is reported to contain Foraminifera similar to those in Schenck's Bassendorf shale and Schenck's Keasey shale, both of which are Oregon formations tentatively assigned to the lower Oligocene.[63] According to Atwill, a *Uvigerina* in this shale is more similar to *U. glabrans* than to *U. cocoaensis*,[64] so that the usage of the term "*Uvigerina cocoaensis* zone" is likely to be confusing. Diatoms

[57] Anderson, F. M., op. cit., p. 173, 1905. Anderson, F. M., A further stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 4th ser., vol. 3, p. 16, 1908.
[58] Clark, B. L., The San Lorenzo series of middle California: California Univ., Dept. Geology, Bull., vol. 11, p. 63-64, 99, 1918.
[59] Atwill, E. R., op. cit., p. 1196.
[60] Jenkins, O. P., op. cit., p. 145.
[61] Idem.

[62] Atwill, E. R., op. cit., fig. 3 (p. 1197).
[63] Goudkoff, P. P., in Condit, D. D., op. cit., p. 260. Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 470.
[64] Atwill, E. R., op. cit., pp. 1199, 1203-1204.

described from this region are presumably from this division.[65]

Atwill's Tumey sandstone (Anderson and Pack's downfaulted Vaqueros; Condit's C horizon) is in the form of a lens that has a maximum thickness of about 800 feet. The sandstone rests with an irregular surface on the underlying shale, pebbles of which are represented in the basal conglomerate, indicating discontinuity. Fossils from the sandstone are considered of Oligocene age.[66]

The underlying shale (Condit's D horizon; restricted Kreyenhagen of Jenkins and Atwill) has a thickness of 1,400 to 2,500 feet[67] and consists of light chocolate-brown porcelaneous mudstone with light-colored porcelaneous and diatomaceous shale toward the top. It rests with apparent gradational contact on Eocene sandstone (Domengine sandstone). The upper part of the shale contains Foraminifera, Church's Markley fauna, which he considered of upper Eocene age.[68] Hughes and Laiming[69] recorded Foraminifera of their upper *Spiroplectammina* fauna from the base of this shale and pointed out its similarity to their lower *Spiroplectammina* fauna found in Eocene shale underlying the Domengine sandstone. Apparently the same fauna is recorded by Atwill.[70]

Anticline Ridge.—On Anticline Ridge the Kreyenhagen shale, corresponding to the upper member of the Tejon formation of Arnold and Anderson,[71] has a thickness of about 1,000 feet. It consists of light chocolate-brown porcelaneous mudstone, porcelaneous shale, cherty shale, and toward the top diatomaceous shale. It appears to correspond essentially to the restricted Kreyenhagen of Atwill and Jenkins farther north. Diatoms and silicoflagellates have been described from the upper diatomaceous shale.[72] Foraminifera from the lower part represent Church's Markley fauna.[73] The "*Leda*" zone and Atwill's Tumey shale are not known to occur on Anticline Ridge.

Reef Ridge.—The Kreyenhagen shale of the type region on Reef Ridge (upper part of Tejon formation of Arnold and Anderson[74]) has been described by Von Estorff.[75] It has a maximum thickness of about 1,000 feet and disappears west of Sulphur Spring Canyon owing to overlap by Temblor sandstone. The Kreyenhagen in this region consists chiefly of light chocolate-brown porcelaneous mudstone that rests with gradational contact on Eocene sandstone (Avenal sandstone). The sandstone, sandy shale, and clay at the base of the formation, representing the transition zone of Arnold and Anderson and of Von Estorff, is excluded by Jenkins[76] from his Kreyenhagen shale proper. According to Von Estorff,[77] sandstone in Arnold and Anderson's transition zone is characterized by about equal amounts of quartz and relatively fresh feldspar, whereas in a sandstone higher in the section quartz greatly predominates. Antigorite in the upper sandstone was attributed by Von Estorff to a Franciscan source. *Propeamussium interradiatus* (Gabb)[78] is found in the upper part of Arnold and Anderson's transition zone and in the lower part of the porcelaneous mudstone overlying their transition zone.[79] The Foraminifera of the Kreyenhagen in this region are assigned by Hughes and Laiming[80] to their upper *Spiroplectammina* fauna and to their lower *Spiroplectammina* fauna, both of which are of Eocene age. Their upper *Spiroplectammina* fauna occurs in the uppermost part of the Kreyenhagen, and their lower *Spiroplectammina* fauna occurs in the lower part of the formation within and below the stratigraphic range of *Propeamussium interradiatus.* The Kreyenhagen exposed on Reef Ridge contains Radiolaria, but no preserved diatoms have been recognized. The "*Leda*" zone, Atwill's Tumey shale, and apparently also strata containing Church's Markley fauna are missing.

Devils Den.—Strata that crop out on the south slope of Wagonwheel Mountain, 10 miles southwest of South Dome, have been assigned to the Kreyenhagen. They consist of an upper shale, a middle sandstone, and a lower shale. The upper shale contains Foraminifera referred to the *Uvigerina cocoaensis* zone,[81] but according to Atwill,[82] the *Uvigerina* in this part of the section is *Uvigerina* cf. *U. glabrans.* The middle sandstone contains a few fossils of probable Oligocene age.[83] This sandstone is part of Johnson's Wagonwheel formation.[84] Oil-bearing sands in nearby oil fields correlated with this sandstone have received the designation "Wagonwheel zone." The uppermost part of the lower shale contains Foraminifera of the restricted *Uvigerina cocoaensis* zone of Atwill,[85] and the remainder represents

[65] Hanna, G. D., The lowest known Tertiary diatoms in California: Jour. Paleontology, vol. 1, pp. 103–127, pls. 17–21, 1927. (See data on p. 107 under locality 995.)

[66] Atwill, E. R., op. cit., pp. 1200–1201.

[67] Idem, fig. 3 (p. 1197).

[68] Church, C. C., Foraminifera of the Kreyenhagen shale: Mining in California, vol. 27, no. 2, pp. 202–213, 3 pls., 1931.

[69] Hughes, D. D., and Laiming, Boris, Notes on the distribution of the Kreyenhagen foraminiferal fauna along the western border of the San Joaquin Valley. Unpublished report presented before Pacific Section, Soc. Econ. Paleontologists and Mineralogists, April 6, 1933.

[70] Atwill, E. R., op. cit., p. 1202.

[71] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 65–66.

[72] Hanna, G. D., op. cit. (See data on p. 107 under locality 894.) Hanna, G. D., Diatoms and silicoflagellates of the Kreyenhagen shale: Mining in California, vol. 27, no. 2, pp. 187–201, 3 pls., 1931.

[73] Church, C. C., op. cit., pp. 203–204.

[74] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 69–70, 1910.

[75] Von Estorff, F. E., Kreyenhagen shale of type locality, Fresno County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 1321–1326, 5 figs., 1930.

[76] Jenkins, O. P., op. cit., pp. 156, 181.

[77] Von Estorff, F. E., op. cit., pp. 1327–1330.

[78] Gabb, W. M., Cretaceous and Tertiary fossils: California Geol. Survey, Paleontology, vol. 2, pp. 199–200, pl. 33, figs. 98, 98a, 1869. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pl. 25, figs. 7, 11, 1910. Stewart, R. B., Gabb's Cretaceous and Tertiary type lamellibranchs: Acad. Nat. Sci. Philadelphia Spec. Pub. 3, pp. 123–124, pl. 8, fig. 10, 1930.

[79] Von Estorff, F. E., op. cit., fig. 3, (p. 1326).

[80] Hughes, D. D., and Laiming, Boris, op. cit.

[81] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 469. Hughes, D. D., and Laiming, Boris, op. cit.

[82] Atwill, E. R., op. cit., p. 1203.

[83] Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, Calif.: U. S. Geol. Survey Bull. 406, p. 41, 1910.

[84] Johnson, H. R., Geology of the McKittrick-Sunset district, Calif. [abstract] Science, new ser., vol. 30, pp. 63–64, 1909.

[85] Atwill, E. R., op. cit., p. 1204. Hughes, D. D., and Laiming, Boris, op. cit.

Atwill's restricted Kreyenhagen. *Propeamussium interradiatus* is recorded from the lower part of the lower shale.[86]

Hughes and Laiming [87] found Foraminifera of their lower *Spiroplectammina* fauna in massive sandstone underlying strata assigned to the Kreyenhagen in the Devil's Den district and also in massive sandstone exposed on Carneros and Chico Martinez Creeks. This massive sandstone is the Tejon formation of Bulletins 406 and 721.[88] According to Hughes and Laiming, on Chico Martinez Creek *Propeamussium interradiatus* is associated with the Foraminifera.

SUBSURFACE SECTION

At the present time it is uncertain whether the Kreyenhagen shale of the Kettleman Hills subsurface section resembles the section exposed north of Anticline Ridge or the section exposed on Reef Ridge; that is, it is uncertain whether the subsurface Kreyenhagen is of Oligocene and Eocene age or is entirely of Eocene age. Inasmuch as a fairly complete section may be expected in the Kettleman Hills, it may be expected that the subsurface Kreyenhagen includes strata of Oligocene and Eocene age.

So far only a few wells located at or near the north end of North Dome have penetrated the entire Kreyenhagen shale. Strata penetrated in Continental Gatchell well No. 28–7, in South Dome, were doubtfully assigned to the Wagonwheel zone of drillers, but the Kreyenhagen shale is apparently absent in this well.

In Lillis-Welch well No. 1, sec. 24, T. 21 S., R. 16 E., the thickness of the Kreyenhagen shale is about 1,300 feet, or about 1,000 feet depending on the assignment of sandy strata to the Temblor or Kreyenhagen. In Kenda well 4–18–J the thickness is about 1,150 feet. Kenda well 67–20–J penetrated a thickness of 1,023 feet of Kreyenhagen.

The subsurface Kreyenhagen consists of hard brown or brownish-gray shale and siltstone interbedded with a few thin layers of sand and limestone. Some beds of sand and siltstone contain glauconite and others contain phosphatic pellets. Bentonite reported in ditch samples from the Lillis-Welch well at a horizon 600 feet above the base of the Kreyenhagen may prove to be a useful key bed in future deep drilling.

According to Goudkoff,[89] the upper part of the Kreyenhagen penetrated by the Lillis-Welch well represents the "*Leda*" zone and the *Uvigerina cocoaensis* zone. Inasmuch, however, as paleontologic evidence for the recognition of the "*Leda*" zone is not recorded and inasmuch as the foraminiferal zones that may be designated Atwill's *Uvigerina* cf. *U. glabrans* zone and his restricted *Uvigerina cocoaensis* zone may not have been differentiated, the presence of Oligocene strata in the Kettleman Hills section may be considered uncertain on the basis of available information. *Uvigerina cocoaensis* and other Foraminifera are recorded in the logs of Kenda wells 4–18–J and 67–20–J.

According to the log of Continental Gatchell well No. 28–7, in South Dome, a thickness of 390 feet of strata below a layer of bentonite was doubtfully assigned to the Wagonwheel zone. These strata consist chiefly of fine- to coarse-grained sand, some of which contains pebbles, interbedded with siltstone and silty to sandy shale. No formation lithologically comparable with the Kreyenhagen was penetrated in this well.

AGE AND CORRELATION

The Kreyenhagen north of Anticline Ridge includes a lower division of Eocene age and an upper division of Oligocene age. On Reef Ridge and apparently also on Anticline Ridge only the Eocene division is represented. The Eocene affinities of Kreyenhagen Foraminifera from Reef Ridge have been mentioned by Cushman and Siegfus.[90] The Eocene division of the Kreyenhagen may include the equivalent of the Tejon formation, which in the type region at the south end of the San Joaquin Valley consists of sandstone, siltstone, and bentonite.[91] The mollusks of the Tejon formation [92] have been compared with those of the middle Eocene Claiborne group of the Gulf coast. Strata younger than the Tejon formation may also be included in the Eocene division of the Kreyenhagen.

If the lower part of the Temblor sandstone exposed on Reef Ridge is of lower Miocene age, as indicated by the meager fauna now known, and if the underlying Kreyenhagen shale is Eocene, Oligocene strata are missing and the Kreyenhagen-Temblor contact represents a discontinuity of sufficient magnitude to be designated a disconformity.

A discussion of the age and correlation of the Kreyenhagen shale in the subsurface Kettleman Hills section must await publication of descriptions of Foraminifera in different zones of the Kreyenhagen at outcrop localities and a comparison of the species from the Kettleman Hills with those from outcrop sections. As the age of the upper part of the Kreyenhagen in the Kettleman Hills appears to be uncertain, it is assigned to the Oligocene (?) and Eocene.

EOCENE SERIES

McADAMS SAND

Several deep wells in North Dome have encountered a productive sandstone below the Kreyenhagen shale. This sandstone is designated by drillers the McAdams

[86] Jenkins, O.P., op. cit., p. 155.

[87] Hughes, D. D., and Laiming, Boris, op. cit.

[88] Arnold, Ralph, and Johnson, H. R., op. cit. (U. S. Geol. Survey Bull. 406), pp. 38-39, 1910. English, W. A., Geology and petroleum resources of northwestern Kern County, Calif.: U. S. Geol. Survey Bull. 721, pp. 10-12, 1921.

[89] Goudkoff, P. P., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 18), p. 472, fig. 7 (p. 448).

[90] 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, p. 91, 1935.

[91] Hoots, H. W., Geology and oil resources along the southern border of San Joaquin Valley, Calif.: U. S. Geol. Survey Bull. 812, pp. 250-253, 1930.

[92] Stewart, R. B., Gabb's Cretaceous and Tertiary type lamellibranchs: Acad. Nat. Sci. Philadelphia Spec. Pub. 3, p. 19, 1930.

sand. It was first penetrated in North Kettleman Oil & Gas Co.'s Lillis-Welch well No. 1, sec. 24, T. 21 S., R. 16 E., also known as the McAdams well. On the advance edition of the geologic map of the Kettleman Hills issued by the Geological Survey the sandstone was designated the Avenal (?) sandstone. The term McAdams sand has, however, come into general usage, and a local subsurface designation is preferable to a doubtful outcrop designation.

STRATIGRAPHY, LITHOLOGY, AND FOSSILS

OUTCROP SECTION

On Reef Ridge an Eocene sandstone conformably underlies the Kreyenhagen shale and rests unconformably on Upper Cretaceous shale and sandstone. This Eocene sandstone was named the Avenal sandstone from exposures at the Avenal wells in Big Tar Canyon.[93] The Avenal sandstone was designated the lower part of the Tejon formation by Arnold and Anderson [94] and the Domengine sandstone by Vokes.[95] It has recently been studied by Ralph Stewart, whose report is now in preparation.[96]

According to descriptions by F. M. Anderson, Arnold and Anderson, and Vokes the Avenal sandstone is about 500 feet thick. At the base is a local conglomerate ranging in thickness from a few feet to 100 feet or more. Reed [97] reported that the Avenal sandstone is characterized by abundance of feldspar and scarcity of ferromagnesian minerals. Lists of fossils from the Avenal sandstone have been published at different times,[98] and some of the species were figured by Arnold and Vokes.

SUBSURFACE SECTION

Lillis-Welch well No. 1, at the extreme north end of North Dome, penetrated a thickness of 29 feet of sand underlying the Kreyenhagen shale. A 1-foot core recovered from the sand was recorded as poorly sorted coarse-grained light-gray sand stained light brown with oil. Two other wells at the north end of North Dome, Kenda 4–18–J and Kenda 67–20–J, are producing from the McAdams sand. Kenda 4–18–J has penetrated a thickness of 1,061 feet assigned to the McAdams sand and Kenda 67–20–J a thickness of 510 feet. The strata consist chiefly of hard gray sand with some siltstone and claystone. *Discocyclina clarki* and other Eocene Foraminifera are recorded in the log of Kenda 4–18–J.

AGE AND CORRELATION

In the region north of Anticline Ridge an Eocene sandstone underlies the Kreyenhagen shale, but unlike the Avenal sandstone it rests on Eocene shale. This Eocene sandstone was named the Domengine sandstone ("Domijean sands")[99] and was designated the Tejon formation by Anderson and Pack.[1] The Avenal sandstone has been assigned to the Domengine.[2] Both the Avenal sandstone and the Domengine sandstone contain mollusks of middle Eocene age, but a local name is preferable for the sandstone exposed on Reef Ridge. The McAdams sand includes doubtless the equivalent of the Avenal sandstone and perhaps a greater time interval than the Avenal. The absence of lower Eocene and Paleocene formations in the outcrop section on Reef Ridge shows that the Upper Cretaceous-Avenal contact represents a disconformity.

