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ANDREW C. LAWSON
EDITOR

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THE FRANCISCAN SANDSTONE

BY
E. F. DAVIS

UNIVERSITY OF CALIFORNIA PRESS
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THE FRANCISCAN SANDSTONE

BY
E. F. DAVIS

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INTRODUCTION

The Franciscan group, named from its occurrence near San Francisco, presents a variety of peculiar rock types, the uniformity of the occurrences of which is remarkable. Throughout its wide extent in the Pacific Coast Ranges it shows everywhere identical lithologic types; rocks occurring in one limited area of the Franciscan may be duplicated by identical rocks from almost any other area. The Franciscan sandstone, which is one of the most important formations of the group, shows many features not exhibited by ordinary sandstones.

The material presented in the following pages is the result of a study of the Franciscan sandstone made in connection with an investigation of the radiolarian cherts of the Franciscan group.

The writer would make grateful mention of his obligation to Professor A. C. Lawson, for numerous suggestions made during the progress of the work.

THE FRANCISCAN GROUP IN CALIFORNIA

Extent

Rocks of the Franciscan group are exposed over large areas in the Coast Ranges of California. On the mainland, the Franciscan terrane extends from the Santa Ynez River, just north of Santa Barbara, northward into Humboldt County.[1] Franciscan rocks are known on Santa Catalina Island. The Franciscan is confined, as a general rule, to the central portions of the mountain chains where it appears beneath the later sedimentary rocks which are exposed on the flanks.

[1] Fairbanks states on authority of Watts that jaspers and sandstones like the Franciscan have been observed in Del Norte County along the Oregon line. Bull. Geol. Soc. Am., vol. 6, p. 82, 1895.

SEDIMENTARY ROCKS

The total thickness of the sedimentary portion of the Franciscan group varies considerably in the different areas where it has been studied. Professor Lawson measured a section over 6000 feet in thickness in the region of San Francisco.[2] C. F. Tolman, Jr., described a measured section having a minimum thickness of 15,000 feet at Corral Hollow near Livermore.[3] Here neither the top nor the bottom of the section is exposed. Templeton reports a thickness of 15,000 to 20,000 feet in the region of Mount Hamilton.[4] Fairbanks measured a thickness of about 10,000 feet in the neighborhood of San Luis Obispo.[5]

The sedimentary portion of the Franciscan group includes arkose sandstones with some shale and small amounts of conglomerate, radiolarian cherts, and foraminiferal limestones.

The sandstones are, as a rule, poorly stratified and have yielded only a few indeterminate fossils, so that the details of the stratigraphy are often difficult or impossible of determination. In the region around San Francisco, the alternation of sandstones with formations of radiolarian chert enables the sandstone to be separated into distinct formations.

The lowest portion of the Franciscan group, exposed in the region of San Francisco, is a sandstone called the Cahil sandstone. This is divided by a limestone member about sixty feet thick. This limestone—the Calera limestone—shows numerous foraminifera. It is usually white to dark gray in color, but is sometimes black and fetid. It contains considerable amounts of silica in the form of nodules, patchy lenses, and anastomosing, blanket-like masses of chert. The long direction of the blanket-like masses is approximately parallel to the bedding. The chert is often black in color, sometimes pale gray, and rarely greenish. Below the limestone member there are 500 feet of sandstone. The base of the formation is nowhere visible. Above the limestone member there are 2000 feet of sandstone, making a total exposed thickness of 2560 feet for the Cahil sandstone. Above the Cahil sandstone is the Sausalito chert, composed of radiolarian chert of various kinds, having a thickness of about 900 feet. Above the

[2] San Francisco Folio, U. S. Geol. Surv., Folio no. 193, 1914.

[3] Nature and Science on the Pacific Coast. San Francisco, Elder, 1915.

[4] Templeton, E. C., The Mount Hamilton and San Jose Quadrangles, Bull. Geol. Soc. Am., vol. 24, p. 96, 1913.

[5] San Luis Folio, U. S. Geol. Surv., Folio no. 101, 1904.

Sausalito chert is another formation of sandstone, known as the Marin sandstone, about 1000 feet thick. This is succeeded by another formation of radiolarian chert—the Ingleside chert—having a thickness of 530 feet. The upper member of the group is the Bonita sandstone, about 1400 feet thick. The three sandstone formations are so much alike that they cannot be distinguished on the basis of lithology, and the same thing is true of the two chert formations. Except for the general stratigraphic relations, one cannot tell with which formation of chert or sandstone he has to deal.

Near Corral Hollow, there are three formations in the Franciscan group.[6] The lowest formation is a dense blue sandstone, cut by many intersecting quartz veinlets. Above this are the Corral Hollow shales, which contain crumpled beds of radiolarian cherts. The upper member of the group is the Oakridge sandstone, which is slightly metamorphosed. The top and bottom of the section are not exposed.

In the San Luis Quadrangle,[7] the Franciscan—called there the San Luis formation—is represented by about 10,000 feet of sandstone, in which there are numerous scattered lenses of radiolarian chert.

Igneous Rocks

Beside the sedimentary rocks of the Franciscan group there are certain igneous rocks, intimately associated with the sediments, which appear to have been intruded into the sediments shortly after their deposition.

The first of these intrusives occurs in irregular masses and consists of basalt and diabase, often characterized by a "pillow-form," or ellipsoidal structure. These rocks are commonly referred to as the "pillow basalts." Numerous well exposed sections at Hunter's Point, Angel Island, Point Bonita, Mount Diablo, and in the Santa Ynez Mountains, and other parts of the Coast Ranges, leave no doubt as to the *intrusive* nature of a large part of these pillow basalts. Certain other occurrences show no evidence of intrusive action and represent contemporaneous lavas, extruded during the deposition of the Franciscan sediments.

The basalts and diabases are associated with intrusions of peridotite. These peridotites are now largely altered to serpentine, which forms a conspicuous feature of the Franciscan terrane. Gabbros, pyroxenites, and related rocks are found intrusive into the Franciscan,

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[6] Tolman, *op. cit.*

[7] San Luis Folio, U. S. Geol. Surv., vol. 101, 1904.

often intimately associated with the serpentine, and in some instances the relations are such as to indicate a genetic relation between these igneous rocks.

Metamorphic Rocks

In close association with the intrusive masses of ellipsoidal basalt and of serpentine, there are local and irregular patches of peculiar metamorphic rocks, which appear to have been produced by contact action at or near the margins of the intrusives. The most common type of these rocks is a blue schist, composed largely of blue amphiboles,[8] of which glaucophane, crossite, and crocidolite[9] are the most common varieties.[10] Mica schists, lawsonite schists, actinolite schists and many other types are encountered in rich variety. They are in many cases characterized by abundant albite and are at many localities cut by veins of albite. The glaucophane schists are peculiar to the Franciscan group, not being found in other formations in California.

THE FRANCISCAN GROUP IN SOUTHERN OREGON

North of Humboldt County, rocks believed to be Franciscan are again encountered in the southern end of the Oregon Coast Range.[11] The sandstone here is the arkosic, well lithified, quartzite-like sandstone, characteristic of the Franciscan group. Scattered through this at irregular intervals are thin lenses of conglomerate. The formation contains occasional lentils of cherty, foraminiferal limestone, apparently identical with the foraminiferal limestone of the San Francisco Peninsula. The characteristic radiolarian cherts occur in isolated patches.

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[8] Murgoci, G., I. Contribution to the Classification of the Amphiboles; II. On some Glaucophane Schists, Syenites, etc., Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, p. 359, 1906.

[9] Louderback, G. D., and Sharwood, W. J., The Crocidolite-bearing rocks of the California Coast Ranges (Abstract), Bull. Geol. Soc. Am., vol. 18, p. 659, 1907.

[10] While these schists contain blue amphiboles other than glaucophane, the writer will, in the following discussion, adopt the common usage and use the term ''glaucophane schist'' as a general expression for these rocks.

[11] Diller, J. S., Geology of Northwestern Oregon, U. S. Geol. Surv., 17th Ann. Rep., pt. 1, 1895–6.

—Roseberg Quadrangle, U. S. Geol. Surv., Folio no. 49, 1898.

—Coos Bay Quadrangle, *ibid.*, Folio no. 73, 1901.

—Port Orford Quadrangle, *ibid.*, Folio no. 89, 1903.

—The Relief of Our Pacific Coast, Science, n. s., vol. 41, p. 48, 1915.

Louderback, G. D., The Mesozoic of Southwestern Oregon, Jour. Geol., vol. 13, p. 514, 1905.

Associated with these sediments, are the usual peculiar types of igneous rocks, including greenstones, gabbros, and serpentine, with some diabase and quartz diorite, together with areas of dacite-andesite. Glaucophane schists, glaucophane-garnet schists, actinolite schists, and many other types consisting of varying proportions of quartz, garnet, epidote, actinolite, chlorite, mica, and glaucophane are found in small sporadic bodies. They occur in such a way as to indicate that they were produced by contact metamorphic action of the basic intrusive rocks.

The extent of the belt of Franciscan areas running from southern Oregon to southern California is nearly 750 miles.

THE FRANCISCAN GROUP IN WASHINGTON

Between southern Oregon and the Olympic Mountains, no Franciscan has been reported, but Franciscan rocks make up a large part of the Olympic Mountains.[12] Mount Olympus consists of a complex mass of metamorphic sandstone, shale, radiolarian chert, glaucophane schist, and greenstone, cut by serpentine.[13] All the rocks closely resemble the Franciscan in the California Coast Ranges.

The total extent of the Franciscan, so far as it is now known, is from the Olympic Mountains to southern California, a distance of a little over 1000 miles.

THE AGE OF THE FRANCISCAN GROUP

Difficulties Encountered

As will appear later, it would be very helpful in discussing the origin of the Franciscan sandstone, if some definite statement could be made as to its age. It would then be possible to fix in a general way, some of the conditions which obtained at the time of deposition of the sandstone.

The Franciscan is sometimes referred to the Jurassic, but its age has never been determined with certainty, since various ways of approaching the problem give contradictory results. The radiolaria in the cherts are not distinctive enough to permit a determination of the age of the formation. The limestones have yielded no fossils other than the foraminifera, and these are of no value for age deter-

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12 Diller, J. S., Science, vol. 41, p. 55, 1915.

13 *Ibid.*, Guide Book to Western United States, U. S. Geol. Surv., Bull. 614, p. 13, 1915.

mination. A few fossils have been found in the sandstones and shales, but they are exceedingly rare, and those which are found appear to be of unusual types and not identifiable with certainty. Age determination by means of fossils is at present impossible. About the only point upon which all agree, is that the fossils belong to the Mesozoic and cannot be older.

The stratigraphic relations are not of much value at the present time for the reason, brought out later, that there is still some uncertainty as to the exact age of both the overlying and underlying rocks.

Stratigraphic Relations

OVERLYING ROCKS

Overlying the Franciscan, is the Knoxville formation, which consists principally of dark shales with limestone lentils and concretions together with some peculiar greenish sandstones. The Knoxville formation rests with angular unconformity on the rocks of the Franciscan group and numerous sections have been described in the Coast Ranges of California where this unconformable relationship has been clearly demonstrated.

UNDERLYING ROCKS

The oldest rocks of the California Coast Ranges are limestones, with some quartzites and schists, intruded by granite. These rocks are exposed at various points through the Coast Ranges. They are seen, for example, at Montara Mountain south of San Francisco, and in the Santa Cruz Mountains north of Santa Cruz, also in the Gavilan and Santa Lucia Ranges in San Benito and Monterey Counties, where they probably reach their maximum development. While the Franciscan group appears almost certainly to be younger than these rocks, it is remarkable that no contact has yet been found between this older group and the Franciscan group. Perhaps further exploration of the little-studied areas in the Gavilan and Santa Lucia Ranges or in Humboldt County may reveal a place where these two groups of rocks actually come in contact at the surface.

Fairbanks[14] described in the region of Slate's Springs in the Santa Lucia Range, a coarse conglomerate of rounded granite boulders in a matrix of arkosic sandstone, having a thickness of 1000 feet and traceable for several miles. This rests on the granite and he regarded

[14] Fairbanks, H. W., Bull. Geol. Soc. Am., vol. 6, p. 82, 1895.

it as the basal conglomerate of the Franciscan. J. O. Nomland,[15] who worked in the region during the summer of 1915, found that this conglomerate is actually younger than the Franciscan and that the position has been reversed by a thrust fault which also brought up areas of granite and old schist above the rocks of the Franciscan group.

The supposed basal conglomerate of the Franciscan at Montara Mountain has been found to be a later formation wedged in by faulting.[16]

In spite of the non-discovery of actual contacts of these two groups of rocks, it is almost certain that the Franciscan is not intruded by the granite, but rests unconformably above it. The considerations which prove this have been summarized by Professor Lawson.[16]

Evidence as to Age of the Franciscan in the California Coast Ranges

The Knoxville formation has commonly been regarded as representing the lowest Cretaceous, so that the stratigraphic relations as outlined above, indicate that the Franciscan must be pre-Cretaceous.

CONCLUSIONS BASED ON RELATION TO GRANITE

The Coast Range granite[17] is exposed at various points throughout the Coast Ranges, and at the southern end of these mountains it apparently continues through the region of Tejon Pass and Tehachapi Pass into the southern Sierra Nevada. If the apparent relation be the true one, then the Coast Range granite must be contemporaneous with the granite of the Sierra Nevada.

The figures 1 and 2 are diagrammatic representations of the relations in the Sierra Nevada and in the Coast Ranges.

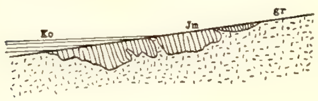

Fig. 1

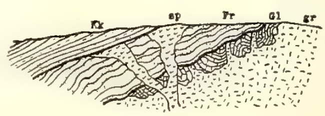

Fig. 2

Fig. 1. Diagrammatic section showing the relation of formations in the Sierra Nevada. Kc—Chico; Jm—Mariposa Slates; gr—Sierra Nevada Granite, intrusive into the Mariposa Slates.

Fig. 2. Diagrammatic representation of the relation of formations in the California Coast Ranges. Kk—Knoxville; Fr—Franciscan Group; sp—serpentine; Gl—Gavilan limestone; gr—Coast Range Granite.

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[15] J. O. Nomland. Unpublished Manuscript.

[16] Lawson, A. C., San Francisco Folio, U. S. Geol. Surv., Folio no. 193, 1914.

[17] In this discussion "granite" is used as a general term to include the various plutonic types which make up the Coast Range and Sierra Nevada granitic areas.

In the Sierra Nevada, the rocks of the Upper Cretaceous Chico formation are found resting on the eroded surface of the granite. This granite has been intruded into the older rocks of the region; the youngest group that it has cut, is the Jurassic Mariposa formation. The Mariposa slates contain a fauna that has been regarded as late Jurassic, since it includes several ammonites which are characteristic of the late Jurassic all over the world.[18]

These facts limit the period of the intrusion of the Sierra Nevada granite to the interval between the end of the Jurassic and the Upper Cretaceous. A considerable erosion interval, during which the granite was revealed, must have elapsed between the intrusion and the deposition of the Chico. It is generally assumed that the intrusion of this granite and the folding of the rocks of the basement complex of the Sierra Nevada occurred during the widespread earth movements that are known to have followed the close of the Jurassic throughout western North America. During early and middle Cretaceous the region which is now the Sierra Nevada was probably undergoing erosion. On the basis of the foregoing facts and assumptions regarding the age of the Sierra Nevada granite, and assuming the contemporaneous intrusion of the Coast Range granite, it would follow that the Franciscan formation must be post-Jurassic. As before stated, its relation to the Knoxville suggests that it must be pre-Cretaceous.

If this reasoning be correct it means that in the interval of time between the close of the Jurassic and the beginning of the Cretaceous there occurred:

1. The intrusion of the granite, with the probable production of a mountain range near the site of the present Coast Ranges.
2. The erosion of the region and the exposure of the granite.
3. The deposition of Franciscan sediments to a thickness of from one to four miles.
4. The intrusion of these sediments by basic igneous rocks and their disturbance by crustal movements.
5. Their erosion in pre-Knoxville time.

All these occurrences took place before the beginning of the Lower Cretaceous as now recognized. As Professor Lawson has pointed out, this complexity of events would seem to require the extension of the geological time scale at the interval between the recognized Cretaceous and the Jurassic.

[18] Stanton cited by Diller in Bull. Geol. Soc. Am., vol. 19, p. 399, 1908.

POSSIBILITY OF DIFFERENT PERIODS OF GRANITIC INVASION

It may be that the continuity of granite from the Sierra Nevada into the Coast Ranges is only apparent, and there are really two distinct periods of plutonic activity in the two regions.

As will be indicated below, certain paleontologists do not agree that the Knoxville belongs entirely to the Lower Cretaceous, but are inclined to correlate the lower Knoxville with the Upper Jurassic Mariposa, and place the upper Knoxville in the Lower Cretaceous. If this be correct, then it follows that the two granites cannot be of the same age, but the granite of the Coast Ranges must be the older.

It is possible that the Coast Range granite is a product of the same cycle of events that produced the granite of the Sierra Nevada. We may imagine that the intrusion was a progressive process which began in the northern Coast Ranges and gradually spread southward and around into the Sierra Nevada. However, the proximity of the Franciscan to granite masses in the San Emigdio Range in the southern Coast Ranges is opposed to this. Nowhere does the Franciscan show any evidence of intrusion by granite; it always shows evidence of being derived in large part from granite.

It is also possible that the Coast Range granite is a separate and independent intrusion and has no relation to anything in the Sierra Nevada. In this event, as far as stratigraphic relations are concerned, the Franciscan group might be Jurassic, Triassic, or even earlier. The fossil evidence, however, limits it to the Mesozoic.

The presence in the Sierra Nevada of an older granite intruded at the end of Carboniferous time, suggests another way out of the difficulty.[19] The Coast Range granite may belong to the earlier period and there may be no equivalent of the post-Mariposa granite in the Coast Ranges. In the southern Sierra Nevada the granite may belong to the earlier period and this older granite may be the one which can be traced into the Coast Ranges. It should be pointed out, however, that the whole of the granitic area of the southern Sierra Nevada cannot be pre-Mesozoic. The Mineral King belt of rocks is in part Triassic[20] and the granite in which it lies is post-Triassic.

[19] The presence of this earlier granite in the Sierra Nevada has been referred to in several of the Gold Belt Folios of the United States Geological Survey.

[20] Turner, H. W., Rocks of the Sierra Nevada, 14th Ann. Rep., U. S. Geol. Surv., pt. 2, p. 451, 1892–93.

EVIDENCE REGARDING THE AGE OF THE FRANCISCAN AT SLATE'S SPRINGS

At Slate's Springs in Monterey County, on the west flank of the Santa Lucia Range, there occurs an area of Franciscan rocks which is of great interest on account of its fossil content. The Franciscan here consists principally of sandstones and slates. The "slates" are somewhat altered shales in which there is a slight development of slaty cleavage. They are well bedded and contain lenses of radiolarian chert. The sandstones contain lenses of conglomerate and also a few thin seams of coal. The whole is intruded by serpentine. This is the best fossil locality known in the Franciscan, so far as explorations have yet gone. The fauna of these beds has been examined by various paleontologists.

In 1895, Stanton[21] reported to Fairbanks that the beds contained an *Inoceramus*, which limited them to the Mesozoic. None of the fossils were like any which had been previously described. He believed the *Inoceramus* to be similar to one form in the Cretaceous beds at Vancouver, but he was inclined to regard the fauna as Jurassic on account of the stratigraphic relations; the other fossils did not conflict with this interpretation.

In 1896, Professor J. C. Merriam[22] stated that the fauna was of Cretaceous rather than Jurassic aspect.

C. H. Davis[23] described some of the fossils from the Slate's Springs locality and concluded from his study that the beds there were not higher than the lower Upper Jurassic; and he rather doubtfully assigned them to the Middle Jurassic.

The beds at Slate's Springs contain a number of plant remains and it was hoped that a study of this flora would give definite information as to their age. The Jurassic flora is highly developed, world-wide in its distribution, and contains forms which are easily identified.[24] However, this hope is not realized and it appears that the flora from Slate's Springs is not that which is so characteristic of the Jurassic, though it has been referred to that period.

In 1896, Ward[25] suggested that the flora was that of a transition between the Cretaceous and the Jurassic.

[21] Jour. of Geol., vol. 3, p. 423, 1895.

[22] 20th Ann. Rep., U. S. Geol. Surv., pt. 2, pp. 338, 339, 1896.

[23] Davis, C. H., New Species from the Santa Lucia Mountains, California, with a Discussion of the Jurassic Age of the Slates at Slate's Springs, Jour. Geol., vol. 21, p. 453, 1913.

[24] Knowlton, F. H., Am. Jour. Sci., vol. 30, p. 47, 1910.

Fontaine[25] was inclined to refer the plant remains to the lowest Cretaceous, but believed it possible that they might be uppermost Jurassic.

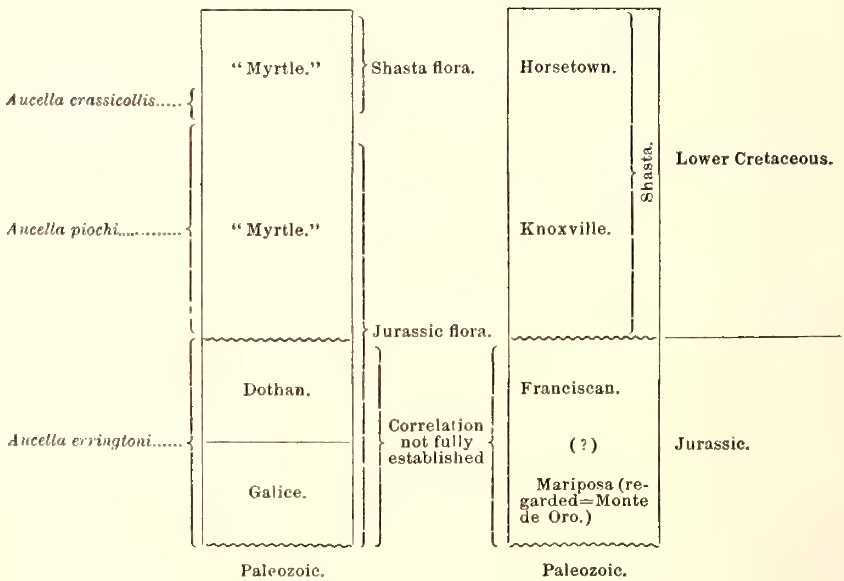
Knowlton,[26] reporting to Nomland in 1915, stated that the plant remains indicated that these beds could not possibly be younger than the Jurassic, and that they were probably not younger than the Middle or Lower Jurassic.

Evidence as to the Age of the Franciscan Group Based on Work in Oregon

The rocks in southern Oregon, that appear to be equivalent to the Franciscan group of California, have been called the Dothan series by Diller.[27] These rocks were first referred to the Franciscan group by Professor Louderback.[28]

In this region, sedimentary formations of earlier periods are better developed than in the Coast Ranges of California, and there would appear to be an excellent opportunity here to settle the question of the age of the Franciscan group. Here again, however, the results are contradictory.

Diller[29] gives the following correlation between the formations of the Klamath Mountains and other formations in California.



[25] 20th Ann. Rep., U. S. Geol. Surv., pt. 2, pp. 338, 339, 1896.
[26] Nomland, J. O., unpublished manuscript.
[27] Diller, J. S., Am. Jour. Sci., vol. 23, p. 401, 1907.
[28] Louderback, G. D., Jour. Geol., vol. 13, p. 514, 1905.
[29] Diller, J. S., Bull. Geol. Soc. Am., vol. 19, p. 369, 1908.

The Galice series is lithologically like the Mariposa slates and contains an Upper Jurassic fauna similar to that of the Mariposa. These facts have led to its correlation with the Mariposa.

The Dothan series is believed by Diller to be younger than the Galice series. The Galice is spatially above the Dothan, but these relations have been interpreted as due to overturning.[30]

The work of Diller is in apparent agreement with the earlier observations regarding the Franciscan in the Coast Ranges of California. According to his work, the Franciscan must be regarded as a group intermediate between the Mariposa and the Knoxville. If the Mariposa be uppermost Jurassic and the Knoxville lowest Cretaceous the Franciscan rocks fill the gap between the Jurassic and the Cretaceous and represent a period hitherto unrecognized in sedimentation.

This would be in agreement with the peculiarity of the fauna and the flora at Slate's Springs, which have been referred by some paleontologists to the Jurassic, by others to the Cretaceous, and by still others to an intermediate transition period. It would agree with the interpretation of a Cretaceous age for the Franciscan made by Whitney and others on the basis of an *Inoceramus* found on Alcatraz Island. Also, if the Franciscan sandstone be a continental deposit, as suggested later, this indicates a wide extension of land in Franciscan time.

This interpretation is opposed to the ideas of C. H. Davis, and the recent opinion of Knowlton. However, these differences of opinion may be due to the unusual nature of the fauna and the small number of species. The flora, moreover, does not appear to be characteristic of the Jurassic, judging from the great differences of opinion among those who have studied it.

Uncertainty as to the Age of the Knoxville

The independent evidence presented by Diller, pointing to the Franciscan as an intermediate group, post-Jurassic and pre-Cretaceous in age, would be almost conclusive if it were not for certain ideas regarding the age of the Knoxville. If the lower Knoxville be the equivalent of the Mariposa, Diller's correlations are wrong, since there is then no room for the Dothan series at the point in the geological column where he would place it. The exact stratigraphic relation of the Knoxville to the Mariposa has never been determined and no locality is known where they are in contact.

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[30] Diller, J. S., Am. Jour. Sci., vol. 23, p. 410, 1907.

J. P. Smith[31] has come to the conclusion that the lower Knoxville is the equivalent of the Mariposa. He states that the fauna of the lower Knoxville is closely related to that of the Mariposa, containing Jurassic types of *Aucella,* with the same poverty of other forms. He believes that the line between the upper and lower Knoxville marks the boundary between the Jurassic and the Cretaceous, since the fauna of the upper Knoxville is certainly Cretaceous.

The same conclusion has been reached by Knowlton,[32] who has studied the flora of the Knoxville of Oregon. He states that the flora of the Jurassic period is an exceedingly satisfactory means of recognizing Jurassic beds, for the reason that it is of world-wide occurrence and is made up of well marked types, which are everywhere about the same and are easily identified. Its horizon has been checked in many places by the stratigraphic relations and by its association with a characteristic Jurassic fauna. On the basis of the presence of this flora in the lower Knoxville, and its absence in the upper Knoxville, he draws the line between the Jurassic and the Cretaceous at the line dividing the upper and lower Knoxville, instead of at the base of the Knoxville.

Two other paleontologists, Pavlow[33] in Russia and Haug[33] in France, also agree with the determinations made by Knowlton. If they are right, the Franciscan must be older than the Mariposa.

Opposed to this division of the Knoxville between two periods, are Diller and Stanton. Diller, apparently on stratigraphic grounds, puts the time-break between the Jurassic and the Cretaceous at the great unconformity at the base of the Knoxville. Stanton[34] points out that the upper Knoxville is unquestionably Cretaceous, containing forms which are everywhere characteristic of that period. He points to the absence of any distinct structural break between the upper and lower Knoxville. He also claims that there is no faunal break between the two divisions. There is a change, he admits, but no sudden break which would justify the separation into different periods.

On account of the fact that the end of the Jurassic on the West Coast was a period of great activity with enormous batholithic intrusions, and wide spread mountain-making movements, one might be

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31 Smith, J. P., Science, n.s., vol. 30, p. 346, 1909.

32 Knowlton, The Jurassic Age of the "Jurassic Flora of Oregon," Am. Jour. Sci., vol. 30, p. 33, 1910.

33 Cited by Knowlton, *ibid.,* p. 57.

34 U. S. Geol. Surv., Bull. 133, p. 30, 1895.

justified in expecting that the Knoxville would show some sort of a structural break if it were actually separable into two periods.

Possibility of a Triassic Age for the Franciscan Group

If, in spite of Diller's positive conclusions, the apparent spatial relation is the true one and the Galice is the younger formation, then the Franciscan must be pre-Mariposa. It may be Lower or Middle Jurassic or Triassic. It would also follow that the granites of the Coast Ranges and the Sierra Nevada are of diverse ages.

In connection with the possibility of a Triassic age for the Franciscan group, it should be remembered that in Alaska there are rocks that are identical with those of the Franciscan. They include radiolarian cherts, pillow basalts, arkosic sandstones, serpentines, and glaucophane schists. These are known certainly to be Triassic. The Franciscan group extends from southern California into Oregon and into the Olympic Mountains. It is possible that the Alaskan rocks are a portion of the same terrane. The lithologic peculiarities suggest this strongly; but the force of the suggestion is weakened when it is remembered that there are somewhat similar rocks of entirely different age in the Pacific Coast region. In Alaska, radiolarian cherts of probable Paleozoic age are known, and radiolarian cherts occur in the Devonian of Oregon, but the peculiar association of lithologic types in the Mesozoic rocks is apparently not duplicated in any of the older series.

It is interesting also to note that the radiolarian cherts of Borneo, the Philippines, and the Malay Peninsula are at an horizon near to those of the cherts of the Franciscan and the cherts of Alaska. Warren D. Smith[35] has studied the radiolarian cherts near Roseberg, Oregon, and finds the radiolaria which they contain to be identical with the radiolaria in the cherts of the Philippine Islands. The cherts of the Philippine Islands are apparently contemporaneous with those of Borneo, Java, the Moluccas, Ceram, and adjacent regions. These have been assigned to the Jurassic or the Triassic by Hinde and Martin. The radiolarian cherts of Roti and Savu are certainly Triassic since they are associated with limestones containing *Halobia* and *Daonella*. Smith calls attention to the lithologic resemblance and the identity of the radiolaria. He does not attempt a correlation, because of the un-

[35] Smith, W. D., Notes on Radiolarian Cherts in Oregon, Am. Jour. Sci., vol. 42, p. 299, 1916.

certainty regarding the range of radiolaria, but points out the remarkable similarity between the geological columns of the two sides of the Pacific.

The foregoing statements summarize the various ideas which have been held, and are now held, regarding the place of the Franciscan group in the geological column. The great uncertainty as to the age of the Franciscan is not wholly due to our lack of knowledge of the relations of the Coast Range granite and the absence of characteristic fossils in the Franciscan itself. The uncertainty regarding the age of the Knoxville adds greatly to the difficulty.

THE FRANCISCAN SANDSTONE

Stratification

The Franciscan sandstone is usually massive, although there are certain facies which are stratified. In the cliffs at Land's End, on the south side of the Golden Gate, sections from one to two hundred feet thick may be seen with only an occasional indication of bedding. Similar sections may be seen in Marin County and also in the recently constructed road cuts on Point Richmond. In certain quarries, faces nearly one hundred feet high are exposed, in which the sandstone is wholly massive and shows no bedding. Looking at such exposures from a little distance, one would be inclined to regard them as composed of igneous rock on account of their massive character.

When the sandstone is stratified this is usually due to the intercalation of fine grained shale, black to gray in color, or of lenses of conglomerate or conglomeratic sandstone. There are no variations in color or lithologic nature of the sandstone itself to mark out stratification planes. Occasionally one may see a bed of shale from fifteen to twenty feet thick, but usually the shale is not more than one to three feet in thickness. In certain localities the sandstone is associated with considerable shale, though this is exceptional. Near San Bruno Mountain, excellent sections are seen in which the sandstone is fairly evenly bedded with black shale. Some of these sections are plainly visible from trains coming into San Francisco in the neighborhood of Visitacion Valley. Near Fleming Point, south of Point Richmond, the waters of the bay have cut low cliffs in which even alternations of sandstone and shale are observable. In some instances the black shale shows a decided lenticular character. Some lenses are fifteen to twenty feet long and a foot or so thick in the central part.

There are occasional lenses of conglomerate in the Franciscan sandstone. These occur at various horizons but are not persistent and usually cannot be traced more than a few rods.

Very small lenses of chert are found occasionally in the sandstone. One occurrence of this sort is seen at a point about a third of a mile above the mouth of Perkins Canyon, Mount Diablo. The surface of the sandstone has been polished by the stream, and on this surface there are shown a number of anastomosing veins of white quartz and calcite. The chert is green, with a faint bluish cast; it has a waxy luster, and is much like green radiolarian chert in appearance, though it contains no radiolaria. It occurs in irregular lenticular bands two or three feet long and two inches in maximum thickness. There are several lenses one above the other separated by sandstone. The general relations are shown in the photograph (plate 1B).

Ransome[36] has described similar occurrences on Angel Island, where he found numerous thin parallel bands of chert in a cliff section composed of rather massive sandstone.

Occurrence of Fossils

One of the significant features of the Franciscan sandstone is the lack of fossils. It is well exposed in many quarries as well as in road cuts and sea cliffs; but notwithstanding the numerous excellent exposures, only a very few fossils have been discovered in it. Whitney[37] reports the finding of an *Inoceramus* in the sandstone of Alcatraz Island in the bay of San Francisco. A fragment of an *Inoceramus* in the collection of the University of California bears the following label:

"Found in a schooner load of broken rock, brought from Goat Island or Angel Island for the construction of the iron draw-bridge over the tidal canal between Alameda and Oakland, F. L. Ransome."

A fragment of either an *Inoceramus* or an *Aucella* was found two and three-quarter miles south of San Mateo.[38] Turner[39] reports finding a few fossils in the Franciscan sandstone on the north side of

[36] Univ. Calif. Publ., Bull. Dept. Geol., vol. 1, pp. 197, 198, 1894.

[37] Geol. Surv. Calif., Geology, vol. 1, p. 77, 1865.

[38] Lawson, A. C., U. S. Geol. Surv. Folio no. 193, 1914.

[39] Turner, H. W., Jour. Geol., vol. 6, pp. 492–93, 1898.

Mount Diablo. Fairbanks[40] reports peculiar pecten-like forms from one locality in the Franciscan sandstone of the San Luis Quadrangle.

This lack of fossils is also a characteristic feature of the black shales of the Franciscan. With the exception of some peculiar markings that resemble worm tracks, no fossils have been found in this shale except those discovered in the slates at Slate's Springs.

Carbon is fairly common in the sandstone. It occurs in the form of pieces of carbonized wood that often show the woody structures, also as fragments of leaves. The sandstone also contains a few very thin lenses of coal. These have been noticed at many localities throughout the Franciscan terrane. So far, no one has discovered identifiable plant remains save at Slate's Springs. In the neighborhood of the seams of coal the sandstones lose their usual hard, well cemented character and are little indurated.

Lithologic Character

When fresh, the typical Franciscan sandstone is dark greenish gray to bluish gray in color. It is frequently cut by small veins of quartz and occasionally by veinlets of calcite. The texture is dense and the grains are closely packed. The strength of the cement is shown by the fact that, in breaking the rock, the fracture passes through the mineral grains as readily as through the cement. In this respect, the sandstone is very much like a quartzite.

In general, the sandstone is medium coarse grained. The diameters of the grains range from a quarter to three-quarters of a millimeter. Occasionally there may be a small lens or pocket of sandstone in which all the grains are coarse, ranging from a millimeter up to three millimeters in diameter.

In hand specimen, quartz, feldspar, muscovite, and biotite are easily recognized. With a hand lens, the striations on the grains of plagioclase are often clearly visible. Numerous small angular blocks and flakes of black shale are present in the sandstone, and frequently fragments of serpentine are found.

The sandstone readily decomposes under the action of the weather and it is usually covered with a deep soil. The process of alteration begins with a discoloration of the rock; it rapidly loses its bluish or greenish color and becomes first yellowish and then brown. At this

[40] Fairbanks, H. W., San Luis Folio, U. S. Geol. Surv. Folio no. 101, 1904.

stage the cement is considerably weakened. On breaking such a discolored sandstone, the grains pull out of the cement instead of fracturing as they do in the fresh rock. As the change proceeds, the rock becomes softer and is cut by large numbers of fracture planes, closely spaced and rather irregular in their distribution. These are probably due to volume changes involved in the oxidation and alteration of the rock minerals. The fresh rock shows none of this sort of fracturing. In the late stages of the alteration, the sandstone becomes so soft that it can be easily crushed in the fingers. In the final stage a sandy soil results.

When the rock begins to alter so that the cement is weakened it is easily recognized as a sandstone; but in the fresh state, the denseness of texture, color, mode of fracture, and the presence of fresh feldspar cause it to resemble an igneous rock. Sometimes, at first glance in the field, one will mistake the sandstone for some of the fine grained gabbroid rocks of the Franciscan group. The presence of quartz grains in the sandstone serves, of course, to distinguish it from these rocks.

In thin section, the clastic nature of the rock is at once apparent. When first examining it, in thin section, one is surprised at the marked angularity of the grains that compose it. Very few of the grains show any evidence of rounding; the greater proportion of them show sharp angular boundaries. Many of the grains have delicate points on their corners. Wedge-shaped pieces are common and occasionally there are thin splinters with fine points. It is evident that there was no great amount of abrasive action in the transportation of the grains of this rock to their place of deposition.

In some instances the closeness of the spacing of the grains is notable. They fit very closely together with only a thin film of cement between them. In other instances the grains are more widely separated and there is considerable interstitial material.

The mineral composition of the clastic grains is also rather unusual. Quartz is the most important constituent of the rock. Next in order are grains of feldspar. These frequently make up a third to a half of the sandstone. Grains of orthoclase and plagioclase are numerous, but micròline is rarely present. The plagioclase feldspars are usually of the more acid varieties. As a rule the feldspars are very fresh; in unaltered specimens of the sandstone, the feldspars are as clear and limpid as the quartz. In a few instances they are slightly clouded by decomposition.

Muscovite is a common constituent and fresh green or brown biotite often occurs. Augite and hornblende are occasionally seen.

Magnetite occurs in small amounts. Usually it is disseminated throughout the rock. Occasionally it becomes more important and is segregated in bands which may reach a thickness of a quarter of an inch. In such instances it occurs in association with zircon and other heavy minerals. Mr. F. E. Turton[41] found monazite in one of these magnetite bands. Pyrite occasionally occurs in single crystals in the sandstone.

Zircon is an important minor constituent. It occurs in large grains of a size comparable with the other clastic grains of the sandstone. Also it is found as small columnar crystals with acute pyramidal terminations, included in the grains of quartz and feldspar.

Epidote is a rather common constituent of the sandstone. It occurs in clastic grains of moderately large size. It is also found occasionally in minute crystals in the cement. Here it may be a secondary mineral.

Large grains and flakes of chlorite which seem to be original constituents of the sand are frequently present. Minute scales, probably often secondary, are found in the cement. In some sections, also, a pale greenish tinge may be observed in the cementing material, which probably represents finely disseminated chlorite. Grains of serpentine are found frequently. In size these are comparable with the other clastic grains. An occasional fragment may be much larger.

A very few grains of pale flesh-colored garnet have been noted in the thin sections.

Besides the grains of single minerals, small fragments of rocks are often present. Angular blocks and splinters of granitic rock, consisting of quartz and plagioclase feldspar are occasionally found. Diabase fragments are common. Angular fragments of vein quartz and of chalcedonic silica are common. One fragment of quartz-biotite schist was noted, and angular fragments of black shale are very numerous.

In a few cases where the interstitial spaces are large, the clastic grains are embedded in a matrix of minute mineral fragments—chiefly quartz and feldspar. In a few instances there seems to have been little change in the grains of finer material, but in others the cement appears to be largely recrystallized.

The larger grains of the sandstone have undergone little recrystal-

[41] Unpublished notes.

lization. Occasionally a few flakes of sericite appear within a feldspar grain, or a veinlet of sericite cuts into it. Sometimes the whole periphery of a feldspar grain will be rimmed with sericite. For the most part, however, these effects are unimportant. No evidence of the shearing of the clastic grains is visible.

In attempting to distinguish the nature of the cement of the sandstone, one is handicapped by the extreme fineness of the grains which compose it. In a few instances the cement appears, as noted above, to be composed in large part of finely broken mineral fragments which have been little affected by recrystallization.

In an occasional specimen, calcite is an important constituent of the cement, but for the most part it is present in only a few scattered grains. These are visible only under the microscope, but their presence is shown by a slight effervescence when the sandstone is treated with acid.

Minute shreds and flakes of a clear, colorless mineral are also seen. This shows a moderate relief, moderately high birefringence, parallel extinction and positive elongation. It is determined as sericite. In places it is quite abundant in the cement, occurring as aggregates of scales and flakes. At other places only a few shreds appear, separated from one another by the minerals of the cement.

A few small flakes of a green mineral also occur in the cement. From their peculiar interference colors, pleochroism, color and form, they are determined as chlorite. The pale greenish color of the cement is probably due to very finely divided chloritic material. On the alteration of the rock, the first change which occurs is a slight discoloration of the cement from pale green to yellowish, suggesting the oxidation of some mineral containing ferrous iron. In this stage the cement is seen, in thin section, to be colored yellowish brown by some very finely disseminated substance not clearly visible under the microscope.

In certain specimens, especially those in which only a little cement is present, and the grain of the cement is very fine, the latter appears to consist wholly of sericite with a little chlorite. However, the great strength of the cement indicates the presence of something else. It is probable that the polarization colors of the sericite mask the presence of silica having a low birefringence. This appears probable from the fact that where the cement is more coarsely crystallized the sericite crystals are intermixed with secondary quartz and with a mineral of low relief, low birefringence and fibrous extinction that is regarded as chalcedony.

In places where little sericite is present one occasionally notices very minute lath-shaped sections of an unknown mineral with very low birefringence and negative elongation.

No other minerals have been recognized in the cement, besides quartz, chalcedony, sericite, chlorite, calcite, epidote and the undetermined mineral just mentioned. Only a small loss of weight occurs on leaching the rock powder with 10 per cent caustic potash solution, so that there can be little opaline silica present.

Possibly other constituents are present which are not visible under the microscope. The presence of some easily decomposed mineral is suggested by the rapid disintegration of the cement on weathering. Possibly this latter effect is the result of the oxidation of the small chlorite flakes and of finely divided chlorite upon exposure to the weather.

In those instances where secondary quartz is present in the cement there is no sign of secondary enlargement of clastic quartz grains. The new silica shows no relation in orientation to the old grains.

The peculiar mineralogical composition of this sandstone is reflected in its chemical analyses:

I. Analysis of a fresh specimen of typical Franciscan sandstone from the quarry of the Oakland Paving Company, Piedmont. James W. Howson, analyst.

II. Analysis of a Franciscan sandstone from Sulphur Bank, California, given by George F. Becker, in U. S. Geol. Surv. Monograph No. 13, p. 92.

III. Composite analysis of 253 sandstones given by F. W. Clarke in U. S. Geol. Surv. Bull. 616, p. 28.

	I.	II.	III.
SiO_2	68.84	68.50	78.66
TiO_2	0.25	0.60	0.25
Al_2O_3	14.54	12.82	4.78
Fe_2O_3	0.62	1.29	1.08
FeO	2.47	3.37	0.30
CaO	2.23	1.82	5.52
BaO	0.04	......	0.05
MgO	1.94	2.21	1.17
K_2O	2.68	1.26	1.32
Na_2O	3.88	6.03	0.45
ZrO_2	0.05	......	......
Water below 110° C.	0.35	0.28	0.31
Water above 110° C.	1.60	2.11	1.33
CO_2	0.14	......	5.04
P_2O_5	0.15	0.16	0.08
SO_3	0.15	......	0.07
MnO	......	0.02	......
Total	99.93	100.47	100.41
Sp. gr.	2.720		

The low silica, indicating the presence of only moderate amounts of free quartz, is the most striking feature of the analyses. The high alumina and alkalies indicate the presence of much feldspar. The content of soda and lime is decidedly different from that of the ordinary sandstone. The low content of carbon dioxide shows that the lime is largely contained in the plagioclase feldspars. The percentage of ferrous iron in this rock is in contrast with that in the ordinary sandstone and is due to the presence of undecomposed ferromagnesian minerals.

Shale Fragments

Reference has already been made to one of the striking features of the Franciscan sandstone. This is the presence of considerable numbers of small angular fragments of shale. Also in many places, there are large numbers of flat flakes of shale (plate 1A). In some cases these shale flakes are so numerous that when the rock is slightly weathered it takes on a fissile character. They may make up as much as 10 per cent by volume of the rock.

The sandstone also contains angular blocks of shale ranging in dimensions up to a couple of feet (plate 2A). These angular blocks occur both in the local lenses of conglomerate and entirely alone in the midst of massive sandstone. At Point Richmond, sections may be seen where numerous isolated angular blocks of shale, up to a foot in diameter, lie in the midst of a fresh massive sandstone of moderately coarse grain. The resemblance of the sandstone to an igneous rock, together with the scattered blocks of black shale, gives one the impression of baked shale fragments included in an intrusive rock. While these shale blocks are often angular they are more commonly subangular, the corners being worn down slightly. The material of which the blocks are composed is often striped with thin layers of sand in exactly the same manner as ordinary Franciscan shale. These bands are truncated by the boundaries of the block in such a way as to prove that the shale was hardened first and then later embedded in the sandstone as a fragment (fig. 3). In one section, seen in the

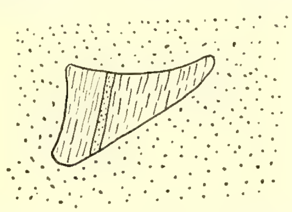

Fig. 3. Block of shale in Franciscan sandstone

Santa Ynez Mountains, the sandstone rests on an irregular surface of black shale and contains several blocks of shale, apparently torn from the bed below (fig. 4).

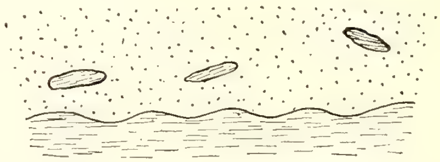

Fig. 4. Irregular contact of Franciscan sandstone and shale with slabs of shale in sandstone

In certain cases isolated lenses of shale ten to fifteen feet long may show a peculiar disruption as indicated in figure 5. No indica-

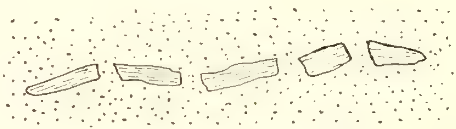

Fig. 5. Broken lens of shale in Franciscan sandstone

tion of faulting or shearing can be seen in the sandstone between the blocks; it is as massive there as elsewhere. The only conclusion the observer can draw is that the shale must have been first hardened and then broken up by some disturbance which occurred at a time when the sand, in which it was embedded, was still unconsolidated.

Veins

The Franciscan sandstone is in many localities cut by veins of quartz and calcite, most of them small and many of them very irregular. Their general character is indicated in the photographs (plates 1B and 2A).

At Point Richmond some peculiar veins of quartz were found. The walls of these veins have been impregnated with silica in unusual amount, so that the resulting rock bordering the vein resembles green chert, save that it contains sand grains. Some of the veins are very narrow, and show very little or no quartz, yet there is an impregnation of the wall of the fissure for an inch or more on each side. A few of them show very little evidence of an original fissure, looking like dykes of cherty rock running through the sandstone. At this locality there are great numbers of these veins with silicified walls and irregular branching courses, inclined to the bedding.

Conglomerates

The conglomerates of the Franciscan sandstone occur in lenses at many horizons and are one of its most interesting features. The matrix of the conglomerate consists of medium fine grained sandstone, in all respects like the ordinary sandstone of the Franciscan.

The pebbles and boulders may be divided into two classes: those derived from older formations, and those which appear to have been derived from the Franciscan itself. Those of the first class are almost invariably well rounded and range in size from less than an inch up to a foot in diameter, the usual size being from two to three inches. They comprise various lithologic types. Pebbles of black chert, unlike anything in the Franciscan, are very common. There are also boulders of granite, quartzite, and porphyritic igneous rocks of various kinds.

Those of the second class, which are apparently derived from the Franciscan itself, show about the same range of size as do the boulders of the first class. They may be rounded, but are usually subangular; some are decidedly angular. They comprise black shale, identical in appearance with the black shales of the Franciscan, red and green radiolarian cherts that cannot be distinguished from the red and green cherts of the Franciscan, arkosic sandstones, containing shale flakes and identical with the typical Franciscan sandstone, diabase, serpentine, and glaucophane schist.

In the Franciscan area of Mount Diablo there is a conglomerate which is of interest since it contains many boulders of glaucophane schist. This conglomerate outcrops at two points, within a course of half a mile. The best locality is in Section 5, Township 1 South, Range 1 East of the Mount Diablo Base and Meridian. The point of the outcrop lies about 0.54 mile south and 1.45 miles east of Mount Diablo. The second locality lies southwest of the first one and is in the northwest corner of Section 8, about one mile east and 1.15 miles south of the South Peak.

At the first locality the stream falls over a cliff about fifty feet high. Back of the cliff the stream has cut a sharp notch in the solid rock from eight to ten feet deep. In the bottom of this notch there is a pothole four feet across, and at least five feet deep, the bottom being filled with stream pebbles. The stream has scoured the walls of the notch and the pothole, and in the clean, fresh surfaces an excellent section is presented. The second locality is an outcrop on a ridge;

here the rock is not so well exposed, due to partial weathering of the matrix.

There are several bands of conglomerate from one to three feet thick, interbedded with ribs of sandstone (plate 2B). In these sandstone partings there may be an occasional isolated pebble, entirely surrounded by medium grained sandstone. The matrix of the conglomerate and the interbedded sandstone is typical Franciscan arkosic sandstone. It is a hard, bluish-green rock with a quartzite-like fracture. It contains specks of carbonaceous material and also flakes of shale, which are sometimes so abundant that the rock is fissile when slightly weathered. The matrix is cut by numerous thin veins of white quartz. The boulders include various lithologic types and are well rounded, the exceptions usually being shale boulders.

The shale boulders are usually subangular, showing somewhat rounded corners, but a few are decidedly angular. Generally they are rather flat and are often arranged in bands. The photographs show their character (plates 2A and B). In some places they overlap each other in the peculiar way characteristic of stream gravels. Usually the shale boulders are of dark or black color, but occasionally they are gray. Many show a striping, due to the presence of fine sandy layers, which probably represents the original bedding; the stripes are generally inclined to the sides of the boulder.

This conglomerate also contains boulders of sandstone. These are lithologically identical with the matrix in which they are embedded. They are easily seen for the reason that they show a slight lamination which is different in direction from the lamination of the matrix. Many are cut by veins which end abruptly at the margins of the boulder, having been formed before its detachment from the parent rock.

Igneous rocks of various types are well represented among the boulders. Some are diabase which resembles certain phases of the Franciscan diabase. A few rounded boulders of a rock containing large bastite pseudomorphs may also be noted. The boulder shown in the photograph directly above the notebook, is of this type (plate 2B).

The conglomerate contains boulders of black chert and also numerous boulders of green radiolarian chert. There are some pebbles of white quartz. Boulders of schist are fairly common. A few boulders of green schist occur, and four or five boulders of glaucophane schist were collected in a short time.

The section shown (fig. 6) is generalized somewhat, and represents the relations at the first locality. The distance from the conglomerate to the Knoxville shales is between 500 and 600 feet. This body of conglomerate lies within a large area of Franciscan rocks. Its relations to the sandstone indicate that it is not an outlier of Knoxville conglomerate preserved in the Franciscan by infolding or by faulting. The conglomerate is seen, in the section exposed by the downcutting of the stream, to be completely enclosed in sandstone of the ordinary Franciscan type, and to be a part of a conformable succession of sediments. The sandstone overlying and underlying the conglomerate is entirely unlike anything seen in the Knoxville around the mountain. The conglomerate passes gradually into the surrounding sandstone by a decrease in the number of pebbles and there are also thin ribs of sandstone intercalated in the conglomerate. The nature of the matrix of the conglomerate is identical with the associated sandstone so that there is no plane of parting between the sandstone and the conglomerate.

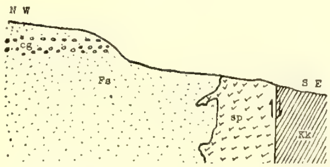

Fig. 6. Franciscan conglomerate at Mount Diablo. Fs—Franciscan sandstone; cg—conglomerate; sp—serpentine; Kk—Knoxville shale.

Conglomerates of this kind, with boulders of glaucophane schist, have been described before. Ransome[42] mentions a conglomerate on Angel Island containing numerous pebbles of a rock bearing blue amphibole.

Fairbanks[43] reports a boulder of glaucophane schist in a Franciscan conglomerate. The conglomerate consists of a sandstone matrix containing scattered pebbles and a boulder of glaucophane schist two feet in diameter. Fairbanks interprets this to mean one of two things. Either there is a formation of glaucophane schist in the region older than the Franciscan or else there was a period of erosion and redeposition in the Franciscan after the formation of the glaucophane schist.

Nutter and Barber[44] have suggested that the glaucophane schists

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[42] Univ. Calif. Publ., Bull. Dept. Geol., vol. 1, p. 197, 1894.

[43] San Luis Folio, U. S. Geol. Surv. Folio no. 101, 1904.

[44] Nutter, E. H., and Barber, W. B., On Some Glaucophane and Associated Schists in the Coast Ranges of California, Jour. Geol., vol. 10, p. 738, 1902.

are not due to contact action of Franciscan igneous rocks, but are members of a pre-Franciscan group of rocks:

No one explanation seems to satisfactorily account for the many different aspects and occurrences of the glaucophane and related schists. That there has been some development of glaucophane at the contact of basic igneous masses seems certain. It seems improbable, however, that the main portion of the normal glaucophane and actinolite schists is a result of contact action. That the schists have not resulted from contact action by peridoite masses seems probable, for at some points the same masses have certainly produced but slight alteration in adjoining sandstones and shales, and the thickness and character of the schists is such that they could only have been produced by metamorphosing agents acting on a large scale. It seems difficult to believe, also, that the schists could be formed by serpentine dikes which are smaller than the schist masses themselves. Besides, the inclusions of schist in the Healdsburg and Angel Island serpentines render it almost certain that the schists are the older of the two rocks. In addition, the evidence points to the massive glaucophane rocks and normal schists being older than the Golden Gate or Franciscan series of rocks, for the schists are unconformably beneath what appears to be the Golden Gate or Franciscan rocks in the Calaveras Valley, and they probably have similar relations at Healdsburg. Finally, serpentinized dikes are frequently found intrusive in Golden Gate or Franciscan rocks, while at Mount Diablo, near Gilroy, and in San Luis Obispo County there are serpentine dikes intrusive in the Knoxville beds. This would of course make the dikes younger than the schists, if the schists are older than the Golden Gate or Franciscan series. . . .

It can hardly be doubted that glaucophane schists have been developed in rocks of different ages, and older than the Knoxville. It seems probable, also, that there is a series of glaucophane schists older than the Golden Gate or Franciscan, and the possibility suggests itself that these may be but isolated outcrops of extensive masses which underlie the Coast Ranges.

The only hypothesis that seems to satisfactorily explain the occurrences of these rocks is that they are the result of dynamic agencies, and may or may not be the products of widespread regional metamorphism.

However, Franciscan sandstones and radiolarian cherts have actually been observed at many places to pass into glaucophane schists, at their contacts with Franciscan igneous rocks. It is unlikely that there is a pre-Franciscan formation of glaucophane schist in the Coast Ranges. Glaucophane schists are rare in their occurrence and appear to require special conditions for their production. In California they are not found outside areas of the Franciscan group and no one has ever reported an occurrence of glaucophane schist in the Coast Ranges in any pre-Franciscan area.

Similarly, it is not known that there are any older formations of red and green radiolarian cherts in the California Coast Ranges or formations of arkose sandstone.

The presence of these conglomerates with boulders of many of the typical rocks of the Franciscan group, implies that there are breaks within the Franciscan itself. These represent periods when earlier formed rocks were eroded and their detritus deposited in new places. Otherwise, one is forced to assume that there is an older assemblage of rocks, somewhere in the Coast Ranges, that is identical in most respects with the Franciscan.

The presence of breaks within the Franciscan has been suggested by Roderick Crandall in a paper on the geology of the San Francisco Peninsula.[45] He noted the presence of chert boulders within the Franciscan sandstone, and points to these as evidence of the presence of an erosion interval.

THE ORIGIN OF THE FRANCISCAN SANDSTONE

The mineralogical composition of this rock, its angularity of grain, and its uniformity of character over wide areas and through great thicknesses all combine to make it an unusual formation. The lithologic uniformity points to persistence of conditions over a large area and during a long period of time.

Lack of Fossils

The absence of fossils in the greater part of the sandstone strongly suggests a continental origin, though as Kindle points out, this may not be an infallible criterion. Kindle[46] shows that in certain regions of the sea bottom, where currents are strong, the shifting of the sands prevents colonies of mollusks from getting a foothold, or covers them and prevents their growth. As a result there are many large areas of the sea bottom over which no shells are now found. Grabau,[47] who also discusses this criterion, states that marine clastics are usually well bedded, and are as a rule, fossiliferous. He says:

> . . . Indeed, it may be seriously questioned if marine clastics are ever wholly free from organic remains, though for considerable distances off certain shores organisms may be so rare as to escape detection. Thus Kindle reports dredging off the coast of Alaska for a hundred miles or more along the shore, without finding any organic remains whatever. This of course does not prove their absence but only indicates their scarcity, and indeed at another point off the same coast organisms were abundant. Moreover, such dredging affects only the surface layers of the sea floor, and does not prove the absence of remains in somewhat deeper layers.

[45] Proc. Am. Philos. Soc., vol. 46, 1907.

[46] Kindle, E. M., Cross-bedding and Absence of Fossils Considered as Criteria of Continental Deposits, Am. Jour. Sci., vol. 32, p. 225, 1911.

[47] Grabau, A. W., Principles of Stratigraphy, p. 641, New York, 1913.

It is perfectly well known that marine organisms migrate with the seasons, and that at a certain locality, where life was abundant during one season, it is almost entirely absent in another, the organisms having migrated into deeper water. What is true of seasons is also true of longer periods, some regions formerly well stocked with organisms being barren for years at a time, after which a return of the fauna takes place. Such migration up and down the ocean floor is often determined by factors difficult to ascertain. In the Alaskan case it may be due to the abundance of cold water carried in from the land by the melting of the glaciers, which, as shown by Tarr, has recently become very marked through changes which also caused an advance of the glaciers in certain localities.

Later the same writer states:

. . . absence of marine fossils is not an absolute indication of the non-marine character of a formation, though absence over a very large area may probably be taken as a fairly certain guide.

It would seem, therefore, that the lack of fossils over a wide area, and throughout great thicknesses, points very strongly to the continental deposition of the Franciscan sandstone. If the sandstone is continental, one is inclined to wonder why no remains of land animals have been found. Such remains may be present and it is possible they have been overlooked, though it is not probable that they are very numerous.

Angularity of Grain

The striking angularity of the clastic grains of the sandstone indicates that the processes of transportation were not such as to produce much rounding of grains. There could have been no great amount of abrasion of grains either during transportation or deposition of this material.

Significance of Feldspar

The presence of much feldspar has an important bearing on the question of origin of this sandstone. The source of supply appears to have been the granite of the Coast Ranges.[48] The mineralogical composition of the sandstone shows that it was derived from granitic rocks, and the angular nature of the grains indicates that they could not have traveled very far.

It is possible to imagine a granitic rock subjected to rock decay in a temperate, humid climate where, due to the reworking of the

[48] It is, of course, possible that there was an uplifted area of granite on the west side of the present Great Valley of California. This granite may have been continuous with the granite of the Sierra Nevada.

products of decomposition by streams, the unweathered residuals of feldspathic grains, together with quartz, might be segregated from the products of decay. This concentration would give rise to a rock containing fresh feldspar. This possibility is improbable in this instance because of the marked angularity of the grains. This angularity is opposed to any idea of origin which involves much sorting and transportation. Also it is a well known fact that feldspar breaks down very quickly under the abrasive forces acting in stream transportation.[49] Such action would tend to produce a rock high in quartz with only a small amount of feldspar.

The presence of fresh grains of ferromagnesian minerals also shows that the conditions under which the sandstone was formed were not those of ordinary humid weathering.

The mineralogical nature of the sandstone indicates, then, that it was formed under conditions which favored the mechanical disintegration of the original rock and its separation into grains. After this mechanical disintegration the constituent grains underwent little chemical alteration during transportation and deposition.

Barton[50] has investigated the special conditions under which mechanical, granular disintegration of granitic rocks will occur. He has summarized the localities where such granular disintegration products are known, and investigated the climatic conditions under which they were formed.

His work shows that the granular disintegration of granitic rocks may occur in a variety of climates. It is favored by high altitudes where the daily temperature range is extreme. It appears that in cold climates the rock breaks into large blocks; there is little tendency for granular disintegration, so that under such climates feldspathic sand is not likely to occur. In humid, tropical climates, decomposition is so rapid that feldspathic sand will not accumulate. In humid climates, therefore, accumulations of felspathic sand will be limited to the temperate zone. In arid climates, granular disintegration may occur either in the tropics or in the temperate zone.

Barton finds that under aridity, all things combine to favor granular disintegration, together with the deposition of mineral grains in a fresh condition, and under such a climate, arkose deposits may be very extensive.

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49 Barrel, J., Climate and Terrestrial Deposits, Jour. Geol., vol. 16, pp. 364–65, 1908.

50 Barton, D. C., The Geological Significance and Genetic Classification of Arkose Deposits, Jour. Geol., vol. 24, p. 417, 1916.

Ransome[51] has described sands, with fresh feldspar grains, formed by the granular disintegration of rocks under arid conditions in Arizona:

With the exception of the timbered slopes of the Pinal Mountains, and of a few alluvial areas along the main arroyos, the surface of the region is almost destitute of soil. The scanty shrubbery, and the sparse grass and herbage which spring up with wonderful rapidity after the rains, are insufficient to prevent such soil as may form from being quickly washed away. The humus acids, which in moister climates and beneath a covering of soil aid in rock decay, have in this region little opportunity to form or to attack the rocks. The latter crumble or flake under the influence of sharp atmospheric changes, and these fragments are rapidly carried into the valleys. The granitic masses crumble into particles of quartz, flakes of mica, and angular fragments or crystals of comparatively fresh feldspar. The rains acting on this disintegrated material soon wash it down to the larger streams, which carry off the quartz and mica. The larger fragments of feldspar often build up alluvial fans at the mouths of the small ravines heading in a granitic area, and such fans are remarkable for the purity and freshness of the feldspathic material which composes them, the numerous cleavage faces flashing brightly in the sun.

Similar conditions have been described by other writers.

The possibility that the deposition of the Franciscan sandstone may have occurred in an ordinary humid climate would appear to be barred by the mineralogic nature of the rock. While granular disintegration may be produced in such climates, still the amount of chemical decay is considerable. This question has been considered by Barton, who finds that under such conditions the chemical decay of feldspar is important, and the resulting deposits of arkose show certain characteristics:

1. They are of small size.
2. They grade into quartzites.
3. The matrix will contain much argillaceous material from the decomposition of the feldspars.
4. The arkosic material will be associated with beds of argillaceous material.
5. The feldspar grains will show decomposition.

Only the fourth criterion could be applied to the Franciscan sandstone. All its other characteristics are opposed to the idea of such an origin. The presence of fresh and angular feldspars, together with fresh biotite and other ferromagnesian minerals, all combine to show that there was little opportunity for the decomposition which would have occurred if the climate had been of the temperate humid type. The wide extent of the formation is also opposed to the idea of humidity.

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[51] Ransome, F. L., Geology of the Globe Copper District, Arizona, U. S. Geol. Surv. Professional Paper no. 12, p. 21, 1903.

This conclusion is in agreement with ideas advanced by Mackie[52] as a result of his studies of sedimentary rocks, recent deposits of various kinds, and the mineral composition of stream transported sands. Mackie believes that high percentages of fresh feldspar indicate either a very cold, or else a warm and dry climate. He states that in the absence of ice action, one should conclude that the climate was warm and dry. No evidence is known which would suggest ice action during the Franciscan, though the possibility of a cold climate is discussed later.

Conditions of Deposition

SUGGESTION OF CONTINENTAL DEPOSITION

While the considerations just set out indicate the probability that the Franciscan sandstone was laid down under an arid climate, the petrographic nature of the rock does not furnish much evidence as to the conditions of deposition.

The absence of fossils from the greater part of the sandstone strongly suggests that the sandstone was deposited subaerially.

The presence of much feldspar and the angularity of the grains indicate little abrasion and show that the material was not carried for long distances in streams. By this the possibility of continental deposition is again *suggested.*

POSSIBILITY OF WIND ACTION

It seems certain that the deposit was not due to wind action, nor was it produced under conditions in which wind played an important part. The grains are not rounded as wind blown grains should be, nor are they frosted like wind blown sands. The sandstone never shows dune stratification, and exhibits no faceted pebbles.

FLUVIATILE DEPOSITION ON PIEDMONT SLOPES

The sands which now compose the Franciscan sandstone may have been deposited by rivers on a piedmont slope which lay to the east of a young mountain range, produced at the time of the intrusion of the Coast Range granite. Such a mountain range would act as a barrier against moisture laden winds coming in from the Pacific

52 Mackie, W., Tran. Edin. Geol. Soc., vol. 7, p. 443, 1898.

Ocean.[53] It would act as the present Coast Ranges, which, in a measure, screen the west side of the San Joaquin Valley from precipitation. The conditions would be analogous to those in Patagonia. The plains of Patagonia are semiarid and barren, due to the fact that moisture laden winds from the Pacific Ocean lose their moisture in passing over the Andes and descend upon the plains to the east as drying winds.[54]

On the arid piedmont plains, there would be deposited the materials brought down from the mountains to the west. In a general way, the conditions would be somewhat like the deposition of material by rivers of the peninsular region of India, or analogous to the deposition of material by aggrading streams on the Great Plains at the eastern base of the Rocky Mountains, or on the plains of southern Argentina. In the high mountains to the west mechanical disintegration of rocks would predominate. Large amounts of granitic sand would be produced there and from time to time swept down in flooded streams during occasional torrential rains. The material would be deposited on the gentler slopes at the base of the mountains and, on its consolidation, would give rise to a sandstone of the Franciscan type. The angular character of the grains and the heterogeneous nature of the rock, due to very poor sorting of the component minerals, are both accordant with such a picture. Under the conditions postulated, the feldspathic sand would be carried down in large amounts in heavily loaded streams in which sorting and abrasion would be at a minimum. Between times of torrential rains the normal drainage of the mountains would be by streams which would run down in occasional channels across the piedmont slope.

MARINE DEPOSITION

As far as the petrographic evidence goes it is possible that such a formation as the Franciscan sandstone might have been deposited beneath the sea, the sand being carried down during torrential rains and covered quickly. If it had been supplied gradually in small amounts and worked over by the waves on beaches, the greater part of the feldspar would have been disintegrated and the residual quartz grains would have become rounded.

[53] The assumption is here made of course that the prevailing winds were from the west as at the present time; also with differences in the path of storms there might result an arid coastal belt.

[54] Hatcher, J. B., Narrative of the Princeton Patagonia Expedition, vol. 1, p. 216, 1903.

Deposits of the sort suggested are being formed, under conditions somewhat similar to those postulated, on the eastern shore of the Gulf of Lower California, on the west coast of the state of Sonora. They have been described by W J McGee.[55]

The region is one of broad plains and rugged mountains, the rocks of which consist mostly of granites and old schists. In the mountains, the rocks are nearly bare and the plains are covered with a thin veneer of coarse alluvium. The precipitation is very slight. Rock decomposition is practically absent and the mechanical debris is washed down by occasional sheet floods. The sands accumulating on the outer margin of the wave-cut terrace and in the reëntrants of the shore are typical arkose. They consist of rather coarse angular fragments of quartz, feldspar, and mica, which are usually clean but sometimes mixed with more finely broken material. Such a deposit on cementation would result in a rock much like the Franciscan sandstone.

SHALE FLAKES

One feature of the Franciscan sandstone is the occurrence in it of flakes of shale, often with angular outlines, reaching an inch or so in cross section and about one-sixteenth of an inch thick. Locally these may be very numerous. These appear to be similar to certain mud flakes in the Spokane formation, described by Calkins:[56]

> A prominent characteristic of the sandstone of the Spokane formation is the presence in many layers of abundant flat masses of dark argillite from a small fraction of an inch to two inches in diameter, similar to the finest-grained portion of the shales. Commonly these masses, whose larger dimensions are in the bedding planes, are smooth and well rounded, like pebbles. The rock containing them differs in two respects from typical conglomerate, however; first, the volume of the matrix of sandstone greatly exceeds that of the pebbles, and, second, the pebbles are virtually homogenous in composition and consist of a kind of material abundantly interbedded with the sandstone. These beds grade into others in which the argillaceous particles are sharply angular. It is believed, in view of the common association of these rocks with mud cracks, that the argillaceous fragments were derived from mud flakes curled up and loosened in the process of drying, and buried by the next deposit of sand. The rounding of the fragments in certain beds is certainly the result of attrition, but as fragments of mud could hardly survive transportation by water for any considerable distance it is probable that some of them were rolled by the wind after drying.

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[55] McGee, W J, The Formation of Arkose (abstract), Science, n. s., vol. 4, p. 962, 1896.

[56] Calkins, F. C., Geology and Ore Deposits of the Phillipsburg Quadrangle, Montana, U. S. Geol. Surv., Professional paper no. 78, p. 46, 1913.

The shale flakes of the Franciscan are like the "clay galls" of Grabau. No other origin has ever been suggested for these other than that outlined in the description of the Spokane formation. According to Grabau,[57] they are very common in sandstones known certainly to be subaerial in origin, and their presence in a sandstone may be regarded as practically positive evidence of a subaerial origin.

Occasional small shale fragments occur in some of the Knoxville sandstones at Mount Diablo. The Chico sandstones used in the buildings at Stanford University also contain small fragments of shale. As far as the writer is aware, no marine fossils occur in the sandstones at the points where these shale fragments occur and they probably mark a subaerial facies of sedimentation. However, their presence in formations which frequently contain marine fossils, indicates the need for caution in the use of shale fragments as a criterion of continental origin.

LENSES OF CONGLOMERATE

The numerous lenses of conglomerate, at various horizons throughout the sandstone, favor the fluviatile hypothesis rather than the hypothesis of marine deposition.

Beach conglomerates usually show rounded boulders. They are generally well washed and the matrix is not normally feldspathic. Marine conglomerates should be more persistent than these conglomerates are. The frequent repetition of horizons of conglomerate is in favor of the fluviatile hypothesis. The lens-like character of the conglomerates at once leads to the idea that they represent sections of old stream courses. On the fluviatile hypothesis these conglomerates represent pebbles accumulated in stream channels which were abandoned by the aggrading streams from time to time. The great variety of lithologic types represented in the conglomerate is in accordance with this view of the nature of the conglomerates.

On the assumption of continental deposition of the sandstone, one can easily explain the presence of numerous boulders of Franciscan rocks in these conglomerates. They represent portions of the formation deposited at an earlier date, consolidated, and subjected to local erosion with deposition elsewhere in the accumulating sediments.

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[57] Principles of Stratigraphy, pp. 564, 711.

SHALE BLOCKS AND SLABS

The presence of numerous shale blocks and slabs in the conglomerates is opposed to the idea of their marine origin. Such angular fragments of shale could not be carried very far without breaking up, nor could they withstand the action of waves on a beach for any length of time (plate 2A).

Masses of tough clay are not uncommon on the sand beaches south of San Francisco, where they appear to have been torn off clay banks beneath the water since they show the perforations of boring mollusks. Such masses, if embedded in the shore deposits, would give rise to shale boulders upon consolidation. Grabau[58] describes similar examples. However, these masses of clay are not like the shale boulders which occur in the Franciscan sandstone. The clay masses on the beaches are invariably rounded by beating against the shore. The shale blocks of the Franciscan are angular, showing sharp corners which indicate brittleness at the time of their formation. They show bedding planes marked out by sand layers. These are truncated by the sides of the block in such a way as to indicate that the mass was consolidated into shale before breaking. The clay masses on the present beaches hold together fairly well under the action of the waves because of the toughness of the plastic clay. Hardened shale, however, is brittle and would be easily broken down in a beach zone by the action of the waves, and the alternate drying and wetting.

The presence of isolated blocks of shale with angular boundaries, embedded in the midst of massive sandstone, is not explainable on the hypothesis of the marine origin of the sandstone. If, however, the sandstones were deposited by the action of streams, in the manner above suggested, then the blocks may be due to a process observed by Blanford and Theobald[59] in certain rivers of India (the Brahmini and Mahanuddi). During the rains much sand is brought down by these rivers and deposited on their flood plains. In the dry season the rivers retire into small channels and leave large bodies of water, charged with fine mud, in the river bottoms. As the water evaporates, the mud becomes hardened, cracks, and breaks into blocks. A sudden influx of water in a freshet may cause the shale beds thus formed to be broken up and their fragments embedded in the newly deposited sand. Such behavior explains the breaking up of shale lenses without perceptible planes of faulting or shearing in the sandstone (fig. 5).

[58] *Ibid.*, p. 711.

[59] Mem. Geol. Surv. India, vol. 1, pp. 52–53, 1859.

CONCLUSIONS

From the evidence presented, it seems reasonable to conclude that the Franciscan sandstone is, in large part, a continental deposit. This mode of origin has been suspected by Professor Lawson for some time since in the San Francisco Folio[60] he suggested the possibility that the Franciscan sandstone might be a non-marine deposit.

The Franciscan sandstone appears to have accumulated in a region sufficiently arid so that the chemical decay of rock minerals was very slight. It appears to have been deposited by aggrading streams which occasionally, possibly due to local uplifts, attacked and reworked portions of the formation that had previously been deposited and consolidated.

Certain parts of the Franciscan sandstone are undoubtedly marine. The black slates at Slate's Springs are in part marine as shown by their fossils. The lenses and larger bodies of radiolarian chert which occur in the sandstone are unquestionably marine. These occurrences are not inconsistent with the idea of continental deposition of the sandstone. They simply mean that certain portions of the area must, from time to time, have been invaded by the sea. This is to be expected since most formations recognized as continental deposits show, here and there, portions which may be proved by their fossil content to be marine.[61]

The presence of small coal seams favors the idea of continental deposition, and is not opposed to the idea of aridity. In the river bottoms where moisture was present there would be local swamps where vegetation would flourish even though the general region were arid.

The absence of cross-bedding in the sandstone might seem unusual on the hypothesis of continental deposition by fluviatile action. Deposits laid down by ordinary streams might reasonably be expected to be cross-bedded. If, however, deposition occurred from an overloaded stream carrying large quantities of feldspathic sand, no great amount of sorting could occur and the absence of cross-bedding should be expected. Barrell[62] states that ripple marks and current marks are

[60] San Francisco Folio, U. S. Geol. Surv. Folio no. 193, 1914.

[61] Barrell, Jour. Geol., vol. 14, p. 354, 1906.

[62] Recognition of Ancient Delta Deposits, Bull. Geol. Soc. Am., vol. 23, p. 433, 1912.

rare or absent in deposits from sheet floods, and false bedding may not be apparent.

The absence of ripple marks, mud cracks, and similar features in the black shales is peculiar. So far the writer has never found definite ripple marks on any of the black shales, nor have mud cracks or rill marks been discovered. It might be possible that the shale is not of the sort to preserve such surface features. Barrell has shown that certain shales swell when wet by the rain and are therefore not adapted for preservation of surface markings. However, the presence of many angular blocks and slabs of shale in the sandstone indicates that the Franciscan shale did not undergo this sort of swelling on wetting after dessication.