STRUCTURE

GENERAL RELATIONS

The Kettleman Hills lie along the trend of the Coalinga anticline. As shown in figure 15, the Coalinga anticline begins in the Diablo Range with an eastward trend. Farther east it bends southeastward parallel to the trend of the range and of the other major structural features of the region, of which the San Andreas fault zone is the most prominent.

Structurally the Kettleman Hills consist of three anticlines: North Dome, Middle Dome, and South Dome. The anticlines trend northwestward, are slightly asymmetrical, with the steeper limb to the southwest, and are en echelon to each other, each fold being offset westward with reference to the one to the north. North and Middle Domes are doubly plunging anticlines, and the plunging northwest end of North Dome is offset westward in relation to the southeastward-plunging end of the Coalinga anticline. Only the northwest end of South Dome anticline is exposed, the southeastern part being covered by alluvium of the San Joaquin Valley. About 10 miles southeast of South Dome, the southeastward-trending doubly plunging anticline of Lost Hills rises out of the alluvium. The relations between the anticlines of Lost Hills and South Dome are obscured by the intervening cover of alluvium, but there is said to be subsurface evidence that South Dome and Lost Hills form a continuous anticline in Miocene formations, but that a saddle may lie between them in the Pliocene formations.[3] In the Lost Hills, strata probably representing

[93] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, p. 164, 1905.

[94] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 67–70.

[95] Vokes, H. E., Molluscan faunas of the Domengine and Arroyo Hondo formations of the California Eocene: New York Acad. Sci. Annals, vol. 38, pp. 20–21, 1939.

[96] Stewart, Ralph, Geology of Reef Ridge, Calif.: U. S. Geol. Survey Prof. Paper (in preparation).

[97] Reed, R. D., Role of heavy minerals in the Coalinga Tertiary: Econ. Geology, vol. 19, pp. 731, 733, 738, 1924; Geology of California, p. 127, Tulsa, Am. Assoc. Petroleum Geologists, 1933.

[98] Anderson, F. M., op. cit., p. 164. Arnold, Ralph, op. cit. (Bull. 396), pp. 12–16, 49–54, pls. 2–4, 1909 [1910]. Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 70–74, pls. 24–26, 1910. Von Estorff, F. E., Kreyenhagen shale at type locality, Fresno County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 1327, 1930. Vokes, H. E., op. cit., pp. 24–26, 40–184, pls. 1–22.

[99] Anderson, F. M., op. cit., p. 167.

[1] 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. 69–70, 1915.

[2] Von Estorff, F. E., op. cit., p. 1325. Vokes, H. E., op. cit., pp. 20–21.

[3] Cunningham, G. M., and Kleinpell, W. D., Importance of unconformities to oil production in the San Joaquin Valley, Calif.: Problems of Petroleum Geology, p. 796, Tulsa, Am. Assoc. Petroleum Geologists, 1934.

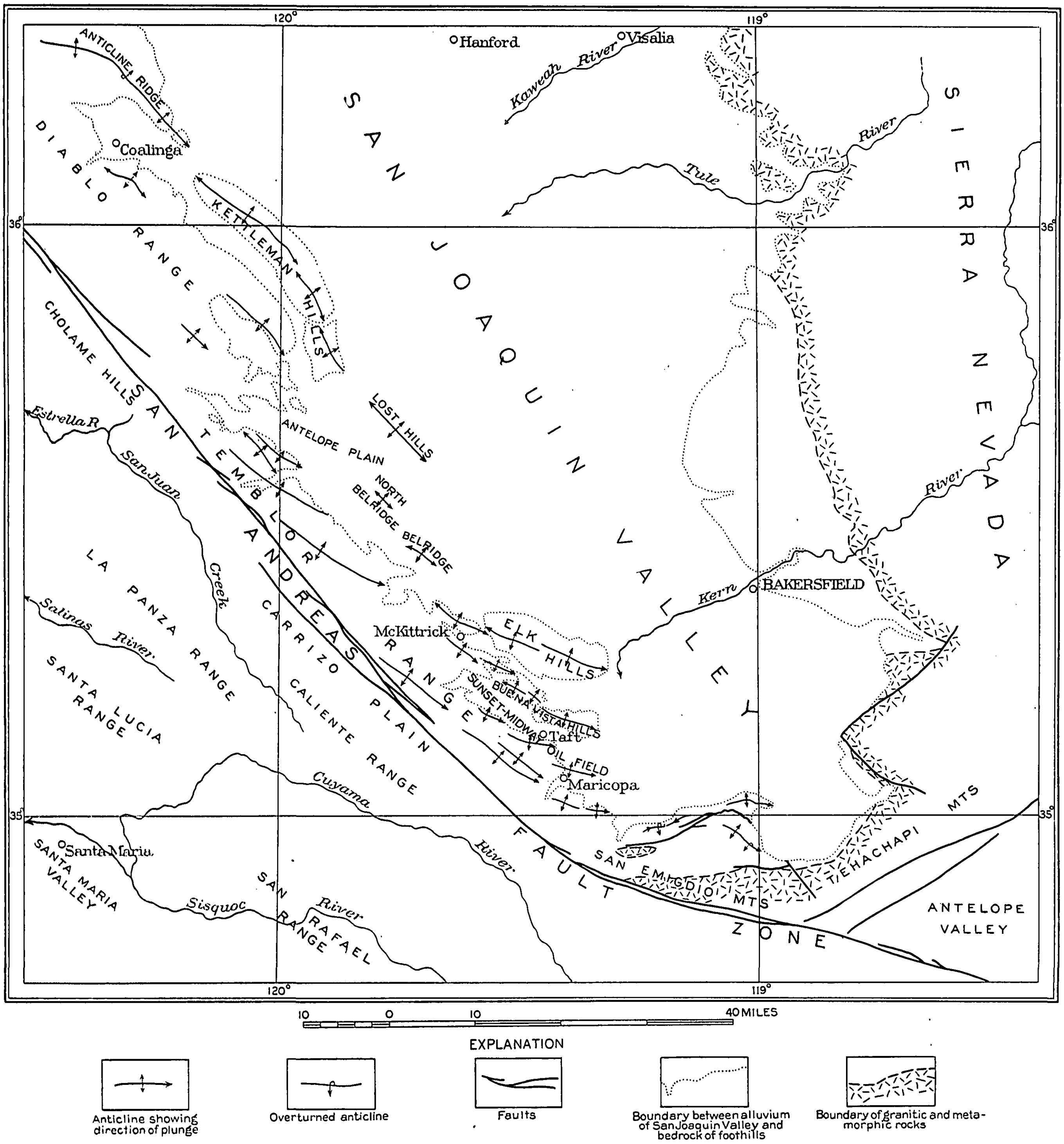


FIGURE 15.—Sketch map showing location of anticlines in Kettleman Hills with relation to other anticlines along west border of southern San Joaquin Valley. (Compiled from published and unpublished reports of Geological Survey. Geographic base and San Andreas fault zone adapted from Fault map of California, issued by Seismological Society of America, 1922.)

the Tulare formation are only slightly folded and rest unconformably on more steeply folded strata assigned to the Etchegoin formation,[4] and several thousand feet of Pliocene beds represented in the Kettleman Hills are missing beneath the unconformity. In the Kettleman Hills the unconformity is absent and the Tulare formation is as steeply folded as the underlying strata. Folding, therefore, took place in the Lost Hills before the deformation of the Kettleman Hills.

The attitude of the formations exposed in the Kettleman Hills is shown by means of structure contours on plate 51; and the structure sections on the same plate show some features of the subsurface structure. The structure contour map is essentially the same as the advance edition issued in 1934 by the Geological Survey.

[4] Cunningham, G. M., and Kleinpell, W. D., op. cit., fig. 3.

The *Littorina* zone of the Etchegoin formation is the datum plane for the contours in North Dome. The contours of Middle Dome and South Dome are drawn on the *Pseudocardium-Anadara* zone of the Etchegoin formation, which is regarded as the essential equivalent of the *Littorina* zone. The contours and faults are based on mapping of varying degrees of certainty represented by appropriate symbols on the areal geologic map (pl. 3), but for the sake of legibility solid lines are used to represent the contours and also the projections of the faults at the horizon of the contoured bed. The area along the faults represented by stippling indicates the part of the fault plane between the displaced edges of the contoured bed. It is shown only where the displacement is great enough or where the dip of the fault plane is low enough to be shown on a map of this scale. Computations of stratigraphic thickness were made on an assumption of no appreciable thickening or thinning of individual beds as a result of folding, which appears to agree with subsurface data more closely than an assumption of appreciable change in thickness of beds as a result of folding.

NORTH DOME

General description.—North Dome is the northernmost of the three northwestward-trending anticlines of Kettleman Hills. It is about 18 miles long and 5 miles wide. In the central part the axis is essentially horizontal for about 8 miles. At the southeast end it plunges at an angle of about 6° toward the saddle that separates North and Middle Domes, and the structural rise from the saddle to the crest of the anticline is about 1,600 feet. At the northwest end the axis plunges about 7°, and the structural rise from the northwesternmost exposed strata involved in the folding is about 3,100 feet. The anticline is slightly asymmetrical, the average dip on the southwest flank being about 5° higher than on the northeast flank. The maximum observed dip on the southwest flank is 43° and on the northeast flank is 40°. The central part of the anticline is broken by numerous normal faults with displacements ranging from a few feet to about 300 feet. The faults belong to two sets: (1), strike faults on both sides of the anticline that trend northwestward about parallel to the crest; (2), diagonal faults that trend slightly east of north at an angle of about 60° to the axis of the anticline and to the general strike of the strata. (See pl. 52.) The general faulting of the crest was mentioned by McCollough[5] and described by Gester and Galloway.[6]

Strike faults.—More than half of the faults in North Dome are strike faults that trend about parallel to the axis of the anticline. The strike faults, which are about equally numerous along each side of the axis, have displacements ranging from a few feet to about 300 feet. Most of the strike faults dip toward the axis at angles that average about 60°. A few on each side of the anticline, however, dip away from the axis of the anticline at angles that average slightly more than 60°. Comparatively few striae were observed on the fault planes, but the observed striae almost invariably lie parallel to the dips of the fault planes. At most places the axis of the anticline lies in the block between the southwesternmost of the southwestward-dipping faults and the northeasternmost of the northeastward-dipping faults. At a few localities, however, the axis lies between the southwesternmost two of the southwestward-dipping faults or the northeasternmost two of the northeastward-dipping faults. The axis of the middle part of the anticline, therefore, lies in the structurally lowest part of a complex fault trough that extends along the crest of the fold. The structurally lowest part of the trough and the axis of the anticline are not, however, equally distant from each side of the trough at all places. In the middle part of the anticline the structurally lowest part lies near the north side of the trough, and toward each end it lies near the south side.

A minor graben about 30 feet wide, too small and too poorly exposed to be shown on the map, is on the west side of the trough near the center of North Dome (east side of La Cima, sec. 20, T. 22 S., R. 18 E.). Similar minor grabens are probably present southeastward along the La Cima-Cerro Alto ridge. The few faults that strike westward may be associated with the strike faults because some of the strike faults on the south flank appear to change near their ends to a more westerly strike.

Diagonal faults.—Normal faults of the second set have displacements of less than 100 feet. They trend slightly east of north and cross the axis of the anticline and the general strike of the strata at angles of about 60°. These faults may be referred to as diagonal faults. Diagonal faults, which are present along the axis of the entire anticline except the extreme ends, are most numerous in zones surrounding the area near each end where pronounced plunge of the axis begins. Most of the diagonal faults on and near the plunging ends of the anticline dip in the general direction of the plunge at an average angle of about 60°, but a few of the faults dip in the opposite direction. In the central part of the anticline, where the axis is essentially horizontal, eastward-dipping and westward-dipping diagonal faults are about equally numerous, but in the western part the greater number dip eastward and in the eastern part the greater number dip westward. The trend and angle of inclination of striae on the planes of many diagonal faults were measured, and with only a few exceptions they were found to be oblique to the strike and dip of the fault

[5] McCollough, E. H., Kettleman Hills oil field, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 1481, 1929.

[6] Gester, G. C., and Galloway, John, Geology of Kettleman Hills oil field, Calif.: Idem., vol. 17, pp. 1187-1189, 1933.

planes and to lie at angles of about 60° to the strike. (See pl. 52.) The trend of the striae down the plane of the diagonal faults on the northeast flank is south of the direction of dip of the fault planes, and on the southwest flank the trend of the striae down the planes of the diagonal faults is north of the direction of dip of the faults. Thus the striae are inclined toward the axis of the anticline.

Joints.—Abundant closely spaced tight joints lie almost parallel to the planes of the diagonal faults in a zone about 5 feet wide on each side of the faults (pl. 53, *C*). Beyond this zone and also near the strike faults are numerous more widely spaced open joints, some of which strike and dip parallel to the plane of the closest fault; some strike parallel to the closest fault but dip in the opposite direction; and many other joints both strike and dip at various angles to the plane of the closest fault and are not obviously related geometrically to any of the more pronounced structural features.

MIDDLE DOME

Because of unsatisfactory exposures over a large part of Middle Dome, its structure is not as well known as the structure of North Dome. Outcrops of the *Pseudocardium-Anadara* zone, on which the structure contours are drawn, and of the underlying *Pseudocardium*-bearing conglomerates are for the most part well defined, but the observed relations in some of the areas where these strata are exposed may be interpreted in different ways. Normal contacts and faults may have been confused in mapping the boundary between the lower and upper parts of the Etchegoin formation at the north and south ends of the anticline. The structure of the area underlain by the lower part of the Etchegoin is a matter of inference.

Middle Dome is about 7½ miles long and about 5 miles wide. As the structure has been interpreted, Middle Dome has a closure of 800 feet and is 400 feet lower structurally than the highest part of North Dome. The saddle between Middle and South Domes is 150 feet lower structurally than the downthrown side of the fault through the saddle between North and Middle Domes. The virtual symmetry shown on plate 51 may be incorrect. No dips are recorded in the Tulare formation along the central part of the east limb, whereas dips of 35° and 40° are recorded on the west limb. It appears probable that the west limb is a little steeper than the east one but that the asymmetry is less than in North Dome. Middle Dome consists of three parts, the main central part and a faulted minor dome at each plunging end. At both ends of the anticline the 1,000-foot structure contour crosses the axis almost a mile beyond the place where it approaches the axis in the central part. In the faulted saddles between the central part and the minor domes the axis of the anticline bends sharply. On the concave side of the bend faults are more numerous than in other parts of the anticline.

The faults recognized in Middle Dome are normal faults. They have a maximum displacement generally of about 150 feet. Most of the faults trend almost at right angles to the strike of the strata (radial faults) or are diagonal to the strike (diagonal faults); a few are parallel to the regional strike (strike faults).

Aside from some diagonal faults at the ends of the anticline that pass into strike faults, the only strike faults recognized are near the base of down-dropped wedges pointing toward the concave side of sharp bends in the anticlinal axis between the central part of the anticline and the minor domes. In both areas of such wedges the outcrops of the *Pseudocardium-Anadara* zone and the *Pseudocardium*-bearing conglomerate are interpreted as indicating strike faults dipping toward the axis of the anticline. These faults are nearly parallel to the regional strike but are diagonal to the strike in the faulted areas. Exposures of the strike faults were not seen in either area, and the displacement of radial and diagonal faults by strike faults is based on the assumption that the strike faults are later than the other faults. Toward the ends of the anticline the strike faults are limited by diagonal faults; in the opposite direction they appear to die out. The structure of the central part of the anticline appears to be simple, but the contours in the area underlain by the lower part of the Etchegoin formation are uncontrolled, and the location of the axis itself is uncertain. It is reasonably certain, however, that there are no faults in this area with displacements great enough to drop strata in the upper part of the Etchegoin.

The pattern of approximately radial faults is partly determined by the assumed extension of faults exposed for short distances and therefore may not be genuine. As these faults are drawn, most of them have a more northward trend than a strictly radial trend. The diagonal faults also have a general north-northeastward trend; a few trend northwestward or westward. The greatest displacement is along diagonal faults with a north-northeastward trend. Toward the ends of the anticline diagonal faults apparently cross the axis. On the east limb most of the faults in the central part of the anticline and in the area adjoining the minor dome at the north end dip westward; on the west limb most of the faults as far south as the minor dome at the south end dip eastward.