In the foregoing pages the conclusion is reached that the climate in Franciscan time was arid. Another possibility is suggested by the reference of the Franciscan group to the Jurassic period. In the Mariposa slates, near Colfax, certain remarkable breccias occur.[63] These show numerous angular blocks embedded in a fine argillaceous matrix and by analogy with other occurrences elsewhere one might regard these as glacial deposits of upper Jurassic age. While no evidence of ice action is found in the Franciscan itself, this occurrence at Colfax, in connection with a possible Jurassic age for the Franciscan group, suggests an interesting possibility. The Franciscan sandstone may be of glacial origin, representing outwash deposits of sand from a glaciated region.

While no evidence is known to warrant the conclusion that granular disintegration of rocks occurs in glaciated regions, it is known that grains of fresh feldspar and ferromagnesian minerals occur in glacial deposits. Scherzer[64] states that the grains of glacial sands show little evidence of weathering or wear, being fresh, bright, and sharply angular. The sands are also very poorly sorted.

Boswell[65] has shown that the drift in northern Europe contains remarkably fresh grains of many minerals, including such easily decomposed minerals as amphiboles, pyroxenes, biotite, epidote, and feldspars.

Coleman[66] describes the matrix of the Keewatin tillites as an arkose

[63] C. L. Moody, Univ. of Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 383–420, 1917.

[64] Scherzer, W. H., Criteria for the Recognition of the Various Types of Sand Grains, Bull. Geol. Soc. Am., vol. 21, p. 628, 1910.

[65] Boswell, P. G. H., The Petrology of the North Sea Drift and Upper Glacial Brick Earths in East Anglia, Proc. Geol. Assoc., vol. 27, p. 79, 1916.

[66] Coleman, A. P., The Lower Huronian Ice Age, Jour. Geol., vol. 16, p. 152, 1908.

consisting of angular grains of quartz, orthoclase and plagioclase feldspar, embedded in very fine grained material. It is usually massive and in appearance may resemble a fine grained, basic eruptive. The matrix of the Dwyka tillite is much the same.

The presence of carbon at many places in the Franciscan sandstone is not opposed to the idea of glacial conditions. Regarding this point Barrell says:[67]

> . . . it may be concluded that the broad association of carbon with sediments which are thoroughly decomposed and leached throughout is the mark of continuously rainy climates which are tropic or at least warm temperate; with sediments imperfectly decomposed and incompletely leached the mark of more or less continuously rainy climates which are in addition cool or cold.

However, the presence of carbon in the Franciscan sandstone is not inconsistent with a warm, arid climate, as before suggested. Near seams of coal the Franciscan sandstone is soft and unlike the normal rock.

While the possibility of glacial origin of the Franciscan sandstone is worth consideration, there are certain facts which make this hypothesis improbable.

There is some doubt concerning the true nature of the Jurassic breccias near Colfax. Moody professes to be unable to decide whether these breccias are really glacial or whether they represent deposits laid down on alluvial fans.

Even though a Jurassic age be ascribed to the Franciscan it does not appear to be the correlative of the Mariposa slates. Diller's work in Oregon, indicates that the Franciscan is post-Mariposa. If the Galice be the equivalent of the Mariposa, the Franciscan must be either younger or older than the Mariposa.

The presence of numerous radiolaria in the cherts associated with the sandstone is also opposed to the idea of a glacial climate in Franciscan time. Radiolaria are abundant in tropical waters and while they may live in colder waters they are not abundant there. It is conceivable, however, that under certain special conditions, radiolaria might thrive in waters adjacent to a region subject to glaciation.

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[67] Climate and Terrestrial Deposits, Jour. Geol., vol. 16, p. 268, 1908.

EXPLANATION OF PLATE 1

Fig. A. Franciscan sandstone, showing shale flakes (one-half natural size).

Fig. B. Showing small lenses of chert in Franciscan sandstone in Perkins Canyon, Mount Diablo. The head of the hammer lies parallel to the trend of the chert lenses.

Fig. A

Fig. B

EXPLANATION OF PLATE 2

Fig. A. Irregular slab of black shale in Franciscan conglomerate, Mount Diablo (one-quarter natural size).

Fig. B. Franciscan conglomerate, Mount Diablo. Shows numerous subangular blocks of black shale, together with boulders of other types. Note the separation of the conglomerate into bands by ribs of sandstone.

Fig. A

Fig. B

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THE SAN LORENZO SERIES OF MIDDLE CALIFORNIA

BY
BRUCE L. CLARK

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A STRATIGRAPHIC AND PALAEONTOLOGIC STUDY OF THE SAN LORENZO OLIGOCENE SERIES OF THE GENERAL REGION OF MOUNT DIABLO, CALIFORNIA

BY
BRUCE L. CLARK

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INTRODUCTION

Only within the last few years have West Coast geologists and palaeontologists begun to realize that there are certain beds in the Coast Ranges of California and farther to the north, the position of which is between the Tejon (Upper Eocene) and the Monterey (Lower Miocene), which contain a fauna distinct from that of either of these horizons. This intermediate fauna has usually been included with that of the Lower Miocene. In 1895 W. H. Dall[1] expressed his belief that a portion of the Tertiary section of Oregon was Oligocene in age, and in several papers published later, which are referred to in the historical review, he reiterates this belief. The discovery of this intermediate horizon in California is due to the work of Dr. Ralph Arnold.[2] In 1906, he described the San Lorenzo formation, the outcrops of which occur in the Santa Cruz Mountains near the town of Boulder. These beds were found to be beneath beds containing a typical Lower Miocene fauna. In the paper, containing the first announcement of this discovery, we find the following statement:

> Within the last five years strata have been discovered in the Santa Cruz Quadrangle which contain a fauna representing a horizon probably lower than any of the known Lower Miocene horizons of California. The faunal relations and stratigraphic position of this new formation have led the writer to believe that it belongs to the Oligocene.

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[1] Dall, W. H., *in* Diller, J. S., A geological reconnaissance of northwestern Oregon, 17th Ann. Rep., U. S. Geol. Surv., pt. 2, p. 404, 1895.

[2] Arnold, Ralph, The Tertiary and Quaternary pectens of California, U. S. Geol. Surv., Prof. paper no. 47, p. 16, 1906.

During the last three or four years considerable exploration work upon the Tertiary of Oregon, Washington and Vancouver Island has been done, and large collections from the different horizons have been made. These data have given us a better idea as to the distinctness of the different faunal horizons. Probably the most important information obtained is that pertaining to the distinctness of the Oligocene and Miocene faunas in Oregon and Washington.

Between 1906 and 1914 very little new information concerning the presence of Oligocene in California was added to that already known. In the summer of 1914, the writer found evidence of a stratigraphic break between beds containing a Lower Miocene fauna and those containing a fauna believed by him to be closely related to that of the San Lorenzo and to the fauna of the Oligocene as recognized in Oregon and Washington. The announcement of this discovery was published in a short paper entitled "The occurrence of Oligocene in the Contra Costa Hills of Middle California."[3] Since the publication of this paper, a more careful study has been made of all the sections in the Concord and Mount Diablo quadrangles, where beds containing this fauna are found; the number of species from these beds has been greatly increased and some important data obtained as to correlation and local stratigraphic relationships. It is the purpose of this paper to give as clearly as possible first, the detailed information concerning the history of the development of our knowledge of the marine Oligocene of the West Coast; second, a detailed description of the stratigraphy, lithology and fauna of the beds referred to the Oligocene in the region of Mount Diablo; and third, a discussion of correlation on the West Coast.

Up to the present time no species have been recognized as common to the East Coast Oligocene and to the fauna referred to the Oligocene on the West Coast. Not only are these faunas specifically different, but they also have a considerably different generic assemblage. As far as the writer is aware the chief evidence of the Oligocene age of these western beds is their stratigraphic position and relationships, together with the intermediate character of the fauna, taken as a whole, in comparison with that of the Tejon (the uppermost Eocene recognized on the West Coast) and that of the Monterey or Vaqueros (Lower Miocene of the West Coast). The lower beds of this so-called Oligocene contain a number of fairly highly ornamented molluscan species, which are also found in the fauna of the Tejon. These two faunas also contain a rather large number of

[3] Clark, B. L., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 9–21, 1915.

species which are undoubtedly very closely related. On the other hand, the fauna which is found in beds classed as Upper Oligocene, the Acila gettysburgensis zone,[4] has a somewhat similar relationship to that found in the Monterey or Vaqueros, Lower Miocene. However, when these faunas, forming the Upper and Lower Oligocene as recognized on the West Coast, are compared, they apparently show a much greater similarity to each other than does the one to the Eocene and the other to the Lower Miocene.

So little direct evidence is there as to the Oligocene age of these western beds that the writer is tempted to raise the question as to whether or not at least a certain portion of them might not be Upper Eocene. It is generally held by those who are familiar with the fauna of the Tejon, Upper Eocene of the West Coast, that it does not represent the uppermost Eocene as recognized in the Gulf region to the east, that is, the Jacksonian. Thus, on the West Coast there is a time interval which apparently is not accounted for and the thought naturally suggests itself, why might it not be that the fauna on the West Coast that is referred to the Oligocene is in reality, at least in part, Upper Eocene? There is a number of facts that could be used in support of this contention. However, the work of describing the faunas of the Eocene, Oligocene and Miocene of the West Coast and of establishing the proper sequence and stratigraphic relationships has only begun; this is especially true of the so-called Oligocene. It is for this reason that no attempt is made to discuss in detail the possible general correlation with the eastern and European sections. The writer believes that the chief contribution of this paper, outside of describing the fauna of the San Lorenzo as found in the vicinity of Mount Diablo, is the establishment of the stratigraphic relations of these so-called Oligocene beds in California and their correlation with the Oligocene as found in Oregon, Washington and British Columbia.

The name San Lorenzo series is applied, in this paper, to all of the known marine beds, which in California, Oregon, Washington and British Columbia have generally been referred to the Oligocene; this is synonymous with the name, Astoria series, as used by Arnold and Hannibal,[5] and to the Clallam formation, the name recently applied by Weaver[6] to the marine Oligocene of Washington.

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[4] The Upper Oligocene, Acila gettysburgensis zone, at the present time is known for a certainty only in Oregon, Washington and British Columbia.

[5] Arnold, Ralph, and Hannibal, Harold, The marine Tertiary stratigraphy of the North Pacific Coast of America, Proc. Amer. Philos. Soc., vol. 52, pp. 576–578, 1913.

[6] Weaver, C. E., The Tertiary formations of Western Washington, Wash. Geol. Surv., Bull. 13, p. 166, 1916.

The writer[7] formerly accepted the term Astoria as a general name for the marine Oligocene of the West Coast and applied the same to the so-called Oligocene beds of middle California, but after visiting the type section of the Astoria in the summer of 1917, it is his conclusion that this name should not be used for the marine Oligocene of the West Coast. Some of the reasons for this are as follows: The most fossiliferous portion of the type section of the Astoria, the part from which Conrad undoubtedly obtained the most of his fossils (see review of literature on page 57) is the upper sandstones, which are apparently Lower Miocene in age. The black shales below this fossiliferous sandstone have been referred to the Oligocene by Dall.[8a] Apparently this age determination was based principally upon the presence of *Aturia angustata* Conrad in the lower beds, the genus *Aturia* being taken as characteristic of the Oligocene. One other species, which is probably characteristic of the Oligocene, was listed from these beds; that is *Miopleiona indurata* Conrad. The genus *Aturia* is now known to be present in the Lower Miocene of California. F. M. Anderson reports finding it in the Astoria sandstones mentioned above. At the present time the outcrops of these lower shales, from which originally the so-called Oligocene fossils were obtained, have been covered by sand which was pumped in from the river during the dredging of the channel and it is impossible to get more faunal evidence as to the age of the beds. Under the circumstances it would seem best not to use the name Astoria as a general name for the marine West Coast Oligocene.

Both names, Clallam and San Lorenzo, were first used as formational names by Arnold[8b] in the year 1916; the latter name, however, precedes the former by several months and should therefore have preference in use.

ACKNOWLEDGMENTS

The writer is especially indebted to Professor J. C. Merriam, who has made possible the work of which the results are presented in this paper; he is also indebted to him for many suggestions and criticisms.

Acknowledgment is due to F. M. Anderson and Dr. R. E. Dickerson, curators of Palaeontology of the California Academy of Sciences,

[7] Clark, B. L., Astoria series, Oligocene, in the region of Mount Diablo, Middle California, Bull. Geol. Soc. Amer., vol. 28, pp. 227–229, 1917.

[8a] Dall, W. H., The Miocene of Astoria and Coos Bay, Oregon, U. S. Geol. Surv., Prof. paper 59, p. 9, 1909.

[8b] Arnold, Ralph, Tertiary and Quaternary pectens of California, U. S. Geol. Surv., Prof. paper 47, pp. 15–16, March, 1906; Geologic reconnaissance of coast of Olympic Peninsula, Bull. Geol. Soc. Amer., vol. 17, p. 461, September, 1906.

who have very kindly given the writer access to the Academy's large collections from the Oligocene and Miocene of Oregon and Washington. These collections have been a very great aid to the writer in establishing the relative position of the Oligocene of the region of Mount Diablo. The writer is also indebted to Dr. Dickerson for many friendly criticisms and suggestions.

Acknowledgment is also due to Dr. Ralph Arnold, who has given the writer charge of his large collections of fossils from the Oligocene and Miocene of Oregon, Washington and Vancouver Island, from which some very valuable data pertaining to correlation have been obtained.

The following are a few of the others to whom acknowledgments are due: Dr. W. H. Dall, Professor J. P. Smith, Professor A. C. Lawson, Professor G. D. Louderback, Professor C. E. Weaver, R. W. Pack, Graham Moody, E. F. Davis and M. C. Edwards.

REVIEW OF LITERATURE PERTAINING TO THE MARINE OLIGOCENE OF THE WEST COAST

One of the first descriptions of a geological section on the Pacific Coast was of the Tertiary formations in the vicinity of the town of Astoria, Oregon, and along the Columbia River, by J. D. Dana,[9] who was the geologist of the Wilkes Exploring Expedition. In his report, certain beds in this region, now believed to be of Oligocene age, were referred to the Miocene. The palaeontological work of this expedition was done by T. A. Conrad,[10] who described a number of invertebrate species from the locality above mentioned, some of which may prove to be characteristic of the Oligocene, others of the Lower Miocene.

A year previous to this, Conrad[11] had published the descriptions of a number of species sent to him by J. K. Townsend from the Tertiary deposits on the Columbia River near Astoria. Several of these species have been found to have a wide geographical range, being present in the Tertiary of Washington and California as well as in Oregon.

During the years 1854 and 1855, the fifth, sixth and seventh volumes of the Pacific Railroad Reports were published. The palaeon-

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[9] Dana, J. D., Geol. U. S. Expl. Exped., vol. 10, pp. 626, 652–654, 657–659, 1849.

[10] Conrad, T. A., Fossils from northwestern America, Geol. U. S. Expl. Exped., vol. 10, app. 1, pp. 723–729, pls. 17–20, 1849.

[11] Conrad, T. A., Fossil shells from Tertiary deposits on the Columbia River near Astoria, Amer. Jour. Sci., ser. 2, vol. 5, pp. 432–433, 1848.

tological work of these publications, done by Conrad, includes the description of a number of new species from the Tertiary. These descriptions are, for the most part, very meager and the illustrations in many cases are so poor that some of the species will have to be classed as indeterminate. Conrad[12] was one of the first to attempt to correlate the invertebrate faunas of the Tertiary of the West Coast with those in the East. He pointed out the similarity between certain fossil species of the two regions. His correlation for all horizons above the Eocene, however, was very general and only vaguely defined.

J. D. Whitney,[13] the head of the first Geological Survey of California, included what is now recognized as Eocene in the Cretaceous; everything above these horizons was referred either to the Miocene, Pliocene or post-Pliocene or, as in many localities, the beds were described as Tertiary. W. M. Gabb, who was the palaeontologist of the Survey and whose excellent descriptions of Cretaceous and Tertiary fossils have been of so much assistance to later geologists and palaeontologists on the West Coast, described a few fossils from beds in the Contra Costa Hills and in the region of Mount Diablo.[14] These beds were designated as Miocene and Pliocene respectively, no attempt being made to distinguish faunal zones. Of the species described, some were listed as coming from the region near the town of Martinez; a number of these came from the beds described and named in this paper as the San Ramon formation, which is regarded as a part of the San Lorenzo.[15]

It was more than thirty years after the time of Gabb's report before any attempt was made to differentiate further the faunas of the Tertiary of the West Coast. In 1892 a paper by W. H. Dall[16] and G. D. Harris appeared, entitled "The Neocene of North America." The portion of this paper which deals with the marine Neocene formations of the West Coast is largely a compilation of previous literature; the most important exception to this is the description of the Astoria beds in Oregon. A detailed discussion is given by Dall of the lithology and of the occurrence of the fossils in these beds, the name Astoria group being applied to a series of shales and sand-

[12] Conrad, T. A., Proc. Acad. Nat. Sci. Phila., vol. 7, p. 441, 1831; also, Pac. R.R. Reports, vol. 7, p. 189, 1857.

[13] Whitney, J. D., Geol. Surv. Calif., Geol., vol. 1, pp. 1–498, 1860–1864.

[14] Gabb, W. M., Palaeontology of California, vol. 2, pp. 1–63, 1869.

[15] Some of the Oligocene species described by Gabb from this general locality are *Antigona mathewsonii* (*Chione mathewsonii*), *Dosinia mathewsonii*, *Dosinia whitneyii* (*Chione whitneyii*), *Mytilus mathewsonii*, *Spisula occidentalis* (*Hemimactra occidentalis*), *Agasoma gravidum*, *Ancilla fishii* (*Ancillaria fishii*), *Molopophorus biplicatus* (*Cuma biplicata*).

[16] Dall, W. H., and Harris, G. D., U. S. Geol. Surv., Bull. 84, pp. 1–349, 1892.

stones above certain strata, which were called the Aturia beds and referred to the Eocene. Later, these Aturia beds were referred by Dall[17] to the Oligocene.

Up to 1892 practically nothing had been done toward working out faunal zones in the Tertiary. The formations above the Eocene were still classed as either Miocene or Pliocene. Marine deposits of the Oligocene period had not been recognized on the West Coast. The first announcement of the presence of an Oligocene marine fauna on the Pacific Coast was by W. H. Dall in 1895 in a paper by J. S. Diller entitled "A geological reconnaissance of northwestern Oregon."[18]

The following year (1896) marine Oligocene on the West Coast was again referred to by the same author,[19] but no discussion was given in either of these papers as to the reasons for making this determination.

Professor J. C. Merriam's paper entitled "Note on two Tertiary faunas from the rocks of the southern coast of Vancouver Island" appeared in 1896.[20] Thirty species were listed from Carmanah Point and twenty-five from the Sooke district, both near the southern end of Vancouver Island. These beds are now considered to be of Oligocene age. The following statement concerning the age of the beds at the former locality was made by Merriam:

> The fauna of the Carmanah Point beds seems, on the whole, to be the same as that of Conrad's Astoria Miocene, excluding, however, the lower portion of the latter series, which has been supposed to be of Eocene age.[21]

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[17] Dall, W. H., The Miocene of Astoria and Coos Bay, Oregon, U. S. Geol. Surv., Prof. paper no. 59, p. 9, 1909.

[18] Dall, W. H., *in* Diller, J. S., 19th Ann. Rep. U. S. Geol. Surv., pt. 2, pp. 464–469, 1895. Some of the localities in Oregon from which fossils were determined by Dall as of Oligocene age are the Aturia beds at Astoria, already referred to; on the road to Mist two miles south of Clatakanie; on the North Fork of the Scappoose, about five miles northwest of the station of the same name at the mouth of Fall Creek; at Wilson's Bluff on the river three miles above Veronia; Tillamook Bay; at Pittsburg on the Nehalem River. This last locality is one of the most important localities in Oregon of the Lower Oligocene as recognized in this paper. The fossils identified by Dall from this locality are *Nucula truncata*, *Solen parallelus* Gabb, *Mya praecesa* Gould, *Neverita saxea?* Conrad, besides *Leda*, *Dentalium*, *Diplodonta*, *Macoma*, *Tellina*, *Callista*, *Mactra*, *Lunatia*, *Cylichna*, and *Molopophorus*, of which most of the species were new (*op. cit.*, p. 466).

It is interesting to note at this point that Dall, in a later publication, described and figured *Macrocallista pittsburgensis* from this locality; also, *Acila shumardi*, listing it at that time as *Acila decisa* Conrad; both of these species were referred to the Tejon Eocene (Trans. Wagner Free Inst. Sci., vol. 3, p. 1253, 1903).

[19] Dall, W. H., A table of North American Tertiary horizons correlated with one another and with those of Western Europe, with annotations, 18th Ann. Rep., U. S. Geol. Surv., pt. 2, face page 334, 1896–1897.

[20] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, pp. 101–108, 1896.

[21] *Op. cit.*, p. 104.

Merriam's final conclusion was that the faunas of the Carmanah Point beds and the Sooke beds were very different:

> This may be explained either by supposing the interval between the deposition of the original sediments containing the Carmanah Point fauna and the deposition of the Sooke beds to have been a very long one, allowing time for radical faunal changes, or by supposing considerable topographic and climatic changes to have taken place in a shorter interval, accompanied by immigration of new forms.... The evidence at our command indicates that the Sooke beds are of middle Neocene age, and that the time of their deposition was considerably later than that of the Carmanah Point beds. (*Op. cit.*, pp. 107, 108.)

The year after the appearance of the paper just referred to, Merriam published the descriptions of the following species:[22] *Cytheria newcombei, Cytheria vancouverensis, Bullia buccinoides, Nassa newcombei, Patella geometrica,* and *Turritella diversilineata.* The last species came from Carmanah Point; the others were collected from the Sooke beds.

All the species described by Merriam from the Sooke beds were figured and the descriptions republished in a short paper entitled "The fauna of the Sooke beds of Vancouver Island." A complete list is given in this paper of the species known at that time from the Sooke beds, together with their geologic range.[23]

Professor Merriam's paper entitled "A note on the fauna of the Lower Miocene in California," which appeared in 1904,[24] is of especial importance in that here we find the first outline of the faunal zones in the Upper Tertiary in the Contra Costa Hills of Middle California, and also the first attempt to correlate the faunas of these zones with those found in other parts of the state. Three distinct faunas were recognized in the Contra Costa Hills below the San Pablo (Upper Miocene); a fauna found in the sandstones immediately below this latter horizon was described as follows: "The upper division has its nearest affinities with the San Pablo, from which it can be distinguished by the presence of *Clypeaster(?) brewerianus, Trochita costellata,* several new species of *Modiola* and other forms." The fauna of this division belongs to the Briones formation, which is generally referred to as the Scutella breweriana zone. Below this, a distinctive fauna in the shale was recognized. In the lower division of these beds, below the lowest shale member, a fauna was found which Mer-

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[22] Merriam, J. C., The Nautilus, vol. 11, pp. 64–65, October, 1897.

[23] Merriam, J. C., Proc. Calif. Acad. Sci., Geol., ser. 3, vol. 1, pp. 175–180, pl. 23, figs. 1–5, 1899.

[24] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, no. 16, pp. 377–381, 1904.

riam believed to be distinct from that found either in the shales or in the sandstones of the upper division. This was referred to as the fauna of the Agasoma gravida zone, and is the fauna of the beds referred to the Oligocene in this paper. From the following extract it will be seen that Merriam recognized the distinctness of this lower fauna from that of the Scutella breweriana zone:[25]

> The fauna of the lower division is much more characteristic than that of the upper; that is to say, it differs more decidedly from that of the beds immediately above and below it.... The most characteristic species are *Agasoma gravida, Dosinia mathewsoni, Chione mathewsoni,* and *Mytilus mathewsoni.* These beds rest upon the Tejon, which is very fossiliferous only a few yards below the contact. A large percentage of the species in this horizon do not appear in the upper Miocene and as yet not a single species has been found to extend down into the Tejon. In Contra Costa County the fauna of this zone is more distinctive than that of the Monterey shale, considering even that the latter species represents a deep-water facies.

Merriam, in the latter part of this paper, discusses the probable correlation of the Agasoma gravidum beds with certain beds in the southern part of the state, the horizon of which is known as the Turritella ocoyana zone, a part of the Lower Miocene. This will be referred to more in detail in a later part of the paper, under the head of correlation.

Following Dall, the next publication in which marine Oligocene is definitely referred to as occurring on the Pacific Coast was by Ralph Arnold. Certain beds along the coast of the Olympic Peninsula, which are unconformably above the Eocene in that section, were described under the name of Clallam formation, and referred to the Oligocene-Miocene. He describes these beds as follows:[26]

> Resting unconformably upon the Eocene and older rock of the Olympic peninsula is a series of conglomerates, sandstones and shales rich in fossils and extensive in occurrence. The formation is well exposed in the region between Clallam Bay and Pillar Point, to the east, and for that reason is here named the Clallam formation. According to Dr. Dall, the fossils of the formation indicate that the basal portion of the series is Oligocene in age, while the upper part is certainly Miocene. Since the separation of the two members will necessarily have to be made on palaeontologic grounds and will require a more detailed study of the material in hand than time has yet permitted, the term "Oligocene Miocene series" will be used temporarily to designate the age of the beds. A portion of the formation is unquestionably the equivalent of the Astoria sandstones and shales occurring at the mouth of the Columbia river, 130 miles farther south.

[25] *Op. cit.,* p. 378, 1904.

[26] Arnold, Ralph, Geologic reconnaissance of the coast of the Olympic Peninsula, Bull. Geol. Soc. Amer., vol. 17, p. 461, 1906.

Arnold was the first to recognize Oligocene in California.[27] In his paper on the "Tertiary and Quaternary pectens of California," the San Lorenzo formation is described and referred to the Oligocene, a fauna of over fifty species being listed from these beds. The following extract from this paper gives Arnold's principal reasons for calling these beds Oligocene:

> The fauna of the San Lorenzo formation consists, for the most part, of forms best suited by conditions prevalent during the deposition of sandy shales. In other words, it is a moderately deep-water fauna. It shows several species found in the Monterey shale, but it also contains many species which appear to be closely related to Tejon Eocene forms. Bearing in mind these faunal relations and the stratigraphic position of the formation, it appears probable that it belongs in the Oligocene.

The new species from the San Lorenzo formation were described by Arnold in a paper entitled "Descriptions of New Cretaceous and Tertiary fossils from the Santa Cruz Mountains, California."[28] Later, a more complete description of these beds, together with a map showing their areal distribution, was given in the Santa Cruz Folio of the United States Geological Survey.[29] The San Lorenzo of the type section has a maximum thickness of twenty-five hundred feet, being composed chiefly of fine-grained sandstones and shale. The final conclusion of those who studied this section was that this formation graded up into the Lower Miocene (Vaqueros). Certain beds between the two were designated as transitional Oligocene-Miocene.

During the last ten years considerable work has been done in mapping the geology of the Coast Ranges of California, and with this has come a much better knowledge of the stratigraphy and faunal sequence than was had before. The United States Geological Survey has been one of the chief contributors to this work. A number of bulletins pertaining to the geology and oil resources of California have appeared from time to time, and these have been a great stimulus to the students of geology and palaeontology on the West Coast. The statement is made in several of these bulletins that certain of the beds described may be of Oligocene age. In their report on the McKittrick-Sunset oil region, Arnold and Johnson[30] describe certain beds which they think may possibly belong to that period; in the

[27] Arnold, Ralph, U. S. Geol. Surv., Prof. paper no. 47, pp. 15–17, 1906.

[28] Arnold, Ralph, Proc. U. S. Nat. Mus., vol. 34, no. 1617, pp. 345–390, 1908.

[29] Branner, J. C., Newsom, J. F., and Arnold, Ralph, Santa Cruz Folio 163, U. S. Geol. Surv., p. 3, 1909.

[30] Arnold, Ralph, and Johnson, Harry, A preliminary report on the McKittrick Sunset oil region, Kern and San Luis Obispo counties, California, U. S. Geol. Surv., Bull. 406, p. 41, 1910.

Devil's Den region and southwest of Wagon Wheel Mountain, a series of sandstone and shale was found below the Vaqueros with a thickness of nearly two thousand feet. The following statement is made concerning the age of these beds:

With the exception of *Pecten peckhami* Gabb, which ranges from the Eocene or Oligocene to the Miocene, the stratigraphic position of none of the fossils mentioned is known. The stratigraphic affinities of the beds are with the Eocene, and while the palaeontologic are with the lower Miocene, they are possibly to be correlated with the white diatomaceous shale tentatively mapped with the Tejon in the Coalinga district and may possibly be of Oligocene age.

In a recent paper by Robert Pack and Robert W. Anderson,[31] a series of shales, the Kreyenhagen shales, found in the region of Coalinga and to the north, are placed questionably in the Oligocene. These are the shales referred to as the white shale in the extract given in the paragraph above; they were described by Arnold and Anderson[32] in their paper entitled, "Geology and oil resources of the Coalinga district, California," and doubtfully referred to the Tejon. The following quotation in reference to these shales is taken from the paper by Anderson and Pack:

In the report on the Coalinga district this body of shale was included tentatively with the Tejon (Upper Eocene) and treated as an upper member of that formation, although the possibility of its being of Oligocene age was pointed out. Positive evidence as to the exact age of this shale is still lacking but numerous facts lead to the belief that it constitutes a distinct formation more recent in age than the Tejon. This conclusion, combined with the evidence afforded by the fauna, which, though meagre, is distinct from that of the underlying and overlying formations and is suggestive of the Oligocene, warrants the tentative assignment of these beds to the Oligocene series.[33]

Fossils collected by John Ruckman from the Kreyenhagen shale, which are in the collections of the Department of Palaeontology of the University of California, show conclusively that these beds are of Oligocene age and belong to the San Lorenzo series, as defined by the writer in this paper. One of the common species found in this collection is *Fusinus* (*Exilia*) *lincolnensis* Weaver, the type of which came from the Lincoln beds in southern Washington, which beds are considered by Weaver to be of Lower Oligocene age; associated with it are *Macrocallista pittsburgensis* Dall and *Leda lincolnensis* Weaver,

[31] Anderson, Robert, and Pack, Robert W., Geology and oil resources of the west border of the San Joaquin Valley, north of Coalinga, California, U. S. Geol. Surv., Bull. 603, pp. 1–220, pls. 1–14, 1915.

[32] Arnold, Ralph, and Anderson, Robert, U. S. Geol. Surv., Bull. 398, pp. 1–354, pls. 1–52, 1910.

[33] Anderson and Pack, *op. cit.*, p. 74.

also found in the Lower Oligocene of Washington and Oregon. *Fusinus* (*Exilia*) *lincolnensis* is found in the San Ramon formation, which is described in this paper (p. 74) and referred to the Astoria series; the same species, together with *Leda lincolnensis,* is also found in the type section of the San Lorenzo.

Several papers by F. M. Anderson have contributed much to our knowledge of the faunas of the Tertiary of the West Coast, especially of the Turritella ocoyana zone. The fauna of this horizon is of importance in connection with the Oligocene problem in that until very recently the fauna of the Oligocene of the Mount Diablo region was correlated with it; all of the papers in which a general list of the Lower Miocene invertebrate marine species of California was given included the two faunas in the same horizon. The work of the writer, which will be discussed later in this paper, shows that the fauna of the Turritella ocoyana zone is much later in age than that of the Agasoma gravidum zone of the Mount Diablo region, and that the two zones are separated by a marked hiatus. A discussion of the relative positions of the two zones will be found in a later part of this paper under the heading ''Correlation'' (p. 101).

In the region to the east of Bakersfield, near Kern River, the preservation of the fossils in the Turritella ocoyana zone is excellent. In his paper entitled ''A Stratigraphic Study in the Mount Diablo Range of California,'' Anderson described a number of species from this general locality.[34] It was in this paper that the name ''Kreyenhagen shales'' was first applied to certain shales found to the north of Coalinga and which at that time were thought to be a part of the Tejon (Upper Eocene). In a later publication Anderson[35] described the Lower Miocene beds in the vicinity of Kern River in more detail, the fauna from this section being divided into three zones, designated A, B, and C respectively. This fauna, taken as a whole, is that of the Turritella ocoyana zone, *Pecten andersoni, Agasoma barkernianum* and *Turritella ocoyana* being some of the most common and characteristic species. Anderson uses the term Temblor as the general name for these beds, instead of Vaqueros as used by the United States Geological Survey.

In a recent paper by F. M. Anderson and Bruce Martin,[36] entitled

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[34] Anderson, F. M., Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 2, no. 2, pp. 155–248, 1905.

[35] Anderson, F. M., Neocene deposits of Kern River, California, and the Temblor Basin, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 73–148, 1911.

[36] Anderson, F. M., and Martin, Bruce, Proc. Calif. Acad. Sci., ser. 4, vol. 4, pp. 15–112, pls. 1–10, 1914.

"The Neocene record of the Temblor Basin, California, and the Neocene deposits of the San Juan District, San Luis Obispo County," a number of species are described from the Miocene of California and from the Oligocene and Miocene of Oregon and Washington.

The first attempt to separate the faunas of the marine Miocene and Oligocene of Oregon and Washington was made by W. H. Dall in his paper entitled "The Miocene of Astoria and Coos Bay, Oregon."[37] He recognized how incomplete was the knowledge at that time of the faunas of these horizons in that region. In commenting on a list of invertebrate species given in his paper, which were obtained from the beds in the vicinity of the town of Astoria, Dall says:

The following list of fossils collected at Astoria contains species referable both to the Aturia beds and to the Miocene above it. Before these can be finally disentangled from one another to form two distinct and accurate lists, the Oligocene and Miocene faunas of the region must be much more fully worked out than has hitherto been done. The species that have been recognized in other Oligocene horizons are indicated, and the general locality is stated in the list, but with regard to most of them we do not know whether they are exclusively Oligocene or not. Unfortunately the beds at Coos Bay which may be referred with some probability to the Oligocene, and might have enabled us to solve the problem had they contained a fully representative fauna, are almost destitute of fossils.[38]

Out of a total fauna of sixty-three, only nine are listed as belonging exclusively to the Oligocene. Other points where Dall believed he recognized the presence of the Oligocene fauna are at Tillamook, Oregon, and near Port Blakeley on Puget Sound. Apparently Dall placed much confidence in the genus *Aturia* as being distinctive of the Oligocene; later collecting has shown that it extends into higher formations than was supposed.

A. B. Reagan, in his paper entitled "Some Notes on the Olympic Peninsula, Washington,"[39] covers very much the same field as did Arnold in his paper, "Reconnaissance of the Olympic Peninsula," to which reference has already been made. Very little that is new is added to the results already presented by Arnold, except the descriptions of a few new species and the addition of a few more species to the lists already known from the different localities.

The following year, Reagan published several faunal lists almost

[37] Dall, W. H., U. S. Geol. Surv., Prof. paper no. 59, pp. 1–278, 1909.

[38] Dall, W. H., *op. cit.*, p. 11.

[39] Reagan, A. B., Trans. Kans. Acad. Sci., vol. 22, pp. 131–238, pls. 1–6, with sketch map, 1909.

identical with those in the earlier paper.[40] Some of the localities, from which species are listed as belonging to the Clallam formation, are from his "Gettysburg series," along the Strait of Juan de Fuca, East Clallam Bay, Vancouver Island, the Sooke District of Vancouver Island, and from the region of Astoria, Oregon. These lists, excepting that from the vicinity of Clallam Bay, are largely compiled from lists of other writers. Reagan's conclusion was that the beds of these various localities were in general of the same age.

C. E. Weaver's paper, "A preliminary report on the Tertiary palaeontology of western Washington,"[41] appeared in 1912. In this he described five formations above the Eocene, four of which were referred to the Miocene and one to the Oligocene. The beds placed in the Oligocene he called the Lincoln formation. Three formations, the Blakeley, Wahkiakum and Chehalis, were referred to the Lower Miocene. Weaver's reason for calling the Lincoln beds Oligocene was the presence in them of a number of Tejon (Upper Eocene) species.

Following this, a paper by Ralph Arnold and Harold Hannibal appeared, entitled "The marine Tertiary stratigraphy of the North Pacific Coast of America."[42] These authors differed very radically from Weaver in his divisions. A considerable part of what they recognized as Oligocene had been placed by Weaver in the Miocene. A thickness of about twelve thousand feet of sediments found in Oregon and Washington are referred by them to the Oligocene and given the general name Astoria series. This larger division is divided into three formations, to which the names San Lorenzo, Seattle, and Twin River are given. The fauna of the San Lorenzo beds, which belonged to the oldest of the three formations, was correlated with that found in type sections of the San Lorenzo in the Santa Cruz Mountains. This fauna was the same as that found in Weaver's Lincoln formation. The faunas of the Seattle and Twin River formations were stated to correspond in part to Weaver's Blakeley and in part to his Wahkiakum formation. The beds above the Astoria series were called by Arnold and Hannibal the Monterey, the fauna of which was correlated with that of the Turritella ocoyana zone of the

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[40] Reagan, A. B., Die Fossilien der Clallam-formation mit derjenigen der Tertier-formation in Vancouver Insel und mit derjenigen der Astoria Miocän-formation in Oregon verglichen. Centralbl. für Mineralogie, 1910, pp. 646–651.

[41] Weaver, C. E., Wash. Geol. Surv., Bull. 15, pp. 1–80, 1912.

[42] Arnold, Ralph, and Hannibal, Harold, Proc. Amer. Philos. Soc., vol. 52, pp. 559–605, 1913.

Miocene of California. An unconformity is inferred to exist between the latter beds and those of the Astoria series.