For the most part, fault planes in Middle Dome are inaccessible without extensive excavations. They are assumed to have a dip of 60°, the average of many measurements in North Dome. Closely spaced tight joints give a clue to faults in sandstone, and the jointed sandstone generally projects above the unjointed sandstone as a narrow rib. According to observations in North Dome, tight joints are practically parallel to the fault plane. The trend of such joints at many places in

Middle Dome was assumed to represent the trend of faults.

The two areas of pronounced faulting constitute the most striking feature of Middle Dome structure as it is now understood. Both areas form wedges that taper toward the axis and lie on the concave side of bends in the axis between the central part of the anticline and the minor dome at each end. The change of strike in these areas is well shown by the strike of the *Pseudocardium-Anadara* zone and of the *Pseudocardium*-bearing conglomerate. The location and relations of the areas of pronounced faulting indicate that they are related to the doming of the ends of the anticline. Though there is little indication of asymmetric doming at the surface, the pronounced faulting may perhaps be due to asymmetric doming at greater depth.

SOUTH DOME

The part of South Dome that is exposed has a length of about 5½ miles and a maximum width of about 4 miles. The structure appears to be simple. Only minor diagonal or approximately radial faults were recognized in the area underlain by the San Joaquin formation and the upper part of the Etchegoin formation, where the structure is adequately controlled, and also in the area underlain by the lower part of the Etchegoin, where the structure is uncertain. The trend of the axis is reasonably certain as far south as the southeastern part of sec. 34, T. 24 S., R. 19 E. Beyond this the trend is not known except by inference from a few strike and dip observations. There may be undetected complications on the exposed part of the east limb, where the structure contours are drawn on an assumption of simple structure. At all events, in the area underlain by the lower part of the Etchegoin formation there are no faults that have a displacement great enough to drop strata in the upper part of the Etchegoin formation or in the San Joaquin formation.

Though details of the structure are uncertain, South Dome is evidently part of an anticline that is considerably wider and structurally higher than North and Middle Domes. The area underlain by the Etchegoin formation, measured across the axis from the place where the San Joaquin-Etchegoin boundary is overlapped by alluvium on the east limb, is about half again as wide as the widest part of North Dome or Middle Dome; and, according to the trend of the boundary, the South Dome anticline is even wider south of the overlap. The axis of South Dome apparently rises rapidly southward. That it is still rising virtually as far south as the hills extend is supported by the occurrence of a faunal zone that appears to represent a lower horizon than the lowest exposed part of the Etchegoin in North Dome. The highest structure contour shown in South Dome is 800 feet higher than the highest one in North Dome and 1,200 feet higher than the highest one in Middle Dome. Arnold and Anderson recognized the absence of closure at the south end of the hills.[7]

Location of axis of Kettleman Plains syncline west of South Dome.—The location of the axis of the Kettleman Plain syncline west of southern South Dome is uncertain. As tentatively located on plate 51, the axis extends obliquely across the southwest end of the Kettleman Hills. This location is essentially the same as that shown by English on the geologic map accompanying Bulletin 721.[8] The boundary between the alluvium and the Tulare formation cropping out in the hills is represented to be farther east on his map than on plate 51. The boundary, however, is indefinite in this region, where low hills imperceptibly merge into the plain. The axis of the syncline as shown on plate 51 is based on airplane photographs on which patterns are interpreted as indicative of outcrops with northeasterly dips. The inferred outcrop patterns could not be confirmed on the ground. In view of the close relation between structure and outline of the hills in areas where the hills rise more abruptly above the alluvium, the tentative location of the axis of the syncline needs confirmation.

ORIGIN OF STRUCTURE

GENERAL AND REGIONAL FEATURES

The deformation of the Kettleman Hills is attributed to compression in a north-south direction applied to a northwestward-trending zone of weak strata in which echelon anticlines were being formed. The upward squeezing of incompetent material lifted and folded the strata; the faulting is attributed to shearing that accompanied differential vertical stresses in competent strata overlying the rising incompetent material. The strike faults of the axial fault trough of North Dome were evidently formed after the strata had been lifted above the levels of direct influence of the north-south compression. Inasmuch as nearly all the strike faults dip toward rather than away from the axis of the anticline it is inferred that the compression on the flanks sufficed to localize the movement on these inward-dipping faults, which may be regarded as shear planes. The diagonal faults appear to have been formed before the strata had been raised entirely above the levels of the effect of the north-south compression. The oblique striae of the diagonal faults (pl. 52) appear to have been formed in a stage intermediate between the formation of the diagonal and strike faults. Greater pressure on the flanks of Middle Dome than on North Dome may account for the absence of an axial fault trough there and for the general strike of the faults almost at right angles to the axis. On South Dome the dimensions of the incompetent material may have been such as to balance the horizontal and vertical stresses in

[7] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 124, 165.

[8] English, W. A., Geology and petroleum resources of northwestern Kern County, Calif.: U. S. Geol. Survey Bull. 721, pl. 1, 1921.

the overlying competent rocks during the uplifting of the strata; under these conditions no axial fault trough would be formed.

The exposed strata of the Kettleman Hills may represent an early stage in a structural sequence in which thrust faulting was not reached, because the mass of the incompetent material was thick enough to lift the competent material above the direct action of the horizontal compression prior to any faulting of the competent material.

The structural features of the Kettleman Hills appear to be related in origin to nearby structural features, notably the Coalinga anticline, to the northwest, and the San Andreas fault, to the west. As mapped by Arnold and Anderson [9] the Coalinga anticline swings westward at its north end. Apparently the greatest uplift has taken place where the axis is east-west, perhaps because of a fundamental north-south horizontal compression or shortening. The San Andreas fault [10] appears to be a great flaw along which considerable horizontal displacement has occurred. It may thus be a shear plane due to failure under fundamental north-south compression. The suggestion of north-south compression in this nearby structure is so strong that it seems reasonable to attribute the fundamental cause of the Kettleman Hills uplift to the same forces.

The zone of weak strata in the Kettleman Hills is oblique to the assumed north-south compression. In order to account for the echelon arrangement, not only of the Kettleman Hills but of the structural features of the region in general, Arnold and Anderson [11] suggested two main sets of compressional forces—an earlier, acting along a roughly N. 50° E. trend and a later, along a N. 20°–30° trend. Such a second set of stresses might produce broad saddles in the main folds formed by the earlier northeastward-trending compression, but it is not evident how the axes of the main folds would thereby be offset. Under a north-south shortening, echelon anticlines could form with their individual axes lying more or less parallel but with more westerly trends than the trend of the zone of weakness. This weak zone would be oblique to either an east-west or a north-south compression. If the compression had been east-west the anticlines would be expected to be offset to the left instead of to the right. Offsetting to the left by a regional north-south compression would require rotation of stresses reaching almost 90°. But before rotation to this degree would be attained, the stresses operating with gradually changing directions would first produce folds offset to the right.

One long anticline or a series of parallel anticlines in the pre-existing zone of weakness in the Kettleman Hills could be produced under horizontal compression acting uniformly from all directions. The effects of such compression would be the same as those of northeast-southwest compression, but under either condition the echelon arrangement of the three anticlines in the Kettleman Hills would be fortuitous.

The weak zone in the Kettleman Hills is presumably either a thick prism of sedimentary rocks trending northwestward or a flaw like the San Andreas fault buried beneath sedimentary strata; or it may consist of both such a prism and a flaw. The sinking of the San Joaquin Valley may somehow be connected with this zone of weakness. Seismographic observations made on the San Joaquin Valley side of the Kettleman Hills have been interpreted as indicating a major syncline trending northwestward.[12] The Kettleman Hills have recently been called "a youthful appendage to an ancient perhaps Mesozoic fold," the Joaquin-Coalinga Anticline Ridge.[13] In a recent discussion by Clark [14] the distribution of strata of the Coalinga region is in part attributed to faulting, and rather large-scale folding is attributed to drag along fault planes.

TIME OF DEFORMATION

The Tulare formation, which is assigned to the upper Pliocene and Pleistocene (?), is involved in the folding of the Kettleman Hills, the main part of which preceded the deposition of the older alluvium in the hills. The amount of erosion that has occurred in the hills seems sufficient to place the beginning of the folding somewhere in the Pleistocene epoch, and it may have been contemporaneous with deformations in other areas of California in which lower Pleistocene strata were involved. Such deformations are usually considered mid-Pleistocene; they have recently been named Pasadenan.[15] There is perhaps some value in grouping deformations of this type together under periods of deformation, and the term may be quite useful, particularly in southern California. Unfortunately the term was expanded to include any Pleistocene folding.

It seems possible that the general stress that deformed the Kettleman Hills existed before the folding of the hills, and it may have been locally relieved by the downward bulging that formed the trough in which the sediments were deposited and by upward relief farther

[9] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pl. 1.

[10] Gilbert, G. K., The San Francisco earthquake and fire: U. S. Geol. Survey Bull. 324, p. 5, pl. 1, 1907. Lawson, A. C., and others, The California earthquake of April 18, 1906: Carnegie Inst. Washington Pub. 87, vol. 1, p. 148, 1908. Reid, H. F., The elastic rebound theory of earthquakes: California Univ., Dept. Geology, Bull., vol. 6, pp. 417–425, 1911. Willis, Bailey, Folding or shearing, which?: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 34, 35, 39, 1927. Noble, L. F., The San Andreas rift in the desert region of southeastern California: Carnegie Inst. Washington Year Book 31, pp. 355–365, 1932. Bucher, W. H., The deformation of the earth's crust, pp. 311–318, Princeton University Press, 1933. Reed, R. D., Santa Margarita conglomerate of the Temblor Range [abstract]: Geol. Soc. America Proc., 1933, pp. 309–310, 1933.

[11] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398,) p. 160.

[12] Vaughan, F. E., in Lawson, A. C., Sierra Nevada in the light of isostasy: Geol. Soc. America Bull., vol. 47, p. 1699, 1936.

[13] Reed, R. D., and Hollister, J. S., Structural evolution of southern California: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 1613, 1936.

[14] Clark, B. L., Tectonics of the Mount Diablo and Coalinga areas, middle Coast Ranges of California: Geol. Soc. America Bull., vol. 46, pp. 1030–1034, 1049–1074, pl. 89, 1935.

[15] Stille, Hans, The present tectonic state of the earth: Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 867, 869, 1936. A translation by Hans Ashauer of part of the following: Stille, Hans, Der derzeitige tektonische Erdzustand: Preuss. Akad. Wiss., Phys.-Math. Kl., Sitzungsber., pp. 179–219, 3 figs., 1935. [Kettleman Hills mentioned on p. 207.]

west during late Pliocene time as suggested by the presence of conglomerates in the San Joaquin formation. When the sinking ceased and the direction of relief became upward, the sediments deposited in the trough formed an incompetent mass lying oblique to the assumed north-south compression. The deformation forming the hills would result from a local change in direction of relief. Some areas in California may have been sinking and receiving sediments while others were being folded, though all these areas were under north-south compression. The recent displacements along the San Andreas fault suggest that the north-south compression is still active. The regional forces that folded the Kettleman Hills may now be maintaining the strata in their present attitudes and may cause additional folding.

PHYSIOGRAPHY

GENERAL FEATURES

The Kettleman Hills are an elongate group of hills about 30 miles long and 5 miles wide that rise fairly abruptly several hundred feet above the plains on the west side of the San Joaquin Valley. They are separated from the Diablo Range by Kettleman Plain, an almost flat plain 3 to 5 miles wide. The hills attain a maximum altitude of 1,366 feet above sea level near the north end, and they decrease in height more or less gradually toward the south until they merge almost imperceptibly into the plain of the San Joaquin Valley. As pointed out by Arnold and Anderson [16] and by Reed,[17] the Kettleman Hills represent land forms carved from a deformed surface of low relief developed across folded beds of the Tulare (upper Pliocene and Pleistocene (?)) and older formations. The deformation of this surface is here interpreted as renewed arching along the axis of the Kettleman Hills anticline without further movement on the faults. This old surface has been modified and largely destroyed by erosion. The Kettleman Hills contain two concentric rows of hills, which are locally cuestas. The crests of these hills in some localities may represent parts of the old surface as modified by subsequent erosion.

The amount of relief and ruggedness in general decrease from north to south. Most of the streams are consequent and flow down the slopes roughly at right angles to the trend of the hills, but many of the tributaries are more or less parallel to the strike of the strata, and their courses are determined mainly by the resistance of the rocks to erosion. One stream, however, flows entirely across the hills at Avenal Gap, between Middle and South Domes, and has evidently maintained itself during the later uplift of the hills.

[16] Arnold, Ralph, and Anderson, Robert, op. cit. (Bull. 398), pp. 37, 45.

[17] Reed, R. D., Geology of California, p. 262, Tulsa, Am. Assoc. Petroleum Geologists, 1933.

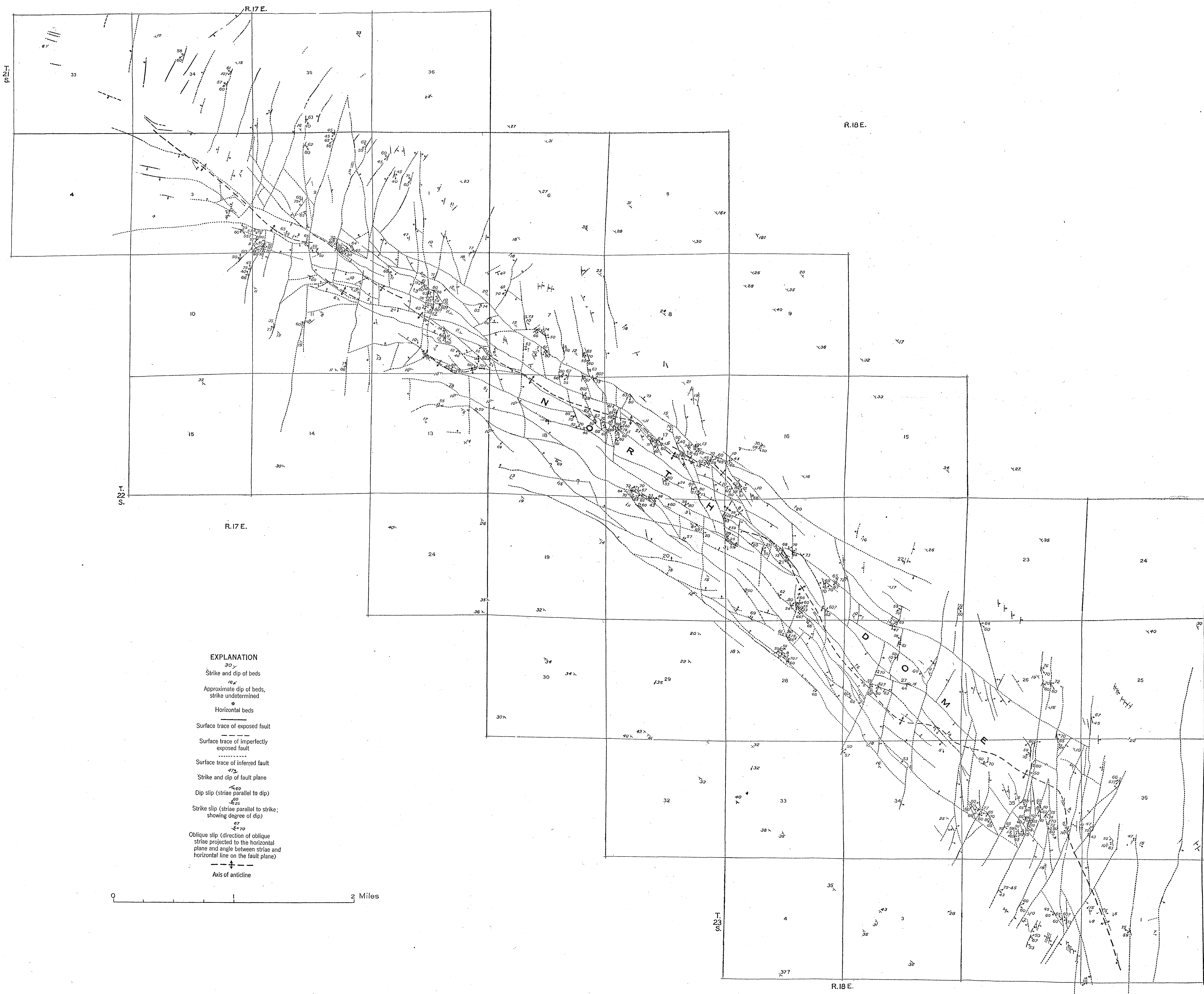
OLD SURFACES OF LOW RELIEF

A nearly flat surface covers an area a mile long and a quarter of a mile wide at El Prado, near the north end of Kettleman Hills, in sec. 32, T. 21 S., R. 17 E. As shown on plates 53, *A*, and 54, this surface is remarkably smooth and truncates strata in the upper part of the San Joaquin formation. It ranges in altitude from 1,100 to 1,225 feet and drops about 100 feet to the mile northwestward. The underlying strata dip about 400 feet to the mile in the same direction. This erosion surface has such low relief and covers such a large area that it evidently was formerly much more extensive than now and presumably covered the entire Kettleman Hills, but it has not been traced with certainty beyond its present limits. A surface truncating the lower part of the San Joaquin formation on La Palomera (pl. 53, *B*), in sec. 16, T. 22 S., R. 18 E., may be a remnant of the surface at El Prado, but it seems to lie below the probable projection of that surface. Dissected surfaces on Las Alturas, in Middle Dome, and on Las Colinas, in South Dome, correspond probably to one or the other of the North Dome surfaces.

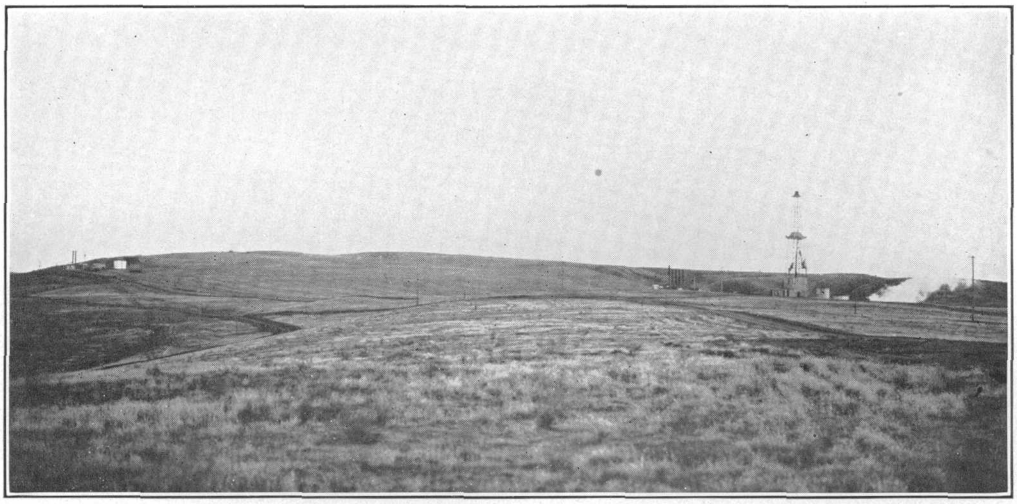
In the central part of North Dome in the vicinity of La Cima, in sec. 20, T. 22 S., R. 18 E., some of the hilltops that consist of resistant sandstone rise above benches that seem to fall in the projection of the old erosion surface at El Prado. They perhaps represent hills that stood above the old surface. La Cima itself is the highest point in the Kettleman Hills, and its prominence is due to resistant strata that have been exposed over a relatively wide area owing to repetition by faulting.

The erosion surface at El Prado bevels the San Joaquin formation; and the probable projection of this surface truncates the younger Tulare formation, which conformably overlies the San Joaquin. The strata on the flanks of the hills have been tilted as much as 43°, and about 5,000 feet of Tulare, San Joaquin, and Etchegoin beds has been eroded from the central part of the anticline. As the Tulare is assigned to the upper Pliocene and Pleistocene (?), the folding and truncating of the sediments presumably took place mainly in the Pleistocene.

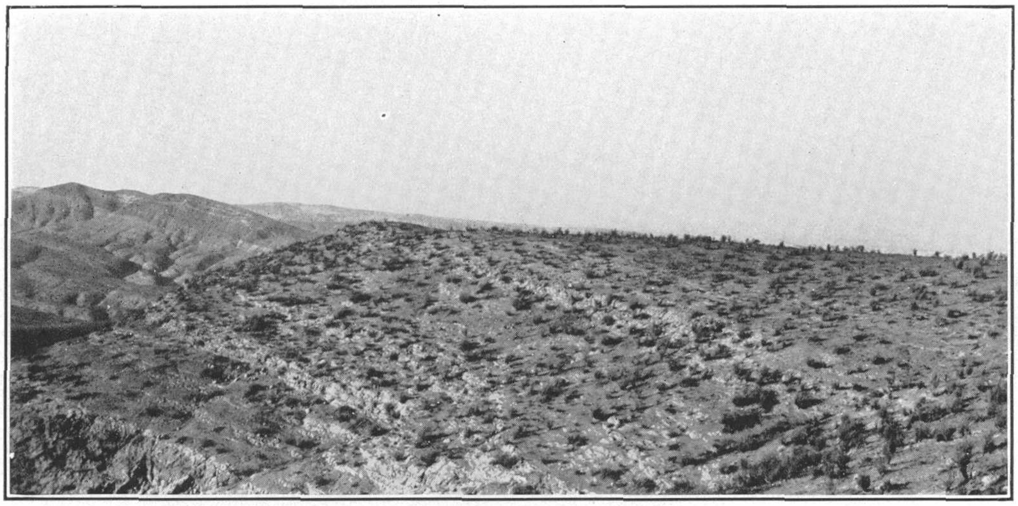
A determination of the degree of arching of the erosion surfaces in the Kettleman Hills depends upon an exact correlation of the present remnants of these surfaces. These correlations have not been attempted because the surfaces appear to have been too greatly modified and destroyed to justify such correlation. The general altitude of the hills becomes less toward the south. The old surfaces probably also sloped in that direction. The alluvium at the edge of the hills also is lower at the south end of the hills than at the north end, but the difference is not so great as that of the general altitude nor presumably so great as that of the old surfaces. The hills, therefore, have been tilted



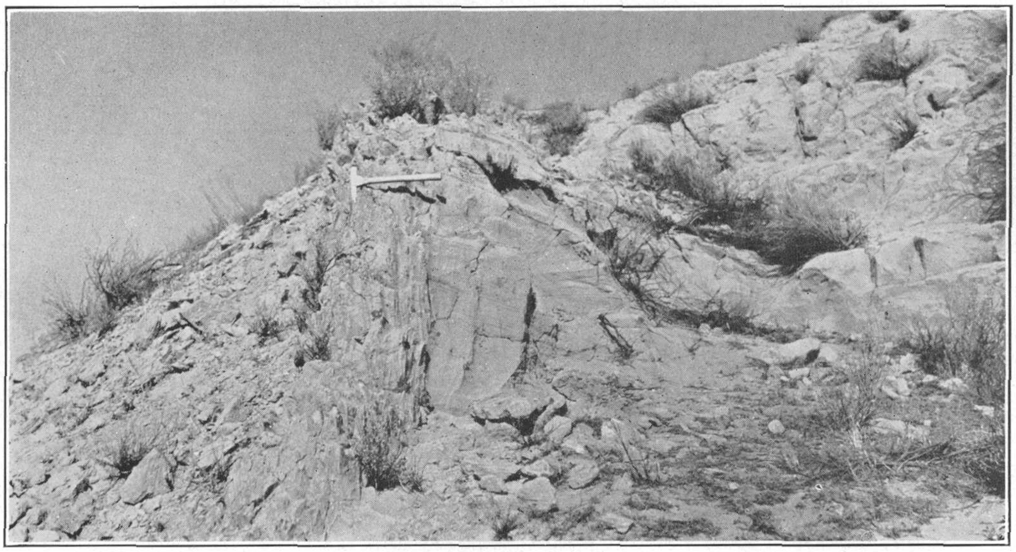
FAULT MAP OF NORTH DOME.



A. EROSION SURFACE VIEWED FROM THE NORTHWEST AT EL PRADO, SEC. 32, T. 21 S., R. 17 E. THE SURFACE TRUNCATES TILTED STRATA IN THE UPPER PART OF THE SAN JOAQUIN FORMATION.



B. EROSION SURFACE VIEWED FROM THE SOUTHEAST AT LA PALOMERA, SEC. 16, T. 22 S., R. 18 E. THE SURFACE TRUNCATES TILTED STRATA IN THE LOWER PART OF THE SAN JOAQUIN FORMATION.



C. JOINTS PRACTICALLY PARALLEL TO FAULT PLANE (TO LEFT OF HAMMER) IN CROSS-BEDDED BLUE SANDSTONE ON NORTHWEST RIDGE OF EL TOLETE, SEC. 7, T. 22 S., R. 18 E.

PHYSIOGRAPHIC AND STRUCTURAL FEATURES IN NORTH DOME.

WEST FLANK OF NORTH DOME.

Airplane view looking southeastward. El Prado in left center. Asymmetric tributaries and flat floors of arroyos, in which present streams lie in shallow trenches, shown in left foreground. Note straight trend of contact (a) between tilted strata of Tulare formation and flat-lying alluvium at edge of hills. Photograph by Fairchild Aerial Surveys.

EAST FLANK OF NORTH DOME.

Airplane view looking northwestward showing rounded hilltops and steep gullied slopes adjoining streams. Gullies are more numerous on southward-facing slopes than on northward-facing slopes. Upper course of north fork of Arroyo Robador (a) is evidently a former tributary of Arroyo Degollado (b). Photograph by Spence Air Photos.

WEST FLANK OF NORTHERN MIDDLE DOME.

Airplane view looking northward. Las Alturas in center. Note irregular and indefinite contact (a) between tilted strata of Tulare formation and flat-lying alluvium at edge of hills. Photograph by Fairchild Aerial Surveys.

NORTHERN MIDDLE DOME.

Airplane view looking northwestward along crest. Shows southward decrease in altitude and ruggedness from North Dome (in background) and straight east front of Las Alturas (a). Photograph by Spence Air Photos.

a. Las Alturas.
b. *Neverita* zone of San Joaquin formation.
c. Third *Mya* layer of San Joaquin formation.
d. Cascajo conglomerate member at base of San Joaquin formation.
e. *Pseudocardium-Anadara* zone of Etchegoin formation.
f. *Pseudocardium*-bearing conglomerate of Etchegoin formation.
g. Contact between lower and upper parts of Etchegoin formation.

southward relative to the alluvium, unless the alluvium has accumulated faster at the south end than at the north since the uplift of the hills. The alluvium has probably been deformed also, for the position of the divide in the Kettleman Plain appears to be due to uplift.

MINOR EROSIONAL FEATURES

The lowest dissected erosion surface recognized is the most conspicuous because of the older alluvium associated with it. La Vega, in sec. 36, T. 21 S., R. 17 E., shows this surface very well. The older alluvium is located mainly on the east side of North and Middle Domes in areas underlain by the San Joaquin formation, though a few scattered patches are found higher in the hills on the Etchegoin formation.

Several areas of cobbles and boulders lie 125 to 150 feet above the floor of Avenal Gap. These gravels, which are described under the heading "Older alluvium," probably came from Reef Ridge. At least some lie at lower elevations than the probable southward projection of the erosion surface at El Prado. These gravels were presumably deposited by the predecessor of the stream flowing through Avenal Gap and may have been contemporaneous with the deposition of older alluvium on La Vega and elsewhere.

PRESENT LAND FORMS

The topography of North Dome is more rugged than that of Middle and South Domes (pls. 54–57). The entire area of the Kettleman Hills is characterized by rounded hilltops, but in most of North Dome and on the west side of Middle Dome the lower parts of the sides of the stream valleys are relatively steep (pl. 55), and locally the land is gullied, as in badland topography. The streams are all ephemeral and form alluvial fans where they empty onto the adjoining plains. The headwaters of the streams in North Dome have relatively narrow valleys and steep sides, and they are actively degrading their courses; but the lower parts of some streams have moderately wide and flat bottoms and are depositing alluvium in their channels. In most of Middle Dome and in South Dome the valley slopes are less steep and the stream bottoms are wider than in North Dome.

The profiles of many of the valleys are asymmetrical. The north or northwest sides of such valleys (pl. 54), particularly Arroyo Recto, in sec. 30, T. 21 S., R. 17 E., are commonly less steep than the south or southeast sides. The northwest sides are more exposed to the sun and thus support less vegetation and have less soil. They accordingly are more subject to erosion and hence wear away faster than the southeast sides, and thus develop gentler slopes.

Several streams seem to have captured other streams during the development of the hills. The most noteworthy is Arroyo Robador (the robber stream), which in the northwest corner of sec. 22, T. 22 S., R. 18 E., has captured a part of Arroyo Degollado (pl. 55). The older alluvium exposed in the lower part of the course of Arroyo Degollado contains sand dollars that are not found in strata now cropping out in the present course of that stream. Such strata, however, are exposed in the headwaters of Arroyo Robador. The inference therefore follows that the original course fo Arroyo Degollado has been diverted by headward erosion of Arroyo Robador, and this inference is further borne out by the departure of Arroyo Robador from the usual stream pattern of the east flank of North Dome.

Patches of dune sand are found in a few places in the Kettleman Hills, notably at Los Medanos, in sec. 30, T. 22 S., R. 19 E.; the south side of Mesa Roida, in sec. 28, T. 22 S., R. 18 E.; along Arroyo del Paso in sec. 7, T. 23 S., R. 19 E.; and near La Llanura, in sec. 18, T. 23 S., R. 19 E. The two small areas of depression contours on El Prado, in sec. 32, T. 21 S., R. 17 E., and at La Marmita, in sec. 15, T. 22 S., R. 18 E., may perhaps have been formed by the wind.

In the San Joaquin Valley east of the north end of North Dome are long northwestward trending ridges of sandy material. They are asymmetric, the northeast slope being the steeper. These ridges have attracted the attention of some geologists, for they ar especially conspicuous on airplane photographs, and they have been cited in nontechnical publications as evidence of recent faulting. It is suggested that they may be old dunes.

FOSSIL LOCALITIES

In the following list the fossil localities are described, and the locality numbers used in this report (see pl. 3) are correlated with the permanent Geological Survey locality numbers and the field numbers. The figures following the land-net data represent distances from the section lines to the fossil locality.