Besides the three Oligocene formations referred to above, the San Lorenzo, Seattle and Twin River, Arnold and Hannibal placed the Sooke beds of Vancouver Island in the Oligocene. These beds have already been referred to as having been described by Merriam (see p. 59), and considered by him to be Upper Miocene in age. Only a brief statement is given by Arnold and Hannibal concerning the fauna and stratigraphy of the Sooke beds. Apparently, however, there was no doubt in their minds but that the Sooke fauna came from beds which were stratigraphically lower than their San Lorenzo formation as recognized in Oregon and Washington.

Reference has already been made to the paper by the writer[43] in which it was first announced that certain of the beds heretofore included in the Miocene were in reality Oligocene in age. The present paper is a more complete review of the evidence for this separation, together with a description of the fauna.

A recent paper by Chester Washburne,[44] "Reconnaissance of the geology and oil prospects of northwestern Oregon," is of especial interest in connection with the problem of the relationship of the Oligocene and Miocene as recognized in Oregon, in that here we find the latest views of W. H. Dall as to the point at which the separation should come. Washburn gives a detailed description of the lithology and occurrence of the formations in the vicinity of Astoria, Oregon. Eocene, Oligocene and Miocene beds are recognized in that section. It is stated that tuffaceous Eocene beds are overlain, probably unconformably, by the Astoria shale, the thickness of which is estimated to be about fourteen hundred feet.

The Astoria shale, so named by Thomas Condon, is stratigraphically an indivisible lithologic unit, being a homogeneous mass of dark-colored marine shale. The lower 400 feet or more is of Oligocene age and the remaining 1000 feet or less is Miocene, probably Lower Miocene. In the field there is no way of distinguishing the two parts of the formation. So many fossil species pass across the invisible dividing line that a collection made below the top of the Aturia zone (Oligocene) at Knappton, Washington, opposite Astoria, has been referred to the Miocene. *Aturia angustata,* which is regarded as typical of the Oligocene, has been found in concretions from 300 to 400 feet above the base of the formation. Dall later used the expression Astoria group for both the Miocene shale and overlying sandstone, excluding the Oligocene part of the shale. The name

[43] Clark, B. L., The occurrence of Oligocene in the Contra Costa Hills of Middle California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, pp. 9–21, 1915.

[44] Washburne, C. W., U. S. Geol. Surv., Bull. 590, pp. 1–108, 1914.

[45] Washburne, C., *op. cit.*, pp. 15–16.

Astoria is used in this paper only for the shale lying above the Eocene strata and below the massive sandstone at Harrington Point. This usage, corresponding to the first definition of Condon and to the use of the term by Diller, includes the Oligocene shale as part of the formation. This part may be referred to as the Aturia zone of the Astoria shale, since it is not definitely recognizable except by the presence of the rare *Aturia* fauna.[45]

Washburne agrees with Dall that the sandstones immediately above the Astoria shale are apparently conformable with it. Lists of species are given from a number of localities from the Eocene, Oligocene and Miocene of Washington, the determinations of which were made by Dall. It is of interest to note at this point that *Acila shumardi* and the fauna listed with it in this paper are again referred to the Eocene.[46] The writer has already pointed out (see note at bottom of page 59) that the beds at Pittsburg along the Nehalem River, Oregon, from which the types of *Acila shumardi, Macrocallista pittsburgensis,* and *Molopophorus gabbi* were obtained, are referred to the Eocene by Dall. Washburne's definition of the Astoria shale, which excludes the sandstone member formerly included by Dall in his definition of the Astoria group, agrees with that of Arnold and Hannibal.

A later discussion of the Oligocene of Washington by C. E. Weaver appeared in a paper entitled "Tertiary faunal horizons of western Washington."[47] In this paper, a number of new invertebrate species are described from the Oligocene and a general discussion pertaining to the faunal zones is given. The statement is made that the Oligocene deposits in the vicinity of the Cape Flattery section have an aggregate thickness of nearly 15,000 feet. "In the Puget Sound Basin and in southwestern Washington they range in thickness from 1000 to 10,000 feet. Marine fossils are abundant within the Oligocene deposits and constitute several faunal zones." Weaver expresses the opinion that there does not seem to be sufficient evidence to divide the strata of the Oligocene into a series of formations. He refers all the deposits of that region to the Clallam formation and recognizes three faunal zones:

The faunal zones, beginning with the oldest, are the Molopophorus lincolnensis zone, the Turritella porterensis zone and the Acila gettysburgensis zone. The corresponding sedimentary deposits containing these zones may be referred to as the Lincoln, Porter and Blakely horizons. The term *horizon* is used in the sense of a deposit formed at a particular time and identified by distinctive fossils. The

[46] Washburne, C., *op. cit.*, p. 31.

[47] Weaver, C. E., Univ. Wash. Publ. Geol., vol. 1, no. 1, pp. 1–67, 1916.

faunas occurring in each of the following zones are distinct and many of the species do not range into the zones below or above. (Weaver, C. E., *op. cit.*, p. 4.)

From the above it will be seen that Weaver has very radically revised his ideas of the Oligocene, as published in the first paper referred to.[48] The zones, as outlined, correspond only in general with those given by Arnold and Hannibal. The beds of the Turritella porterensis and Acila gettysburgensis zones were originally included by Weaver in his Blakely formation and referred to the Lower Miocene. The Molopophorus lincolnensis and Turritella porterensis zones[49] are equivalent to the San Lorenzo formation of Arnold and Hannibal, and the Acila gettysburgensis zone or Blakely horizon apparently includes both their Seattle and Twin River formations.

In a still more recent paper by Weaver,[50] the Oligocene is discussed in essentially the same manner as in the last paper just referred to. Lists of characteristic species are given of the different faunal horizons; there is also a check list at the end of the paper of post-Tejon species of western Washington, together with their range indicated in a table on the side. The following extracts, taken from this paper, give Professor Weaver's ideas as to the probable correlation of these beds and the relationships to each other of the different zones, as recognized by him:

Sufficient evidence is not as yet at hand to warrant a direct correlation of the faunas or faunal zones of western Washington with those of California. . . . The Molopophorus lincolnensis and Turritella porterensis zones of Washington may be the equivalent of the Agasoma gravidum zone of California. It is possible that the Acila gettysburgensis zone is in part higher than the Agasoma gravidum zone in the south. . . . The faunas of the Oligocene in western Washington show a gradual gradation from one zone into another.[51]

A detailed study of the Oligocene beds opposite Seattle, Washington, on Puget Sound, the type section of his Acila gettysburgensis zone is given by Weaver in a short paper entitled "The Oligocene of

[48] Weaver, C. E., A preliminary report on the Tertiary palaeontology of western Washington, Wash. Geol. Surv., Bull. 15, pp. 1–80, 1912.

[49] The type section of the Molopophorus lincolnensis zone is situated in Thurston County along the banks of the Chehalis River between five and ten miles west of the city of Centralia and west of the mouth of Lincoln Creek. This corresponds to the type locality of Weaver's Lincoln formation, described in the first paper by him referred to. The type section of the Turritella porterensis zone is located in Chehalis County in the region where Porter Creek joins Chehalis River. The type section of the Acila gettysburgensis zone is in the vicinity of Bremerton Navy Yard on Bainbridge Island, opposite the city of Seattle.

[50] Weaver, C. E., The post-Eocene formations of western Washington, Proc. Calif. Acad. Sci., ser. 4, vol. 6, no. 2, pp. 19–40, 1916.

[51] Weaver, C. E., *op. cit.*, pp. 33–34.

Kitsap County, Washington.''[52] A list of forty-four invertebrates is given from three localities.

The latest and most complete discussion of the marine Tertiary of Washington by Weaver is found in his paper, ''The Tertiary formations of western Washington.''[53] Detailed descriptions, which were lacking in his former papers, of the stratigraphy, lithology and distribution of the different formations, together with the maps, cross-sections and beautiful illustrations, make the paper a valuable contribution to the geologic literature of the state of Washington. That portion of the paper dealing with the Oligocene of Washington, except for the descriptions of the lithology and stratigraphy, is essentially the same as that found in the last three papers by the same author which have just been reviewed. The following extract,[54] taken from this paper, is of general interest, as it gives Weaver's idea as to the palaeogeography of western Washington during Oligocene time.

> The Olympic Mountains and Vancouver Island were probably land areas. The Olympics were at least 1000 feet lower in elevation than at present, as marine deposits occur at that elevation where the wagon road from Clallam Bay to Forks crosses the main divide. Presumably the region had been partly reduced to a peneplain during the Cretaceous and Eocene and during the Oligocene the Strait of Juan de Fuca was depressed, allowing marine sediments to form upon the submerged borders of the peneplain.
>
> There are insufficient exposures to the Oligocene sediments to determine definitely the successive extent of the seas or embayments during the epoch. Sediments containing the Acila gettysburgensis zone are much more widely distributed and are much thicker than those of the two lower zones. Apparently there was a partial withdrawal of the seas at the close of the Eocene and new invasion at the opening of the Oligocene. The embayments in which the Lincoln and Porter horizons were deposited were restricted in area and possibly did not cover the Puget Sound Basin area. During the upper Oligocene the larger part of western Washington west of the foothills of the Cascades was covered with the waters of the ocean. There may possibly have been a lowland area connecting the Cascades with the Olympics in Pierce and southern Kitsap counties. This problem is still unsolved.
>
> At the close of the Oligocene there was an emergence over a large portion of western Washington and all of Puget Sound Basin became a land area. Embayments were still in existence in the Strait of Juan de Fuca region as well as in southwestern Washington.

In a recent paper by Dickerson a very well-preserved fauna of fifty species, collected by F. M. Anderson and Bruce Martin from the lower Oligocene on the Cowlitz River, southwestern Washington, is listed and thirty-six new species described. The fauna is referred

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52 Weaver, C. E., Proc. Calif. Acad. Sci., ser. 4, vol. 6, no. 3, pp. 41–52, 1916.

53 Weaver, C. E., Wash. Geol. Surv., Bull. 13, pp. 1–327, 1916.

54 Weaver, C. E., *op. cit.*, p. 185.

to Weaver's Molopophorus lincolnensis zone. The following extracts are taken from this paper:

Our knowledge of the Oligocene of the Pacific Coast is very inadequate. In order that we may study the Oligocene, its fauna must be first described. The description of thirty-six new species from a fauna of forty-eight specifically identifiable forms obtained from a single locality are given below. Better testimony concerning our ignorance of the Oligocene could hardly be given when the discovery of a new locality by two such good collectors and enthusiastic palaeontologists as Mr. F. M. Anderson and Mr. Bruce Martin results in finding a fauna which is seventy-five per cent new.[55]

. . . .

No Tejon species occur in this fauna, yet its general cast is eocenic and some of the species such as *Exilia weaveri, Galeodea dalli, Neverita nomlandi, Triforis martini, Solen lincolnensis,* are apparently congeneric with forms found in the Tejon Eocene of the Cowlitz River, Washington. Likewise no living forms are contained in this fauna.

The character of the sediments and the abundance of *Hipponyx ornata, Hipponyx arnoldi, Patella subquadrata, Crepidula* sp. and *Acmaea simplex,* sessile shore forms, mark this fauna as a strictly littoral one. In conclusion the fauna appears to belong to a lower facies of the Molopophorus lincolnensis zone of Weaver, and its distinctiveness is due in part to its strictly littoral character and in part to having lived in a portion of Oligocene time older than that of the typical Molopophorus lincolnensis zone.

The presence of the genera *Actaeon, Conus, Epitonium, Exilia, Fasciolaria, Marginella, Serapis, Strepsidura, Barbatia* and *Lima* mark this fauna as subtropical. This character is in accord with the assignment of this fauna to the Molopophorus lincolnensis zone, the San Lorenzo of Arnold and Hannibal, who inferentially recognized the tropical character of the Lower Oligocene.[56]

. . . .

Arnold and Hannibal's list from their Seattle horizon[57a] is essentially the same. The disappearance of many tropical genera, the introduction of several temperate genera, are noteworthy temperate faunal conditions. That the Turritella porterensis zone was tropical or semi-tropical is well attested by the occurrence of the reef-building coral, *Dendrophyllia hannibali* Nomland and other tropical genera. All the known facts considered, we may then conclude that the Molopophorus lincolnensis and Turritella porterensis zones were deposited under tropical or subtropical conditions and the Acila gettysburgensis zone, under temperate conditions somewhat warmer than those of today in that latitude. What was the reason for this faunal change? May we invoke the great god Diastrophism to aid us in explanation? Probably a depression in the vicinity of the Bering region of Alaska occurred at the beginning of the deposition of the Acila gettysburgensis zone and cold boreal waters of the Arctic sea brought with them a boreal fauna some of whose members managed to establish themselves in Washington, in some cases even crowding out the native species. The known history of Oligocene vertebrates gives some decided support to this hypothesis. Accord-

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[55] Dickerson, R. E., Climate and its influence upon the Oligocene faunas of the Pacific Coast, with descriptions of some new species from the Molopophorus lincolnensis zone, Proc. Calif. Acad. Sci., ser. 4, vol. 7, no. 6, p. 158, 1917.

[56] *Op. cit.*, pp. 161–163, 165.

[57a] The Seattle horizon of Arnold and Hannibal is the equivalent of the Acila gettyburgensis zone of Weaver.

ing to Osborn, the White River Oligocene is very different from the upper Oligocene of the John Day region and further shows distinct Asiatic and European affinities indicating that the Bering portal was closed during Lower Oligocene time. The John Day Oligocene fauna, however, lacks European affinities, thus indicating that the Bering portal was open at this time. That a portion of the John Day is the land laid equivalent of the Upper Marine Oligocene, the Acila gettysburgensis zone is a probability.

. . . .

Since the climatic conditions of the Tejon and Lower Oligocene were much the same, several species common to the two might be expected. Weaver reports *Brachysphingus clarki, Leda uvasana, Crassatellites washingtoniana, Exilia dickersoni,* and *Hemifusus washingtonianus,* as Tejon forms which also occur in the Molopophorus lincolnensis zone. This is a very small number and, moreover, further collecting has not increased it. It appears probable that a great interval of erosion occurred between the beds bearing the Upper Eocene and Lower Oligocene faunas and that the Tejon species finished their life course during the time now represented in the rocks by an unconformable contact yet to be discovered.

The most recent paper[57b] to appear, which deals with the marine Oligocene of the West Coast, is by Katherine E. H. Van Winkle—entitled "Palaeontology of the Oligocene of the Chehalis Valley, Washington." Miss Van Winkle, after a brief historical review, gives a description of the stratigraphy, together with a faunal list of over one hundred and fifty invertebrate species obtained from the Oligocene of this general region of southwestern Washington. She accepts the two faunal zones of the Lower Oligocene as outlined by Professor Weaver, i.e., the Molopophorus lincolnensis and Turritella porterensis zones, and besides these, also recognizes a new zone below the Molopophorus lincolnensis zone, which she calls the Barbatia merriami zone. Following the general part of the paper are the descriptions of eighteen new species, accompanied by figures.

DESCRIPTIONS OF LOCAL SECTIONS OF SAN LORENZO SERIES

Two general sections of the Oligocene, both considered by the writer as belonging to the San Lorenzo series, are found in the region of Mount Diablo; one to the west and south of the mountain, along the sides of the San Ramon Valley and in the Contra Costa Hills farther to the west, and the other to the north, in the vicinity of Kirker Creek. The beds of these two sections are so different, both in lithology and faunas, that it seems best to consider them separately.

[57b] Van Winkle, Katherine E. H., Univ. Wash. Publ. in Geol., vol. 1, no. 2, pp. 67–97, pls. 6, 7, 1918.

San Lorenzo Series to West and South of Mount Diablo

GENERAL STATEMENT

The beds of the San Lorenzo series of the Concord Quadrangle to the west of Mount Diablo were originally mapped and described in the San Francisco folio as a part of the Monterey group.[58] Below is given a table taken from page 10 of the Folio, showing the lithologic and faunal zones of the Monterey as seen in the section to the southeast of the town of Pinole.

Palaeontologic subdivisions	Stratigraphic subdivisions	Petrographic character	Thickness feet
Upper Faunal Zone	Briones sandstone	Sandstone	800
	Hercules shale member	Bituminous shale	500
	Briones sandstone	Sandstone	1000
Middle Faunal Zone	Rodeo shale	Bituminous shale	670
	Hambre sandstone	Sandstone	1200
	Tice shale	Bituminous shale	460
	Cursan sandstone	Sandstone	600
	Claremont shale	Bituminous shale and chert	250
Lower Faunal Zone	Sobrante sandstone	Sandstone	400
		Total thickness	5880

The lower faunal zone of the above section is known as the Agasoma gravidum zone, the middle as the Arca montereyana zone, and the upper as the Scutella breweriana zone. Mention has already been made of the fact that there is a stratigraphic break between the beds containing the Arca montereyana fauna and those containing the Agasoma gravidum fauna, which latter beds are, in this paper, referred to the San Lorenzo series, also that this break occurs in the Sobrante sandstone. The name Sobrante sandstone is retained for the basal sands and conglomerates of the Monterey Group above this break.[59]

To the west of Mount Diablo, beds containing the Agasoma gravidum fauna are known in three general sections in the Concord Quadrangle, Contra Costa County: (1) In the northwest quarter of the Concord Quadrangle near Bear Creek; (2) in the vicinity of the town of Walnut Creek on both sides of a tightly folded syncline which will be referred to as the San Ramon syncline; (3) to the southeast of the town of Martinez and east of Muir station on both sides of the Pacheco syncline.

[58] Lawson, A. C., San Francisco Folio, no. 193, U. S. Geol. Surv., pp. 1–21, 1914.

[59] The faunal list from the Agasoma gravidum beds, given in the Folio, needs revision, as it contains a number of species which are characteristic of the Arca montereyana zone.

SAN LORENZO SERIES OF THE SOBRANTE ANTICLINE

What is probably the most complete section of the San Lorenzo series of the Concord Quadrangle is found on the flanks of the Sobrante anticline in the northwest quarter of the Concord Quadrangle. The strata exposed in the center of this fold are of Tejon age; immediately above, on both sides of the anticline, are the Oligocene beds.

In this section there is apparently an angular unconformity between the upper shales of the Tejon (Upper Eocene) and the coarse basal sandstones of the San Lorenzo, as shown by the fact that the shales, in certain localities, are dipping more steeply than the sandstones. It is difficult, however, to find good contacts and therefore this difference in dip might possibly be due to the buckling of the shales, rather than to an unconformity.

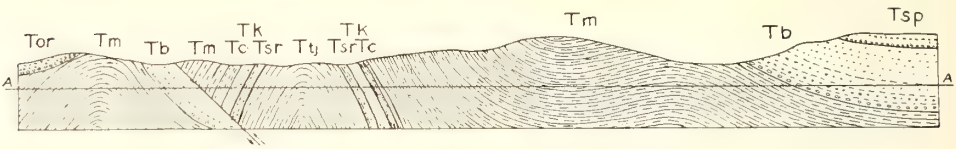

Fig. 1. A north-south section through the Sobrante anticline (AA on plate 3) taken in part from Lawson's geological map of Concord Quadrangle, San Francisco Folio, no. 193, U. S. Geol. Surv., 1914. Ttj, Tejon; Tsr, San Ramon; Tk, Kirker tuff; Tc, Concord formation; Tm, Monterey; Tb, Briones; Tsp, San Pablo; Tor, Orinda.

The San Lorenzo of this section is divisible into at least three distinct lithologic units, to which local formational names have been given. The lowest of these is the San Ramon formation; above it are the Kirker tuffs and above them, the Concord formation. The maximum thickness of the San Lorenzo beds in this section is about four hundred feet.

San Ramon Formation

The San Ramon formation, as measured to the west of Bear Creek on the south side of the anticline, has a thickness, of from forty to fifty feet. It consists, for the most part, of medium-fine gray sandstones which at the base are massive, rather coarse and somewhat calcareous. Fossils are found in these basal beds in abundance at a number of localities.[60] Toward the top of the formation, the beds are not so

[60] The principal fossil localities in the basal beds of the San Ramon formation of this section are University of California localities 14, 1173, 2954, 2955. Locality 3081, one of the most important localities in this section, is possibly fifty feet above the base.

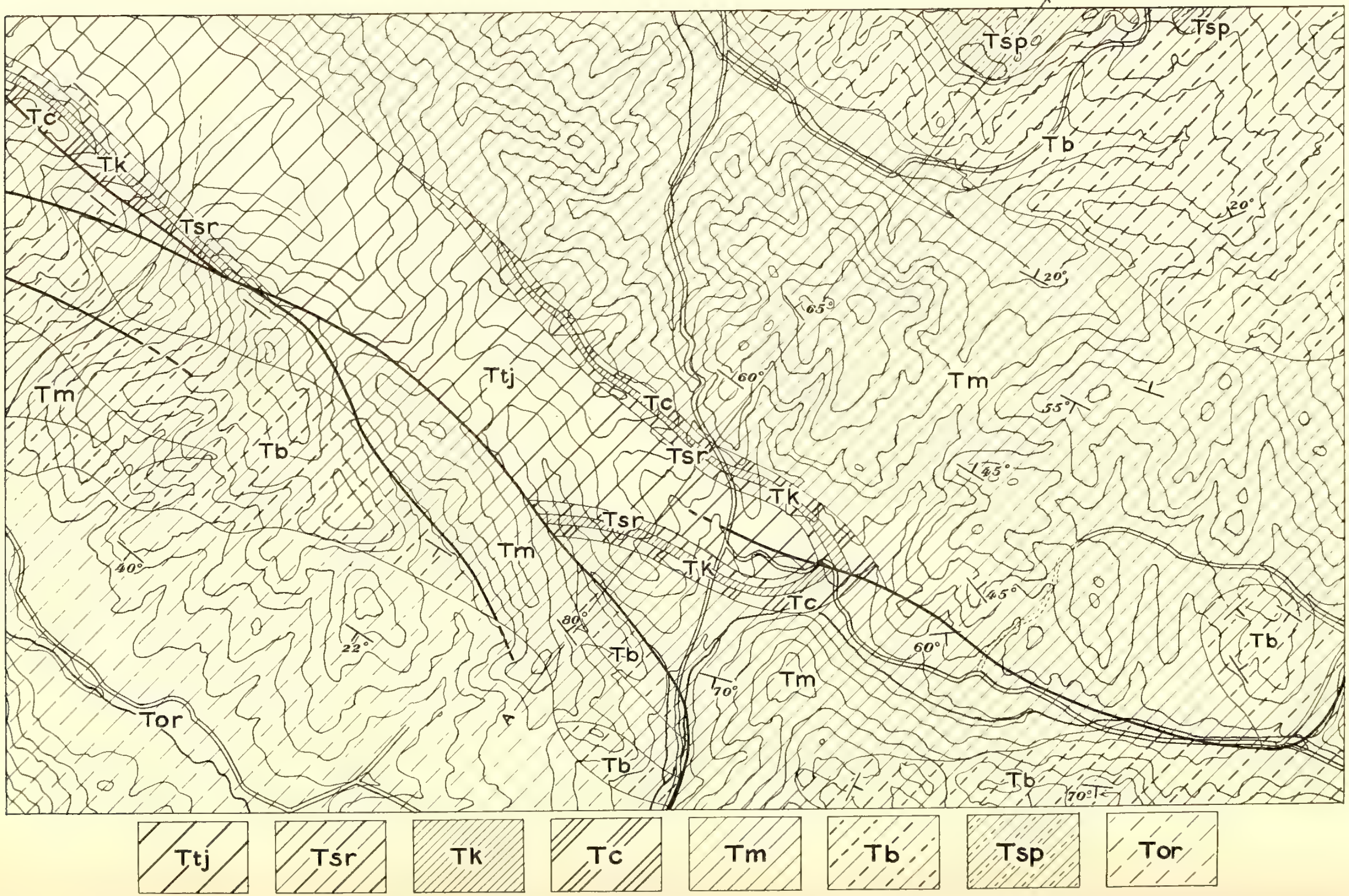

Plate 3. Areal map of the formations flanking the Sobrante anticline, taken in part from Lawson's geological map of the Concord Quadrangle, San Francisco Folio, no. 193, U. S. Geol. Surv., 1914.

massive; here thin beds of micaceous, gray, medium-fine sandstone alternate with thinner layers of sandy shale and clay-shale. Very good exposures of this part of the section may be seen on the side of the road just south of the divide between Bear and Pinole creeks on the north side of the anticline. Here the formation is somewhat thicker than at the other locality, mentioned above.

Kirker Tuffs

Overlying the San Ramon formation are about one hundred feet of fairly indurated white tuff beds, which contain a few minor layers of tuffaceous sandstone. Taken as a whole, these beds are very fine and homogeneous in texture. The separation between the Kirker tuffs and the San Ramon formation is marked by a very sudden change from the sandstone of the latter to the tuff of the former.

The Kirker tuffs are correlated by the writer with the tuff of the Kirker formation, the upper member of the Oligocene on the north side of Mount Diablo, the beds being named after Kirker Creek of that vicinity.[61] Evidence for the correlation of these beds with the tuffs of the Sobrante anticline will be considered with the discussion of the fauna, further on in the paper.

Concord Formation

Resting disconformably upon the Kirker tuffs is the Concord formation, the beds of which consist chiefly of fine grayish sandstone. The thickness of the formation is about two hundred and fifty feet. At the base is a thin layer of conglomerate, the boulders of which are composed mainly, if not entirely, of tuff, sandstone and shale, apparently derived from the Oligocene beds immediately below. The close lithologic similarity of the tuff boulders to the Kirker tuff is especially convincing. At none of the localities studied was this conglomerate over six inches thick. Some of the larger boulders are rather angular.

A very interesting and important character of the basal sandstone of the Concord formation, including the matrix between the boulders of the conglomerate, is that it is white, due to the presence of tuff found in between and coating the grains of sand. This character was undoubtedly the result of the reworking of the tuff beds by the advancing sea as it encroached upon the Kirker beds, which had, just previously, been subjected to erosion. The beds which contain this reworked tuff have a thickness of from six inches to possibly one foot.

[61] The most important fossil locality in the Kirker tuffs of the Sobrante anticline is University of California locality 3055.

Above this, the strata consist chiefly of fine, gray sandstone, becoming finer and more shaly near the top.

Fossil wood and fairly good leaf impressions were found in abundance at several localities in the basal beds; none of these forms have as yet been determined.[62]

Summary of section of San Lorenzo and basal Monterey as measured from the south side of Sobrante anticline, a little to the west of Bear Creek.

Basal part of Monterey Group (Arca montereyana zone)	250 feet—*Claremont shale.* Soft and diatomaceous in some localities, in others, hard and flinty; layers of chert with partings of shale. 80 feet—*Sobrante sandstone.* Medium coarse, massive, light gray sandstone, grades into Claremont shale.
San Lorenzo series (Agasoma gravidum zone)	Unconformity 250 feet—*Concord formation.* Fine, grayish sandstone which apparently becomes rather shaly near the top; thin layer of tuffaceous conglomerate at base, as described above. (Fossils found at base of these beds listed under University of California locality 3053.) Disconformity 100 feet—*Kirker tuffs.* White, fine, fairly indurated tuffs; contain *Schizaster californica* and *Glycimeris tenuimbricata* in abundance. 40 feet—*San Ramon formation.* Massive, medium coarse to fine, fossiliferous, gray sandstone. University of California locality 14 is the basal bed of this section.
Tejon	Uncomformity Shale.

Evidence for a Stratigraphic Break Between the San Lorenzo and the Monterey

Fairly conclusive evidence for a stratigraphic break of considerable importance between the San Lorenzo and the Monterey of the Sobrante anticline is brought out in the mapping of these beds. Apparently there is no appreciable difference in dip between the beds of the two horizons, but a considerable difference in strike was found at several localities. The beds representing the San Lorenzo series a little to the west of Bear Creek are much thinner on the north side of the anticline than on the south side, the latter locality being not more than a half-mile from the former. Only a few feet of the Concord formation is present on the north side of the anticline, the entire thick-

[62] Two of the most important fossil localities in the Concord formation are University of California localities 3055 and 3053.

ness of the beds below the Claremont shale down to the Tejon being less than one hundred and fifty feet; on the south side, the thickness of the beds in the corresponding section is nearly five hundred feet. The difference in thickness of the San Lorenzo beds on the two sides of the anticline is apparently due to erosion. This is borne out by the fact that along this line there is a slight difference in strike between the beds of the two horizons, six to eight degrees, and that only a short distance to the northwest of the locality on the north side of the anticline mentioned above, less than a half-mile, the San Lorenzo beds are entirely absent; the basal Monterey beds here rest directly upon the Eocene. At Selby Station on San Pablo Bay (Napa Quadrangle), about six miles to the northwest of this locality, the basal beds of the Monterey (Arca montereyana zone) rest with a marked unconformity upon the Martinez (Lower Eocene). In the Berkeley Hills to the west and southwest of the Sobrante anticline, a distance of less than four miles, the Monterey rests directly upon the Chico (Upper Cretaceous), deposits of the Eocene and Oligocene periods being absent.

SAN LORENZO SERIES OF THE SAN RAMON SYNCLINE

General Statement

The San Lorenzo section of the San Ramon syncline is considerably different from that just described. Only one distinct formation was recognized; this is called the San Ramon, the name already applied to the basal member of the San Lorenzo of the Sobrante anticline. Outcrops of the San Ramon formation are found on both sides of the southeast plunging, closely folded, overturned San Ramon syncline. Here the formation rests upon the Tejon (Eocene), being separated by a questionable disconformity, and is overlain disconformably by beds containing the fauna of the Arca montereyana zone (Miocene). The beds on the west side of the syncline dip about sixty-five degrees to the east with a strike of about twenty degrees west of north; on the east side of the syncline the strike is about north fifty degrees west, while the dip, due to the fact that the strata here have been overturned, is sixty or seventy degrees to the east.

It seems very probable that the San Ramon formation of this section represents a longer period of deposition than the San Ramon formation of the Sobrante anticline, but whether the time of the deposition of the Kirker tuffs and the Concord formation are represented in this record may be open to doubt. On the north side of Mount Diablo there is a marked disconformity between the Kirker tuffs and sands and the Oligocene beds below, described a little further on in this paper. If there was an erosion period between the San Ramon formation and the Kirker sands of Sobrante Ridge section, this might easily account for the former beds in that section being so much thinner than to the south of the town of Walnut Creek, where no tuff beds are present. More will be said about the correlation of the different sections in a later part of this paper.

San Ramon Formation on West Side of Syncline

Lithology.—On the west side of the San Ramon syncline, to the southwest of the town of Walnut Creek, the beds of the San Ramon formation have a thickness of about 525 feet, consisting for the most part of a fine gray sandstone which in some localities has a bluish

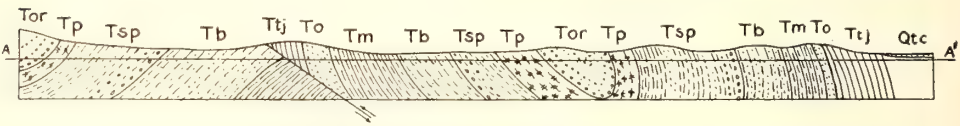

Fig. 2. A northeast-southwest section through the San Ramon syncline (AA on pl. 4). Ttj, Tejon; To, San Ramon; Tm, Monterey; Tb, Briones; Tsp, San Pablo; Tp, Pinole tuff; Tor, Orinda; Qtc, Quaternary.

cast and is tuffaceous. A little above the middle of the section there is a thin bed of a siliceous gray shale. This shale, as is suggested later, is very possibly in part equivalent to the diatomaceous shales of the Markley formation of the section on the north side of the mountain.

Relation to Tejon

Relation to Tejon.—The San Ramon formation, as found on the west side of the San Ramon syncline, shows an unconformable relationship to the Tejon (Upper Eocene). At one locality in the creek bed about one-half mile south of the town of Walnut Creek, University of California locality 1131, this contact may be seen separating the beds of these two horizons.

The uppermost beds of the Tejon, as exposed on the north bank of the creek, consist of a soft bluish clay-shale which butts into the basal sandstone of the San Ramon along an irregular contact with a difference in strike of more than fifteen degrees. Only a few feet distant on the south bank of the creek, a sandstone member, which, on the north side of the creek, is below the shale, comes in contact

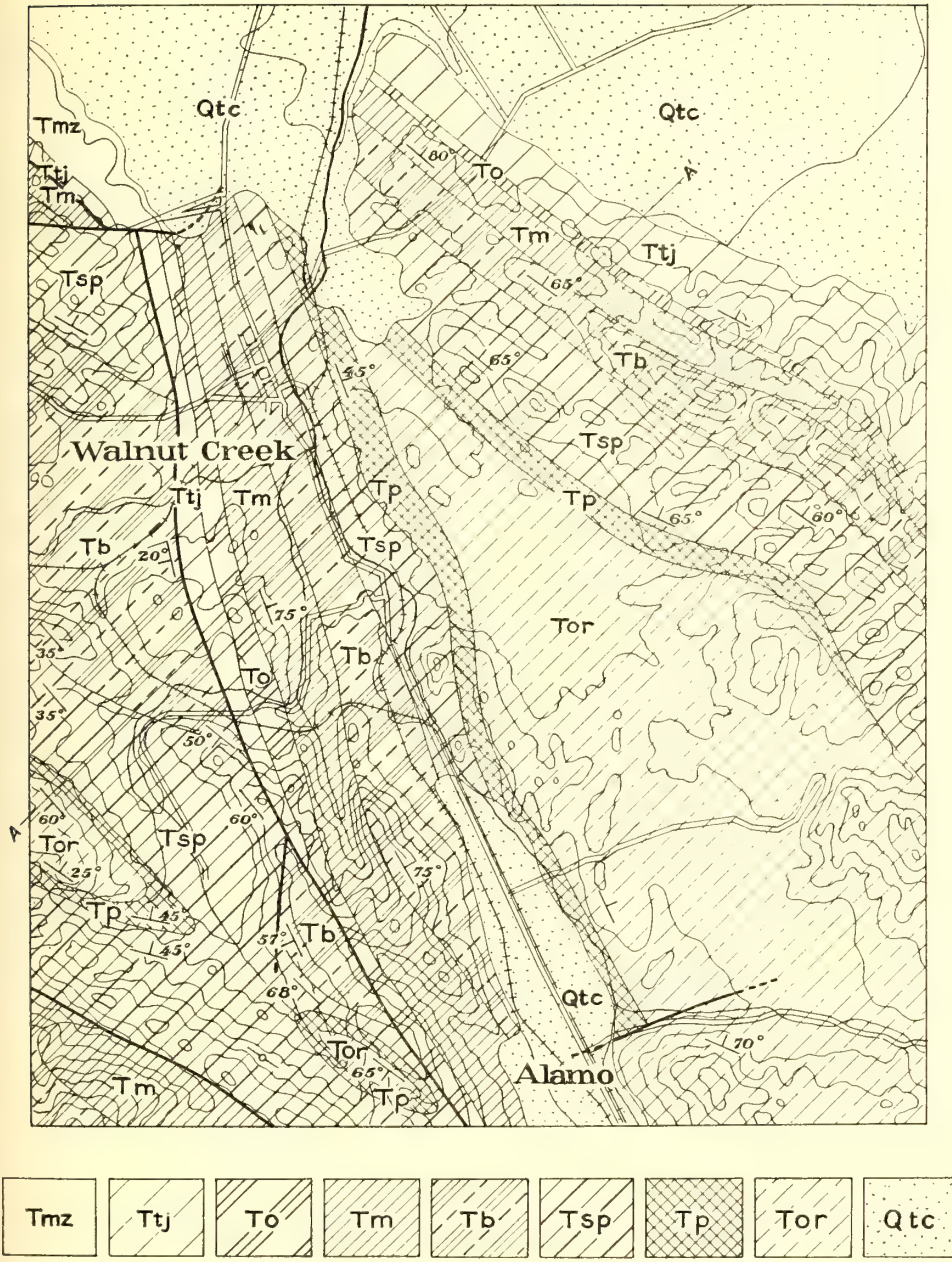

Plate 4. Areal map of the formations in the vicinity of the town of Walnut Creek.

Tz—Martinez	Tm—Monterey	Tp—Pinole Tuff
Ttj—Tejon	Tb—Briones	Tor—Orinda
To—San Ramon	Tsp—San Pablo	Qtc—Quaternary

with the basal sandstone of the San Ramon formation, the shale having been eroded away.

Pholad borings were found in abundance on the north side of the creek. The basal beds of the San Ramon formation, at this locality, consist of a rather coarse, grey sandstone, in places finely conglomeratic, together with communuted shells scattered through it.

Water-worn coal pebbles of considerable size and abundance are found in the lower sandstones of the San Ramon at this locality. It seems very probable that these pebbles were derived from the Tejon, which is the only horizon in this general region known to contain coal in any considerable abundance. The presence of these coal pebbles, therefore, furnishes additional evidence for the unconformity between the San Ramon formation and the Tejon.

Lithology of Lower Monterey (*Miocene*).—Only one well-defined shale member is present in this section of the "Monterey Group"; this is about one hundred feet above the base. The beds below this shale represent shallow-water deposits, consisting of coarse gray sandstone, in which cross-bedding is common, together with lenses of conglomerate and shale.

The line of contact between the basal beds of the Monterey (Sobrante formation as redefined) and the San Ramon formation is marked by conglomerate and coarse, massive, gray sandstone. The conglomerate is lenticular and, in some localities, has a thickness of from ten to fifteen feet; in other localities it is entirely absent. The boulders and pebbles found in it were derived from many sources, both igneous and sedimentary.