Fossil localities

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			TULARE FORMATION
1	[1] 839	--------	North Dome, sec. 20, T. 21 S., R. 17 E.; 980 feet north, 730 feet west; on road west of Arroyo Vadoso. White clay at base of formation.
2	12544	3M	North Dome, sec. 28, T. 21 S., R. 17 E.; 930 feet south, 770 feet west; between Arroyo Vadoso and Arroyo Largo. Lower *Amnicola* zone.
3	12542	1M	North Dome, sec. 28, T. 21 S., R. 17 E.; 1,190 feet south, 600 feet west; between Arroyo Vadoso and Arroyo Largo. Below lower *Amnicola* zone.
4	13253	21W	North Dome, sec. 27, T. 21 S., R. 17 E.; 2,000 feet north, 650 feet west; north end of La Ceja. Below lower *Amnicola* zone.
5	[1] 838 [1] 1678	--------	North Dome, sec. 35, T. 21 S., R. 17 E.; on north section line; 2,340 feet east; prospect pit, La Ceja. White clay at base of formation.
6	12478	3W	North Dome, sec. 35, T. 21 S., R. 17 E.; 370 feet south, 2,080 feet west; La Ceja. Lower *Amnicola* zone, unit 4a of section (p. 17).
7	12479	5W	North Dome, same locality. Lower *Amnicola* zone, units 7d and 7e of section (p. 17).
8	12677	7T	North Dome, sec. 14, T. 22 S., R. 18 E.; 430 feet north, 1,200 feet east; Arroyo Degollado. Lower *Amnicola* zone.
9	--------	--------	North Dome, sec 14, T. 22 S., R. 18 E.; 2,050 feet north, 1,800 feet west; float in Arroyo Degollado.
10	12705	64T	North Dome, sec. 23, T. 22 S., R. 18 E.; 2,360 feet north, 850 feet west; ridge north of Arroyo Robador. Lower *Amnicola* zone.
11	[1] 1053	156W	North Dome, sec. 25, T. 22 S., R. 18 E.; 1,040 feet south, 2,670 feet east; south fork of Arroyo Robador White clay at base of formation.
12	12702	40T	North Dome, sec. 8, T. 23 S., R. 19 E.; 170 feet south, on west section line; Los Viejos. Upper *Amnicola* zone.
13	12703	59T	North Dome, sec. 8, T. 23 S., R. 19 E.; 1,160 feet south, 2,000 feet west; Los Viejos. Above upper *Amnicola* zone.
14	13254	117W	Middle Dome, sec. 17, T. 23 S., R. 19 E.; 1,690 feet south, 1,870 feet east; La Salida. Lower *Amnicola* zone, unit 1a of section (p. 19).
15	13252	119W	Middle Dome, same locality. Lower *Amnicola* zone, unit 2c of section (p. 19).
16	[1] 1061	122W	Middle Dome, same locality. Lower *Amnicola* zone, unit 6b of section (p. 19).
17	12683	26M	Middle Dome, sec. 17, T. 23 S., R. 19 E.; 1,980 feet south, 1,960 feet east; La Salida. Lower *Amnicola* zone.
18	12681	21M	Middle Dome, sec. 20, T. 23 S., R. 19 E.; 350 feet south, 1,910 feet west; El Portillo. Lower *Amnicola* zone.
19	12843	163W	Middle Dome, sec. 28, T. 23 S., R. 19 E.; 1,700 feet north, 410 feet west; south of La Porteria. Upper *Amnicola* zone.
20	12546	5M	North Dome, sec. 30, T. 21 S., R. 17 E.; 860 feet south, 1,960 feet west; east of La Luneta. Lower *Amnicola* zone.
21	12548	7M	North Dome, sec. 30, T. 21 S., R. 17 E.; 240 feet north, 2,210 feet west; between Arroyo Recto and Arroyo Corto. Lower *Amnicola* zone.
22	12554	13M	North Dome, sec. 32, T. 21 S., R. 17 E.; 1,100 feet north, 1,350 feet east; west of El Prado. Lower *Amnicola* zone.
23	12555	15M	North Dome, sec. 5, T. 22 S., R. 17 E.; 620 feet south, 2,270 feet west; branch of La Cañada Simada. Lower *Amnicola* zone.
24	12552	12M	North Dome, sec. 9, T. 22 S., R. 17 E.; 2,640 feet south, on west section line; east of Arroyo Curvo. Lower *Amnicola* zone.
25	12556	16M	North Dome, sec. 14, T. 22 S., R. 17 E.; 100 feet north, 2,350 feet west; west of Arroyo Chico. Lower *Amnicola* zone.
26	12689	36M	North Dome, sec. 33, T. 22 S., R. 18 E.; 1,600 feet north, 2,280 feet east; between Arroyo Delgado and Arroyo Raso. Below lower *Amnicola* zone.
27	12674	21T	North Dome, sec. 33, T. 22 S., R. 18 E.; 1,270 feet north, 2,460 feet east; between Arroyo Delgado and Arroyo Raso. Below lower *Amnicola* zone.
28	12704	60T	North Dome, sec. 3, T. 23 S., R. 18 E.; 2,400 feet north, 1,250 feet east; between Arroyo Raso and Arroyo Escaso. Upper *Amnicola* zone.
			SAN JOAQUIN FORMATION
			Upper *Mya* zone
29	12477	2W	North Dome, sec. 35, T. 21 S., R. 17 E.; 320 feet south, 2,400 feet west; La Ceja.
30	12701	36T	North Dome, sec. 35, T. 21 S., R. 17 E.; 500 feet south, 1,800 feet west; La Ceja.
31	12480	6W	North Dome, sec. 35, T. 21 S., R. 17 E.; 630 feet south, 1,630 feet west; La Ceja.
32	12325	3S	North Dome, sec. 35, T. 21 S., R. 17 E.; 1,370 feet south, 380 feet west; Arroyo Bifido.
33	12326	4S	North Dome, sec. 36, T. 21 S., R. 17 E.; 1,840 feet south, 150 feet east; south end of La Ceja.

[1] U. S. Geol. Survey diatom locality number.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			SAN JOAQUIN FORMATION—Continued
			Upper *Mya* zone—Continued
34	--------	29M	North Dome, sec. 6, T. 23 S., R. 19 E.; 2,220 feet south, 1,360 feet west; float at north end of Los Viejos.
35	12840	155W	North Dome, sec. 6, T. 23 S., R. 19 E.; 1,670 feet north, 1,000 feet west; north end of Los Viejos.
36	12699	27T	North Dome, sec. 7, T. 23 S., R. 19 E.; 2,140 feet north, 300 feet west; Los Viejos.
37	12549	8M	North Dome, sec. 30, T. 21 S., R. 17 E.; 280 feet north, 1,500 feet west; west of El Prado.
38	12688	34M	Middle Dome, sec. 11, T. 23 S., R. 18 E.; 1,560 feet north, 1,480 feet east; Las Alturas.
39	12686	32M	Middle Dome, sec. 14, T. 23 S., R. 18 E.; 240 feet south, 1,950 feet east; Las Alturas.
40	12685	31M	Middle Dome, sec. 14, T. 23 S., R. 18 E.; 2,650 feet north, 2,350 feet east; Las Alturas.
41	12697	24T	Middle Dome, sec. 23, T. 23 S., R. 18 E.; 1,640 feet south, 2,140 feet west; Las Alturas.
42	12684	30M	Middle Dome, sec. 23, T. 23 S., R. 18 E.; 1,940 feet south, 2,200 feet west; Las Alturas.
43	12698	25T	Middle Dome, sec. 23, T. 23 S., R. 18 E.; 970 feet north, 1,500 feet west; Las Alturas.
44	12679	19M	South Dome, sec. 17, T. 24 S., R. 19 E.; 150 feet north, 1,380 feet west; Las Colinas.
45	12776	106S	South Dome, sec. 20, T. 24 S., R. 19 E.; 950 feet south, 1,340 feet west; Las Colinas.
46	12680	20M	South Dome, sec. 9, T. 25 S., R. 19 E.; 1,000 feet south, 1,150 feet west; east of Arroyo Ancho.
			Strata between upper *Mya* zone and *Acila* zone
47	12550	9M	North Dome, sec. 31, T. 21 S., R. 17 E.; 1,250 feet south, on west section line; branch of Arroyo Corto.
48	12682	25M	Middle Dome, sec. 34, T. 23 S., R. 19 E.; 2,070 feet north, 1,380 feet east; north of Boulder Hill.
49	12492	19W	North Dome, sec. 27, T. 21 S., R. 17 E.; 1,790 feet north, 770 feet west; La Ceja.
50	12551	11M	North Dome, sec. 30, T. 21 S., R. 17 E.; 800 feet north, 400 feet west; west slope of El Prado.
51	12476	1W	North Dome, sec. 35, T. 21 S., R. 17 E.; 500 feet south, 2,450 feet west; La Ceja.
52	12547	6M	North Dome, sec. 30, T. 21 S., R. 17 E.; 1,830 feet south, 840 feet west; branch of Arroyo Seco.
53	12687	33M	Middle Dome, sec. 11, T. 23 S., R. 18 E.; 1,070 feet north, 1,890 feet east; east slope of Las Alturas.
54	12839 12387	154W 92S	Middle Dome, sec. 14, T. 23 S., R. 18 E.; 2,300 feet south, 2,550 feet east; east slope of Las Alturas.
55	12700	30T	Middle Dome, sec. 25, T. 23 S., R. 18 E.; 2,340 feet north, 580 feet east; northwest of La Zanja.
56	12545	4M	North Dome, sec. 28, T. 21 S., R. 17 E.; 1,250 feet south, 2,060 feet west; branch of Arroyo Vadoso.
			Acila zone
57	12330	10S 10aS	North Dome, sec. 28, T. 21 S., R. 17 E.; 3,000 feet north, 1,020 feet west; Arroyo Vadoso.
57a	14124	57S	North Dome, sec. 29, T. 21 S., R. 17 E.; 2,300 feet south, 1,800 feet east.
58	12340	25S	North Dome, sec. 5, T. 22 S., R. 18 E.; 1,080 feet north, 220 feet east; excavation for driller's mud on north side of Arroyo Hondo.
59	12337	22S	North Dome, sec. 8, T. 22 S., R. 18 E.; 75 feet south, 2,100 feet east; Arroyo Hondo.
60	12353	40S	North Dome, sec. 9, T. 22 S., R. 18 E.; 1,825 feet north, 950 feet east, and 100 yards southeast along strike; ridge between Arroyo Pequeño and Arroyo Finito.
61	12358	45S	North Dome, sec. 15, T. 22 S., R. 18 E.; 820 feet north, 1,150 feet west; Arroyo Degollado.
62	12363	55S	North Dome, sec. 31, T. 22 S., R. 19 E.; 1,440 feet south, 300 feet east; south fork of Arroyo Pino.
63	12364	60S	North Dome, sec. 6, T. 23 S., R. 19 E.; 2,500 feet south, 3,070 feet east; Arroyo Estrecho.
64a	12710	79T	North Dome, sec. 5, T. 22 S., R. 17 E.; 200 feet south, 475 feet west; La Cañada Simada.
64	12368	67S	North Dome, sec. 4, T. 22 S., R. 17 E.; 1,350 feet north, 2,200 feet west; El Perro.
65	12367	66S	North Dome, sec. 10, T. 22 S., R. 17 E.; 2,040 feet south, 980 feet east; ridge between Arroyo Curvo and Arroyo Esquinado.
66	12372	71S	North Dome, sec. 15, T. 22 S., R. 17 E.; 180 feet south, 1,100 feet west; Arroyo del Camino.
67	12349	34S	North Dome, sec. 14, T. 22 S., R. 17 E.; 650 feet north, 510 feet west; Arroyo Chico.
68	12351	37S	North Dome, sec. 19, T. 22 S., R. 18 E.; 1,450 feet north, 370 feet east; west fork of Arroyo Conchoso east of El Dombo.
			Pecten zone and *Trachycardium* zone
71	12322	16S	North Dome, sec. 29, T. 21 S., R. 17 E.; 450 feet north, 1,800 feet west; east fork of Surprise Canyon.
72	12427	15S	North Dome, sec. 29, T. 21 S., R. 17 E.; 2,230 feet north, 1,600 feet west; east fork of Surprise Canyon.
73	12333	17S	North Dome, sec. 28, T. 21 S., R. 17 E.; 2,450 feet north, 1,780 feet east; near Arroyo Vadoso, north of Elephant Hill.
74	12331a	11aS	North Dome, 950 feet west of locality 75.
75	12331	11S	North Dome, sec. 28, T. 21 S., R. 17 E.; 2,100 feet north, 160 feet west; near divide between Arroyo Vadoso and Arroyo Largo.
76	12462	9S	North Dome, sec. 27, T. 21 S., R. 17 E.; 1,030 feet north, 1,680 feet west; Arroyo Largo.
77	12463	8S	North Dome, about 600 feet southeast of locality 76.
78	12327a	5aS	North Dome, sec. 35, T. 21 S., R. 17 E.; 1,075 feet south, 1,950 feet east; west fork of Arroyo Bifido.
79	12327	5S	North Dome, sec. 35, T. 21 S., R. 17 E.; 1,630 feet south, 2,340 feet east; Arroyo Bifido.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			SAN JOAQUIN FORMATION—Continued
			Pecten zone and *Trachycardium* zone—Continued
79a	12328	6S	North Dome, about 200 feet east of locality 79.
80	12329	7S	North Dome, sec. 36, T. 21 S., R. 17 E.; 1,300 feet north, 800 feet east; northwest end of La Vega.
81	12334	19S	North Dome, sec. 6, T. 22 S., R. 18 E.; 2,870 feet south, 2,500 feet east; east fork of Arroyo Torcido.
81a	--------	19aS	North Dome, 100 feet northwest of locality 81, altitude 725 feet; small arroyo draining southwestward into east fork of Arroyo Torcido. Mastodon remains.
82	12335	20S	North Dome, sec. 6, T. 22 S., R. 18 E.; 990 feet north, 725 feet west.
83	12336	21S	North Dome, sec. 5, T. 22 S., R. 18 E.; 600 feet north, 40 feet east; west branch of Arroyo Hondo.
84	12338	22S	North Dome, sec. 5, T. 22 S., R. 18 E.; 125 feet north, 1,040 feet east; west branch of Arroyo Hondo.
85	12339	24S	North Dome, sec. 8, T. 22 S., R. 18 E.; 2,600 feet north, 700 feet west; Arroyo Pequeño.
85a	12339a	24aS	North Dome, 600 to 900 feet northwest of locality 85.
86	12342	27S	North Dome, sec. 9, T. 22 S., R. 18 E.; 1,925 feet north, 250 feet east; Arroyo Pequeño.
87	12343	28S	North Dome, sec. 9, T. 22 S., R. 18 E.; 1,520 feet north, 625 feet east; divide between Arroyo Pequeño and Arroyo Finito.
88	12344a	29aS	North Dome, 670 feet northwest of locality 89.
89	12344	29S	North Dome, sec. 9, T. 22 S., R. 18 E.; 310 feet north, 2,260 feet east; Arroyo Finito.
90	12345	30S	North Dome, sec. 16, T. 22 S., R. 18 E.; 100 feet south, 2,700 feet east; Arroyo Finito.
91	12354	41S	North Dome, sec. 16, T. 22 S., R. 18 E.; 475 feet south, 2,100 feet west; Arroyo Finito.
92	12355	42S	North Dome, sec. 15, T. 22 S., R. 18 E.; 1,550 feet north, 1,830 feet east; Arroyo Degollado.
93	12356	43S	North Dome, sec. 15, T. 22 S., R. 18 E.; 380 feet north, 1,750 feet west; Arroyo Degollado.
93a	12357	44S	North Dome, sec. 15, T. 22 S., R. 18 E.; 160 feet north, 1,390 feet west; Arroyo Degollado.
94	12359	46S	North Dome, sec. 22, T. 22 S., R. 18 E.; 320 feet south, 780 feet west; Arroyo Degollado.
95	--------	47S	North Dome, sec. 23, T. 22 S., R. 18 E.; 2,450 feet north, 1,100 feet east; El Campo road, Arroyo Robador. Below *Pecten* zone.
96	--------	50S	North Dome, sec. 23, T. 22 S., R. 18 E.; 2,070 feet north, 2,380 feet east; Arroyo Robador.
97	--------	48S	North Dome, sec. 25, T. 22 S., E. 18 E.; 900 feet south, 750 feet east; Arroyo Robador.
98	12360	51S	North Dome, sec. 25, T. 22 S., R. 18 E.; 1,500 feet north, 2,480 feet west; Arroyo Pino.
99	12361	52S	North Dome, sec. 25, T. 22 S., R. 18 E.; 650 feet north, 1,575 feet west; Arroyo Pino, west of Los Medanos.
100	12362	54S	North Dome, sec. 31, T. 22 S., R. 19 E.; 2,330 feet south, 380 feet east; Arroyo Pino south of Los Medanos. *Trachycardium* zone.
101	12364	60S	North Dome, sec. 6, T. 23 S., R. 19 E.; 550 feet south, 1,670 feet east; north of Arroyo Robador and south of Hanford road.
102	12365 12767	61S	North Dome, sec. 6, T. 23 S., R. 19 E.; south of quarter cor.; La Lomica.
102a	12365a 12768	61aS	North Dome, 1,300 feet south-southeast of locality 102.
102b	12365b	61bS	North Dome, 2,650 feet south of locality 102.
102c	12365c	61cS	North Dome, 3,050 feet south of locality 102.
103	12366	62S	Middle Dome, sec. 18, T. 23 S., R. 19 E.; 1,970 feet south, 710 feet west; west of La Salida.
103a	--------	62aS	Middle Dome, sec. 18, T. 23 S., R. 19 E.; 2,430 feet north, 200 feet west; west of La Salida.
104	12385	90S	Middle Dome, sec. 17, T. 23 S., R. 19 E.; 200 feet north, 1,360 feet east; west of El Portillo.
105	12386	91S	Middle Dome, sec. 20, T. 23 S., R. 19 E.; 750 feet south, 2,000 feet east; west of El Portillo.
105a	12803	151S	Middle Dome, sec. 20, T. 23 S., R. 19 E; 1,090 feet north, 850 feet west. *Trachycardium* zone.
106	14126	115S	Middle Dome, sec. 28, T. 23 S., R. 19 E.; 1,150 feet south, 600 feet east; northwest of La Porteria. *Trachycardium* zone.
107	12782	115aS	Middle Dome, sec. 28, T. 23 S., R. 19 E.; 2,620 feet north, 1,760 feet east; west of La Porteria.
108	12783	116S	Middle Dome, sec. 28, T. 23 S., R. 19 E.; 160 feet north, 1,690 feet west; Arroyo Recodo.
109	--------	117aS	Middle Dome, sec. 3, T. 24 S., R. 19 E.; 2,570 feet south., 2,060 feet east; north of Boulder Hill.
110	12784	117S	Middle Dome, sec. 10, T. 24 S., R. 19 E.; 270 feet south, 1,760 feet west; Avenal Gap., southeast of Boulder Hill.
111	12832	118S	South Dome, sec. 26, T. 24 S., R. 19 E.; 590 feet south, 690 feet east; south of Arroyo Tozo.
112	12785	119S	South Dome, sec. 26, T. 24 S., R. 19 E.; 1,770 feet south, 1,500 feet east; south of Arroyo Tozo.
113	12369	68S	North Dome, sec. 9, T. 22 S., R. 17 E.; 250 feet south, 200 feet west; Arroyo Curvo.
114	12370	69S	North Dome, sec. 10, T. 22 S., R. 17 E.; 400 feet north, 800 feet west; Arroyo del Camino.
114a	12371	70S	North Dome, sec. 10, T. 22 S., R. 17 E.; 130 feet north, 625 feet West; Arroyo del Camino.
114b	12370a	69aS	North Dome, 250 feet north-northwest of locality 114; Arroyo del Camino.
115	12373	72S	North Dome, sec. 14, T. 22 S., R. 17 E.; 1,110 feet south, 1,150 feet east; Arroyo Somero.
116	12384	33S	North Dome, sec. 24, T. 22 S., R. 17 E.; 700 feet south, 1,850 feet east; Arroyo Mellado.
117	12347	32S	North Dome, sec. 24, T. 22 S., R. 17 E.; 1,800 feet south, 1,950 feet west; Arroyo Mellado.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			SAN JOAQUIN FORMATION—Continued
			Pecten zone and *Trachycardium* zone—Continued
118	12352	38S	North Dome, sec. 19, T. 22 S., R. 18 E.; 1,660 feet north, 1,380 feet east; Arroyo Conchoso east of El Dombo.
118a	--------	39S	North Dome, about 400 feet northwest along strike from locality 118.
119	12374	74S	North Dome, sec. 19, T. 22 S., R. 18 E.; 660 feet north, 2,600 feet east; Arroyo Conchoso.
119a	12376	77S	North Dome, about 650 feet southeast of locality 119.
120	12375	75S	North Dome, sec. 19, T. 22 S., R. 18 E.; 120 feet north, 2,340 feet west; Arroyo Conchoso. *Trachycardium* zone.
120a	12375a	75aS	North Dome, 600 feet southeast along strike from locality 120.
121	12377	78S	North Dome, sec. 30, T. 22 S., R. 18 E.; 760 feet south, 1,100 feet west; south side of Arroyo Conchoso. *Trachycardium* zone.
122	12378	89S	North Dome, sec. 29, T. 22 S., R. 18 E.; 1,375 feet north, 1,725 feet west; north side of Cerro Alto road, S. of Arroyo Ramoso.
123	12381	82S	North Dome, sec. 29, T. 22 S., R. 18 E.; 350 feet north, 1,135 feet west; west fork of Arroyo Delgado. *Trachycardium* zone.
124	--------	--------	North Dome, sec. 33, T. 22 S., R. 18 E.; 1,200 feet south, 1,400 feet east; Arroyo Delgado.
125	--------	85S	North Dome, sec. 33, T. 22 S., R. 18 E., 700 feet south, 2,100 feet east; Arroyo Delgado. *Mya* layer below *Pecten* zone.
125a	12383	84S	North Dome. sec. 33, T. 22 S., R. 18 E.; 900 feet south, 1,440 feet east; Arroyo Delgado. Below *Pecten* zone.
126	12380	81S	North Dome, sec. 33, T. 22 S., R. 18 E.; 2,575 feet north, 750 feet west; Arroyo Raso. *Mya* layer below *Pecten* zone.
127	14085	78yS	North Dome, sec. 33, T. 22 S., R. 18 E.; 1,960 feet north, 1,720 feet west; west of Arroyo Raso. *Trachycardium* zone.
128	12379	80S	North Dome, sec. 3, T. 23, S., R. 18 E.; 1,250 feet north, 70 feet west; north of El Paso. *Trachycardium* zone.
129	--------	95aS	North Dome, sec. 11, T. 23 S., R 18 E.; 970 feet north, 2,130 feet west; northeast of El Bulto.
130	12384	86aS	North Dome, sec. 14, T. 23 S., R. 18 E.; 1,450 feet south, 2,050 feet west; southeast of El Bulto.
130a	12388	95S	Middle Dome, sec. 23, T. 23 S., R. 18 E.; 2,270 feet south, 790 feet west; south-southeast of La Morra.
130b	12388	96S	Middle Dome, sec. 23, T. 23 S., R. 18 E.; 425 feet north, 125 feet west; north of El Caballete.
130c	12390	97S	Middle Dome, sec. 25, T. 23 S., R. 18 E.; 1,310 feet north, 2,030 feet east; La Brecha.
131	--------	--------	Middle Dome, sec. 36, T. 23 S., R. 18 E.; 1,160 feet south, 700 feet west; El Caballete. Freshwater layer below *Pecten* zone. Fossils observed but not collected.
132	12774	104S	Middle Dome, sec. 6, T. 24 S., R. 19 E.; 1,720 feet south, 2,220 feet west; El Caballete, hill 641.
134	14103	121aS	Middle Dome, sec. 8, T. 24 S., R. 19 E.; 240 feet south, 1,000 feet east; south end of El Caballete.
135	12787	121S	Middle Dome, about 800 feet south of locality 134.
136	12773	103aS	Middle Dome, sec. 8, T. 24 S., R. 19 E., 2,370 feet south, 1,200 feet east; south end of La Zanja, 536-foot hill. Conglomerate above *Pecten* zone.
137	12792	133S	South Dome, sec. 21, T. 24 S., R. 19 E.; 1,880 feet south, 790 feet east; Badger Hill.
138	12791	132S	South Dome, sec. 20, T. 24 S., R. 19 E.; 1,720 feet north, 10 feet west; west of El Rincon.
139	12781	113S	South Dome, sec. 10, T. 25 S., R. 19 E.; 870 feet north, 2,000 feet west; west side of Los Morones.
140	12780	112bS	South Dome, sec. 10, T. 25 S., R. 19 E.; 20 feet north, 1,120 feet west; west side of Los Morones.
140a	12779	112aS	South Dome, 600 feet southeast of locality 140.
140b	12778	112S	South Dome, sec. 15, T. 25 S., R. 19 E.; 910 feet south, 280 feet west; west side of Los Morones.
			Neverita zone
141	12639	66W	North Dome, sec. 36, T. 22 S., R. 18 E.; 1,000 feet north, 200 feet west; between Arroyo Pino and Arroyo Estrecho. *Mya* layer above *Neverita* zone.
142	12661	116W	South Dome, sec. 22, T. 24 S., R. 19 E.; 2,550 feet south, 1,650 feet east; highway north of Arroyo Tozo. Freshwater fossils above *Neverita* zone.
143	[1]1056	71W	North Dome, sec. 6, T. 23 S., R. 19 E.; 1,430 feet south, 80 feet east; Paso Robles-Hanford road, west of Arroyo Estrecho. Unit 4 of section, page 40; silty clay above *Neverita* zone.
143a	[1]1057	72W	Same locality, bed 1 of section. Silty clay above *Neverita* zone.
144	[1]1054	160W	North Dome, sec. 3, T. 22 S., R. 17 E.; 1,500 feet north, 1,230 feet east; La Cumbre. Tuffaceous sandstone above *Neverita* zone.
145	12498	26W	North Dome, sec. 34, T. 21 S., R. 17 E.; 1,470 feet south, 1,760 feet east; west fork of Arroyo Largo.
146	12496	25aW	North Dome, sec. 34, T. 21 S., R. 17 E.; 2,620 feet south, 2,250 feet west; between main forks of Arroyo Largo.
146a	12497	25bW	Same locality, 4 feet higher stratigraphically.