Evidence for Stratigraphic Break.—The evidence in this section for a stratigraphic break between the Monterey beds and those of the San Ramon formation is as follows: First, it is suggested by lithology; conglomerates and coarse sandstone occur along a line of contact below which there is a sudden change to a fine sandstone; second, this line of contact is irregular; the irregularities, in some localities, are as much as three to four feet and often are quite sharp; third, fossiliferous boulders which contain characteristic species of the Agasoma gravidum beds are found in the conglomerates at the base of the Arca montereyana zone. At some localities these boulders are so abundant that one must be careful in collecting from the matrix of the conglomerate, lest he get a mixture of the upper and lower faunas. The writer has collected over ten species of the Agasoma gravidum fauna from these boulders and undoubtedly a much larger number could be obtained. Some of the larger boulders are over a foot in diameter and usually consist of a hard, calcareous, gray sandstone. Some are quite angular and apparently could not have been transported far. It seems probable that they were derived from a cliff in the vicinity of the beach during Monterey time.

Summary of Section of San Ramon Formation, Including the Upper Part of the Tejon and the Lower Part of the Monterey, Measured About Two Miles to the South of Walnut Creek

Basal beds of Monterey Group (Arca montereyana zone)	Claremont shale. Sobrante sandstone. 85 feet—Coarse sands and thin layers of shale; shallow-water deposits. 15 feet—Coarse basal conglomerates.
	Disconformity
San Lorenzo series	San Ramon formation. 210 feet—Fine, light gray sandstone; not very hard; outcrops very poor. 20 feet—Fairly hard, siliceous gray shale; laminations not distinct. 290 feet—Fine gray sandstone which, for the most part, is not well indurated; part of this sandstone has a bluish cast and is tuffaceous; thin lentals of harder, calcareous, fossiliferous gray sandstone are quite common. 3 feet—Coarse gray tuffaceous sandstone.
	Unconformity
Tejon	25 feet—Fine yellowish brown sandstone; not very hard; exposures few. About 6 feet—Hard, massive, calcareous gray sandstone. About 50 feet—Shaly sandstone and soft, argillaceous shale; exposures few.
	Fault

San Ramon Formation on East Side of San Ramon Syncline

Occurrence and Lithology.—Beds of the San Ramon formation are found about three miles to the east of the section just described and on the east limb of the same syncline. These outcrops occur on the first ridge to the north of Shell Ridge near the east edge of the Concord Quadrangle, where they have a thickness of only between fifty and seventy-five feet. They consist mostly of a fine gray sandstone similar to the basal Agasoma gravidum beds south of Walnut Creek. and are overlain by coarse, cross-bedded sandstones and conglomerates

Loci	1686	2754	2755	2033	3051	3055	C	R	K
PELECYPODA									
Acila gettysburgensis Reaga	----	----	----	----	×	×	----	×	×
Acila muta, n. sp.	----	×	----	----	----	----	×	----	×
Acila shumardi Dall	----	----	----	----	----	----	----	×	----
Anomia inconspicua, n. sp.	----	----	----	----	----	----	----	×	----
Antigona (Artena) mathew	----	×	----	----	----	----	×	----	×?
Antigona (Artena) neglec	----	×	----	----	----	----	----	×	×
Antigona (Ventricola) und	----	×	----	----	----	----	----	×	×
[illegible]	----	----	----	----	----	×	×		×
Turris (Drillia) thursto	----	----	----	----	×	----	----	×	×
Turritella diversilineata	----	----	----	----	×	----	×	----	×
Turritella porterensis W	----	----	----	----	×	×	----	×	×
Turritella porterensis so	----	----	----	----	----	----	×	----	×
SCAPHAPODA									
Dentalium conradi Dall	----	----	----	----	----	----	----	×	----
Dentalium petricola Dal	----	----	----	----	----	----	×	----	----
Dentalium radiolineata,	----	----	----	----	----	----	×	----	×
Dentalium radiolineata s	----	----	----	----	----	----	----	×	×
VERMES									
Serpula rectiforma, n. s	----	----	----	----	----	----	----	×	×?
ECHINODERMATA									
Schizaster californica W	----	----	×	----	×	×	----	×	×
ANTHOZOA									
Dendrophyllia californi	----	----	----	----	----	----	----	×	×
Sidastrea clarki Nomla	----	----	----	----	----	----	----	×	×
Trochocyathus sp. indt.	----	----	×	----	----	----	----	----	----
CEPHALAPODA									
Aturia sp.	----	----	----	----	----	----	----	----	----

Localities	14	51	126	165	189	231	517	702	708	1151	1164	1165	1173	1175	1213	1309	1311	1312	1314	1315	1343	1658	2754	2765	2933	3051	3055	O	R	M
PELECYPODA																														
Acila gettysburgensis Reagan																										x	x		x	x
Acila muta, n. sp.	x						x	x	x	x		x	x			x		x					x					x		x
Acila shumardi Dall																														
Anomia inconspicua, n. sp.										x																				
Antigona (Artena) mathewsoni (Gabb)	x									x						x					x		x							?
Antigona (Artena) neglecta, n. sp.	x								x	x						x							x						x	x
Antigona (Ventricola) undosa, n. sp.					x									x						x			x						x	x
Arca (Barbatia) mediimpressa, n. sp.										x		x				x					x						x	x		x
Arca (Scapharca?) submontereyana, n. sp.		x																											x	x
Callocardia (Agriopoma) californica, n. sp.										x																			x	x
Cardium dickersoni, n. sp.										x																			x	x
Cardium lorenzanum Arnold										x																			x	x
Cardium cf. vaquerosensis Arnold										x																				
Chione cryptolineata, n. sp.										x											x	x						x		x
Chione lirocolata, n. sp.										x																		x		x
Chione mediostriata, n. sp.										x												x				x		x		x
Cyathodonta weaveri, n. sp.										x																	x		x	x
Diplodonta stephensoni, n. sp.										x																			x	x?
Donax, sp. indt.																														
Dosinia (Dosinidea) mathewsoni Gabb																														
Dosinia (Dosinidea) whitneyi (Gabb)	x																						x						x	x
Glycymeris buwaldi, n. sp.										x							x				x								x	x
Glycymeris tenuimbricata, n. sp.		x				x				x				x							x		x	x			x	x		x
Leda elongorostrata, n. sp.																								x					x	x
Leda pulchrisinuosa, n. sp.										x		x					x				x		x	x			x	x		x
Macrocallista? incognita, n. sp.																														
Macrocallista weaveri, n. sp.																														
Macrocallista, sp. A.																														
Mallettia packardi, n. sp.																														
Metis rostellata, n. sp.																														
Modiolus pittsburgensis, n. sp.																														
Mulinia? sp.																														
Mya (Cryptomya) incognita, n. sp.																														
Mytilus arnoldi, n. sp.																														
Mytilus (Mytiloconcha) mathewsoni Gabb																														
Nucula? bifila, n. sp.																														
Nucula postangulata, n. sp.																														?
Ostrea, sp. indt.																														
Pandora acutirostrata, n. sp.																														
Pecten cf. estrellana Conrad																														
Pecten (Lyropecten) gabbi, n. sp.																														
Pecten (Pseudamusium) alternilineatus, n. sp.																														
Periploma undulata, n. sp.																														
Phacoides cf. acutilineatus (Conrad)																														
Pholadidea aff. penita Conrad																														
Pitaria lorenzana, n. sp.																														
Psammobia aff. edentula Gabb																														
Solen (Plectosolen) curtus Conrad																														
Solen gravidus, n. sp.																														
Spisula occidentalis Gabb																														
Spisula ramonensis Packard																														
Spisula ramonensis attenuata, n. var.																														
Spisula? saxidomoides, n. sp.																														
Tellina lorenzoensis Arnold																														
Tellina oregonensis Conrad																														
Tellina praeacuta, n. sp.																														
Tellina tenuilineata, n. sp.																														?
Teredo sp.?																														
Thracia condoni Dall																														
Yoldia cooperi tenuissima, n. var.																														
GASTROPODA																														
Agasoma acuminatum Anderson and Martin																														
Agasoma gravidum Gabb																											x	x		
Agasoma gravidum multinodosum, n. var.																														
Amphissa pulchrilineata, n. sp.																														
Ancilla fishi Gabb																														
Bullia buccinoides Merriam																														
Bursa mathewsoni (Gabb)	x									x			x	x																
Calliostoma lawsoni, n. sp.	x					x				x							x													
Calyptrae cf. excentrica (Gabb)								x								x														
Calyptrae radians (Lamarck)										x																				
Cancellaria andersoni, n. sp.																										x				
Cancellaria pinolensis, n. sp.																														x
Cancellaria sobrantensis, n. sp.																														x
Cancellaria sp. indt.																										x				
Chrysodomus? pulcherrimus, n. sp.																														x
Columbella (Mitrella) tenuilineata, n. sp.																										x				x
Crepidula praerupta Conrad																					x					x				
Crepidula rostralis Conrad																														
Cylichna ramonensis, n. sp.																										x				x
Epitonium pinolensis, n. sp.																										x				x
Epitonium ventricosum, n. sp.																										x				x
Epitonium sp.																														
Ficus pyriformis Gabb																														
Fusinus (Priscofusus) hecoxi Arnold																										x	x			x
Fusinus (Exilia) lincolnensis Weaver																														x
Fusinus (Exilia) pinolensis, n. sp.																											x			x
Miopleiona indurata (Conrad)												x														x				x
Miopleiona sp.												x														x				
Molopophorus biplicatus (Gabb)																					x									
Murex (Ocinebra) sobrantensis, n. sp.																														
Natica (Ampullina?) gabbi, n. sp.										x																				
Natica (Euspira) ramonensis, n. sp.										x																				
Natica (Neverita) recluziana Petit					x					x										x			x							
Natica (Neverita) recluziana andersoni, n. var.										x																				
Olivella quadriplicata, n. sp.										x				x						x	x		x							
Pseudoperissolax merriami, n. sp.																									x					
Pseudoperissolax? sp.																														
Perse corrugata, n. sp.																														
Potamides (Cerithidea) branneri, n. sp.										x													x							
Scarlesia dalli, n. sp.	x																						x							
Sinum scopulosum (Conrad)																							x							
Solarium lorenzoensis (Arnold)																														
Thais packi, n. sp.										x										x	x									
Turbonilla sp.?										x																				
Turris altuscollus, n. sp.			x							x											x		x							
Turris nomlandi, n. sp.										x																x				
Turris perissolaxoides Arnold																										x				
Turris (Drillia) thurstonensis Weaver																										x				
Turritella diversilineata Merriam										x																x				
Turritella porterensis Weaver																										x		x		
Turritella porterensis sobrantensis, n. var.																										x				
SCAPHAPODA																														
Dentalium conradi Dall																														
Dentalium petricola Dall																														
Dentalium radiolineata, n. sp.										x																				
Dentalium radiolineata sobrantensis, n. var.																														
VERMES																														
Serpula rectiforma, n. sp.																														?
ECHINODERMATA																														
Schizaster californica Weaver																								x			x			
ANTHOZOA																														
Dendrophyllia californiana Nomland																														
Balanophyllia clarki Nomland																														
Trochocyathus sp. indt.																														
CEPHALAPODA																														
Aturia sp.													x																	

of the Monterey beds, in which the shells of *Ostrea* n. sp. aff. *titan* Conrad occur in abundance. A sharp line of contact was found separating the Agasoma gravidum beds from the Tejon below.

Relation to Monterey (Miocene).—The San Ramon beds are absent only a few miles to the southeast of the section just described; here the basal beds of the Arca montereyana zone (Lower Monterey) rest directly upon the Tejon. These basal beds, in places, are composed of fairly heavy conglomerates similar to those seen on the west side of the syncline. At a number of localities tuff boulders were found in the conglomerate, similar to the Kirker tuffs of the Sobrante anticline and to the tuffs found in the Kirker formation, the upper member of the Oligocene to the north of Mount Diablo in the vicinity of Kirker Creek. It seems probable that these boulders, found in the conglomerates of the basal Monterey, were derived from the Kirker tuffs of the San Lorenzo, as tuffs of this character are not known to be present in this general region in any of the formations below that horizon.

San Lorenzo Series in the Pacheco Syncline

Occurrence and Lithology.—The third general section of the Concord Quadrangle in which beds containing the San Lorenzo fauna occur is to the east of Muir Station and to the southeast of the town of Martinez; here they outcrop on either side of what Lawson has designated the Pacheco syncline. The highest beds in this syncline belong to the "Monterey Group." The three faunal zones of the Monterey, as outlined in the Folio, are present, though the entire thickness is only a few hundred feet.

The San Lorenzo fauna is found on both sides of the syncline in fine gray sandstones immediately above the Tejon. The beds containing this fauna have a thickness of only about one hundred feet. They are overlain by heavy conglomerates which in some localities are as much as a hundred feet thick. These conglomerates yield the fauna of the Arca montereyana zone (Lower Monterey); as at Walnut Creek, the species *Ostrea* n. sp. aff. *titan* Conrad is found in abundance in the conglomerate.

Fauna of the San Lorenzo Series to the West of Mount Diablo

Opposite this page is a complete list of the invertebrate species obtained from the San Lorenzo beds to the west of Mount Diablo with the localities at which they were found indicated in the columns at the side. Besides this, there is a column for each of the formations described above, in which is indicated whether a species is rare or common, or whether it has been found only in that particular horizon.[63]

Comparisons of Fauna of San Lorenzo West of Mount Diablo with that Found in the Lower Part of Monterey of the Same Area

The distinctness of the San Lorenzo fauna from that of the Lower Miocene will be discussed in considerable detail in a later part of this paper. The fauna found in the lower Monterey of the Concord Quadrangle belongs to what is generally known as the Temblor horizon of the Lower Miocene, the Turritella ocoyana zone. There is very little in common between this fauna and that of the San Lorenzo series.

The following are some of the most important described species found in the basal beds of the Monterey of the Concord Quadrangle:

- Arca montereyana Osmont
- Chione cf. temblorensis Anderson
- Marcia oregonensis (Conrad)
- Mulinia densata Conrad
- Ostrea n. sp. aff. titan Conrad
- Pandora scapha Gabb
- Panope cf. estrellana Conrad
- Pecten andersoni Arnold
- Pecten cf. nevadensis Conrad
- Spisula catilliformis (Conrad)
- Spisula selbyensis Packard
- Tellina arctata Conrad
- Thracia trapezoides Conrad
- Agasoma barkernianum Cooper
- Crepidula princeps (Conrad)
- Fusinus stanfordensis (Arnold)
- Natica (Neverita) recluziana (Arnold)

Of the species listed above, the only ones which have been found in the San Lorenzo beds of this region are *Panope* cf. *estrellana* and *Natica* (*Neverita*) *recluziana*.

Possibility of Faunal Zones in San Lorenzo to the West of Mount Diablo

The fauna from the different horizons of the San Lorenzo series to the west of Mount Diablo, taken as a whole, appears to be fairly homogeneous. A considerable number of species extend from the lower beds into the upper, among which are several highly ornamented gastropods such as *Agasoma gravidum, Calliostoma lawsoni, Cancellaria andersoni, Fusinus hecoxi, Molopophorus biplicatus, Turris thurstonensis, Turritella porterensis sobrantensis,* etc. On the other hand, as indicated in the list above, there are a number of species which have

[63] The following abbreviations are used to indicate this information: *C,* common; *R,* rare; *K,* characteristic, that is, so far not found in higher or lower horizons.

been found only in the lower portion of this series of beds, while a number have been found only in the middle and upper beds, the Kirker tuffs and Concord formation. The collecting in the lower part of the San Ramon formation of the different sections is much better, the fossils are better preserved and more work has been put on that part of the series than in the other formations; for these reasons the known species in these lower beds are more numerous than they are higher up. Thus, we may expect that a considerable number of the species listed here as having been found only in the lower beds of the San Lorenzo will eventually, with further collecting, be found to extend into the higher horizons. However, it may well be that the species found in the upper beds which have not been found in the lower are good horizon markers, provided that the difference

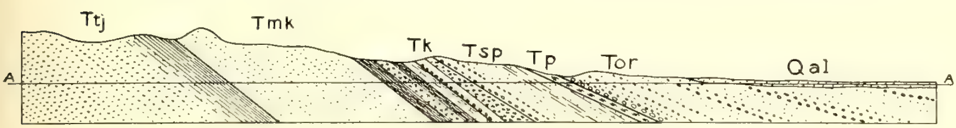

Fig. 3. A north and south section to the north of Mount Diablo, including the San Lorenzo series. Ttj, Tejon; Tmk, Markley formation; Tk, Kirker formation; Tsp, San Pablo; Tp, Pinole tuff; Tor, Orinda formation; Quat, Quaternary.

in the faunas may not be due to a difference in the conditions of environment. The solution of this problem must be left for future work.

THE SAN LORENZO SERIES TO THE NORTH OF MOUNT DIABLO

General Statement

The San Lorenzo beds to the north of Mount Diablo, which were studied by the writer in detail, lie in an area to the south and southeast of the town of Pittsburg, the nearest point being a little over three miles distant; here the outcrops are found along a strip extending from a little over a mile west of Kirker Creek to about three miles east of Markley Cañon (see Mount Diablo topographic sheet, United States Coast and Geodetic Survey); the width of this strip is about a mile. The Oligocene formations extend to the northwest of this area onto the Napa Quadrangle, where, in the vicinity of the town of Bay Point, they disappear below the alluvium; to the southeast these beds, together with those of Miocene and Pliocene age, form the low, rolling hills which lie to the south and southeast of the town of Antioch; farther east, all these formations are covered by the alluvium of the San Joaquin Valley.

Markley Formation

Only one of the Oligocene formations found on the north side of Mount Diablo can with certainty be correlated with beds to the west of the mountain; this is the Kirker formation, the tuffs of which are believed to be contemporaneous with the tuffs of the Sobrante anticline, and to which the name Kirker tuffs has been applied. The lithology and thickness of the beds between the Tejon (Eocene) and the Kirker formation, as found to the north of the mountain, is very different from that of the San Ramon formation, which in the Concord Quadrangle occupies the same stratigraphic position. This, together with the fact that the known fauna in these beds to the north of the mountain is meager, makes it seem best to give them a different formational name; though, as will be brought out later, it is very probable that they are contemporaneous, at least in part, with the San Ramon formation. The name Markley formation is proposed for this portion of the section.

The Markley formation has a thickness of approximately 3300 feet; it consists of a heterogeneous assemblage of beds which are mostly of shallow-water origin. The lower two thousand feet of deposits are predominantly sandstone, the remaining portion being composed of alternating layers of clay-shale, sandy shale and sandstone. The basal bed of the Markley formation rests with apparent conformity upon the Tejon, the uppermost beds of which in this vicinity consist of a clay-shale. This shale, as seen at the old town of Somersville, has a thickness of about five hundred feet.

The lower two thousand feet of the Markley formation is unfossiliferous. These beds are apparently conformable with the Eocene deposits below and with the fossiliferous Oligocene above; therefore the period to which they belong might be an open question. The writer in a former paper[64] included these lower beds in the Tejon (Upper Eocene). Later work, however, has caused him to believe that they are probably Lower Oligocene in age for the reason that they apparently grade up into strata containing an Oligocene fauna, and have a lithology which is similar to the sandstones immediately above these fossiliferous beds and different from any of the sandstones of the Tejon of this general region.

Lithology.—The first distinct lithologic member of the Markley formation, commencing at the base, consists of about seven hundred

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[64] Clark, B. L., The Neocene section at Kirker Pass, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, no. 4, pp. 49–52, 1912.

feet of medium-coarse, gray, micaceous sandstones, interbedded with which are minor layers of softer sandstones and clay-shales. Reddish-brown, elongate concretions, which in some cases are two to three feet or more in length, are scattered in fairly definite layers throughout. The sandstone is arkosic and contains a great abundance of fairly large flakes of white mica, some of which are almost a quarter of an inch in diameter. The sandstone, in places, is loosely consolidated and certainly has not been subjected to metamorphism. The arkosic character, together with the great abundance of the mica, apparently shows that these sediments were derived in large part directly from igneous rocks.

Above the seven hundred feet of micaceous sandstone is about two hundred feet of soft brown carbonaceous shale. This grades up into a series of alternating sandstones and shale, the thickness of which is about 1400 feet. The sandstones, for the most part, have the same general character as the basal sandstones. Very few exposures of the shale were found; usually it is brown to gray, argillaceous in character, and contains carbonaceous material in considerable abundance The uppermost bed of this general unit of the section is a medium brown sandstone.

The sandstone just mentioned apparently grades up into a series of shales which, at the base, are rather dark and argillaceous and contain an abundance of carbonaceous material; at about three hundred feet from the base, the shale is lighter in color and much harder, and the outcrops are fairly conspicuous. The thickness of this part of the section is about one hundred and sixty feet. The shale of this horizon varies from a chocolate color to almost a pure white; some of the layers, especially near the base, are rather thick and massive; higher up they are thinner-bedded and in places form typical paper shale. Marine diatoms are abundant in the lower beds, the genus *Coscinodiscus* being the most common form. Impressions of leaves and rushes are rather common in the upper part of this shale member and diatoms are conspicuous by their absence.

The light-colored shales, just described, grade up into soft carbonaceous shales with alternating layers of rather coarse, micaceous gray to yellowish brown sandstone. The sandstone layers predominate toward the top. The different shale layers vary from a few inches to several feet in thickness; some of the layers are white and fairly hard; some are almost black, while others are reddish brown in color. Leaf impressions and carbonaceous material are abundant in these beds. At one horizon near the top (the outcrops are along the same creek but stratigraphically below locality 78) a layer of white shale was found full of impressions of Pteropods, thus indicating the marine origin of these upper beds. This portion of the section in the vicinity of Markley Cañon has a thickness of between four hundred and five hundred feet. The thickness is somewhat greater in the vicinity of Kirker Creek.

Probable relation to Kreyenhagen shale.—It will be pointed out later that the San Lorenzo series of the region of Mount Diablo represents the same general period of deposition as that of the Kreyenhagen shales, recently described by Robert Anderson and R. W. Pack,[65] which extend from the Coalinga district to within a few miles of the Mount Diablo Quadrangle. The greater portion of the Kreyenhagen shales to the south represents fairly deep-water conditions of deposition; the Oligocene deposits around Mount Diablo are, for the most part, of shallow-water origin. The diatomaceous shales of the Markley formation represent the same condition of deposition as existed during most of the Oligocene time further south.

Fauna.—The following molluscan species were obtained from the diatomaceous, light-colored shales of the Markley formation: *Acila muta, Leda pulchrosinuosa, Malletia packardi, Pecten alterlineata* and *Yoldia* species. Of these, *Acila muta, Leda pulchrosinuosa* and *Pecten alterlineata* are found in the San Ramon formation of the Concord Quadrangle, while *Malletia packardi* occurs in the Kirker formation, both in this section and in that of the Sobrante anticline.

Kirker Formation

The Markley formation is overlain by about four hundred feet of sandstones, tuffs and tuffaceous sandstones, to which has been given the name Kirker formation. These beds of the Kirker formation, like the larger part of those of the Markley formation, represent shallow-water conditions of sedimentation.

Disconformity.—Before the Kirker formation was laid down, there was a period of erosion which, if we may judge from the coarse conglomerates found at the base of the Kirker formation, was probably due to crustal movements in the general region of the Coast Ranges.

At one locality,[66] a little less than a mile west of Kirker Creek, a

65 Anderson, Robert, and Pack, Robert W., Geology and oil resources of the west border of the San Joaquin Valley, north of Coalinga, California, U. S. Geol. Surv., Bull. 603, pp. 74–78, 1915.

66 University of California locality 78.

thin layer of conglomerate, the basal bed of the Kirker formation, is underlain by ten or fifteen feet of coarse, poorly assorted conglomerate and sandstone which apparently are fluviatile in origin, and which overlie the upper micaceous sandstone and shale of the Markley formation. Less than a quarter of a mile east of this locality, the basal conglomerate of the Kirker formation rests directly upon these micaceous sandstones and shales. Some of the important evidences of erosion found at the contact, as observed at the last locality, are as follows:

1. The contact is irregular; in places, the conglomerate of the Kirker formation rests upon the micaceous sandstone, and in places upon the shale of the Markley formation.
2. Large boulders of micaceous sandstone and clay-shale, derived from the beds immediately below, are found in the basal conglomerate of the Kirker formation. Some of the sandstone boulders are as much as three feet and a half in length and over two feet both in width and thickness. The shale boulders are elongate, flat slabs, some of which are over three feet in length.
3. A zone of weathering is found around the edges of most of the sandstone and shale boulders; this is especially noticeable on the latter.
4. Pholad borings of great abundance extend from the upper into the lower beds.

Lithology.—The basal conglomerate of the Kirker formation is thin, varying from a foot or two in thickness to only a few inches; at some localities it is absent altogether. Besides the sandstone and shale boulders, described above, boulders of quartzite, chert, and various kinds of igneous rock are found in the conglomerate; the largest of these are about five or six inches in diameter, and as a rule are well rounded.

Immediately above the basal conglomerate is about fifty feet of light-gray sandstone, which becomes more and more tuffaceous toward the top. This is followed by about three hundred and fifty feet of fine white tuff and tuffaceous sandstones, the tuff being by far the more predominant.

W. H. Turner[67] and C. E. Weaver[68] included the tuffs of this

[67] Turner, W. H., The rocks of Mount Diablo Range of California, Jour. Geol., vol. 6, pp. 488–499, 1898.

[68] Weaver, C. E., Stratigraphy and palaeontology of the San Pablo formation of Middle California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 5, no. 16, pp. 258–259, 1909.

horizon in the San Pablo (Upper Miocene). Turner determined the tuff to be rhyolitic in composition.

The tuff beds, as found about a mile west of Kirker Creek, grade up into a fine, fossiliferous sandstone, which has a thickness of less than fifty feet; leaf impressions are quite common in these sandstones and also at a number of horizons in the tuff beds below. To the east of Kirker Creek, these upper beds are lacking and the tuff beds come in contact with the San Pablo; this is due to the unconformity between the Kirker beds and the San Pablo. As the beds of the Kirker formation are followed to the east, they gradually thin out, and the San Pablo beds rest on lower and lower horizons, until, two and a half miles east of Kirker Creek, on the west side of Markley Cañon, only ten or fifteen feet of the tuff is present, while on the east side of the cañon the tuffs are absent and the San Pablo rests first upon the sandstones just below the tuffs and then, a little farther to the east, upon the upper beds of the Markley formation.

In the vicinity of Markley Cañon and of Kirker Creek there is a general difference in strike of about twelve degrees and in many places a difference in dip of ten degrees or more between the upper San Lorenzo beds and those of the San Pablo. *Pholad* borings are very common along the contact, and boulders derived from the San Lorenzo are common in the basal conglomerates of the San Pablo.

Fauna.—A fairly large fauna has been obtained from the Kirker formation. Some of the species found in the basal beds are: *Acila shumardi, Dosinia mathewsonii, Macrocallista pittsburgensis, Solen gravidus, Spisula occidentalis, Spisula ramonensis, Tellina oregonensis, Yoldia* cf. *oregona, Agasoma gravidum, Molopophorus* cf. *biplicatus, Solarium lorenzoensis,* etc.

Some of the species found in the tuffaceous beds above are: *Acila muta, Acila gettysburgensis, Cardium lorenzoensis, Malletia packardi, Modiolus kirkensis, Modiolus pittsburgensis, Tellina lorenzoensis, Pseudoperissolax merriami, Dentalium conradi,* etc.

SUMMARY OF SAN LORENZO SECTION ON NORTH SIDE OF MOUNT DIABLO

San Pablo Group (Upper Miocene)	Basal conglomerates of San Pablo.
	Unconformity
Kirker formation	50–0 feet—Tuffaceous sandstone. 350 feet—Rhyolitic, white tuff beds with lentals of bluish tuffaceous sandstones. 50 feet—Sandstone, tuffaceous toward the top.
	Disconformity
Markley formation	500 feet—Micaceous, gray to yellow-brown sandstones and shales, the latter variegated in color. 160 feet—Light-colored shales, diatomaceous in part. 300 feet—Dark, carbonaceous, arenaceous and argillaceous shales. 1400 feet—Micaceous sandstones and argillaceous and arenaceous shales alternating; poor outcrops of shale. 200 feet—Soft, argillaceous shale. 700 feet—Medium-coarse, gray, arkosic, micaceous sandstones.
	Total, 3700 feet.
Tejon Group (Upper Eocene)	500 feet—Tejon shale.

LIST OF SPECIES FROM SAN LORENZO BEDS TO NORTH OF MOUNT DIABLO

Following is a complete faunal list of the known species from the San Lorenzo beds on the north side of Mount Diablo, with the localities indicated in the columns on the side. Abbreviations used are: *R*, rare; *C*, common. Those species marked with an asterisk in front of them are also found in the San Lorenzo beds to the west of the mountain in the Concord Quadrangle.

FAUNA FROM THE SAN LORENZO SERIES TO THE NORTH OF MOUNT DIABLO

Pelecypoda	76	78	1524	1895	1897	1900	2022	2033	2043	3080	3081	R.	C.
*Acila gettysburgensis Reagan	×	....	....	....	....	....	....	....	....	....	....	×	....
*Acila muta, n. sp.	....	....	....	....	×	....	....	×	....	×	....	×	....
*Acila muta markleyensis n. var.	....	....	....	×	....	....	....	....	....	....	×	....	×
*Acila shumardi Dall	....	×	....	....	....	....	....	....	....	....	....	....	×
Cardium kirkerensis, n. sp.	....	....	....	....	....	....	....	×	....	....	....	×	....
*Cardium lorenzanum Arnold	....	....	....	....	....	....	....	×	....	....	....	×	....
*Diplodonta stephensoni, n. sp.	....	×	....	....	....	....	....	....	....	....	....	×	....
*Dosinia mathewsonii Gabb	....	×	....	....	....	....	....	....	....	....	....	×	....
Leda markleyensis, n. sp.	....	....	....	....	....	....	....	....	....	....	×	×	....
*Leda pulchrisinuosa, n. sp.	....	....	....	....	....	....	....	....	....	×	....	×	....
Macoma aff. nasuta Conrad	....	....	....	....	....	....	×	....	....	....	....	×	....
Macrocallista pittsburgensis Dall	....	×	....	....	....	....	....	....	....	....	....	×	....
*Malletia packardi, n. sp.	....	....	×	....	×	....	....	×	....	×	....	....	×
Modiolus kirkerensis, n. sp.	....	....	....	....	....	....	....	....	....	....	×	....	×
*Modiolus pittsburgensis, n. sp.	....	....	....	....	....	....	....	×	....	....	....	....	×
Mulinia? sp.	×	....	....	....	....	....	....	....	....	....	....	×	....
*Mytilus arnoldi, n. sp.	....	×	....	....	....	....	....	....	....	....	....	....	×
*Mya (Cryptomya) incognita, n. sp.	....	×	....	....	....	....	....	....	....	....	....	×	....
*Panope estrellana Conrad	....	....	....	....	....	×	....	....	....	....	....	×	....
*Pecten (Pseudomusium) alternilineatus, n. sp.	....	....	....	....	....	....	....	....	....	×	....	×	....
Phacoides sp.	....	....	....	....	....	....	....	×	....	....	....	....	....
Pholad sp.?	....	....	....	....	×	....	....	....	....	....	....	....	×
Pitaria sp.	....	×	....	×	....	....	....	....	....	....	....	....	×
Siliqua aff. lucida Conrad	×	....	....	....	....	....	....	....	....	....	....	×	....
*Solen gravidus, n. sp.	×	×	....	....	×	×	....	....	....	....	....	....	×
*Spisula occidentalis Gabb	....	×	....	....	....	....	....	....	....	....	....	×	....
*Spisula ramonensis, n. sp.	....	×	....	....	....	....	....	....	....	....	....	....	×

	76	78	1524	1895	1897	1900	2022	2033	2043	3080	3081	R.	C.
*Tellina lorenzoensis Arnold	....	....	....	×	....	....	....	×	....	....	....	....	×
*Tellina oregonensis Conrad	....	×	....	....	....	....	....	....	....	....	....	×	....
Teredo sp.?	....	....	....	....	....	....	....	....	....	....	....	....	×
Yoldia cf. oregona Shumard	....	×	....	....	....	....	....	....	....	....	....	×	....
GASTROPODA													
*Agasoma gravidum Gabb	....	×	....	....	....	....	....	....	....	....	....	×	....
Calyptraea cf. excentrica Gabb	....	×	....	....	....	×	....	....	....	....	....	....	....
Clavella californica, n. sp.	×	....	....	....	....	....	....	....	....	....	....	×	....
*Crepidula praerupta Conrad	....	....	....	....	....	....	....	....	....	....	×	×	....
*Molopophorus cf. biplicatus (Gabb)	....	×	....	....	....	....	....	....	....	....	....	×	....
*Natica recluziana andersoni, n. var.	....	×	....	....	....	....	....	....	....	....	....	×	....
*Pseudoperissolax merriami, n. sp.	....	....	....	....	....	....	....	×	....	....	....	×	....
Scaphander sp.?	....	....	....	×	....	....	....	×	....	....	....	×	....
*Solarium lorenzoensis (Arnold)	....	×	....	....	....	....	....	....	....	....	....	×	....
Strepsidura? sp.	....	....	....	....	....	....	....	....	....	....	×	....	....
Styliola sp.?	....	....	....	....	....	....	....	....	....	....	....	....	....
Vermicularia sp.	....	....	....	×	....	....	....	×	....	....	....	....	....
SCAPHAPODA													
Dentalium conradi Dall	....	....	....	....	....	....	....	×	....	....	×	....	×
ANTHOZOA													
Trochocyathus sp. indt.		....	....	....	....	....	....	....	....	....	....	×	....
CRUSTACEA													
Balanus sp.	....	....	....	×	....	....	....	....	....	....	....	....	×
ECHINODERMATA													
Amphiura sp.?	....	....	....	....	....	....	....	....	....	×	....	....	....

Relation of San Lorenzo Beds to North of Mount Diablo to Those to the West

The contrast between the different sections of the San Lorenzo beds, just described, is so striking that it brings up the question, what were the conditions of deposition that would cause such a difference? Below, in diagrammatic form, the sections are placed side by side, and lines drawn from one to the other to indicate the writer's ideas as to the probable relationships of the three most important sections.

None of the formations to the west of the mountain are comparable in thickness and lithology to the Markley formation. The few fossils found in the diatomaceous shales of this formation show that the beds are of Oligocene age. This alone, perhaps, should not be sufficient evidence for saying that these beds were contemporaneous in deposition with those of the San Ramon formation. In general, the lithology of the San Ramon beds is very different from that of the Markley; however, south of Walnut Creek we find, a little above the middle of the San Ramon formation, the thin band of siliceous shale which possibly represents the westward continuation of the light-colored diatomaceous shale of the Markley formation.

The greater thickness of the Markley formation, compared with that of the San Ramon formation, together with the fact that the two sections are separated by only a few miles, suggests the probability that deposition began in the area to the north of Mount Diablo before it did in the area to the west. The distribution of the marine Oligocene to the south of Mount Diablo shows that these deposits were laid down in a long north-and-south trough or geosyncline, the axis of which extended from the southern end of the San Joaquin Valley northward along the most eastern line of major folding in the Coast Ranges to at least as far north as the area under discussion. This is shown by the distribution of the Oligocene diatomaceous shale (the Kreyenhagen shale), which is found in a long, narrow area between Coalinga and Mount Diablo. It has already been suggested that the narrow band of diatomaceous shale in the Markley formation represents the northward extension of the same conditions of sedimentation as those found farther to the south, i.e., during the period of deposition of the Kreyenhagen shales. The presence of the great thickness of arkosic sandstone and lignitic shale, both below and above the diatomaceous shale to the north of Mount Diablo, shows that this Oligocene trough was shallower at its northern end than in the region to the south. As has already been suggested, it seems probable that these

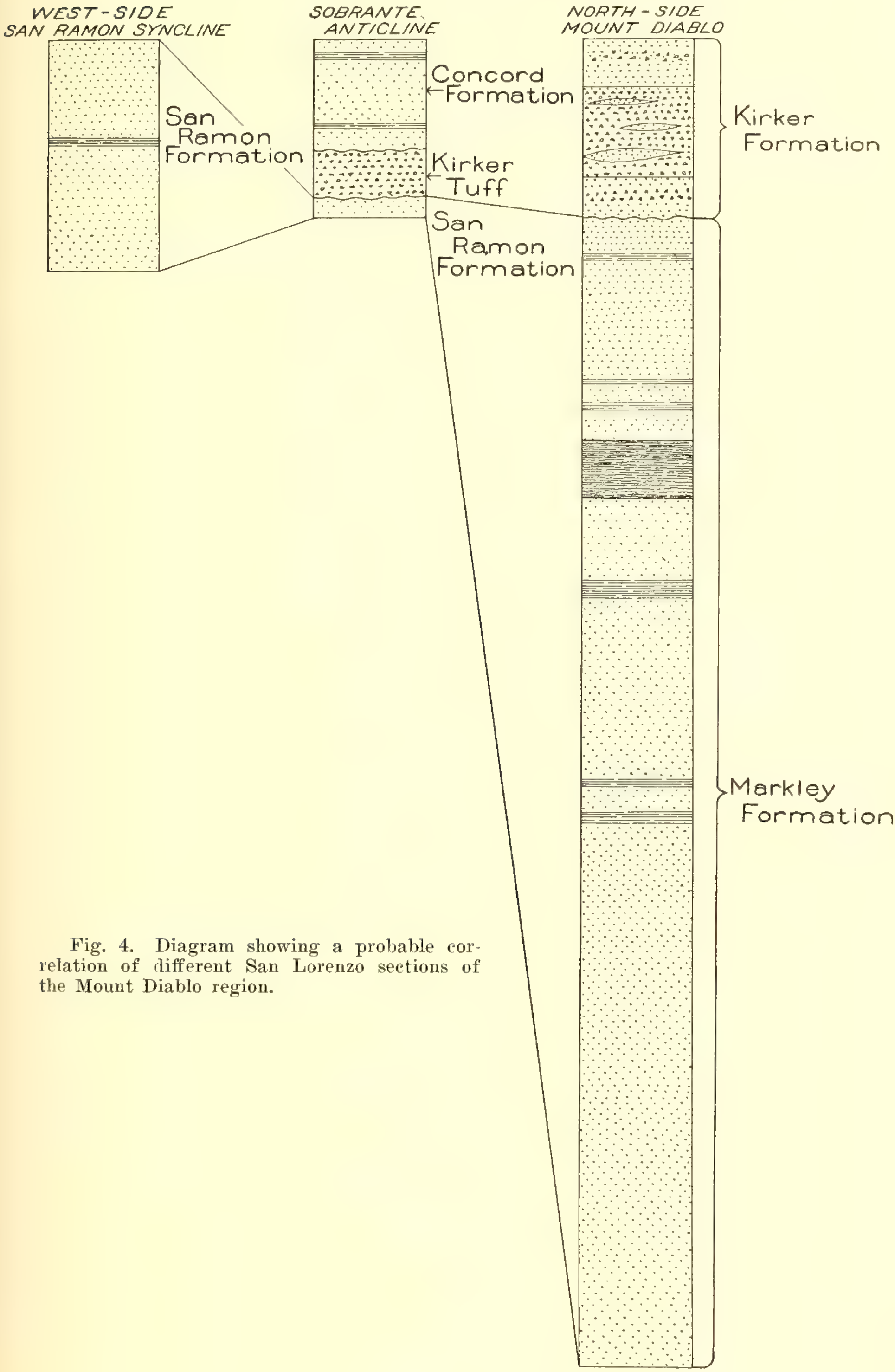

Fig. 4. Diagram showing a probable correlation of different San Lorenzo sections of the Mount Diablo region.

coarser beds represent continental deposits. The explanation for the fact that the Markley formation is thicker than the San Ramon may be that sedimentation began first in the middle of the trough, the location of which now would be in the area to the north of Mount Diablo, and then spread to the west. When the sea came in, probably from the south, the trough was already partly filled with the continental deposits, which had not extended as far west as the area in which the outcrops of the San Ramon formation are found; deposition extended over a wider area and sedimentation took place for the first time in the western area.