[1] U. S. Geol. Survey diatom locality number.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			SAN JOAQUIN FORMATION—Continued
			Neverita zone—Continued
147	12495	24W	North Dome, sec. 35, T. 21 S., R. 17 E.; 2,530 feet north, 300 feet east; east of Arroyo Large.
148	12493	22aW	North Dome, sec. 35, T. 21 S., R. 17 E.; 1,620 feet north, 2,600 feet west; Arroyo Bifido.
148a	12494	22bW	Same locality, 3 feet higher stratigraphically.
149	12506	34W	North Dome, sec. 35, T. 21 S., R. 17 E.; 440 feet north, 2,130 feet west; Arroyo Bifido.
150	12512	43W	North Dome, sec. 1, T. 22 S., R. 17 E.; 860 feet south, 1,570 feet east; Arroyo Torcido.
151	12511	42W	North Dome, sec. 1, T. 22 S., R. 17 E.; 1,270 feet south, 2,480 feet west; Arroyo Torcido.
152	12510	41W	North Dome, sec. 6, T. 22 S., R. 18 E., 270 feet north, 2,500 feet east; ridge of Arroyo Murado.
153	12509	40W	North Dome, sec. 7, T. 22 S., R. 18 E.; 170 feet south, 1,470 feet west; east fork of Arroyo Torcido.
154	12508	39W	North Dome, sec. 7, T. 22 S., R. 18 E.; 250 feet south, 1,340 feet west; east fork of Arroyo Torcido.
155	12513	44W	North Dome, sec. 7, T. 22 S., R. 18 E.; 750 feet south, 950 feet west; between east fork of Arroyo Torcido and west fork of Arroyo Hondo.
156	12514	45W	North Dome, sec. 7, T. 22 S., R. 18 E.; 1,000 feet south, 250 feet west.
157	12515	46W	North Dome, sec. 8, T. 22 S., R. 18 E.; 1,870 feet south, 870 feet, east; between forks of Arroyo Hondo.
158	12516	47W	North Dome, sec. 8, T. 22 S., R. 18 E.; 2,520 feet north, 2,730 feet east; Arroyo Hondo.
159	12636	59W	North Dome, sec. 16, T. 22 S., R. 18 E.; 1,030 feet south, 1,100 feet east; branch of Arroyo Doblegado.
160	12637	60W	North Dome, sec. 16, T. 22 S., R. 18 E.; 1,270 feet south, 1,580 feet east; branch of Arroyo Doblegado
161	12635	58W	North Dome, sec. 16, T. 22 S., R. 18 E.; 2,250 feet north, 1,120 feet west; south of Arroyo Doblegado.
162	12638	62W	North Dome, sec. 22, T. 22 S., R. 18 E.; 1,600 feet south, 2,170 feet west; branch of Arroyo Robador.
163	12499	27W	North Dome, sec. 33, T. 21 S., R. 17 E.; 670 feet north, 270 feet west; butte east of Lower Road.
163a	12500	27aW	Same locality, from overlying sand.
164	12520	51W	North Dome, sec. 24, T. 22 S., R. 17 E.; 50 feet south, 1,200 feet west; branch of Arroyo Mellado.
164a	12521	51aW	Same locality, 15 feet lower stratigraphically.
165	12519	50W	North Dome, sec. 24, T. 22 S., R. 17 E.; 100 feet south, 1,350 feet west; branch of Arroyo Mellado.
166	--------	162W	North Dome, sec. 2, T. 23 S., R. 18 E.; 1,660 feet south, 750 feet east; between Paso Robles-Hanford road and Arroyo del Paso.
167	--------	152W	Middle Dome, sec. 28, T. 23 S., R. 19 E.; 500 feet north, 1,630 feet east; north of Arroyo Recodo.
168	[1] 1051	146W	Middle Dome, sec. 33, T. 23, S., R. 19 E.; 1,680 feet south, 2,130 feet west; south of Arroyo Recodo.
169	--------	145W	Middle Dome, sec. 33, T. 23 S., R. 19 E.; 2,130 feet north, 1,370 feet west; south of Arroyo Recodo. Below *Neverita* zone.
170	12707	76T	Middle Dome, sec. 13, T. 23 S., R. 18 E.; 1,070 feet north, 1,300 feet east.
170a	12708	76aT	Same locality, 5 feet higher stratigraphically.
171	12836	143W	Middle Dome, sec. 24, T. 23 S., R. 18 E.; 1,300 feet south, 1,340 feet east.
172	12696	58M	Middle Dome, sec. 24, T. 23 S., R. 18 E.; 1,600 feet south, 1,340 feet east.
173	[1] 1052	147W	Middle Dome, sec. 8, T. 24 S., R. 19 E.; 610 feet south, 1,850 feet west; east side of Pepper Grass Valley.
174	--------	75T	Middle Dome, sec. 13, T. 23 S., R. 18 E.; 2,210 feet north, 1,180 feet east.
			Strata between *Neverita* zone and Cascajo conglomerate member
175	12841	157W	North Dome, sec. 22, T. 22 S., R. 18 E.; 2,530 feet south, 1,430 feet west; between forks of Arroyo Robador north of El Campo. Upper oolite.
176	13259	131W	Middle Dome, sec. 33, T. 23 S., R. 19 E.; 2,400 feet north, 1,700 feet west; south of Arroyo Recodo. Upper oolite.
177	12842	161W	North Dome, sec. 7, T. 22 S., R. 18 E.; 1,520 feet south, 200 feet west; north fork of Arroyo Hondo. *Cerastoderma*-bearing sandstone.
178	12706	70T	North Dome, sec. 16, T. 22 S., R. 18 E.; 2,730 feet north, 1,750 feet west; branch of Arroyo Doblegado. *Cerastoderma*-bearing sandstone.
			Cascajo conglomerate member and immediately overlying and underlying strata
183	14087	590S	North Dome, sec. 34, T. 22 S., R. 18 E.; 280 feet south, 20 feet east; south slope of Cerro Ultimo.
184	--------	591S	North Dome, sec. 28, T. 22 S., R. 18 E.; 1,540 feet north; 2,200 feet west; Arroyo Delgado, northwest of Cerro Ultimo. Just below blue conglomerate assigned to Cascajo.
185	14088	818S	North Dome, sec. 28, T. 22 S., R. 18 E.; 2,080 feet south, 1,260 feet east; Arroyo Delgado on south side of Cerro Alto.
186	--------	--------	North Dome, sec. 20, T. 22 S., R. 18 E.; 760 feet north, 60 feet west; El Lobo.
189	14089	575S	North Dome, sec. 19, T. 22 S., R. 18 E.; 100 feet south, 1,880 feet east; near head of west fork of Arroyo Conchoso. A foot above first *Mya* layer.
189a	14090	576S	North Dome, sec. 18, T. 22 S., R. 18 E.; 1,440 feet north, 270 feet east; ridge southeast of Los Jinetes. Between Cascajo conglomerate and first *Mya* layer.

[1] U. S. Geol. Survey diatom locality number.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			SAN JOAQUIN FORMATION—Continued
			Cascajo conglomerate member and immediately overlying and underlying strata—Continued
190	14091	579S	North Dome, sec. 14, T. 22 S., R. 17 E.; 30 feet south, 1,580 feet west; head of east fork of Arroyo Somero just below Skyline Road.
191	14092	814S	North Dome, sec. 11, T. 22 S., R. 17 E.; 1,080 feet north, 2,710 feet east; headwaters of Arroyo Somero. Just below blue conglomerate.
192	14136	581aS	North Dome, sec. 11, T. 22 S., R. 17 E.; 2,500 feet north, 570 feet east; upper part of south fork of Arroyo del Camino. Third *Mya* layer.
192a	12501	28W	North Dome, sec. 3, T. 22 S., R. 17 E.; 2,600 feet north, 2,730 feet east; ridge north of La Cumbre. Second *Mya* layer.
193	--------	--------	North Dome, sec. 34, T. 21 S., R. 17 E.; 760 feet north, 2,300 feet east; west side of Arroyo Largo. Second *Mya* layer.
193a	12505	33W	North Dome, sec. 35, T. 21 S., R. 17 E.; 130 feet north, 2,150 feet east; east of Lemoore Road. Third *Mya* layer.
193b	--------	--------	North Dome, sec. 2, T. 22 S., R. 17 E.; 1,780 feet south, 1,100 feet west; in road cut on east side of hill. Between first *Mya* layer and *Littorina* zone.
194	14093	194S	North Dome, sec. 16, T. 22 S., R. 18 E.; 1,930 feet south, 1,470 feet east.
196	--------	227S	North Dome, sec. 26, T. 22 S., R. 18 E.; 1,030 feet south, 2,660 feet west; branch of Arroyo Robador. First blue sandstone, about 75 feet above *Littorina* zone.
197	12663	125W	Middle Dome, sec. 19, T. 23 S., R. 19 E.; 2,020 feet south, 620 feet west; ridge south of south fork of Arroyo Culebrino.
198	12664	126W	Middle Dome, sec. 20, T. 23 S., R. 19 E.; 2,150 feet north, 450 feet east; ridge south of south fork of Arroyo Culebrino.
199	12670	137W	Middle Dome, sec. 24, T. 23 S., R. 18 E.; 2,390 feet south, 2,430 feet west; ridge east of upper part of Arroyo Culebrino.
199a	13118	163W	Middle Dome, sec. 24, T. 23 S., R. 18 E.; 1,000 feet south, 2,600 feet west; Arroyo Culebrino. *Mya* layer below Cascajo conglomerate.
200	12669	136W	Middle Dome, sec. 24, T. 23 S., R. 18 E.; 100 feet north, 1,770 feet west; west of La Escudilla.
201	12695	57M	Middle Dome, sec. 30, T. 23 S., R. 19 E.; 1,300 feet north, 460 feet east; east slope of upper Pepper Grass Valley.
202	12668	134W	Middle Dome, sec. 31, T. 23 S., R. 19 E.; 1,980 feet north, 1,320 feet west; ridge east of Pepper Grass Valley.
203	12645 12802	88W 147S	South Dome, sec. 3, T. 25 S., R. 19 E.; 2,200 feet south, 930 feet east; Cascajo Hill.
204	12801	146S	South Dome, sec. 3, T. 25 S., R. 19 E.; 1,420 feet south, 440 feet east; north end of Cascajo Hill.
205	12800 12834	145S 145aS	South Dome, sec. 4, T. 25 S., R. 19 E.; 250 feet south, 330 feet west; between forks of arroyo at north end of Cascajo Hill.
206	12799 12653	144S 104W	South Dome, sec. 33, T. 24 S., R. 19 E.; 500 feet north, 2,270 feet west; El Arco.
207	12798	143S	South Dome, sec. 33, T. 24 S., R. 19 E.; 2,130 feet south, 2,050 feet east; El Arco.
208	12797	142S	South Dome, sec. 33, T. 24 S., R. 19 E.; 1,200 feet south, 1,880 feet east; El Arco.
209	12796 12654	141S 105W	South Dome, sec. 28, T. 24 S., R. 19 E.; 200 feet north, 1,700 feet east; El Arco.
210	12655	110W	South Dome, sec. 28, T. 24 S., R. 19 E.; 880 feet north, 1,630 feet east; El Arco.
211	12795	140S	South Dome, sec. 28, T. 24 S., R. 19 E.; 1,740 feet north, 1,850 feet east; El Arco.
212	12656	111W	South Dome, sec. 21, T. 24 S., R. 19 E.; 70 feet north, 1,700 feet west; west of Oyster Hill.
213	12657	112W	South Dome, sec. 21, T. 24 S., R. 19 E.; 180 feet north, 290 feet west; north of Oyster Hill.
214	12658 12793 12794	113W 135S 135aS	South Dome, sec. 22, T. 24 S., R. 19 E.; 110 feet north, 170 feet east; north of Oyster Hill.
215	12659	114W	South Dome, sec. 27, T. 24 S., R. 19 E.; 230 feet south, 930 feet east; northeast of Oyster Hill.
216	12660	115W	South Dome, sec. 27, T. 24 S., R. 19 E.; 1,450 feet south, 1,930 feet west; between Oyster Hill and highway.
			ETCHEGOIN FORMATION, NORTH DOME
			Littorina zone
218	12391	200S	Sec. 19, T. 22 S., R. 18 E.; 1,250 feet south, 320 feet west; El Piso on west wide of La Cima.
219	12523	53W	Sec. 18, T. 22 S., R. 17 E.; 600 feet north, 940 feet east; branch of Arroyo Conchoso.
220	12392	203aS	Sec. 13, T. 22 S., R. 17 E.; 2,050 feet north, 1,200 feet west; Arroyo Mellado, south of Los Jinetes.
221	12394	205S	Sec. 13, T. 22 S., R. 17 E.; 2,200 feet south, 2,400 feet east; west fork of Arroyo Mellado, west of Los Jinetes.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			ETCHEGOIN FORMATION, NORTH DOME—Continued
			Littorina zone—Continued
222	--------	578S	Sec. 13, T. 22 S., R. 17 E.; 600 feet south, 1,450 feet east; road cut on east side of El Chichon. *Mya-Pseudocardium* layer.
223	12395	207S	Sec. 13, T. 22 S., R. 17 E.; 440 feet south, 1,100 feet east; near top of west side of El Chichon.
224	--------	--------	Sec. 2, T. 22 S., R. 17 E.; 1,300 feet north, 140 feet east; northeast of Cerro Lodoso.
225	12399	211S	Sec. 2, T. 22 S., R. 17 E.; 310 feet south, 2,080 feet east; upper part of west fork of Arroyo Bifido.
226	12810	405S	Sec. 36, T. 22 S., R. 18 E.; 550 feet north, 2,200 feet west.
227	--------	--------	Sec. 1, T. 23 S., R. 18 E; 1,960 feet north, 2,120 feet west; Arroyo del Paso.
228	--------	--------	Sec. 1, T. 23 S., R. 18 E.; 2,340 feet south, 520 feet east; Arroyo del Paso.
229	12807 12808	401S 402S	Sec. 35, T. 22 S., R. 18 E.; 80 feet north, 1,520 feet west; northeast of top of Pipe Hill.
230	14094	574S	Sec. 29, T. 22 S., R. 18 E.; 650 feet south, 240 feet west; near head of east fork of Arroyo Ramoso, southwest of El Lobo.
231	--------	671S	Sec. 20, T. 22 S., R. 18 E.; 1,120 feet north, 1,690 feet west; on top of ridge southwest of El Loro. *See also* locality 238a.
			Upper *Pseudocardium* zone (upper *Mulinia* zone)
237	14095	669S	Sec. 20, T. 22 S., R. 18 E.; 1,260 feet north, 1,240 feet west; south side of El Loro.
238	14096	671eS	Sec. 20, T. 22 S., R. 18 E.; 2,390 feet north, 2,680 feet east; east side of El Leon.
238a	14096a	671eaS	60 feet stratigraphically above locality 238. *Littorina* zone.
238b	14096b	671eS	120 feet stratigraphically below locality 238. *Siphonalia* zone; fine-grained gray sand 6 feet thick.
239	14097	370S	Sec. 18, T. 22 S., R. 18 E.; 1,250 feet north, 600 feet east; upper part of west fork of Arroyo Conchoso.
239a	12524	54W	Sec. 18, T. 22 S., R. 18 E.; 100 feet west of locality 239.
239b	12414	250S	Sec. 19, T. 22 S., R. 18 E.; 480 feet south, 330 feet west; west slope of ridge north of La Cima.
240	12522	52W	Sec. 13, T. 22 S., R. 17 E.; 830 feet south, 2,060 feet east; south side of Skyline Road.
241	14098	551aS	Sec. 11, T. 22 S., R. 17 E.; 1,560 feet north, 2,050 feet west; headwaters of south fork of Arroyo Torcido.
242	14099	--------	Sec. 11, T. 22 S., R. 17 E.; 840 feet south, 2,450 feet east; between forks of Arroyo Torcido.
243	12517	48W	Sec. 2, T. 22 S., R. 17 E.; 1,160 feet north, 400 feet east; northeast of Cerro Lodoso.
243a	12518	49W	430 feet south, 100 feet west of locality 243.
244	14127	521S	Sec. 3, T. 22 S., R. 17 E.; 1,910 feet south, 860 feet west; upper part of Arroyo Largo.
245	14102	522S	Sec. 3, T. 22 S., R. 17 E.; 1,560 feet south, 630 feet west; upper part of Arroyo Largo.
247	12398	210S	Sec. 3, T. 22 S., R. 17 E.; 530 feet south, 1,560 feet west; Arroyo Largo, northeast of La Cumbre.
248	12504	32W	Sec. 2, T. 22 S., R. 17 E.; 1,400 feet south, 940 feet east; Arroyo Largo.
249	14100	561S	Sec. 2, T. 22 S., R. 17 E.; 1,880 feet south, 2,260 feet east; west of Double Hill.
250	12400	214S	Sec. 2, T. 22 S., R. 17 E.; 2,060 feet south, 1,050 feet west; north branch of Arroyo Torcido, east of Double Hill. The main fossiliferous ledge contains chiefly single valves of *Pseudocardium* and worn valves of *Cerastoderma*. These species are also present in underlying sand, which contains double-valved specimens of *Lucinoma*.
251	12401	215S	Sec. 1, T. 22 S., R. 17 E.; 2,200 feet north, 2,340 feet west; north of El Taco.
252	12405	222S	Sec. 8, T. 22 S., R. 18 E.; 2,100 feet north, 600 feet east; Arroyo Hondo east of La Cuesta.
252a	12460	223S	Sec. 8, T. 22 S., R. 18 E.; 830 feet north, 1,740 feet east; ridge on southeast side of El Perno.
253	12406	224S	Sec. 16, T. 22 S., R. 18 E.; 2,240 feet south, 870 feet east; north branch of Arroyo Doblegado, southeast of El Rascador. About 60 feet below *Littorina* zone.
			Siphonalia zone
255	14101	560S	Sec. 2. T. 22 S., R. 17 E.; 2,420 feet south, 1,710 feet east; southwest of Double Hill. About 15 feet below blue conglomerate.
256	12804	268bS 216bS	Sec. 2, T. 22 S., R. 17 E.; 2,200 feet north, 2,320 feet east; south of Double Hill.
257	--------	219S	Sec. 2, T. 22 S., R. 17 E.; 2,120 feet north, 2,170 feet east; second ridge southwest of Double Hill. About 60 feet below *Mytilus* layer.
257a	--------	--------	Sec. 2, T. 22 S., R. 17 E.; 1,620 feet north, 1,030 feet east; Arroyo Torcido east of Cerro Lodoso.
258	12404	220S	Sec. 2, T. 22 S., R. 17 E.; 1,370 feet north, 1,770 feet east; Arroyo Torcido, second ridge southwest of Double Hill.
259	--------	--------	Sec. 2, T. 22 S., R. 17 E.; 660 feet north, 1,970 feet east; east of Cerro Lodoso.
260	--------	220a	Sec. 2, T. 22 S., R. 17 E.; 2,440 feet north, 1,300 feet east; Arroyo Torcido basin, northeast of Cerro Lodoso.
261	12820	456S	Sec. 1, T. 22 S., R. 17 E.; 780 feet north, 1,830 feet east; first ridge west of El Taco. *Macoma* zone (?).
262	--------	266S	Sec. 1, T. 22 S., R. 17 E.; 970 feet north, 2,560 feet west; north slope of El Taco.
262a	--------	--------	700 feet southeast of locality 262, southeast side of El Taco. About 100 feet below blue conglomerate.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			ETCHEGOIN FORMATION, NORTH DOME—Continued
			Siphonalia zone—Continued
263	14104	--------	500 feet northwest of locality 300.
264	12826	449aS	Sec. 17, T. 22 S., R. 18 E.; 1,240 feet south, 2,640 feet east; southeast slope of Las Paredes. Lowest of three fossiliferous layers.
264a	14128	264S	Sec. 17, T. 22 S., R. 18 E.; 2,200 feet south, 1,000 feet west; south of El Rascador.
264b	12827	471aS	1,100 feet northwest of locality 264, in road cut on top of Las Paredes and along the crest of the ridge.
265	12448	349S	Sec. 26, T. 22 S., R. 18 E.; 40 feet north, 1,850 feet west; Arroyo Pino, north of Bullwheel Ridge. Light-gray sand with shell fragments; possibly same horizon as locality 266, but it could not be traced through.
266	12815	451S	Sec. 26, T. 22 S., R. 18 E.; 50 feet north, 1,500 feet west; Arroyo Pino, north of Bullwheel Ridge.
266a	12814	451aS	About 200 feet east of locality 266.
267	12407	230S	Sec. 35, T. 22 S., R. 18 E.; 240 feet south, 720 feet west; upper part of Arroyo Pino. Same horizon as locality 266.
268	12412	235S	Sec. 36, T. 22 S., R. 18 E.; 1,540 feet north, 730 feet east; sound end of Bullwheel Ridge, 700 feet north of Arroyo Estrecho. Same as *Mytilus* layer of locality 269.
269	12408	231S	Sec. 36, T. 22 S., R. 18 E.; 840 feet north, 1,380 feet east; canyon of Arroyo Estrecho.
270	12812	410S	Sec. 35, T. 22 S., R. 18 E.; 1,480 feet north, 170 feet west; Arroyo Estrecho, southwest of Broken Hill.
270a	12410	233S	240 feet west of locality 270, at about the same horizon.
270b	--------	--------	1,100 feet west of locality 270, fork of Arroyo Estrecho.
271	--------	--------	Sec. 2, T. 23 S., R. 18 E.; 460 feet south, 760 feet west; east of Pipe Hill.
271a	12809	403S	1,150 feet north of locality 271. Leaves from blue sandstone estimated to be just above horizon of upper *Pseudocardium* zone.
272	--------	450S	Sec. 34, T. 22 S., R. 18 E.; 880 feet south, 1,120 feet west; northeast of Block Hill. Just below *Mytilus* layer.
272a	12413	237S	Sec. 27, T. 22 S., R. 18 E.; 1,160 feet north, 1,000 feet east; head of south fork of Arroyo Robador, east of Cerro Ultimo.
273	12439	340S	Sec. 34, T. 22 S., R. 18 E.; 280 feet south, 1,100 feet west; head of north fork of Arroyo Estrecho, south side of El Campo. *Macoma* zone (?).
274	12444	345S	Sec. 26, T. 22 S., R. 18 E.; 2,280 feet north, 530 feet east; ridge east of El Campo.
274a	12440	341S	Sec. 27, T. 22 S., R 18 E.; 2,300 feet south, 1,440 feet west; El Campo.
275	12459	327S	Sec. 28, T. 22 S., R. 18 E.; 2,300 feet south, 2,400 feet west; head of branch of Arroyo Robador, southeast of Cerro Alto. Below blue conglomerate, at about the same horizon as locality 267a.
275a	14105	275aS	Sec. 21, T. 22 S., R. 18 E.; 400 feet north, 1,120 feet east; Skyline Road, east of El Lobo.
276	--------	326S	Sec. 28, T. 22 S., R. 18 E.; 2,340 feet south, 1,730 feet west; ridge southeast of Cerro Alto. Silt just below blue conglomerate and above marine fossiliferous layers of *Siphonalia* zone.
277	--------	325S	Sec. 27, T. 22 S., R. 18 E.; 2,450 feet south, 50 feet east; south end of Mesa Roida. Below blue conglomerate and above marine fossiliferous layers of *Siphonalia* zone.
278	14106	810S	Sec. 21, T. 22 S., R. 18 E.; 1,900 feet north, 1,640 feet east; divide between Arroyo Robador and Arroyo Doblegado, west of La Muralla. Below blue conglomerate.
278a	--------	802S	Sec. 21, T. 22 S., R. 18 E.; 830 feet north, 2,430 feet west; Arroyo Robador, west of El Lobo.
278b	--------	311S	400 feet southeast of locality 278a.
279	12434	313S	Sec. 21, T. 22 S., R. 18 E.; 1,660 feet north, 1,080 feet west; east end of La Muralla. The double-valve *Mytilus* and *Hinnites* are filled with greenish clay.
280	12433	312S	Sec. 21, T. 22 S., R. 18 E.; 1,800 feet north, 500 feet west; east end of La Muralla.
281	--------	--------	Sec. 20, T. 22 S., R. 18 E.; 2,040 feet south, 710 feet west; east of La Meseta and just below Skyline Road. About 25 feet below a *Pseudocardium* layer.
282	12464	305S	Sec. 20, T. 22 S., R. 18 E.; 1,710 feet south, 2,420 feet west; ridge east of La Meseta.
282a	12431	306S	200 feet northwest of locality 282, at practically the same horizon.
283	12712	86T	Sec. 20, T. 22 S., R. 18 E.; 80 feet south, 200 feet west; south side of La Aleta.
284	12430	304S	Sec. 17, T. 22 S., R. 18 E.; 840 feet north, 2,780 feet east; La Aleta.
285	12425	294S	Sec. 18, T. 22 S., R. 18 E.; 820 feet south, 1,440 feet west; north side of La Cuna.
285a	--------	--------	200 feet west of locality 285. Probably *Siphonalia* zone.
286	--------	--------	Sec. 7, T. 22 S., R. 18 E.; 450 feet north, 2,540 feet west.
287	12393	204S	Sec. 13, T. 22 S., R. 17 E.; 1,730 feet south, 1,240 feet west; Los Jinetes.
288	14109	545S	Sec. 12, T. 22 S., R. 17 E.; 860 feet north, 2,570 feet east; ridge extending northwest from La Tusa.
288a	--------	--------	Road cut east end of La Tusa, 1,300 feet southeast of locality 288.
289	--------	546S	Sec. 12, T. 22 S., R. 17 E.; 390 feet north, 1,100 feet east; ridge north of El Chichon. Just beneath blue conglomerate and above marine fossiliferous layer.
290	14107	547S	Sec. 12, T. 22 S., R. 17 E.; 1,280 feet north, 490 feet east; west side of ridge extending north from El Chichon.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			ETCHEGOIN FORMATION, NORTH DOME—Continued
			Siphonalia zone—Continued
291	--------	272yS	Sec. 12, T. 22 S., R. 17 E.; 2,450 feet south, 2,480 feet west; La Loba, top of 1,211-foot hill. Mastodon molar fragments.
292	--------	207S	Sec. 12, T. 22 S., R. 17 E.; 2,040 feet south, 2,310 feet east; La Loba. Pebbly brown sandstone layer about a foot thick. The *Forreria* was collected from silt just below this layer.
293	12418	268S	Sec. 12, T. 22 S., R. 17 E.; 120 feet south, 1,880 feet west; 800 feet northeast of La Clavija. Apparently near base of *Siphonalia* zone.
294	14108	552S	Sec. 11, T. 22 S., R. 17 E.; 1,900 feet north, 1,200 feet west; headwaters of south fork of Arroyo Torcido. About 100 feet below blue conglomerate. The sand dollars were found below the clams.
294a	12397	209S	On ridge 800 feet northwest of locality 294.
294b	--------	--------	300 feet northwest of locality 294.
295	--------	--------	Sec. 11, T. 22 S., R. 17 E.; 1,680 feet south, 1,820 feet west; east of Standard Oil Co. camp. About 15 feet below blue conglomerate and 40 feet above *Mytilus*-barnacle layer.
296	--------	553S	Sec. 11, T. 22 S., R. 17 E.; 800 feet south, 1,340 feet west; southwest of Discovery Ridge.
297	12818	454S	200 feet north and 50 feet east of locality 296.
298	12817	453aS	Sec. 11, T. 22 S., R. 17 E.; 180 feet south, 2,040 feet west; west of discovery well. Probably at same horizon as locality 297.
299	--------	520S	Sec. 2, T. 22 S., R. 17 E.; 580 feet north, 1,140 feet east; Arroyo Torcido, southeast of Cerro Lodoso. About 20 feet below blue conglomerate.
299a	--------	--------	170 feet east and a little north of locality 299. About 30 feet below blue sandstone.
			See also localities 238b and 333a.
			Macoma zone
300	14131	--------	Sec. 7, T. 22 S., R. 18 E.; 1,200 feet north, 1,840 feet west; south side of El Tolete. Top of *Macoma* zone.
300a	14130	--------	900 feet northwest of locality 300; below the road west of El Tolete. Near base of *Macoma* zone.
300b	14129	--------	Same as locality 300a; from underlying *Patinopecten* zone.
300c	13791	56W	Sec. 7, T. 22 S., R. 18 E.; 750 feet north, 600 feet west; southeast of El Tolete. Barnacle layer underlying *Patinopecten* zone.
301	14110	595bS	Sec. 18, T. 22 S., R. 18 E.; 110 feet south, 1,940 feet west; head of Arroyo Hondo, southeast of El Tolete. Phosphatic nodules from base of blue sandstone resting on *Macoma* zone.
302	--------	460S	Sec. 12, T. 22 S., R. 17 E.; 1,930 feet south, 2,180 feet east; Arroyo Murado, south of La Clavija. Near base of *Macoma* zone.
302a	--------	--------	Sec. 12, T. 22 S., R. 17 E.; 940 feet south, 2,440 feet west; west slope of La Clavija.
302b	14111	--------	Sec. 1, T. 22 S., R. 17 E.; 1,000 feet north, 2,240 feet east; in road cut. About 20 feet above base (?) of *Macoma* zone.
303	14112	543S	Sec. 12, T. 22 S., R. 17 E.; 980 feet north, 2,220 feet west; south fork of Arroyo Torcido, north of La Tusa.
305	12416	265S	Sec. 1, T. 22 S., R. 17 E.; 880 feet north, 920 feet east; east end of Discovery Ridge.
306	12424	280S	Sec. 7, T. 22 S., R. 18 E.; 780 feet north, 1,880 feet east; south slope of east end of El Serrijon.
306a	12421	274S	180 feet southeast of locality 290.
			See also localities 261, 273, 283, 314a, 321, and 342a.
			Patinopecten zone and underlying strata
307	14113	307S	Sec. 17, T. 22 S., R. 18 E.; 710 feet south, 1,220 feet east; just above road on west side of Las Paredes.
308	12426	297S	500 feet south of locality 264, branch of Arroyo Doblegado, southeast of Las Paredes. About 20 feet below barnacle layer.
308a	12426a	--------	Worn fossils in cross-bedded sand just above barnacle layer at locality 308.
309	14115	704S	Sec. 17, T. 22 S., R. 18 E.; 2,290 feet north, 1,130 feet west; west fork of Arroyo Doblegado, north of La Aleta. *Pseudocardium* layer about 50 feet below barnacle layer.
309a	--------	--------	Barnacle layer 400 feet northeast of locality 309.
310	12435	316S	Sec. 22, T. 22 S., R. 18 E.; 1,480 feet north, 580 feet east; Arroyo Robador below east end of La Muralla. Barnacle layer.
312	12437	324S	Sec. 27, T. 22 S., R. 18 E.; 1,560 feet south, 1,620 feet east; Arroyo Robador east of Mesa Roida. Barnacle layer.
313	12445	346S	Sec. 35, T. 22 S., R. 18 E.; 920 feet south, 610 feet east; northeast of Block Hill. Just below *Macoma* zone (?).
314	12429	303S	Sec. 20, T. 22 S., R. 18 E.; 130 feet south, 2,640 feet east; branch of Arroyo Doblegado, south of La Aleta. About 40 feet below *Macoma* zone (?).
314a	--------	--------	1,300 feet northwest of locality 314; in road cut. Diatoms in andesitic tuffaceous sand near base of *Macoma* zone.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			ETCHEGOIN FORMATION, NORTH DOME—Continued
			Patinopecten zone and underlying strata—Continued
315	14117	301aS	Sec. 16, T. 22 S., R. 18 E.; 730 feet north, 450 feet east; ridge on east side of La Aleta. About 10 feet below *Macoma* zone.
316	12711	85T	450 feet southeast of locality 315, east of La Aleta. Barnacle layer.
317	12428	301S	Sec. 17, T. 22 S., R. 18 E.; 1,780 feet north, 60 feet west. About 10 feet above barnacle layer.
317a	12428a	300S	220 feet northwest of locality 317.
318	--------	703S	270 feet northwest of locality 319, ridge just south of west fork of Arroyo Doblegado and south of El Rascador.
319	--------	302S	Sec. 16, T. 22 S., R. 18 E.; 1,880 feet north, 110 feet east; fork of Arroyo Doblegado northeast of La Aleta. About 40 feet above barnacle layer.
319a	--------	--------	About 200 feet east of locality 319, and about 10 feet higher stratigraphically.
320	--------	295S	Sec. 17, T. 22 S., R. 18 E.; 2,230 feet south, 340 feet east; La Cuna. Barnacle layer.
320a	12715	88T	200 feet west of locality 320.
321	--------	--------	Sec. 17, T. 22 S., R. 18 E.; 2,060 feet north, 1,240 feet east; west of La Aleta. Base of *Macoma* zone.
322	14118	380S	Sec. 18, T. 22 S., R. 18 E.; 210 feet south, 240 feet east; upper part of Arroyo Murado, northwest of El Pulgar.
323	14119	523S	Sec. 12, T. 22 S., R. 17 E.; 200 feet north, 780 feet west; east slope of La Tusa. Worn specimens at base of *Patinopecten* zone.
328	14120	544S	Sec. 12, T. 22 S., R. 17 E.; 1,900 feet north, 1,030 feet west; west side of Arroyo Murado. Pebbly, silty sand about 25 feet above barnacle layer (?).
329	14121	562S	Sec. 7, T. 22 S., R. 18 E.; 1,680 feet south, 60 feet east; Arroyo Murado, southeast of La Clavija.
330	14122	563S	160 feet southwest of locality 329; Arroyo Murado, southeast of La Clavija. Barnacle layer.
332	12828	269S	Sec. 12, T. 22 S., R. 17 E.; 1,480 feet south, 1,520 feet west.
333	12420	273S	Sec. 12, T. 22 S., R. 17 E.; 1,730 feet south, 1,760 feet east.
333a	--------	--------	About 650 feet northeast of locality 333, road cut in canyon locally known as Cable Canyon, west of El Taco. Probably *Siphonalia* zone.
335	12819	455S	Sec. 12, T. 22 S., R. 17 E.; 820 feet south, 1,100 feet east.
336	12423	276S	Sec. 12, T. 22 S., R. 17 E.; 120 feet south, 1,540 feet east; south fork of Arroyo Torcido northwest of La Clavija. Barnacle layer.
337	12422	275S	Sec. 11, T. 22 S., R. 17 E., 2,510 feet north, 850 feet west; south fork of Arroyo Torcido, east of Standard Oil Co. camp. Barnacle layer.
338	--------	550S	Sec. 11, T. 22 S., R. 17 E., 1,860 feet south, 110 feet west; south fork of Arroyo Torcido. Possibly just below *Patinopecten* zone.
338a	14132	511S	500 feet south of locality 338.
340	14123	548S	Sec. 12, T. 22 S., R. 17 E.; 2,620 feet north, 1,280 feet east; south fork of Arroyo Torcido. About 50 feet above barnacle layer.
342	12403	217S	Sec. 2, T. 22 S., R. 17 E.; 1,380 feet north, 2,140 feet west; Arroyo Torcido, south of Double Hill. 25 feet below *Macoma* zone (?).
342a	14138	--------	North side of Arroyo Torcido, 1,000 feet east of locality 342. Near base of *Macoma* (?) zone.
343	12441	342S	Sec. 26, T. 22 S., R. 18 E.; 2,040 feet north, 40 feet east; lower fork of Arroyo Robador, east of El Campo. About 40 feet below *Macoma* zone and just below a sand bearing sand dollars.
			See also locality 300b.
			ETCHEGOIN FORMATION, MIDDLE AND SOUTH DOMES
344	12662	123W	Middle Dome, sec. 24, T. 23 S., R. 18 E., on north section line, 460 feet west; Arroyo Culebrino. *Pseudocardium-Anadara* zone.
345	12719	73W	Middle Dome, sec. 19, T. 23 S., R. 19 E.; 260 feet south, 830 feet east; hill south of Arroyo Culebrino. *Pseudocardium-Anadara* zone.
346	12640	74W	Middle Dome, sec. 19, T. 23 S., R. 19 E.; 1,370 feet north, 1,430 feet west; north of La Escudilla. *Pseudocardium-Anadara* zone.
347	12643	86W	South Dome, sec. 27, T. 24 S., R. 19 E.; 400 feet south, 600 feet east; east of Oyster Hill. *Pseudocardium-Anadara* zone.
348	12644	87W	South Dome, sec. 27, T. 24 S., R. 19 E.; 2,390 feet south, 790 feet west; highway southeast of Oyster Hill. *Pseudocardium-Anadara* zone.
348a	--------	150aW	Middle Dome, sec. 5, T. 24 S., R. 19 E.; 1,450 feet south, 2,100 feet west; west slope of Pintojo Ridge. Below *Pseudocardium-Anadara* zone.
349	--------	133W	Middle Dome, sec. 4, T. 24 S., R. 19 E.; 2,560 feet south, 1,250 feet west; ridge northwest of Boulder Hill. Sandstone between *Pseudocardium-Anadara* zone and *Pseudocardium*-bearing conglomerate.
350	--------	150W	Middle Dome, sec. 5, T. 24 S., R. 19 E.; 1,710 feet south, 800 feet west; Pintojo Ridge. Sandstone between *Pseudocardium-Anadara* zone and *Pseudocardium*-bearing conglomerate.