The possibility that the lower sandstones of the Kirker formation on the north side of the mountain are the equivalent of the San Ramon formation has been considered. This seems very improbable. In the first place, the diatomaceous shales of the Markley formation contain typical Oligocene species. Further, if the basal sands of the Kirker formation are the equivalent of the San Ramon formation, then the great thickness of the beds of the Markley formation is entirely absent to the west of the mountain; because of the nearness of the two sections to each other this would imply a time-break of considerable importance between the deposition of the beds of the two formations, and of such a time-break the fossils give no evidence. Finally, the fauna found in the basal beds of the Kirker formation to the north of Mount Diablo is somewhat different from that found in the San Ramon beds. Some of the species which are very common in the basal Kirker sandstones and which have not been found in the San Ramon beds are *Acila shumardi, Macrocallista pittsburgensis, Pitaria* sp., *Yoldia* cf. *oregona,* and *Solarium lorenzanum.* Two of these species, *Acila shumardi* and *solarium lorenzanum,* have been found in the Concord formation to the west of the mountain.

There is very good evidence for the correlation of the Kirker formation to the north of Mount Diablo with the Kirker tuffs and the Concord formation of the Sobrante anticline. As has already been stated, there are very few species found in the Concord formation that are not also found in the Kirker tuffs immediately below. It is possible that the Kirker formation on the north side of the mountain represents both the Kirker tuffs and the Concord formation of the Sobrante anticline. The reason for giving a separate formational name to these upper sandstones of the Sobrante section is the presence of the disconformity which separates these beds from the tuff member below.

The following species are common to the Kirker formation to the north of Mount Diablo and to the Kirker tuffs and Concord formation of the Sobrante anticline:

- Acila gettysburgensis Reagan
- Acila shumardi Dall
- Malletia packardi, n. sp.
- Modiolus pittsburgensis, n. sp.
- Phacoides cf. acutilineatus Conrad
- Solen gravidus, n. sp.
- Spisula ramonensis Packard
- Tellina lorenzoensis Arnold
- Agasoma gravidum Gabb
- Pseudoperissolax merriami, n. sp.
- Solarium lorenzanum Arnold

The opinion has already been expressed that beds representing the Kirker formation are not present in the section at Walnut Creek. Whether there was a land area in this vicinity during the deposition of the Kirker beds at the Sobrante anticline and to the north of the mountain, or whether erosion has removed them after deposition, cannot be determined with the data at hand.

It would seem that the shoreline at the time of the deposition of the San Lorenzo beds of this region, or at least during part of the period, was in the vicinity of Mount Diablo and that there were oscillations of the ocean level, as indicated by the disconformities which have been described and by the alternation of fairly deep-water with shallow-water deposits. This is only additional evidence that the earth's crust in the vicinity of Mount Diablo was a positive element during Mesozoic and Cenozoic time, the shorelines of the various seas during the different epochs of deposition being most of the time in the near vicinity. Shallow-water deposits of considerable thickness of Cretaceous, Eocene, Oligocene, and Miocene age are found in this section.

Complete List of Species from San Lorenzo Series in Region of Mount Diablo

A—Species common to Pittsburg beds, Oregon.

B—Species common to Lincoln and Porter Creek beds, Washington. These localities belong to what is usually considered Lower Oligocene.

C—Species common to beds in Oregon, Washington and Vancouver Island, containing the Acila gettysburgensis fauna.

D—Species common to the Lower Miocene, i.e., Turritella inezana and Turritella ocoyana zones.

Pelecypoda	A	B	C	D
Acila gettysburgensis Reagan	....	....	×	....
Acila muta, n. sp.	....	....	×	....
Acila muta markleyensis, n. var.	....	....	....	....
Acila shumardi Dall	×	×	....	....
Antigona (Artena) mathewsonii (Gabb)	×	....	....	....
Antigona (Artena) neglecta, n. sp.	....	....	....	....

	A	B	C	D
Antigona (Ventricola) undosa, n. sp.	....	....	....	....
Anomia inconspicua, n. sp.	....	....	....	....
Arca (Scapharca) mediaimpressa, n. sp.	....	....	....	....
Arca (Scapharca) submontereyana, n. sp.	....	....	....	....
Callocardia (Agriopoma) californica, n. sp.	....	....	....	....
Cardium dickersoni, n. sp.	×	....	....	....
Cardium kirkerensis, n. sp.	....	....	....	....
Cardium lorenzanum Arnold	×	×	×	....
Cardium cf. vaquerosensis Arnold	....	....	....	×
Chione cryptolineata, n. sp.	....	....	....	....
Chione lineolata, n. sp.	....	×	×	....
Chione mediostriata, n. sp.	....	....	....	....
Cyathodonta weaveri, n. sp.	....	....	....	....
Diplodonta stephensoni, n. sp.	....	....	....	....
Donax sp. indt.	....	....	....	....
Dosinia mathewsonii Gabb	....	....	....	×
Dosinia whitneyii (Gabb)	....	....	....	....
Glycimeris buwaldi, n. sp.	....	....	....	....
Glycimeris tenuimbricata, n sp.	....	×	....	....
Leda elongorostrata, n. sp.	....	....	....	....
Leda pulchrisinuosa, n. sp.	....	....	....	....
Leda markleyensis, n. sp.	....	....	....	....
Macoma aff. nasuta Conrad	....	....	....	....
Macrocallista? incognita, n. sp.	....	....	....	....
Macrocallista pittsburgensis (Dall)	×	×	....	....
Macrocallista weaveri, n. sp.	....	....	....	....
Macrocallista sp.	....	....	....	....
Malletia packardi, n. sp.	....	....	....	....
Metis rostellata, n. sp.	....	....	....	....
Modiolus kirkerensis, n. sp.	....	....	....	....
Modiolus pittsburgensis, n. sp.	....	....	....	....
Mulinia? sp.	....	....	....	....
Mya (Cryptomya) incognita, n. sp.	....	....	....	....
Mytilus arnoldi, n. sp.	....	×	....	....
Mytilus mathewsonii Gabb	....	....	....	....
Nucula? bifida, n. sp.	....	....	....	....
Nucula postangulata, n. sp.	....	....	....	....
Ostrea sp. indt.	....	....	....	....
Pandora acutirostrata, n. sp.	....	....	....	....
Panope cf. estrellana Conrad	×	×	×	×
Pecten (Lyropecten) gabbi, n. sp.	....	....	....	....
Pecten (Pseudomusium) alternilineatus, n. sp.	....	....	....	....
Periploma undulata, n. sp.	....	....	....	....
Phacoides cf. acutilineatus (Conrad)	×	×	×	....
Pholadidea aff. penita Conrad	....	....	....	....
Pitaria lorenzana, n. sp.	....	....	....	....
Pitaria? sp.	....	....	....	....
Psammobia aff. edentula (Gabb)	....	....	....	....
Solen curtus Conrad	×	....	×	×
Solen gravidus, n. sp.	×	×	....	×
Spisula occidentalis (Gabb)	....	×	....	....

	A	B	C	D
Spisula ramonensis Packard	×	×	×	....
Spisula ramonensis attenuata, n. var.	×	....	....	....
Spisula? saxidomoides, n. sp.	....	....	....	....
Tellina lorenzoensis Arnold	×	....	....	....
Tellina lorenzoensis Conrad	×	....	....	....
Tellina oregonensis Conrad	×	×	×	×
Tellina praeacuta, n. sp.	....	....	....	....
Tellina tenuilineata, n. sp.	....	....	....	×?
Teredo sp.	....	....	....	....
Thracia condoni Dall	×	×	....	....
Yoldia cooperi tenuissima, n. var.	....	....	....	....
Yoldia cf. oregona Shumard	×	×	....	....
GASTROPODA				
Actaeon kirkerensis, n. sp.	....	....	....	....
Agasoma acuminatum Anderson & Martin	....	×	....	....
Agasoma gravidum Gabb	×	×	....	....
Agasoma gravidum multinodosum, n. var.	....	....	....	....
Ancilla fishii Gabb	×	....	....	....
Amphissa pulchrilineata, n. sp.	....	....	....	....
*Bullia buccinoides Merriam	....	×	×	....
Bursa mathewsonii (Gabb)	×	....	....	....
Calliostoma lawsoni, n. sp.	....	....	....	....
Calyptraea cf. excentrica Gabb	....	....	....	....
Calyptraea radians Lemarck	×	....	....	×
Cancellaria andersoni, n. sp.	....	....	×	×
Cancellaria sobrantensis, n. sp.	....	....	....	....
Cancellaria sp. a	....	....	....	....
Cancellaria? sp. b.	....	....	....	....
Chrysodomus? pulcherrimus, n. sp.	....	....	....	....
Clavella californica, n. sp.	....	....	....	....
Columbella (Mitrella) tenuilineata, n. sp.	....	....	....	....
Crepidula praerupta Conrad	×	×	×	×
Crepidula rostralis Conrad	....	....	....	....
Cylichna ramonensis, n. sp.	....	....	....	....
Epitonium pinolensis, n. sp.	....	....	....	....
Epitonium sp. indt.	....	....	....	....
Epitonium ventricosum, n. sp.	....	....	....	....
Ficus pyriformis Gabb	....	×	....	×?
Fusinus (Exilia) lincolnensis Weaver	....	....	....	....
Fusinus (Exilia) pinolianus, n. sp.	....	....	....	....
Fusinus (Priscofusus) hecoxi Arnold	....	....	×	....
Miopleiona indurata (Conrad)	....	....	....	....
Miopleiona sp.	....	....	×	....
Molopophorus biplicatus (Gabb)	×	×	....	....
Murex (Ocinebra) sobrantensis, n. sp.	....	....	....	....
Natica (Ampullina) gabbi, n. sp.	....	×	....	....
Natica (Euspira) ramonensis, n. sp.	×	....	....	....
Natica (Neverita) recluziana Petit	×	....	....	×
Natica (Neverita) recluziana andersoni, n. subsp.	....	....	....	×
Natica sp.?	....	....	....	....
Olivella quadriplicata, n. sp.	....	....	....	....

	A	B	C	D
Perse corrugatum, n. sp.	....	....	....	....
Pseudoperissolax? sp.	....	....	....	....
Pseudoperissolax merriami, n. sp.	....	....	....	....
Potomides (Cerithidea) branneri, n. sp.	....	....	....	....
Scaphander sp.?	....	....	....	....
Searlesia dalli, n. sp.	....	....	....	....
Sinum scopulosum (Conrad)	×	×	×	×
Solarium lorenzoensis (Arnold)	....	....	....	....
Strepsidura? sp.	....	....	....	....
Styliola sp.?	....	....	....	....
Thais packi, n. sp.	....	....	....	....
Turbonilla sp.?	....	....	....	....
Turris alticollarus, n. sp.	....	....	....	....
Turris nomlandi, n. sp.	....	....	....	....
Turris perissolaxoides Arnold	....	....	....	....
Turris (Drillia) thurstonensis Weaver	....	×	....	....
Turritella diversilineata Merriam	....	....	×	....
Turritella porterensis Weaver	....	×	....	....
Turritella porterensis sobrantensis, n. var.	×	×	....	....
Vermicularia? sp.	....	....	....	....
Scaphapoda				
Dentalium conradi Dall	....	....	....	×
Dentalium petricola Dall	×	×	×	×
Dentalium radiolineata, n. sp.	×	×	×	....
Dentalium radiolineata sobrantensis, n. var.	....	....	....	....
Vermes				
Serpula rectiforma, n. sp.	....	....	....	....
Echinodermata				
Schizaster californica (Weaver)	....	....	....	....
Anthozoa				
Dendrophyllum californiana Nomland	....	....	....	....
Sidastrea clarki Nomland	....	....	....	....
Cephalapoda				
Aturia sp.	....	....	....	....
Crustacea				
Balanus sp. A	....	....	....	....
Balanus sp. B	....	....	....	....

Statistical Summary of Faunal List

Number of species	137
Number of determinable species	112
Number of indeterminate species	25
Number of Recent species	2
Percentage of determinable species which are Recent	1.78
Number of determinable species that extend into Lower Miocene or higher	10
Percentage of determinable species that extend into Lower Miocene or higher	8.9
Number of determinable species that extend into Eocene	0
Number of determinate species common to the San Lorenzo of the Santa Cruz Mountains	13

Percentage of determinable species common to the San Lorenzo of the Santa Cruz Mountains	11.6
Number of species common to the Oligocene of Oregon and Washington	45
Percentage of determinable species common to the Oligocene of Oregon and Washington	40

Review of Occurrence of Beds Referable to the San Lorenzo Series at Other Localities in California

SAN LORENZO BEDS IN NAPA COUNTY

The collections of the University of California summer field class of 1915, which was held in Napa County under the leadership of R. E. Dickerson, show the presence of the Agasoma gravidum fauna in beds to the east of Carnaros Creek, a few miles to the west of the town of Napa.[69] The fauna is confined to beds not much more than a hundred feet in thickness, consisting for the most part of a medium-fine, gray sandstone. They rest, according to Dickerson, upon the Knoxville (Lower Cretaceous), and are overlain by beds containing the fauna of the Arca montereyana zone. The contact with this latter horizon is obscure on account of poor exposures.

KREYENHAGEN SHALE OF COALINGA DISTRICT AND TO NORTH

Reference has already been made in the historical review[70] to the Kreyenhagen shale, originally referred to the Eocene but now known to be of Oligocene age, containing such characteristic species as *Macrocallista pittsburgensis, Leda lincolnensis,* and *Fusinus* (*Exilia*) *lincolnensis.* The Kreyenhagen shales in the Coalinga district and to the north lie unconformably below the Vaqueros. The following statement, concerning the stratigraphic relationships of these shales, is made by Robert Anderson and Robert W. Pack in their paper entitled "The geology and oil resources of the San Joaquin Valley north of Coalinga, California":

> The Kreyenhagen shale is believed to rest unconformably on the Tejon throughout the region, with the possible exception of the area between Gargas and Puerto creeks.... Its relation to the overlying formation is more clearly shown than its relation to the underlying one, and possibly, except at Gargas and Crow creeks, where its relation to the beds mapped as undifferentiated Miocene is not certainly one of unconformity, the Kreyenhagen shale is unquestionably overlain

[69] See Napa, U. S. Geol. Surv. Topographic Sheet.

[70] See page 63.

[71] Anderson, Robert, and Pack, R. W., U. S. Geol. Surv., Bull. 603, pp. 75–76, 1915.

unconformably by younger strata. South of Panoche Creek, it is overlain by the Vaqueros formation (early Miocene), with which it shows distinct angular unconformity. This unconformity is widespread and represents one of the major breaks in the sedimentary record in this region. Distinct angular discordance in dip was noted at several places (see pl. 9) and near Ciervo Mountain the basal beds of the Vaqueros formation, westward from the edge of the San Joaquin Valley, lies on successively lower beds of the Kreyenhagen shale.[71]

The fauna of the Vaqueros of this region is that of the Turritella ocoyana zone.

SAN LORENZO OF SAN EMIGDIO HILLS

Beds of San Lorenzo age are present in the San Emigdio Hills at the south end of the San Joaquin Valley in Kern County, California. Apparently the first to recognize and differentiate the beds in that general region which contain the San Lorenzo fauna were Clark Gester and E. G. Gaylord. During the summer of 1917 a party from the University of California visited this section and spent several weeks mapping the Eocene, Oligocene and Lower Miocene formations. Large invertebrate collections were obtained especially from the Lower Miocene and Oligocene. The results of this work will be published in the near future. The fauna of the San Lorenzo was found in beds, which are unconformable below beds containing the fauna of the Lower Miocene. The maximum thickness of these Oligocene beds, found in the vicinity of San Emigdio Cañon, is between 2500 and 3000 feet.

SAN LORENZO FORMATION OF THE SANTA CRUZ MOUNTAINS

Reference has already been made to the type section of the San Lorenzo, the fauna of which was first listed and described by Ralph Arnold (see p. 62). This fauna is undoubtedly very near to, if not contemporaneous with, that of the San Lorenzo beds in the vicinity of Mount Diablo. A discussion of this relationship will be found on page 101.

Thirteen species of invertebrates were listed by Arnold from beds designated by him as transitional Oligocene-Miocene; of these, all the determinable species are found in the San Lorenzo. Much more work must be done on this section before the stratigraphic relationships of the different horizons, including the Oligocene and Lower Miocene, can be established for a certainty. At the present time the writer is inclined to doubt that these so-called transitional Oligocene-Miocene beds are really transitional.

OTHER LOCALITIES

There are several other general localities in the Coast Ranges, where beds of San Lorenzo age are believed to be present, as indicated by collections which the writer has seen. Beds of this period of deposition are found along the east side of the Salinas Valley, southern Monterey County, lying directly on the Franciscan (Jurassic) and underlying beds of Lower Miocene age. These beds in this area have been generally mapped with those of the Lower Miocene. No one has yet studied this section with the idea that these lower beds might be Oligocene; thus in this locality, it remains for future work to determine the stratigraphic relationship of the Oligocene beds with those of the Lower Miocene.

Another area, in which the writer believes that beds of San Lorenzo age are probably present, is in the Santa Lucia Mountains in southern Monterey County and to the north of Mount Santa Lucia, also southern Monterey County. In the latter locality they are found unconformably below the type section of the Vaqueros formation, Lower Miocene.

CORRELATION

RELATION OF FAUNA OF SAN LORENZO SERIES OF THE REGION OF MOUNT DIABLO TO THAT OF THE SAN LORENZO FORMATION OF THE SANTA CRUZ MOUNTAINS

The number of species common to the faunas of the San Lorenzo series of the Mount Diablo region and the San Lorenzo formation of the Santa Cruz Mountains shows conclusively that both belong to the same general period of deposition. Several species are found in the San Lorenzo of the type section which have not been found in the region of Mount Diablo; this is probably the result of different environment rather than of difference in age; apparently the San Lorenzo beds in the Santa Cruz Mountains, for the most part, were deposited in deeper water than those of the Mount Diablo region.

The following species[72] are common to the San Lorenzo of the type section and to the San Lorenzo beds of the vicinity of Mount Diablo:

Cardium lorenzanum (Arnold)
Malletia packardi, n. sp.
Solen gravidus, n. sp.
Tellina lorenzanum Arnold
Agasoma gravidum (Gabb)
Fusinus (Exilia) lincolnensis (Weaver)
Fusinus hecoxi (Arnold)
Natica (Ampullina) gabbi, n. sp.
Sinum scopulosum (Conrad)
Solarium lorenzoensis (Arnold)
Turris perissolaxoides (Arnold)
Dentalium conradi Dall
Dentalium radiolineatum, n. sp.

[72] The determinations, as given above, were made by the writer from collections obtained at the type locality of the San Lorenzo.

Of the thirteen species listed above, eleven are found in the Oligocene of Oregon and Washington; two of these, *Agasoma gravidum* and *Fusinus* (*Exilia*) *lincolnensis*, are known for a certainty in only the lower phase of the Oligocene of Oregon and Washington, as recognized by Arnold and Hannibal and by Weaver.

RELATION TO OLIGOCENE OF OREGON, WASHINGTON AND BRITISH COLUMBIA

Reference has already been made to the work of Arnold and Hannibal[73] on the Oligocene of Oregon, Washington and Vancouver Island and to that of Weaver on the Oligocene of Washington. The former writers, it will be remembered, recognized four horizons between the Upper Eocene (Tejon) and the Monterey (Lower Miocene); these were designated, beginning with the oldest, the Sooke formation, the San Lorenzo formation, the Seattle formation and the Twin River formation. Weaver,[74] in his more recent publications, separates the fauna of the marine Oligocene beds of Washington, which he refers to the Clallam formation, into three faunal zones, the lowest of which he names the Molopophorus lincolnensis zone and refers to as the Lincoln horizon; the middle zone is called the Turritella porterensis zone or Porter horizon; the upper, the Acila gettysburgensis zone, is referred to as the Blakely horizon.

Weaver now recognizes that his Molopophorus lincolnensis and Turritella porterensis zones are very closely related, if not exactly equivalent, and it is agreed hereafter to refer to them as belonging to one zone, the name Molopophorus lincolnensis zone being used to designate that horizon. Thus, the Molopophorus lincolnensis zone, as redefined, is equivalent to the fauna of the San Lorenzo formation of Arnold and Hannibal. Weaver's study of the section around Puget Sound apparently shows that the Twin River formation of Arnold and Hannibal is the equivalent of their Seattle; the fauna from these beds is the equivalent of that of Weaver's Acila gettysburgensis zone.

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[73] Arnold, Ralph, and Hannibal, Harold, The marine Tertiary stratigraphy of the North Pacific Coast of America, Proc. Amer. Philos. Soc., vol. 52, pp. 573–589, 1912.

[74] Weaver, C. E., Tertiary faunal horizons of western Washington, Univ. Wash. Publ. Geol., vol. 1, no. 1, pp. 1–67, 1916. Post-Eocene formations of western Washington, Proc. Calif. Acad. Sci., ser. 4, vol. 6, no. 2, pp. 19–40, 1916. Tertiary formations of western Washington, Wash. State Surv., Bull. 13, pp. 1–327, 1916.

Summary of Oligocene Sequence in Oregon, Washington and Vancouver Island as Recognized by Different Writers up to the Present Time

Weaver, 1912	Arnold and Hannibal, 1913	Weaver, 1916	As recognized by writer, 1917	
Wahkiakum, referred to the Miocene	Monterey	Wahkiakum Arca montereyana zone	Monterey group Arca montereyana zone	Middle or Lower Miocene
Blakeley formation, referred to the Lower Miocene	Astoria series Twin River formation Seattle formation	Clallam formation Blakeley horizon—Acila gettysburgensis zone	San Lorenzo series Acila gettysburgensis zone	Oligocene
Lincoln formation, referred to the Oligocene	San Lorenzo formation	Porter horizon Turritella porterensis zone Lincoln horizon Molopophorus lincolnensis zone	Molopophorus lincolnensis zone	
	Sooke formation		Fauna of Sooke beds	

Thus, as shown above in the column to the right, three distinct faunas are now recognized in Oregon, Washington and British Columbia as belonging between the Tejon (Upper Eocene) and the Monterey (Lower Miocene) and these faunas are considered to be of Oligocene age, the beds in which they are found being referred to the San Lorenzo series. The lower fauna, that of the Sooke beds, is very distinct from that of the Molopophorus lincolnensis zone, the beds of the latter in a number of localities lie immediately above those containing the Sooke fauna. The upper fauna, that of the Acila gettysburgensis zone, is likewise distinct from that of the Molopophorus lincolnensis zone.

Of the one hundred and thirteen determinable species known from the San Lorenzo beds of Mount Diablo, more than forty have been recognized by the writer in the Oligocene collections from Oregon, Washington and British Columbia; of these species, only eight are known for a certainty to extend into the lower Miocene. This makes a total of over thirty species common between the known Oligocene fauna from the northern localities and the fauna from the San Lorenzo beds of Mount Diablo, none of which species have as yet been found in beds higher than those usually assigned to the Oligocene.

(See page 95) for complete list of species common to San Lorenzo of Mount Diablo region and Oligocene of Oregon, Washington and British Columbia.) A number of these species, such as *Acila shumardi, Acila gettysburgensis, Acila muta, Agasoma gravidum, Agasoma acuminatum, Cardium lorenzanum, Macrocallista pittsburgensis, Fusinus hecoxi, Fusinus (Exilia) lincolnensis, Turritella diversilineata, Turritella porterensis, Turritella porterensis sobrantensis,* and *Turris thurstonensis,* are forms that are generally recognized as good horizon markers.

The work on the faunas of the San Lorenzo of the region of Mount Diablo apparently shows that these three general faunas, as recognized in the north, the faunas of the Sooke beds, of the Molopophorus lincolnensis zone and of the Acila gettysburgensis zone, are fairly closely related in point of time. In the San Lorenzo beds of Mount Diablo are found a number of species, which in Oregon and Washington have been found only in the beds of the Molopophorus lincolnensis zone, the equivalent of the San Lorenzo of Arnold and Hannibal, or in the Sooke horizon. Some of the most important of these species are *Acila shumardi, Macrocallista pittsburgensis, Agasoma gravidum, Agasoma acuminatum, Fusinus (Exilia) lincolnensis, Turris thurstonensis, Turritella porterensis, Turritella porterensis sobrantensis.* On the other hand, associated with the above named species is a fairly large number of forms, which in the northern localities have been found only in the fauna of the Acila gettysburgensis zone. Some of these species are *Acila gettysburgensis, Acila muta, Chione lineolata, Miopleiona indurata,* and *Turritella diversilineata.*

Thus, some of the forms, which have been used as markers of the different faunas as discussed above, are found mixed in a way such as we would not expect if they belonged to distinct geologic horizons. It is also a noticeable fact that over half of the species common to the faunas of the Oligocene of the Mount Diablo region and that of Oregon and Washington are found in the northern localities in all three of the general faunas mentioned above.

Possibly not enough is yet known concerning the range of the different species in the marine Oligocene of the West Coast to definitely place the position of the San Lorenzo fauna as found in California, in reference to the northern sections. The writer is of the opinion, however, that this fauna is probably somewhat older than that of the Acila gettysburgensis zone, the uppermost Oligocene of Oregon and Washington, and that very possibly it is not as old as the oldest Oligocene faunas in these northern localities, that is, the fauna of the Molopophorus lincolnensis zone and that of the Sooke beds.

RELATION OF FAUNA OF THE SAN LORENZO SERIES TO THAT OF THE LOWER MIOCENE

By Lower Miocene in California, as the term is used in this paper, is meant those formations generally described under the names Vaqueros, Temblor and Monterey. It is the writer's conclusion that the fauna of the San Lorenzo series, as described in this paper, is older than that of the lowest horizon that is generally referred to the Lower Miocene, and also that a general stratigraphic and faunal break exists between these horizons. The evidence for this statement will be brought out in the following paragraphs.

Two somewhat different faunas have been recognized in the Lower Miocene; one is known as the fauna of the Turritella ocoyana zone, the other, of the Turritella inezana zone, mentioned above. The first to suggest that the fauna of the "Turritella inezana" zone was older than that of the "Turritella ocoyana" zone was J. C. Merriam[75] in his paper "A note on the fauna of the Lower Miocene." As has been pointed out, Merriam correlated the fauna of the Agasoma gravidum zone of Contra Costa County, the beds of which in the paper are referred to the San Lorenzo series, with that of the Turritella ocoyana zone, as known in the southern part of the state. Both the Turritella ocoyana and Turritella inezana zones were referred to the Lower Miocene. He believed it to be probable that the two faunas belonged to the same general period of deposition. The following extract gives his idea as to the possible conditions of deposition during Lower Miocene time:

> When we come to study the subdivisions of the Lower Miocene both palaeontologically and stratigraphically some interesting things relating to the movements of the Miocene shore lines are suggested. The T. hoffmani[76] zone is found principally in the western or coast region. The T. ocoyana zone occurs in the western region and also to the east of the Great Valley, where the T. hoffmani is not yet known. It would therefore appear that the sea had not reached as far east in the earliest Miocene as it did later, and that the thick shale beds over the lower sands of the western region were formed while sandy T. ocoyana beds were being deposited in the east.

[75] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, no. 16, pp. 380–381, 1904.

[76] *Turritella hoffmani* Gabb equals *Turritella inezana* Conrad.

Since the appearance of Merriam's paper, the Agasoma gravidum fauna of Contra Costa County has generally been correlated with that of the Turritella ocoyana zone. In 1905 F. M. Anderson,[77] in his paper, "A stratigraphic study of the Mount Diablo Range of California," accepted the fauna of the Agasoma gravidum zone, as listed by Merriam, as being of the same age as the fauna from his Temblor. Ralph Arnold, [78] in his paper "The Tertiary and Quartenary Pectens of California," listed the Agasoma gravidum fauna with that of the "Vaqueros sandstone" (Lower Miocene). In this list the Turritella inezana fauna and the Turritella ocoyana fauna are both included. Professor J. P. Smith,[79] in a correlation table of the Neocene section of California in a paper entitled "The geologic record of California," includes the Agasoma gravidum fauna of Contra Costa County in the Turritella ocoyana zone, listing the latter species as having been found in Contra Costa County. In 1912, Smith,[80] in his paper, "The geologic range of Miocene invertebrate fossils of California," again included the Agasoma gravidum fauna with that of the "Temblor," using this name as equivalent to the Turritella ocoyana zone. However, both faunas, "Vaqueros" and "Temblor," are considered by him to belong to the same general period of deposition. In this connection he makes the following statement:

> Instead of the numerous subdivisions recognized by most stratigraphers, there are, in fact, only two major faunal units in the Miocene of California; a lower, including all the faunas up through the Monterey, and an upper, including the San Pablo, Santa Margarita, and Etchegoin faunas. The division line between them corresponds to the period of orogenic activity that came at the end of the Monterey epoch.[81]

At another place in the paper, we find the following statement:

> This lowest horizon of the Miocene has been called by Merriam the zone of the Turritella hoffmani (Turritella inezana); it may eventually be found to be an inshore equivalent of the deep-water San Lorenzo Oligocene, with which it has a few species in common.[82]

G. D. Louderback,[83] in his paper "The Monterey series of California," contends that the formations generally classed as Lower Miocene

[77] Anderson, F. M., Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 2, no. 2, p. 186, 1905.

[78] Arnold, Ralph, U. S. Geol. Surv., Prof. Paper no. 47, p. 19, 1906.

[79] Smith, J. P., Jour. Geol., vol. 18, no. 3, see face plate opposite page 226, 1912.

[80] Smith, J. P., Proc. Calif. Acad. Sci., ser. 4, Geol., vol. 3, pp. 161–182, 1912.

[81] *Op. cit.*, p. 162.

[82] *Ibid.*, p. 165.

[83] Louderback, G. D., Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, no. 10, pp. 177–241, 1913.

throughout the state, such as Vaqueros, Temblor and Monterey, all belong to the same general period or cycle of deposition and ought to be referred to under one general name, "Monterey series." It should also be remembered in this connection that the beds of the San Lorenzo formation of the type section, are described as apparently grading up into the Vaqueros. The following statement is found in the Santa Cruz Folio: "The Vaqueros in general lies conformably above the San Lorenzo formation, and there is often a gradual change from one formation to the other, with no clear line of demarcation between them."[84]

To sum up: At the present time, it is the belief of practically all geologists who are familiar with the marine Upper Tertiary deposits of the West Coast, that the Turritella ocoyana and Turritella inezana beds belong to one general period of deposition. As yet no evidence has been brought forward that they are separated by a stratigraphic break. Also, it has been the belief of Ralph Arnold, who first recognized marine Oligocene in California, that certain beds in the Santa Cruz Mountains between the San Lorenzo and the Vaqueros contained a transitional fauna and that there was no stratigraphic break between the San Lorenzo and Vaqueros of that section. With the above facts in mind, we will review the evidence as to the faunal relationship of the two horizons, the Oligocene and Lower Miocene.

The first question that must be answered before attempting to establish the general relationship of the Oligocene to the Lower Miocene is—What is the relationship of the beds of the Turritella ocoyana zone to those of the Turritella inezana zone? Is the fauna of the latter horizon, as suggested by J. P. Smith, the shallow-water equivalent of the fauna of the San Lorenzo of the Santa Cruz Mountains?

The writer has already, in a former paper,[85] expressed the opinion that future work will show that the fauna of the Turritella inezana zone is more closely related to that of the Turritella ocoyana zone than to the fauna of the Agasoma gravidum zone. This opinion is based upon the fact that a large number of species is known to be common to the first two zones, while very few species are known to be common to the third zone and either of the other two. Very few forms which might be considered good horizon determiners are found

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[84] Branner, J. C., Newsom, J. F., and Arnold, Ralph, U. S. Geol. Surv., Santa Cruz Folio 163, p. 4, 1909.

[85] Clark, B. L., The occurrence of Oligocene in the Contra Costa Hills of Middle California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 16, 1915.

common to the faunas of the two Turritella zones and the Oligocene fauna, either as known in California or in Oregon and Washington.

J. P. Smith, in his paper entitled "Geologic range of Miocene invertebrate fossils of California,"[86] listed one hundred and seventy-three species of invertebrates from the Lower Miocene of California. A number of these belong to the Agasoma gravidum fauna and should be eliminated. Considerable work has been done on the fauna of the Lower Miocene since Smith's paper appeared, and at the present time over two hundred species are known from that general horizon. Smith listed fifty-six species from the "Vaqueros," Turritella inezana zone, only ten of which are confined to that zone, twenty-five species, or nearly half, going into the Turritella ocoyana zone but not higher, ten per cent of this fauna being composed of Recent species.

Out of the one hundred and thirteen determinate species in the San Lorenzo series of the Mount Diablo region, only thirteen extend into the Lower Miocene (T. inezana and T. ocoyana zones) or higher horizons; of these, several are only compared with species in the Miocene. Only eight species of the San Lorenzo series extend into the Lower Miocene beds of the California province. Contrasting this with the much larger number of species common to the San Lorenzo series of the Mount Diablo region and the Oligocene of Oregon, Washington and British Columbia (thirty-nine), it will readily be seen how much closer is the relationship in the latter cases than in the former.

Again, the distinctness of the fauna of the San Lorenzo series from that of the Lower Miocene is shown in the greater number of Recent species in the latter than in the former; according to Smith, ten per cent of the fifty-six species known from the Turritella inezana fauna are Recent. In the San Lorenzo beds of the region of Mount Diablo, out of one hundred and thirteen determinable species, only two are Recent, less than two per cent. The writer's conclusion from these data is, that there is a large faunal break between the Lower Miocene and the Oligocene of California, and that this break is probably a general one.

The existence of a time hiatus between the fauna of the Lower Miocene and that of the Oligocene is substantiated by the presence of a general stratigraphic break. Crustal movements, of considerable magnitude in places, turned up the Oligocene beds so that when the Miocene sea encroached upon the area that had been exposed to

[86] Smith, J. P., Proc. Calif. Acad. Sci., ser. 4, Geol., vol. 3, p. 164, 1912.

erosion, Lower Miocene deposits were laid across the upturned edges of the Oligocene beds. This is seen at a number of localities to the north of Coalinga at the contact between the Kreyenhagen shales and the ''Vaqueros,'' reference to which has already been made. It has also been shown that in the Concord Quadrangle, in the region of Mount Diablo, a stratigraphic break occurs between the San Lorenzo beds and those of the Monterey, which is, apparently more than local. In Washington also the Monterey deposits are reported to be unconformable on those of the Oligocene.

Summary of Stratigraphy

Beds which in this paper are referred to the San Lorenzo (Oligocene) are found to the west and to the north of Mount Diablo, Middle California. To the west of the mountain there are three separate areas in which beds of San Lorenzo age are found. The most complete section of any of these three areas is found on the sides of the Sobrante anticline (northwest quarter of the Concord anticline). Here three distinct lithologic units are recognized and given local formational names; beginning with the lowest these are the San Ramon formation, the Kirker tuffs and the Concord formation. An erosional contact was found between the Concord formation and the Kirker tuffs. The maximum thickness of the section in this area is only about four hundred feet. The second area, in which the San Lorenzo beds are found, is in the vicinity of the town of Walnut Creek. Here the Oligocene beds are found outcropping on both sides of the San Ramon syncline. On the west side of the syncline, to the south of Walnut Creek, these beds have a thickness of over five hundred feet, while on the east side the thickness is in some places not more than fifty feet. The section to the south of the town of Walnut Creek is taken as the type section of the San Ramon formation. It seems probable that beds representing the Kirker tuffs and the Concord formation are absent here.

The third section of the San Lorenzo series, found to the west of Mount Diablo, is that of the Pacheco syncline, Concord Quadrangle; here, only the San Ramon formation is present, the thickness of which is less than one hundred feet.

In all the sections of the three areas to the west of Mount Diablo there is good evidence for the unconformable relationship between the San Lorenzo series (Oligocene) and the Monterey (Miocene).

The San Lorenzo beds in the area to the north of Mount Diablo are in general different from those to the west of the mountain. To begin with, here the maximum thickness is over thirty-seven hundred feet, while to the west of the mountain it is only a little over five hundred feet.

The series to the north of Mount Diablo is divided by the writer into two formations, the lower of which is the Markley, the upper, the Kirker formation. These formations both represent more or less of a heterogeneous assemblage of beds, most of which were formed under shallow-water conditions of sedimentation. The Markley formation is possibly composed, in part, of continental beds; this is suggested by the arkosic character of the sandstones, the grains of which tend to be angular, by the presence of considerable carbonaceous material of plant remains, and by the lack of marine fossils. Evidences of true marine conditions were obtained at least at one horizon. A thin band of typical marine diatomaceous shale was found at about five hundred feet from the top of the formation.

The Kirker formation is separated from the Markley formation by a disconformity; this is shown by an erosional contact, a true basal conglomerate, fluviatile deposits between the two formations, and Pholad borings.

The Kirker formation is composed largely of rhyolitic tuffs and tuffaceous sandstones. It is overlain unconformably by the San Pablo (Upper Miocene), the Monterey group, which is present to the west of the mountain, being absent.

The Kirker formation contains a number of species common to the Kirker tuffs of the Sobrante anticline; this, together with the similarity of lithology, makes the correlation reasonably certain. The Markley formation is provisionally correlated with the San Ramon formation to the west of the mountain. The lithology and thickness of the two, however, are so different that some objection may possibly be made to this.

Summary of Correlation

The San Lorenzo series of the region of Mount Diablo belongs to the same general period of deposition as the San Lorenzo formation of the Santa Cruz Mountains and the Kreyenhagen shales found along the west side of the San Joaquin Valley to the north and to the south of the town of Coalinga. These, in turn, are correlated by the writer with beds generally recognized as Oligocene in Oregon, Washington and Vancouver Island, B.C. The close relationship of the beds in these northern localities with those in California is shown by the fact that over forty per cent of the species obtained from the Astoria series of Mount Diablo have also been found in these northern Oligocene beds.

The fauna of the Oligocene of Mount Diablo is apparently not so old as the lowest Oligocene found in the San Emigdio Mountains at the south end of the San Joaquin Valley, California; it is very probable, though the evidence is not as yet conclusive, that this Mount Diablo Oligocene fauna belongs to a somewhat higher horizon than does the lowest Oligocene fauna in Washington, Weaver's Molopophorus lincolnensis zone, but below the horizon containing the typical *Acila gettysburgensis* fauna.

This Oligocene fauna, taken as a whole, is very distinct from that of the Lower Miocene. It is believed that this difference is largely due to the time factor. This is borne out by the fact that in California there is a large stratigraphic break which separates the Oligocene beds from those of the Lower Miocene.

APPENDIX 1

Unless otherwise stated, all references are to Concord sheet, U. S. Geol. Surv., 1897 edition.

DESCRIPTIONS OF LOCALITIES

14. In valley N of Sobrante Ridge; on W fork of Bear Creek, ½ mile from source; on N bank; elevation 800 feet; Contra Costa Co., long. 122° 12′ 35″, lat. 37° 35′ 58″.

52. 1¼ miles S of town of Walnut Creek, near top of first ridge W of Walnut Creek; elevation 350 feet; Contra Costa Co., long. 122° 1′ 39″, lat. 37° 52′ 44″.

76. About 3 miles S of Pittsburg and 1 mile W of Kirker's Creek; in SW ¼ of Sec. 30, T. 2 N, R. 1 E, M. D. B. and M., Mount Diablo sheet.

78. About 3 miles S of Pittsburg and 1 mile W of Kirker's Creek, in bottom of gulch; close to W edge of SW ¼ of Sec. 30, T. 2 N, R. 1 E, M. D. B. and M., Mount Diablo sheet.

125. On first ridge N of Sobrante Ridge; on top of hill N of source of W fork of Bear Creek; 1⅛ miles W of triangulation station on Lawson Hill; elevation 1075 feet; Contra Costa Co., long. 122° 12′ 55″, lat. 37° 56′ 35″.

189. 1¼ miles SW of town of Pacheco; at source of S fork of creek which flows into Grayson Creek at Pacheco; elevation 300 feet; Contra Costa Co., long. 122° 5′ 30″, lat. 37° 58′ 28″.

199. 1⅞ miles SE of Muir Station and 1¾ miles a little S of E of the town of Pacheco; 100 yards NE of end of first branch road on left side of road leading from Muir Station to Ygnacio Valley; elevation 250 feet; Contra Costa Co., long. 122° 5′ 55″, lat. 37° 58′ 47″.

331. On first ridge N of Sobrante Ridge; ¾ mile SE source of W fork of Bear Creek; elevation 800 feet; Contra Costa Co., long. 122° 12′ 22″, lat. 37° 55′ 58″.

517. 2 miles directly S of town of Walnut Creek; on E side of ridge to E of Tice Valley; elevation 550 feet; Contra Costa Co., near W edge of SW ¼ of Sec. 2, T. 2 S, R. 2 W, M. D. B. and M.

1131. ½ mile SW of town of Walnut Creek; in creek bed about 100 yards to E of Oakland and Antioch bridge; elevation 150 feet; Contra Costa Co., long. 122° 4′ 8″, lat. 37° 53′ 7″.

1132. 3½ miles NW of town of Walnut Creek; 200 yards SE of point where road from Muir Station to Walnut Creek crosses Grayson Creek; elevation 100 feet; Contra Costa Co., long. 122° 4′ 55″, lat. 37° 57′.

1134. On SW side of Martinez Ridge, 2½ miles SE of Muir Station and ⅝ mile N of juncture of Muir Station, Walnut Creek road, and the branch road to town of Pacheco; elevation 325 feet; Contra Costa Co., long. 122° 5′ 45″, lat. 37° 57′ 58″.

1162. On Sobrante Ridge, ¼ mile SW of head of left fork of Bear Creek; on W side near top of 1000-foot hill; elevation 1000 feet; Contra Costa Co., long. 122° 13′ 20″, lat. 37° 56′ 13″.

1164. On top of first ridge N of Sobrante Ridge, ½ mile due E of source of W fork of Bear Creek; elevation 950 feet; Contra Costa Co., long. 122° 12′ 32″, lat. 37° 56′ 17″.

1165. On first ridge N of Sobrante Ridge in road pass; ⅝ mile due E of source of W fork of Bear Creek, 125 feet above road on W side; elevation 825 feet; Contra Costa Co., long. 122° 12′ 20″, lat. 37° 56′ 17.″

1167. On first ridge N of Sobrante Ridge, ⅜ mile NE of head of left fork of Bear Creek; 100 feet from top of ridge; elevation 900 feet; Contra Costa Co., long. 122° 12′ 37″, lat. 37° 56′ 17″.

1173. On Sobrante Ridge, S of a small T-valley and near entrance to pass through which creek flows to join San Pablo Creek; elevation 625 feet; Contra Costa Co., long. 122° 14′ 25″, lat. 37° 57′ 6″.

1175. ⅜ mile E of W end of Briones Valley on N side; near road; elevation 500 feet; Contra Costa Co., long. 122° 12′ 46″, lat. 37″ 55′ 51°.

1309. On Santa Fe Railroad 1¼ miles NE of Muir Station; elevation 150 feet; Contra Costa Co., long. 122° 6′ 21″, lat. 37° 59′ 58″.

1310. 1 mile N of E of Muir Station and 3/7 mile E of Santa Fe Railroad; elevation 225 feet; Contra Costa Co., long. 122° 6′ 40″, lat. 37° 59′ 40.″

1311. 1½ miles SE of Muir Station on a direct line between Muir Station and Pacheco; elevation 200 feet; Contra Costa Co., long. 122° 6′ 8″, lat. 37° 59′ 14″.

1312. 1⅝ miles SE of Muir Station and ¼ mile N of end of road crossing Martinez Ridge; elevation 275 feet; Contra Costa Co., long. 122° 6′ 6″, lat. 37° 58′ 53″.

1314. North edge of Concord sheet ¼ mile W of Santa Fe Railroad, ¾ mile NW of Muir Station, on S side of Muir syncline at contact of Tejon and San Ramon formation.

1315. North edge of Concord sheet, 1¼ miles W of Santa Fe Railroad; S side of Muir syncline contact of Tejon and San Ramon formation.

1343. In creek bed 1⅝ miles S of town of Walnut Creek, ¼ mile W of sharp bend in road; elevation 200 feet; Contra Costa Co., long. 122° 3′ 34″, lat. 37° 52′ 30.″

1458. In SW corner of SE ¼ of Sec. 10, T. 1 S, R. 1 W, M. D. B. and M.; at elevation of 1000 feet, on side of 1608-foot hill. Mount Diablo sheet.

1524. (R. E. D. No. 131.) At elevation of 860 feet, on Sidney Flat, S side of Sec. 34, T. 1 N, R. 1 E, M. D. B. and M. Mount Diablo sheet.

1686. In creek ½ mile SW of town of Walnut Creek; elevation 125 feet; Contra Costa Co., long. 122° 3′ 48″, lat. 37° 53′ 7″.

1687. 1½ miles S of town of Walnut Creek, in valley leading from San Ramon Valley to Tice Valley; on bank of Walnut Creek ⅜ mile W of the point where it turns and flows west; elevation 225 feet; Contra Costa Co., long. 122° 3′ 53″, lat. 37° 52′ 32″.

1895. About 3 miles S of town of Pittsburg, north of Mount Diablo; about ¼ mile E of Kirker's Creek; near center of SE ½ of Sec. 29, T. 2 N, R. 1 E, M. D. B. and M. Mount Diablo sheet.

1897. On S side of small knoll in Kirker's Creek Valley; about 3 miles S of Pittsburg on W edge of SW ¼ of Sec. 29, T. 2 N, R. 1 E, M. D. B. and B. Mount Diablo sheet.

1900. On line between Sec. 32 and Sec. 33, T. 2 N, R. 1 E, M. D. B. and M. Mount Diablo sheet.

2033. Not quite ¼ mile S of 651-foot hill and about ½ mile W of Kirker's Creek, in Kirker tuff; near W edge of Sec. 30, T. 2 N, R. 1 E, M. D. B. and M. Mount Diablo sheet.

2038. On W side of Markley Cañon on SE side of 990-foot hill, in sandstone of Kirker formation; near N edge of SE ¼ of Sec. 33, T. 2 N, R. 1 E, M. D. B. and M. Mount Diablo sheet.

2713. In Monterey series near Kern River on Barker's Ranch.

2754. On Sobrante Ridge on branch of San Pablo Creek, 1⅜ miles NE of California and Nevada Railroad; elevation 350 feet; Conta Costa Co., long. 122° 14′ 1″, lat. 37° 56′ 54″.

2755. In valley N of Sobrante Ridge; on W fork of Bear Creek ½ mile from source; on N bank in tuff beds; elevation 800 feet. Contra Costa Co., long. 122° 12′ 35″, lat. 37° 55′ 58″.

3051. At head of Briones Valley, ⅞ mile SW of triangulation station on Lawson Hill; near head of gully, 50 feet W of electric transmission line; elevation 700 feet; Contra Costa Co., long. 122° 12′ 18″, lat. 37° 56′ 5″.

3055. In valley N of Sobrante Ridge; on W fork of Bear Creek ½ mile from source; on N bank in tuff beds; elevation 800 feet; Contra Costa Co., long. 122° 12′ 35″, lat. 37° 55′ 58″.

3080. In diatomaceous shale of Markley formation, on side of hill on E side of Markley Cañon opposite L. Loughrie's house; elevation 700 feet; SW ¼ of Sec. 34, T. 2 N, R. 1 E, M. D. B. and M. Mount Diablo sheet.

3081. Near mouth of Markley Cañon on west side and almost directly opposite tunnel of Pittsburg railroad; elevation 750 feet; near SE corner of NE ¼ of Sec. 33, T. 2 N, R. 1 E, M. D. B. and M. Mount Diablo sheet.

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Subkingdom **MOLLUSCA**

Class PELECYPODA

Family Nuculidae

Genus ACILA Adams

ACILA GETTYSBURGENSIS Reagan

Plate 13, figure 9

Nucula (Acila) gettysburgensis Reagan, Trans. Kansas Acad. Sci., vol. 22, p. 175, pl. 1, fig. 3, 1909.

Nucula gettysburgensis Reagan, Weaver, Wash. Geol. Surv., Bull. 15, p. 18, 1912.

Acila gettysburgensis Reagan, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, pp. 583, 584, 1913.

Acila gettysburgensis Reagan, Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, p. 28, 1916; Proc. Calif. Acad. Sci., ser. 4, vol. 6, no. 2, p. 35; *ibid.*, no. 3, p. 51, 1916.

The outline of *Acila gettysburgensis* Reagan is very similar to that of *Acila shumardi* Dall, the most conspicuous difference between the two being that on the outer surface of the former there is a distinct sinus or groove, which extends from the beak to the ventral edge and a little anterior to the posterior end. The shell is thicker and heavier, the sculpturing somewhat coarser, and the escutcheon more strongly depressed.

ACILA MUTA, n. sp.

Plate 13, figures 6, 12 and 13

Type specimen 11196, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell subovate to subtrigonal, moderately convex; beaks strongly inturned; posterior end abruptly truncated, subangulate at point of junction between the posterior dorsal and the ventral edges. Anterior dorsal slope long and gently convex; posterior dorsal slope straight; apical angle about 90°; anterior end evenly rounded; posterior ventral edge regularly arcuate. Lunule obsolete; escutcheon large, well-defined by a circumscribed line, pouting in the middle. Surface of shell covered by fine, divaricating threads which extend onto the escutcheon; the line at which the divaricating threads cross, is near the middle of the shell; on some of the larger specimens, a duplication of the divarication may be seen near the ventral edge. Seventeen or eighteen fairly prominent cardinals anterior, and about ten posterior to the beaks; resilium pit narrow and deep, rather long.

Dimensions.—Type specimen: length, 17.8 mm.; height, 10 mm.

Occurrence.—A very common species in the Oligocene of Washington, Oregon and California; found at University of California localities 14, 52, 199, 1131, 1173, 1312, etc.

A. muta resembles *A. castrensis* Hinds,[87], a Recent West Coast species, from which it differs in the following respects: It is somewhat higher in proportion to the length, the anterior end is broader and the ribbing is somewhat finer. The escutcheonal area is more sharply defined on the former than on the latter.

The escutcheon of *A. muta* is very similar to that of *A. shumardi* Dall; the two species differ, however, in sculpturing and in outline; the latter is decidedly the longer, the ventral edge being less arcuate, and the pouting of the escutcheon more prominent; also, the cardinals are more numerous.

The writer feels certain that this species has been determined in several recent faunal lists as *A. conradi* Meek, as redescribed by Dall.[88] The form figured by him as *A. conradi* Meek came from the Empire beds of Coos Bay, Oregon (Pliocene). The sculpturing on *A. muta* is coarser than that on this Pliocene species, and there is a distinct escutcheon on the former which is not seen on the latter.

In the Lower Miocene sandstones, immediately above the Oligocene shale, at the town of Astoria, Oregon, there is a third species of *Acila* which is distinct from both *A. muta* and *A. conradi* as redescribed by Dall. This form is very possibly the true *A. conradi*.[89] The writer has not seen the type of *A. conradi*, but the figure of Conrad's *Acila divaricata*, which is the type of *A. conradi*, is poor and his description meagre; for this reason, for the present, the name *A. conradi* (as redescribed by Dall) is retained for the Pliocene species. The writer has never seen this species, which is found in the Pliocene of Oregon, in any collections from either the Lower Miocene or Oligocene.

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[87] For original description of *A. castrensis*, see Hinds, R. B., Zool. Voyage "Sulphur," p. 61, pl. 17, fig. 5, 1844.

[88] Dall, W. H., U. S. Geol. Surv., Prof. paper no. 59, p. 102, pl. 12, figs. 4–5, 1909.

[89] The writer has had access to two fairly large collections from the Oligocene and Lower Miocene from the vicinity of the town of Astoria, Oregon. One of the collections is in the California Academy of Sciences, the other at the University of California; the latter collection was made by Ralph Arnold and Harold Hannibal, the former by F. M. Anderson and Bruce Martin.

Acila conradi (Meek) was first described and figured by T. A. Conrad as *Nucula divaricata* (Amer. Jour. Sci., vol. 5, p. 432, fig. 1, 1848); later it was found that this name was preoccupied and in a check list by F. B. Meek; the name was accordingly changed to *Nucula conradi*. (Check list Miocene Fossils N. Am., Smithson. Misc. Coll., vol. 7, no. 183, p. 27, Nov., 1864; also, Conrad, Am. Jour. Conch., vol. 1, p. 153, 1865.)

ACILA MUTA MARKLEYENSIS, n. var.

Plate 13, figure 3

Type specimen 11195, Coll. Invert. Palae. Univ. Calif., loc. 1131

This variety is distinguished from the typical *A. muta* in that the height is greater in proportion to the length; this character can readily be seen by comparing the figures of the two forms. The variety is found at locality 1131, about a half-mile to the south of the town of Walnut Creek; here it is associated with the typical form of the species. It occurs in great abundance at locality 3081, on the west side of Markley Cañon, in the section north of Mount Diablo; here all the forms found were of the high type, the typical form apparently being absent.

ACILA SHUMARDI Dall

Plate 13, figures 7, 8 and 17

Nucula (*Acila*) *decisa* Dall, not *Acila decisa* Conrad. Trans. Wagner Free Inst. Sci., vol. 3, pt. 4, p. 573, 1895; figured in vol. 3, pt. 5, pl. 40, figs. 1, 3, 1900.

Nucula (*Acila*) *shumardi* Dall, U. S. Geol. Surv., Prof. paper no. 59, p. 103, 1904.

Nucula dalli Weaver, not Arnold, Wash. Geol. Surv., Bull. 15, p. 18, 1912.

No adequate description has ever been given of this species. It was first listed by W. H. Dall as *Nucula* (*Acila*) *decisa* Conrad; later it was given a new name.[90] Dall at first thought that *Acila decisa* Conrad was the same as *A. divaricata;* afterwards, however, he gave the name *A. conradi* Dall to a form found in the Empire beds (Upper Miocene) near Coos Bay, Oregon, considering this to be synonymous with Conrad's species, *A. divaricata;* at the same time he expressed the opinion that *A. decisa Conrad* was indeterminate and for this reason he gave to the shell formerly figured as that species the name *A. shumardi.* The specimen figured, which must be considered as the type, came from near the old town of Pittsburg, Oregon. The beds in which it was found were originally determined to be Eocene in age. The writer,[91] in his paper, "The occurrence of Oligocene in the Contra Costa Hills of Middle California," listed all the species known by him at that time from the Pittsburg locality, the conclusion being that this fauna is Oligocene rather than Eocene, and is very closely related to the Agasoma gravidum fauna of Contra Costa County, California. One of the specimens figured in this paper comes from

[90] U. S. Geol. Surv., Prof. paper no. 59, pp. 102–103, 1909.

[91] Clark, B. L., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 18, 1915.

the type locality; the other comes from the north side of Mount Diablo, University of California locality 76.

A. shumardi is closely related to *A. muta*, n. sp.; for the comparison of these two species see the description of the latter. The specimen figured came from the type locality on the banks of the Nehalem River at the town of Pittsburg.

Genus NUCULA Lamarck

NUCULA POSTANGULATA, n. sp.

Plate 13, figures 2–5

Type specimen 11260, Univ. Calif. Coll. Invert. Palae., loc. 2754

Shell small, equivalved, inequilateral; subtrigonal to subovate in outline; beaks rather inconspicuous, opisthogyrous. Posterior dorsal slope abrupt, being a little more than at right angles to the anterior dorsal slope. Anterior end regularly rounded; posterior end subangulate. Escutcheon depressed and well-defined, lanceolate to subcordate, extending nearly to the posterior end, pouting rather sharply along its entire length. Lunule absent. Surface smooth except for fine, somewhat irregular incremental lines. Hinge plate unknown.

Dimensions.—Type specimen: length, 6.25 mm.; height, 4.75 mm.

Occurrence.—University of California localities 1131 and 2754.

NUCULA BIFIDA, n. sp.

Plate 12, figures 10, 11 and 12

Type specimen 11184, Coll. Invert. Palae. Univ. Calif., loc. 331

Shell small, subtrigonal in outline; beaks inconspicuous, recurved. Anterior dorsal slope gently convex; posterior dorsal slope very steep; apical angle a little more than 90°. Anterior end broadly and regularly rounded; ventral edge rather strongly and regularly arcuate. Surface of type sculptured by 22 fairly heavy, rounded, radiating ribs, a few of which are bifid or split near their lower ends; interspaces between the radiating ribs about equal to the width of the ribs. Escutcheon only very slightly depressed, but marked off by oblique radiating ribs which branch off from the last rib of the general surface; some of these are bifid distally. Lunule not depressed but marked by a sculpturing similar to that of the escutcheon. Hinge plate unknown.

Dimensions.—Length, 6 mm.; height, 4.5 mm.; greatest diameter of both valves, 3 mm.

Occurrence.—University of California locality 331.

This beautiful species appears to be quite unique; the writer has found nothing on the West Coast, either fossil or recent, with which to compare it. Though the hinge plate is not known, yet the general outline and sculpturing of the shell would seem to place it under the genus Nucula.

Family Ledidae

Genus LEDA Schumacher

LEDA ELONGOROSTRATA, n. sp.

Plate 13, figure 16

Type specimen 11206, Coll. Invert. Palae. Univ. Calif., loc. 2755

Shell small, thin, elongate-ovate, narrow and abruptly attenuated. Anterior end rather narrow but regularly rounded; beaks inconspicuous, anterior to the middle; posterior dorsal margin long, straight, only sloping very slightly; anterior dorsal edge gently convex; ventral edge long and gently arcuate. Lunule and escutcheon both elongate-lanceolate. Surface covered by fine concentric, somewhat irregularly spaced lines of growth. On the rostrate end a shallow, rather broad sulcus extends from the beak to the lower side of the posterior end. Internal character of shell unknown.

Dimensions.—Length, about 18 mm.; height, 7 mm.

Occurrence.—Type specimen from University of California locality 2755; also found at localities 205, 1165 and 1312.

LEDA MARKLEYENSIS, n. sp.

Plate 14, figure 7

Type specimen 11272, Coll. Invert. Palae. Univ. Calif., loc. 3081

Shell small, acutely rostrate posteriorly; beaks opisthogyrous, anterior to middle; posterior dorsal margin strongly concave, longer than anterior dorsal margin, which is gently convex; posterior end sharply pointed; anterior end regularly rounded. Surface covered by medium-fine, regular incremental lines; escutcheonal area flat, fairly broad, depressed nearly at right angles to the main outer surface of shell. Lunule and hinge plate not exposed.

Dimensions.—Type specimen: length, 16 mm.; length from posterior end to medium line, 10 mm.; height, about 7 mm.

Occurrence.—On the west side of Markley Cañon, north of Mount Diablo, at University of California locality 3081.

Leda markleyensis resembles *Leda gabbi* Conrad[92] in outline, from which it differs in being somewhat higher in proportion to the length; the beaks are more anterior, and the escutcheonal area is different.

LEDA PULCHRISINUOSA, n. sp.

Plate 11, figures 5 and 6

Type specimen 11109, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, subovate; beaks near the middle. Dorsal slopes nearly equal, the posterior one, which is slightly the longer, being gently concave; anterior slope nearly straight. Anterior end regularly rounded; posterior end acutely rostrate. Lunule narrow, elongate-lanceolate, extending a little over half the length of the anterior dorsal edge. Escutcheon well defined, strongly depressed, lanceolate,

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[92] For original description of *Leda gabbi*, see *L. protexta*, Geol. Surv. Calif., Palaeontology, vol. 1, p. 199, pl. 26, fig. 185; listed at first by Gabb as *Leda protexta*, renamed by Conrad. *L. protexta* is an East Coast species.

extending from the beaks to the posterior end and enclosing a secondary escutcheon which is more sharply limited and more strongly depressed than the primary one. Surface of shell sculptured by numerous fine concentric ribs. On the surface near the posterior dorsal edge there is a shallow groove which extends from the beaks to a little anterior to the posterior end. Hinge plate unknown.

Dimensions.—Type specimen: Length, 12 mm.; height, 7 mm.

Occurrence.—University of California localities 1131 and 2754. Type from locality 1131.

This form is somewhat like *L. taphra* Dall,[93] a Recent West Coast species. It differs from that species in that it is slightly more elongate, and the concentric sculpturing is somewhat finer. The most important difference, however, is the presence of the double escutcheon; on *L. taphra* the escutcheon is single.

L. pulchrisinuosa somewhat resembles *L. gabbi* Conrad,[94] common in the Eocene of the West Coast: it differs from that species principally in that it is not so acute and elongate posteriorly, also in that the sculpturing is somewhat finer.

L. pulchrisinuosa is also somewhat similar to *L. oschineri* Anderson and Martin,[95] a species described from the Monterey of Kern County. The latter species differs from the former in being more acute anteriorly and posteriorly; the sculpturing is coarser, and the lunule and escutcheon are larger. The escutcheon of the latter species has the double area seen on the former, but the secondary escutcheon on *L. oschineri* is larger than that of *L. pulchrisinuosa.*

LEDA RAMONENSIS, n. sp.

Plate 12, figure 9

Type specimen no. 11167, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small; beaks nearly central, rather inconspicuous; angle of dorsal slopes fairly low, almost equal; both dorsal slopes straight and nearly equal in length. Posterior end acutely rostrate; anterior end regularly rounded. Lunule lanceolate, narrow and not very long; escutcheon elongate-lanceolate, reaching over two-thirds the length of the posterior dorsal edge, slightly pouting. Surface of shell covered by regular, well-marked concentric lines.

Dimensions.—Type specimen: length, about 16 mm.; length of beaks from posterior end, about 9 mm.

The writer at first considered this form to represent immature individuals of *Yoldia cooperi tenuissima,* which is common in the

[93] For original description of *Leda taphra* see Bull. Nat. Hist. Soc. Brit. Columbia, no. 2, p. 7, pl. 2, figs. 6, 8, 1917. For a good redescription and figure of *Leda taphra* Dall see Mem. Calif. Acad. Sci., vol. 3, p. 98, pl. 17, fig. 5, 1903.

[94] For good figure of type specimen of *Leda gabbi* see Geol. Surv. Calif., Palaeontology, vol. 1, pl. 26, fig. 185. Gabb listed it as *Leda protexta?* It was renamed by Conrad.

[95] For original description of *Leda oschineri* see Proc. Cal. Acad. Sci., ser. 4, vol. 4, p. 53, pl. 3, figs. 8*a-c*, 1914.

same beds; however, as more material was obtained it became evident that it was a distinct species. The main distinction between the two is the great difference in size and in proportion.

Genus MALLETIA Desm.

MALLETIA PACKARDI, n. sp.

Plate 12, figure 3; plate 14, figures 5 and 6

Type specimen 11154, Coll. Invert. Palae. Univ. Calif., loc. 2033

Shell rather small to medium in size; beaks anterior to the middle, opisthogyrous. Anterior dorsal slope straight; posterior dorsal slope rather strongly excavated; anterior end regularly rounded; posterior end regularly rounded but narrower than anterior end, the ventral margin sloping up more obliquely to it than to the anterior end. Surface smooth except for somewhat irregular incremental lines. As shown on one of the specimens obtained from the diatomaceous shale of the Markley formation (fig. 6), the escutcheon is well defined, long and narrow and depressed almost at right angles to the main outer surface of the shell. Lunule apparently absent. No well-defined chondrophore. About eighteen taxidont teeth posterior and about twenty-one anterior to the beak, the posterior and anterior rows of teeth meeting at the apex of the beaks.

Dimensions.—Length, 17.5 mm.; height, 10 mm.

Occurrence.—Found at University of California localities 2035, 3055 and 3080.

Species of the genus *Malletia* are rare on the West Coast. Ralph Arnold's species, *Malletia chehalisensis,*[96] from the San Lorenzo formation, is apparently a *Leda;* as figured by him, the type (his fig. 9) shows a well-defined chondrophore. One of the characteristics of the genus *Malletia,* according to Eastman's translation of Zittel's *Textbook of Palaeontology,* vol. 1, is that the chondrophore is lacking.

Genus YOLDIA Möller

YOLDIA COOPERI TENUISSIMA, n. var.

Plate 11, figure 10; plate 12, figures 8 and 14

Type specimen 11110, Coll. Invert. Palae. Univ. Calif., loc. 798

This variety differs from the species *Y. cooperi* Gabb principally in that the distance from the beak to the anterior end is shorter in proportion to the length of the shell; also there is a less number of teeth in the hinge plate; in other respects the species and the variety are very similar. This difference, however, appears to be constant and when better and more specimens of the variety are obtained it may be found that the variety should be listed as a distinct species.

Dimensions.—Length, about 44 mm.; height, 17.75 mm.; greatest height posterior to the beak, 19 mm.

Occurrence.—University of California localities 798, 1131, 1312, 197, 199, etc. Type from locality 798; paratypes from localities 2754 and 1131.

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96 Arnold, Ralph, New Cretaceous and Tertiary fossils from the Santa Cruz Mountains, California, Proc. U. S. Nat. Mus., vol. 34, p. 335, figs. 9, 9*a*, 1908.

Y. cooperi tenuissima resembles *Y. oregoni* Shumard redescribed by Dall;[97] it differs from that species in the following respects: The beaks are more posterior; the posterior-rostrate end is somewhat more attenuate and there are fewer teeth on the posterior margin. On *Y. cooperi tenuissima* there are thirty-two to thirty-five teeth anterior to the beaks and about twelve posterior. Dall states that on *Y. oregoni* the number is thirty-two and seventeen. In the description of *Y. oregoni*[98] Dall states that *Y. cooperi* Gabb has fourteen teeth posterior and forty anterior. The type specimen of *Y. cooperi*, which is in the collections of the University of California, has only eleven teeth posterior and about thirty-six anterior. A Recent specimen from San Pedro, also in the University of California collections, has the same number of teeth as the type. Two specimens of *Y. cooperi* from the Pleistocene of San Pedro, examined by the writer, show some variation in the number of teeth; one has fourteen teeth posterior and forty anterior, the number given by Dall as characteristic of the species; the other has eleven posterior and thirty-nine anterior teeth. The writer does not have enough specimens of *Y. cooperi* of the Recent and Pleistocene to say whether there is a constant difference in the number of teeth between the Recent forms and those of the Pleistocene. It is possible that the Pleistocene form should be considered as a distinct variety.

YOLDIA cf. OREGONA Shumard

Several specimens of a species of Yoldia collected at University of California localities 78 and 1131 appear to be very close if not identical with what Dall has listed and figured as *Yoldia oregona* Shumard,[99] and which came from beds referred by him to the Miocene from the Willamette Valley south of Oregon City, Oregon, and which beds are now believed to be of Oligocene age.

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[97] U. S. Geol. Surv., Prof. paper no. 59, p. 105, pl. 19, fig. 4, 1909.

[98] For original description of *Yoldia cooperi*, see Geol. Surv. Calif., Palaeontology, vol. 2, p. 31, pl. 9, fig. 54, 1866.

[99] U. S. Geol. Surv., Prof. paper no. 59, p. 105, pl. 19, fig. 4, 1909.

Family ARCIDAE

Genus ARCA Lamarck

ARCA (SCAPHARCA) MEDIAIMPRESSA, n. sp.

Plate 7, figures 7 and 8; plate 16, figures 5, 6 and 7

Type specimen 11174, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small to medium in size, rhombic in outline. Umbones rather broad, strongly inturned and anterior to middle of shell, depressed medially, the depression on the smaller specimens extending from the beak well down to the ventral edge; this character is best seen on the smaller specimens, being less noticeable on the larger ones. Posterior end broadly subtruncate to gently rounded, anterior end evenly rounded, narrower than posterior end. Surface sculptured by twenty-seven to thirty flat-topped, radial ribs with interspaces about as wide as the ribs. On one of the specimens figured (pl. 7, fig. 7, specimen 11172) most of the ribs show a medium groove beginning about half way from the beaks and extending to the ventral edge; this groove is similar to that seen on *Arca montereyana* Osmont and on *Arca trilineata* Conrad.[100] On this last, there is often a second and third groove bordering on each side of the medium groove which begin lower down from the beaks than does the medium groove. It is very possible that if larger specimens of *Arca mediaimpressa* are found, the second and third grooves may also appear on the lower part of the ribs. Apparently the ribs were originally somewhat spinose, due to the sharp, imbricating, incremental lines; this is to be seen on a few of the better preserved specimens. Surface rather strongly depressed posteriorly. Cardinal area very narrow; ligamental grooves obscure. Hinge plate narrow, slightly curved, with about thirty-five taxodont cardinals, which, beneath the beaks, are very small; distally they become larger and converge ventrally.

Dimensions.—Type specimen: length, 14.5 mm.; height, 6 m.m.; length of hinge plate, 6 mm.; length of hinge plate anterior to the beak, 3.5 mm.

Occurrence.—University of California locality 1131.

Arca mediaimpressa differs from the typical *A. montereyana*, found in the *Arca montereyana* beds of Contra Costa County, in the following respects: The beaks are more prominent and broader, the latter lacking the depressed area just below the beaks, and the truncated posterior margin being more oblique; *A. montereyana*[101] is the longer and is more strongly produced posteriorly, also the surface is not so strongly depressed near the posterior truncated end.

Osmont seems to have included two distinct species in his description of *Arca montereyana;* the type, which is figure 5 on his plate, undoubtedly came from the *Arca montereyana* beds of Contra Costa

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[100] For original description of *Arca trilineata* see Pacific Railroad Rep., vol. 6, p. 70, pl. 2, fig. 9, 1854–1855; for good redescription see Osmont, Univ. Calif. Publ., Bull. Dept. Geol., vol. 4, no. 4, p. 91, pl. 9, figs. 4–4*c*, 1904.

[101] For original description of *Arca montereyana* see Osmont, V. C., Arcas of the California Neocene, Univ. Calif. Publ., Bull. Dept. Geol., vol. 4, no. 4, p. 96, pl. 9, fig. 5 (not 5*a* and 5*b*), 1904.

County; the paratype, shown in his figures 5*a* and 5*b*, came from the *Turritella ocoyana* beds from Barker's ranch near Bakersfield. This latter form is very distinct from the specimens of *Arca montereyana* found in Contra Costa County. The writer's conclusions are based upon the study of Osmont's original material, together with a large number of specimens both from Contra Costa County and Barker's ranch. The Barker's ranch specimens are different from those from Contra Costa County in being shorter; the posterior end is less obliquely truncated. On the typical *A. montereyana* the surface in front of the truncated margin and below the posterior dorsal margin slopes up evenly to the main surface immediately below the beaks; on the specimens from Barker's ranch this area is rather strongly depressed, giving this portion of the shell a subtabulate appearance very similar to that seen on *A. mediaimpressa.* The beaks on the form from the Barker's ranch locality are more prominent; also, on most of the specimens from this locality there are two grooves bordering the medium groove on the lower parts of most of the ribs, similar to that seen on *A. trilineata* Conrad; this character has not been observed on any specimens of *A. montereyana* from Contra Costa County. To this new species he gives the name *Arca barkeriana.*

Arca mediaimpressa is somewhat similar to *A. barkeriana* in outline and sculpturing; it is narrower anteriorly; the umbones are broader and flatter, with the tendency to the medium impression below the umbones, not seen on the other form; the largest specimen known is much smaller than the average specimen from the Barker's ranch locality; the arrangement of the teeth on the hinge plate is different, those on *A. mediaimpressa* being set obliquely (converging ventrally) to the hinge plate while on the other species they are almost at right angles to it; again, the medium grooving of the ribs on *A. mediaimpressa* is only slightly shown on the larger specimens, while on the other form it is well developed, many times with the second and third grooves bordering it, as described above.

ARCA (SCAPHARCA) SUBMONTEREYANA, n. sp.

Plate 16, figure 2

Type specimen 11186, Coll. Invert. Palae. Univ. Calif., loc. 52

Shell plump, medium in size, fairly heavy, rhombic in outline; beaks rather prominent and anterior to the middle of the shell. Posterior end broadly rounded; anterior end regularly rounded, sloping down rather obliquely to the ventral edge. Ventral edge gently convex. Surface of shell radially sculptured by about twenty-three flat-topped ribs with interspaces averaging about the width of the tops of the ribs; on some specimens, there is a groove or channel down the middle of some of the ribs; this, however, appears to be due to weathering, not being apparent on the best preserved specimens. Incremental lines rather fine. Cardinal area large, crossed by well-defined multivincular grooves.

Dimensions.—Type specimen: length, 17 mm.; height, 14 mm.; length of hinge plate, 13 mm.; length of hinge plate anterior to beak, about 6 mm.

Occurrence.—University of California localities 52, 1131, etc. Type from locality 52.

This species very closely resembles *A. osmonti* Dall, a characteristic species of the *Turritella ocoyana* zone in the southern part of the state. V. C. Osmont,[102] in his paper on the "Arcas of the California Neocene," figured a specimen which he called *Arca microdonta* Conrad. This was renamed *Arca osmonti* by Dall[103] in his discussion of *Arca microdonta* Conrad. Osmont's description included two distinct species. The specimen, shown in outline in figures 3*a* and 3*b*, of his plate 8, is distinct from the one figured in full, his figures 2 and 2*b*, which is the type of *Arca osmonti.* The other form, outlined only, appears to agree with Conrad's species *Arca microdonta.* Osmont's type material is in the University of California collections, therefore the writer has had the opportunity of studying it at first hand. *A. submontereyana* is not so large or inflated as *A. osmonti* and the number of radial ribs is not so great. The type specimen of *A. osmonti* Dall has twenty-seven ribs; the maximum number on any of the specimens of *A. submontereyana* examined by the writer is twenty-three. In other respects the two species are quite similar.