Fossil localities—Continued

This report No.	Permanent Geological Survey No.	Field No.	Locality data
			ETCHEGOIN FORMATION, MIDDLE AND SOUTH DOMES—Continued
351	12665	128W	Middle Dome, sec. 29, T. 23 S., R. 19 E.; 2,650 feet north, 1,510 feet west; Parejo Hill. *Pseudocardium*-bearing conglomerate.
352	12666	129W	Middle Dome, sec. 33, T. 23 S., R. 19 E.; 2,070 feet south, 1,450 feet east; south of Arroyo Recodo. *Pseudocardium*-bearing conglomerate.
353	12667	130W	Middle Dome, sec. 33, T. 23 S., R. 19 E.; 1,850 feet north, 2,070 feet east; south of Arroyo Recodo. *Pseudocardium*-bearing conglomerate.
354	12671	139W	Middle Dome, sec. 32, T. 23 S., R. 19 E.; 1,750 feet north, 350 feet east. *Pseudocardium*-bearing conglomerate.
355	12837	148W	Middle Dome, sec. 32, T. 23 S., R. 19 E.; 950 feet north, 2,570 feet west. *Pseudocardium*-bearing conglomerate.
356	12838	149W	Middle Dome, sec. 32, T. 23 S., R. 19 E.; 400 feet north, 2,250 feet west. *Pseudocardium*-bearing conglomerate.
357	12672	140W	Middle Dome, sec. 19, T. 23 S., R. 19 E.; 1,720 feet south, 630 feet east; hill south of Arroyo Culebrino. Below *Pseudocardium*-bearing conglomerate.
358	12673	141W	Middle Dome, sec. 32, T. 23 S., R. 19 E.; 1,530 feet north, 1,740 feet west. Below *Pseudocardium*-bearing conglomerate.
359	12642	77W	South Dome, sec. 28, T. 24 S., R. 19 E.; 350 feet south, 1,100 feet west; road west of Oyster Hill. *Pseudocardium*-bearing sandstone.
360	12641	75W	South Dome, sec. 28, T. 24 S., R. 19 E.; 430 feet south, 210 feet west; Oyster Hill. *Pseudocardium*-bearing sandstone.
361	[1] 1058	79W	South Dome, sec. 11, T. 25 S., R. 19 E.; 2,330 feet north, 460 feet east; hill east of Los Morones. Below horizon of *Pseudocardium*-bearing sandstone.
362	12716	1G	Middle Dome, sec. 32, T. 23 S., R. 19 E.; 370 feet south, 1,220 feet west; north of Arroyo Recodo. Lower part of Etchegoin.
363	12647	93W	South Dome, sec. 34, T. 24 S., R. 19 E.; 450 feet south, 2,440 feet west; Las Lomas. Lower part of Etchegoin.
364	[1] 1060	94W	South Dome, sec. 34, T. 24 S., R. 19 E.; 1,700 feet north, on east section line. Lower part of Etchegoin.
365	12646	92W	South Dome, sec. 34, T. 24 S., R. 19 E.; 220 feet north, 1,630 feet west. Lower part of Etchegoin.
366	12650	98W	South Dome, sec. 11, T. 25 S., R. 19 E.; 300 feet south, 1,070 feet west; ridge south of El Vejon. Lower part of Etchegoin.
367	12651	99W	South Dome, sec. 11, T. 25 S., R. 19 E.; 500 feet south, 950 feet west; ridge south of El Vejon. Lower part of Etchegoin.
368	12652	100W	South Dome, sec. 2, T. 25 S., R. 19 E.; 690 feet north, 1,670 feet west; ridge south of El Vejon. Lower part of Etchegoin.
369	12649	97W	South Dome, sec. 11, T. 25 S., R. 19 E.; 170 feet south, 850 feet west; ridge south of El Vejon. Lower part of Etchegoin.
370	12648	96W	South Dome, sec. 1, T. 25 S., R. 19 E.; 320 feet north, 550 feet east; east slope of ridge south of El Vejon. Lower part of Etchegoin.
			See also locality 199a.

[1] U. S. Geol. Survey diatom locality number.

INDEX

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