Genus GLYCIMERIS Da Costa

GLYCIMERIS BUWALDI, n. sp.

Plate 7, figures 10 and 11

Type specimen 11150, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, subcircular in outline; anterior dorsal slope gently convex; posterior dorsal slope short; posterior end subtruncated. Surface covered by fairly coarse, irregular incremental lines; also sculptured by numerous obscure radiating ribs, with interspaces which possibly average somewhat less than the width of the ribs; extending from the beak to the lower angle of the subtruncated end is an indistinct ridge, the narrow margin posterior to which is rather strongly depressed. Hinge plate heavy; cardinal area very narrow; posterior to the beak there are eight, and anterior to it, seven cardinals. A large part of the hinge plate is not covered by the cardinals both below and on the sides; ventral margin denticulate.

Dimensions.—Height, 9 mm.; length, 9 mm.; semidiameter, 2.5 mm.

Occurrence.—University of California locality 1131.

Named in honor of Dr. J. P. Buwalda of the Department of Geography of the University of California.

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[102] Osmont, V. C., *op. cit.*, p. 90, pl. 8, 1904.

[103] U. S. Geol. Surv., Prof. paper no. 59, p. 110, 1909.

Only one specimen of this species has so far been obtained. It was found at the locality where *Glycimeris tenuimbricata* is very abundant. Here *G. tenuimbricata* is found in rather coarse sandstones while *G. buwaldi* was found in a thin layer that might be classed as a sandy mudstone.

Glycimeris buwaldi is very similar in outline and sculpturing to *G. intermedia* Broderip,[104] a Recent West Coast species, in fact so much so that the writer would have hesitated to separate the two had it not been that a good hinge plate was obtained on the former, which is quite different from that of the latter. It is heavier; there is a less number of cardinals; there is a narrow interspace below the beak between the anterior and posterior cardinals, which is not present on *G. intermedia;* also the cardinal area on *G. buwaldi* is much smaller.

GLYCIMERIS TENUIMBRICATA, n. sp.

Plate 16, figures 4, 8, 9 and 10

Type specimen 11183, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell subtrigonal, somewhat variable in outline and diameter, medium in size, equivalved, nearly equilateral, valves moderately convex. Apical angle about 90°; dorsal slopes straight, the anterior slope being a little the shorter; ventral edge strongly and regularly convex; posterior dorsal margin, as a rule, slightly more depressed than anterior dorsal margin. Surface sculptured by twenty-three to twenty-nine radiating ribs which become obsolete near the dorsal edges; ribs separated by interspaces which generally average a little less than their width; surface also covered by heavy incremental lines which, on unweathered specimens, are very strongly and beautifully imbricated. Hinge plate fairly heavy, with seven or eight teeth anterior to the beak, and ten or eleven posterior to it. The teeth do not reach the ventral margin of the hinge plate; they are noticeably long and heavy near the ligamental area, which is narrow and ventrally is wedged in between the anterior and posterior rows of teeth; ligamental grooves numerous and well marked. Muscle impressions equal and fairly heavy.

Dimensions.—Type specimen: length, 27.5 mm.; width, 26 mm.; paratype: height, 21 mm.; width, 20 mm.

Occurrence.—University of California localities 14, 513, 1131, 173, 1175, 2754, etc. Type from locality 1131; paratype from locality 2754.

Family Ostreidae

Genus OSTREA Lamarck

OSTREA, sp. indt.

An imperfect valve of an oyster was found at University of California locality 1131; it is determinate generically but not specifically. Two other specimens of *Ostrea* were found at locality 792; these are

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[104] For original description see Proc. Zool. Soc. London, 1832, p. 126; also for description and figures see Conchologia Iconica, vol. 1, pl. 1, fig. 1, 1843.

not specifically determinable and it is not even certain that they are the same species as the specimen obtained at locality 1131.

Family PECTINIDAE

Genus PECTEN Muller

PECTEN (LYROPECTEN) GABBI, n. sp.

Plate 15, figures 1 and 2

Type specimen 11138, Coll. Invert. Palae. Univ. Calif., loc. 1311

Shell fairly large, heavy, equivalved; right valve flat; left valve convex. Apical angle about 100°; dorsal edges very nearly straight; ventral edge rather strongly convex. Left valve sculptured by about nineteen prominent and variable, rounded radiating ribs; on the type specimen, a left valve, seven of these ribs are heavier than the others; one radiating from the beak down to the middle of the ventral edge, three of the other ribs being anterior and three posterior to this; in each interspace between these major ribs is a less prominent and narrower rib, and in the interspaces between this narrower rib and the major ribs on each side of it is a still less prominent and more narrow rib; besides this, in some of the interspaces, there is a fourth set of ribs still less prominent than the others. The valve originally had strong and beautiful imbricated sculpturing, which does not show on the type specimen but is seen on some of the external casts. Ears large and heavy. One specimen of a cast of the anterior ear shows eight or nine radiating ribs; the ones next the dorsal margin being much finer than the others; surface of ear strongly imbricated. Right valve flat, sculptured by nineteen or twenty fairly heavy, rather broadly rounded, radiating, somewhat variable ribs; as on the left valve there is a tendency for some of the ribs to be heavier than the others, but this difference is not so great nor is the distribution of the heavy ribs so regular; apparently there were no riblets in the interspaces. Surface of right valve sculptured by imbricated incremental lines, which are coarser than on the left valve. Sculpturing of ears of right valve not preserved.

Dimensions.—Type specimen: height, about 55 mm.; length, about 46 mm.; diameter of both valves, about 37 mm.

Occurrence.—University of California locality 1311.

This form appears to be related to *Pecten perrini* Arnold,[105] which is very common in the Vaqueros, the Turritella inezana zone, of the southern part of the state. *P. perrini* is a very variable species, the sculpturing being more irregular than on *P. gabbi;* it has about the same number of ribs, and on some specimens certain of the ribs stand out more prominently than others, as is the case with *P. gabbi.* The imbricated concentric sculpturing appears to be much stronger on the former, is more irregular, and the inter-ribbing and striations are heavier.

[105] For original description of *P. perrini,* see U. S. Geol. Surv., Prof. paper no. 47, p. 80, pl. 14, figs. 1, 1*a*; pl. 15, fig. 1, 1906.

P. fucanus Dall[106] is of the same general type as *P. gabbi;* it differs from this form in that it has a less number of ribs, the interspaces are wider, and the radial striations, seen on the ribs of the former, are lacking on the latter.

PECTEN (PSEUDOMUSEUM) ALTERNILINEATUS, n. sp.

Plate 13, figures 14 and 15

Type specimen 11203, Coll. Invert. Palae. Univ. Calif., loc. 1131

Pecten peckhami Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 14, 1915.

Shell small, thin, subcircular, compressed, equivalved, nearly equilateral. Apical angle close to 90°. Surface covered by numerous fine, radiating, raised, bifurcated lines, which are nearly obsolete on most of the specimens examined, interspaces between the lines averaging a little wider than the width of the lines. Posterior ear of right valve not separated by a well-defined line from main surface of shell; posterior edge of ear straight, sloping outward; surface smooth on specimens at hand but probably originally radially sculptured, similar to that on the main surface of shell. Anterior ear of right valve very distinct, with a rather deep and acutely angular byssal notch; surface of ear covered by about five subnodose to spinose radiating lines. Ears of left valve similar to those of right except that anteriorly there is no byssal notch.

Dimensions.—Type specimen: length, 5 mm.; height, 5.5 mm.; diameter of both valves, 75 mm.; paratype: length, 5.5 mm.; height, 6 mm.

Occurrence.—University of California locality 1131.

Pecten alternilineatus is about the same size and belongs to the same general type as *P. vancouverensis* Whiteaves,[107] from which it differs in the following respects: The radiating lines on the main surface of the shell are not so numerous nor so closely crowded; the ears are larger and the radiating sculpturing is not so coarse; the hinge line is longer in proportion to the width of the shell, and the margins below the ears are less convex than on *P. vancouverensis.*

Pecten alternilineatus resembles rather closely *P. peckhami* Gabb,[108] a common species in the Lower Miocene of the West Coast, from which it differs as follows: On the left valve the ears are considerably narrower in a dorsal-ventral direction, and in the vicinity of the anterior ear the swell of the main surface of the shell commences as an inclined slope rather than at right angles, as is the case on *P. peckhami* as described by Gabb; the anterior edge of the anterior ears comes out

106 For original description of *P. fucanus* see Trans. Wagner Free Inst. Sci., vol. 3, pt. 4, p. 704, pl. 26, fig. 7, 1898. For good redescription, see Arnold, U. S. Geol. Surv., Prof. paper no. 47, p. 66, pl. 10, figs. 1, 2 and 2*a*, 1906.

107 For description of *P. vancouverensis* see Arnold, U. S. Geol. Surv., Prof. paper no. 47, p. 140, pl. 52, figs. 3, 3*a*, 1906.

108 For original description of *P. peckhami* see Geol. Surv. Calif., Palaeontology, vol. 2, p. 59, pl. 16, fig. 19*a*, 1868.

practically flush with the anterior edge of the shell, while on *P. peckhami* this edge is considerably back of the edge of the shell; also on the former the byssal notch is deeper than on the latter.

Family ANOMIIDAE

Genus ANOMIA Muller

ANOMIA INCONSPICUA, n. sp.

Plate 13, figures 19 and 20

Type specimen 11205, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, thin, subcircular and somewhat variable in outline; beaks inconspicuous, subcentral in position, on some specimens slightly twisted but on others not; left valve convex; right valve flat, with a large byssal notch. Surface smooth except for rather heavy, irregular incremental lines. Muscle area, as seen on left valve, with one fairly large, distinct scar which is slightly posterior to the beak; other scars indistinct. Hinge line very thin, with a small, deeply sunken resilifer.

Dimensions.—Type specimen: (left valve) height, 4 mm.; length, 4.5 mm.; paratype (a right valve): height, 4.5 mm.; width, 4.5 mm.

Occurrence.—University of California locality 1131.

This species appears to be quite distinct from anything described from the West Coast. Possibly the form that is nearest is *Anomia linatula* Dall,[109] from which it differs in being much smaller, in the hinge not being so heavy, and in lacking the faint radiating lines seen on the latter.

Family MYTILIDAE

Genus MODIOLUS Lamarck

MODIOLUS KIRKERENSIS, n. sp.

Plate 9, figure 8

Type specimen 11121, Coll. Invert. Palae. Univ. Calif., loc. 3081

Shell medium in size; base straight or nearly so, on some specimens being slightly concave; anterior end rather strongly produced; posterior margin angulated back of middle of shell; posterior to this the margin slopes in rather obliquely to the posterior end, which is regularly rounded but not very wide. Umbones prominent; umbonal ridge distinct but not extending to the posterior end of the shell. Surface rather acutely arched in the anterior third of the shell but gently rounded near the posterior end; anterior slope steep, slightly excavated in front of the umbonal ridge. Posterior slope not so steep as anterior; in the vicinity of the posterior angle the surface is depressed or flattened, giving the shell an alate appearance similar to that seen on *Modiolus rectus* Conrad, a common Recent West Coast species. Surface, except for an elongated,

[109] For original description of *A. linatula,* see Proc. U. S. Nat. Mus., vol. 1, p. 15, 1879, and Trans. Wagner Free Inst. Sci., vol. 3, pt. 4, p. 785, pl. 35, fig. 19, 1898.

smooth, triangular space between the base and the umbonal ridge, sculptured by numerous fine radiating dichotomous ribs, with interspaces averaging less than the width of the ribs. The dichotomous character of the ribbing is more marked toward the posterior margin.

Dimensions.—Length, 38 mm.; greatest width, 17 mm.; semidiameter, about 6 mm.

Occurrence.—University of California locality 2038.

This species belongs to the same general type as *Modiolus multiradiatus* Gabb[110] and *Modiolus gabbi* B. L. Clark. The type of *M. multiradiatus* Gabb came from San Emigdio ranch, west of Fort Tejon, and is either Lower Miocene or Oligocene. Gabb's original description included two species, the type and a species common in the Upper Miocene of Middle California, *Modiolus gabbi* B. L. Clark.[111] *M. multiradiatus* differs quite decidedly from *M. kirkerensis,* both in outline and sculpturing; the anterior end is not produced as strongly as that of *M. kirkerensis* and there is no well-marked posterior angle; also the sculpturing is much coarser.

MODIOLUS PITTSBURGENSIS, n. sp.

Plate 9, figure 9

Type specimen 11122, Coll. Invert. Palae. Univ. Calif., loc. 1895

Shell rather small, thin; umbones not prominent; umbonal ridge indistinct, unseen in the anterior third of the shell; anterior end strongly produced beyond the beaks; base straight; posterior margin long, with no distinct posterior angulation; posterior end broad and regularly rounded, the base and the posterior margin diverging in approaching the posterior end. Surface rather strongly arched, the highest point of convexity being posterior to the middle of the shell. Anterior slope broad and fairly steep; posterior slope shorter but more steep than the anterior. Surface smooth except for medium fine incremental lines.

Dimensions.—Type specimen: length, about 32 mm.; maximum width measured at right angles to base, 18.5 mm.; diameter of both valves, about 12 mm.

Occurrence.—Type specimen from University of California locality 1895, in the Kirker formation near the top of the Astoria series to the north of Mount Diablo.

This species appears to be quite distinct in outline from any of the known Recent or fossil species of the West Coast. In outline it somewhat resembles *Modiolus inflatus* Dall;[112] both have the broadly rounded posterior end; on the former the anterior end is more strongly produced and the shell is more slender just back of the beaks.

[110] For original description of *Modiolus multiradiatus,* see Geol. Surv. Calif., Palaeontology, vol. 2, p. 30, pl. 8, fig. 52, 1868.

[111] For original description of *Modiolus gabbi,* see Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 22, p. 458, pl. 48, fig. 1, 1915.

[112] For original description of *Modiolus inflatus,* see Dall, W. H., U. S. Geol. Surv., Prof. paper no. 59, p. 114, pl. 12, figs. 8 and 9, 1909.

Genus MYTILUS Linné

MYTILUS ARNOLDI, n. sp.

Plate 12, figure 1

Type specimen 11153, Coll. Invert. Palae. Univ. Calif., loc. 78

Shell medium in size; beaks subacute; posterior end rather narrow, somewhat acutely rounded; base straight or nearly so; posterior dorsal margin straight, extending not quite to the middle of the shell; posterior to this, the margin converges very strongly to the posterior end, the converging margin being gently convex; the change from the posterior dorsal margin to the converging posterior margin is not marked by an angulation but by a broad, regular curve. Convexity of surface rather broad, the posterior slope being gentle, with the anterior slope slanting more steeply though being considerable from vertical. Surface smooth except for medium coarse, somewhat irregular lines of growth.

Dimensions.—Type specimen: maximum length, 63.5 mm.; maximum width, 33 mm.

Occurrence.—Type from near the base of the Kirker formation near Kirker Creek, University of California locality 78. Localities 1131 and 1309 in the San Ramon formation.

The type of this species came from the north side of Mount Diablo, where it was associated with *Acila shumardi* Dall. It is also found in the Agasoma gravidum beds to the west of Mount Diablo. The specimens in these latter beds are smaller than those found to the north of Mount Diablo, but they seem to be referable to the same species.

MYTILUS (MYTILOCONCHA) MATHEWSONII Gabb

Plate 18, figures 1 and 2

Mytilus mathewsonii Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, sec. 1, p. 30, pl. 8, fig. 51; 1866.

Mytilus mathewsonii Gabb, Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, no. 16, p. 378, 1904.

Mytilus mathewsoni Gabb, Dall, Trans. Wagner Free Inst. Sci., vol. 3, part 4, p. 789, 1898.

Mytilus mathewsonii Gabb, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, p. 172, 1912.

Mytilus mathewsonii Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 14, 1915.

M. mathewsonii is distinguished by its comparatively large size, smooth surface, blunt beaks and straight base. The shell is noticeably high, rather narrow; the slopes from the line of highest convexity are steep both anteriorly and posteriorly. It belongs to the subgenus Mytiloconcha Conrad; the hinge plate just under the beak is thick and on this thickened area is a broad, deep, V-shaped groove. The ligamental groove is long, fairly deep and heavy.

Occurrence.—A common species in the basal Agasoma gravidum beds, University of California localities 1131, 14, 1309, etc.

This species has been listed in several papers as having a range from Lower Miocene to Upper Miocene. The writer doubts very much whether it occurs above the Oligocene.

Family Periplomidae

Genus PERIPLOMA Schumacher

PERIPLOMA UNDULATA, n. sp.

Plate 15, figures 3 and 4

Type specimen 11141, Coll. Invert. Palae. Univ. Calif., loc. 1309

Shell elliptical, thin, inequivalves; beaks in the posterior third of the shell strongly inturned and opisthogyrous. Anterior end broadly and regularly rounded; posterior end subtruncate, the margin being almost at right angles to the posterior ventral edge. Anterior dorsal margin long, nearly straight; posterior dorsal margin short and slightly concave. Surface covered by irregular concentric undulations, on and between which are the finer incremental lines. On the type, a right valve, these undulations are rather conspicuous; on other specimens they do not show so prominently; valves also finely striated, the striations being internal and showing only on eroded specimens. Right valve with posterior dorsal margin strongly depressed; just anterior to the depressed area there is a somewhat obscure, shallow sulcus, which extends from the beak to the ventral side of the posterior end. On the left valve the depression along the posterior margin is not so strong, and there is no sulcus corresponding to that seen on the right valve.

Dimensions.—Type specimen: length, 27 mm.; height, 15.5 mm.

Occurrence.—University of California localities 1309 and 1131. Type from locality 1309.

P. undulata is closely allied to *P. argentaria* Conrad,[113] a Recent West Coast species. The two are very similar in outline and the depressed posterior dorsal area of both valves are almost exactly alike. The most important differences between the two species are as follows: The posterior end of *P. argentaria* is rounded, while on *P. undulata* it is subtruncate; the surface of *P. argentaria* lacks the irregular undulations described above. The hinge plate of a right valve of *P. undulata* was exposed; this shows the chondrophore to be deeper than that of *P. argentaria,* the axis being almost parallel with the anterior dorsal margin, while on the latter the axis has a considerable angle between it and the posterior dorsal margin.

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[113] For original description of *P. argentaria* Conrad, see Jour. Phila. Acad. Sci., vol. 7, p. 238, pl. 18, fig. 8, 1837. *P. planiscula* Sowerby is listed by Arnold as a synonym of *P. argentaria.* The former name is given by Keep in his "West Coast shells," 1911 edition, as having precedence; figure 84 on p. 108 by Keep, shows the interior of this species.

Family THRACIIDAE

Genus THRACIA Leach

THRACIA CONDONI Dall

Plate 11, figure 12; plate 12, figure 2

Thracia condoni Dall, U. S. Geol. Surv., Prof. paper no. 59, p. 135, pl. 19, fig. 5, 1909.

Thracia condoni Dall, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, p. 581, 1913.

Thracia condoni Dall, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, pp. 15, 18, 1915.

Thracia condoni was referred to by Dall as belonging to the Miocene; the type came from Smith's Quarry near Eugene, Oregon. These beds are referred to by Arnold and Hannibal as belonging to their San Lorenzo horizon of the Astoria series. *T. condoni* is listed by them as being a characteristic species of their San Lorenzo horizon. The writer has seen it from a number of localities of Oregon and Washington; in every case it was associated with a fauna, considered by him to be Oligocene.

Genus CYATHODONTA Conrad

CYATHODONTA WEAVERI, n. sp.

Plate 13, figure 10; plate 14, figure 1

Type specimen 11131, Coll. Invert Palae. Univ. Calif., loc. 1131

Shell thin, medium in size to fairly large, broadly ovate. Beaks fairly conspicuous, slightly posterior to the middle. Anterior dorsal margin gently convex, sloping away from the beaks rather steeply; posterior dorsal margin straight; anterior end broadly and regularly rounded; posterior end broadly and squarely truncated; ventral margin regularly and rather strongly arcuate. Surface covered by fairly broad and prominent concentric undulations, on and between which are finer and somewhat irregular incremental lines; seven of the major undulations can be distinguished on the type. A fairly distinct ridge extends from the beaks to the basal angle of the truncated posterior end; posterior to this the surface is rather strongly depressed. Muscle scars faint.

Dimensions.—Type specimen: height, 22.5 mm.; length, 27.5 mm.

The outline of this species is very similar to that of *Thracia trapezoides* Conrad,[114] a species common in the Oligocene, Miocene and Pliocene of Oregon and Washington, from which it is distinguished by the prominent undulations, characterizing the genus *Cyathodonta*.

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[114] For original description of *Thracia trapezoides* Conrad, see Geol. U. S. Expl. Exped., p. 723, pl. 17, figs. 6*a* and 6*b*, 1849. For good redescription of this species by Dall, see U. S. Geol. Surv., Prof. paper no. 59, p. 1135, pl. 2, fig. 14; pl. 13, fig. 7, 1909.

Family Pandoridae

Genus PANDORA Brug.

PANDORA (PANDORA) ACUTIROSTRATA, n. sp.

Plate 11, figures 7, 9 and 13

Type specimen 11111, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell thin, rather small, elongate-ovate, rostrate posteriorly; beaks inconspicuous, situated about two-thirds the distance from the posterior to the anterior end; anterior dorsal slope short, nearly straight; posterior dorsal slope straight; anterior end rather broad, evenly rounded; posterior end narrow, obliquely truncated; ventral edge regularly and rather strongly arcuate. Posteriorly there is a faint, broad, elongate, strongly depressed, slightly concave escutcheonal area, the larger part of which is on the left valve where it is separated from the main outer surface of the shell by a distinct ridge; parallel to this ridge and about half way between it and dorsal edge there is a faint groove which extends from the beak to the posterior end. Left valve convex; right valve flat; surface smooth except for the incremental lines. Muscle scars elongate, subquadrate in outline; anterior scar on the type more distinct than the posterior; two short but well-defined cardinals in right valve. Dental formula of right valve R 1010; this, according to the classification given by Dall,[115] places the species in the subgenus Pandora.

Dimensions.—Type specimen: length, 14 mm.; height, 8 mm.; diameter, about 3 mm.

Occurrence.—University of California locality 1131.

Family Lucinidae

Genus PHACOIDES Blainville

PHACOIDES cf. ACUTILINEATUS (Conrad)

Lucina acutilineatus Conrad, Geol. U. S. Expl. Exped., p. 725, pl. 18, figs. 2, *2a, 2b,* 1849.

Pectunculus patulus Conrad?, Geol. U. S. Expl. Exped., p. 726, pl. 18, figs. 8, *8a,* 1849.

Several species of the genus Phacoides in the Tertiary of the West Coast have been confused with one another. This is especially true of the species *P. acutilineatus* Conrad. The species, common in the Lower Miocene of the West Coast and listed in nearly all the faunal lists of that horizon as *P. acutilineatus,* is very close to *P. annulatus* Reeve, a common Recent species on the West Coast. A careful study, based on a larger amount of material than the writer has at hand, may show it to be different; apparently it is not *P. acutilineatus* Conrad. In Professional paper, United States Geological Survey, no. 59, p. 116, pl. 12, fig. 6, W. H. Dall has described and figured a form from the

[115] Trans. Wagner Free Inst. Sci., vol. 3, pt. 6, p. 1516, 1903.

Empire beds (Upper Pliocene) of Coos Bay, Oregon, which he refers to as a young form of *P. acutilineatus.* This does not agree with Conrad's figure nor with the species determined by the writer as *P. acutilineatus* from Oregon and Washington. The specimen figured by Dall has a different apical angle from Conrad's species and it lacks the marked depressed anterior and posterior areas. The specimens of *Phacoides* obtained from the Astoria series of Mount Diablo are too poorly preserved for us to be certain of the specific determination.

Family Diplodontidae

Genus DIPLODONTA Brown

DIPLODONTA STEPHENSONI, n. sp.

Plate 12, figure 6

Type specimen 11171, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell subcircular, medium in size, only moderately inflated; beaks nearly central, rather inconspicuous; height and length about equal. Posterior dorsal edge straight; about equal to anterior dorsal edge which is straight to slightly convex. Posterior end broadly subtruncate; anterior end very broadly rounded. Ventral edge gently and regularly arcuate. Surface smooth except for medium fine incremental lines of growth. Nymph plates heavy, fairly high with no well-defined resilifer pit. In the right valve, the posterior cardinal and in the left valve the anterior cardinal is so deeply bifid that each has the appearance of being two distinct teeth instead of one.

Dimensions.—Type specimen: height, 8 mm.; length, 8 mm.; diameter of one valve, about 2.5 mm.

Occurrence.—University of California locality 1131.

Named in honor of L. W. Stephenson, palaeontologist in the United States Geological Survey.

Diplodonta stephensoni somewhat resembles in outline *D. serricata* Reeve,[116] a Recent West Coast species; the two are only slightly different in outline; the beaks of the latter are possibly more conspicuous and the shell slightly more inflated. The chief difference between the two is the hinge plate. *D. serricata* has a well-defined resilifer pit while *D. stephensoni* has not; on the latter species the nymph plates are heavier and better defined; also the posterior tooth of the right valve and the anterior of the left valve of the latter species are more deeply bifid than on the former.

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[116] For a good description and figures of *D. serricata* see Arnold, Mem. Calif. Acad. Sci., vol. 3, p. 134, pl. 18, figs. 5, 5*a*, 1903.

Family CARDIIDAE

Genus CARDIUM Linnaeus

CARDIUM DICKERSONI, n. sp.

Plate 13, figures 11 and 18

Type specimen 11207, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, ventricose, subcircular, subequilateral; beaks central, not very conspicuous, slightly prosogyrous. Dorsal slopes straight or nearly so, the anterior slope apparently being somewhat the longer; posterior end broadly subtruncate; anterior end broadly and evenly rounded. Surface sculptured by about thirty prominent radial ribs, with interspaces averaging about the width of the ribs; tops of ribs on uneroded specimens V-shaped. Surface also covered by medium fine incremental lines, which on the less eroded portions of the shell are rather strongly imbricated.

Dimensions.—Height, about 55 mm.; length, 6 mm.; diameter of both valves, 2.5 mm.

Occurrence.—University of California locality 1131.

Named in honor of Dr. R. E. Dickerson, assistant curator of Palaeontology of the California Academy of Sciences.

This species is very similar in outline and sculpturing to *Cardium lincolnensis* Weaver;[117] it is somewhat smaller and lacks the narrow thread-like rib, described by Weaver as occurring in the interspaces. Otherwise, the two are very similar.

CARDIUM KIRKERENSIS, n. sp.

Plate 12, figure 5

Type specimen 11165, Coll. Invert. Palae. Univ. Calif., loc. 2033

Shell small, inequilateral; beaks fairly prominent and rather strongly prosogyrous; anterior dorsal slope very slightly concave; posterior dorsal slope straight, about equal in length to the anterior slope; anterior end broadly and regularly rounded; posterior end broadly subtruncate, the lower angle of the truncation being obscure. Surface sculptured by from seventeen to twenty V-shaped, nodose, radial ribs, with interspaces averaging somewhat wider than the width of the ribs. Growth lines rather fine.

Dimensions.—Height, 9 mm.; length, 8 mm.; diameter of one valve, about 3 mm.

Occurrence.—In the tuff beds of the Kirker formation, about one-half mile W of Kirker Creek near the W edge of Sec. 30, T. 2 N, R. 1 E, M. D. B. L.

This species appears to be quite unique, differing from any of the known Recent or fossil cardiums of the West Coast.

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[117] For original description of *Cardium lincolnensis*, see Univ. Wash. Publ., Geol., vol. 1, no. 1, p. 40, figs. 36, 37, 1916.

CARDIUM LORENZANUM Arnold

Cardium cooperi Gabb *lorenzanum* Arnold, Proc. U. S. Nat. Mus., vol. 34, no. 1617, p. 366, pl. 33, fig. 6, 1908.

Cardium cooperi Gabb *lorenzanum* Arnold, Santa Cruz Folio, U. S. Geol. Surv., no. 163, p. 4, illus. 2, fig. 17, 1909.

Cardium cooperi Gabb *lorenzanum* Arnold, Weaver, Wash. State Geol. Surv., Bull. 15, p. 18, 1912.

Cardium lorenzoanum Arnold, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, pp. 581, 588, 1913.

Cardium lorenzanum Arnold, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, pp. 14 and 18, 1915.

Occurrence.—Rare in the San Ramon formation but fairly common in the Kirker formation north of Mount Diablo.

CARDIUM cf. VAQUEROSENSIS Arnold

Cardium vaquerosensis Arnold, Proc. U. S. Nat. Mus., vol. 34, p. 378, pl. 34, fig. 3, 1908.

Cardium vaquerosensis Arnold, U. S. Geol. Surv., Folio 63, p. 4, illus. 2, fig. 34, 1909.

Cardium vaquerosensis Arnold, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 165 and 171, 1912.

Cardium vaquerosensis Arnold, Anderson and Martin, Proc. Calif. Acad. Sci., ser. 4, vol. 4, pp. 40–41, 1914.

Cardium vaquerosensis Arnold, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 14, 1915.

The type of *Cardium vaquerosensis,* as figured by Arnold, is very poor; a specimen, which is here referred questionably to that species, was obtained at University of California locality 1131, at the base of the San Ramon formation; this also is incomplete, and one would be justified only in comparing this form with Arnold's species.

Family Veneridae

Genus DOSINIA Scophield

DOSINIA (DOSINIDIA) MATHEWSONII Gabb

Plate 7, figures 1, 2, 5, 6, and 9

Dosinia mathewsonii Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 57, pl. 15, fig. 16, 1867.

Dosinia mathewsonii Gabb, Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, no. 16, p. 378, 1904.

Dosinia mathewsonii Gabb, F. M. Anderson, Calif. Acad. Sci., ser. 3, vol. 2, pp. 186, 188.

Dosinia mathewsonii Gabb, Arnold, U. S. Geol. Surv., Prof. paper no. 47, p. 19, 1906.

Dosinia ponderosa Arnold, U. S. Geol. Surv., Bull. 309, pl. 33, fig. 47, 1907; Proc. U. S. Nat. Mus., vol. 32, no. 1545, pl. 46, fig. 4, 1907, not *Dosinia ponderosa* Gray.

Dosinia whitneyi F. M. Anderson, Calif. Acad. Sci., ser. 3, vol. 3, p. 99, 1911, not *D. whitneyi* Gabb.

Dosinia mathewsonii Gabb, Smith, Calif. Acad. Sci., ser. 4, vol. 3, pp. 165 and 171, 1912.

Dosinia whitneyi, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, no. 212, p. 588, 1913, not *D. whitneyi* Gabb.

Dosinia mathewsonii Gabb, Anderson and Martin, Calif. Acad. Sci., ser. 4, vol. 4, p. 41, 1914.

Dosinia whitneyi Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 14, 1915, not *D. whitneyi* Gabb.

This species is listed by Gabb as coming from the Miocene of Martinez, and at Griswold's on the road from San Juan to New Idria. The type evidently came from the Agasoma gravidum beds near the town of Martinez, Contra Costa County. The writer has been fortunate in finding good specimens, showing the hinge plates of both valves of *D. mathewsonii,* from the Agasoma gravidum beds of Contra Costa County and from the Lower Miocene of the Kern River section, Kern County, California. The specimens from the Lower Miocene of Kern River appear to be identical with those from the Agasoma gravidum beds of Contra Costa County. In the right valve the posterior cardinal, which is situated on the nymph plate, is long, slender and low, and on some specimens is almost obsolete; the posterior of the two middle cardinals is long, fairly broad and high, with a broad, rather deep groove. On the left valve the posterior and anterior cardinals are narrow and slender; the middle cardinal is broad and heavy; upon its upper surface there are two distinct ridges, the posterior one being more prominent and longer than the anterior. Anterior lateral short, fairly prominent.

D. mathewsonii appears to be very closely related to *D. elegans* Conrad,[118] an East Coast species, the range of which is from Upper Miocene to Recent. In outline and sculpturing the two are very similar; the hinge plates are almost identical; the chief differences between them are that the anterior lateral in the left valve of *D. elegans* is not so heavy and the posterior dorsal edge is apparently sharper than on *D. mathewsonii.* Outside of these slight differences it would be hard to differentiate the two species.

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[118] For original description of *Dosinia elegans* see Proc. Phila. Acad. Nat. Sci., vol. 1, p. 325, 1843.

DOSINIA (DOSINIDIA) WHITNEYII (Gabb)

Plate 7, figures 3 and 4

Chione whitneyii Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 23, pl. 5, fig. 40, 1866.

This species, which was originally described by Gabb as a *Chione* from a rather fragmentary specimen, appears to be distinct from *D. mathewsonii* Gabb; it is higher in proportion to the length, the beaks are more prominent, it is not so strongly produced anteriorly and the lunule is larger. The concentric sculpturing of the two forms is the same.

Genus ANTIGONA Shumacher

ANTIGONA (ARTENA) MATHEWSONII (Gabb)

Plate 15, figures 5, 6 and 7

Chione mathewsonii Gabb, Geol. Surv. Calif., Palacontology, vol. 2, sec. 1, p. 23, pl. 5, fig. 39, 1866.

Chione mathewsonii Gabb, Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, no. 16, p. 378, 1904.

Chione mathewsonii Gabb, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, p. 171, 1912.

Chione mathewsonii Gabb, San Francisco Folio 193, U. S. Geol. Surv., p. 11, 1914.

Macrocallista? mathewsonii Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 14, 1915.

Gabb's description of the type is as follows:

Shell very thick, obliquely cordate, very inequilateral; beaks anterior; anterior end sinuous; base broadly rounded; posterior end prominent, narrow. Lunule lanceolate, impressed. Surface marked by numerous irregular, concentric ribs; adjoining the cardinal edge and posterior to the beaks is a narrow space running almost to the posterior end of the shell; inner margin entire, not crenulated. Pallial sinus deep; lower side curved, upper side straight.

The hinge plate and the escutcheon of this species show that it belongs to the genus *Antigona; Antigona* equals the old genus *Cytheria* Bolton. Dr. W. H. Dall informs me that the name *Cytheria* "is preoccupied in insects by Fabricius; the next oldest name, *Antigona* Schumacher, 1817, not Roemer, will have to be adopted for the genus." On the left valve the middle cardinal is heavy and bifid; the posterior cardinal is long and narrow and is situated on top of the nymph plate; the anterior lateral is long, pointed and rather low. The posterior cardinal of the right valve is bifid, as is probably also the middle cardinal. A good hinge, showing the middle and anterior cardinals of the right valve, was not exposed.

This species has been listed in a number of papers as coming from the Lower Miocene, both the Turritella ocoyana and Turritella inezana zones. It is rather doubtful whether it is found in these horizons.

Gabb's type, as shown by his figure (Geol. Surv. Calif., Palaeontology, vol. 2, pl. 5, fig. 39, 1866), appears to have a somewhat more acute posterior end than the specimens here figured. Figure 6 of this paper shows one of a number of specimens which came from the old state survey collection at the University of California and which were labeled *Chione mathewsonii.* It is not certain that this determination was made by Gabb. Gabb's descriptions of his localities are very vague; in this case, the locality and position are given as "not rare in the Miocene south of Martinez." In this region the Agasoma gravidum beds are not found directly south of Martinez but to the southeast and southwest.

ANTIGONA (ARTENA) NEGLECTA, n. sp.

Plate 8, figures 3, 4 and 6

Type specimen 11135, Coll. Invert. Palae. Univ. Calif., loc. 14.

Shell medium in size, heavy, subtrigonal to subovate; beaks fairly prominent, well forward and strongly inturned. Anterior dorsal edge long, gently convex; ventral edge regularly and rather strongly arcuate. Lunule large, elongate-lanceolate, slightly impressed, being almost as long as the anterior dorsal slope; posterior dorsal margin strongly depressed into an elongate, narrow escutcheonal area. Surface covered by somewhat irregular, medium coarse, lamelliform incremental lines. Middle cardinal of left valve heavy, faintly bifid ventrally; posterior cardinal long, situated on top of lymph plate; anterior cardinal thin, fused to the side of the middle cardinal before reaching dorsal edge; anterior lateral long and prominent. A good specimen of the right valve of this species was not obtained but, judging from other species of this type, we may infer that the escutcheonal area on this is probably not so strongly depressed as that of the left; also, that the posterior edge is grooved to receive the corresponding edge of the opposite valve.

Dimensions.—Length, 59 mm.; height, 5 mm.

Occurrence.—University of California localities 11 and 1131.

This form, in sculpturing and size, resembles *A. mathewsonii* Gabb; it occurs also in the same horizon. It differs from that species in the following respects: the anterior end is less produced; the lunule is larger, and the escutcheonal area is larger and more strongly depressed. The hinge plates also differ in minor details.

ANTIGONA (VENTRICOLA) UNDOSA, n. sp.

Plate 8, figures 1, 2 and 5

Type specimen 11136, Coll. Invert. Palae. Univ. Calif., loc. 14

Shell subtrigonal in outline, medium in size, heavy; beaks fairly prominent, strongly inturned, prosogyrous. Anterior slope straight, steep and rather short; posterior slope long and gently convex; anterior and posterior ends evenly and broadly rounded; ventral edge regularly arcuate. Lunule fairly large, slightly depressed, lanceolate, wider on right valve than on left. Escutcheon well defined as a narrow, elongate, depressed area, more distinct on the left than on the right valve. Surface of shell sculptured by numerous, fairly regularly spaced, prominent, rounded undulations, on and between which are finer incremental lines. Hinge plate rather heavy; ligamental groove deep. Three unbifid cardinals on left valve; posterior cardinal rather thin and low, and fused with nymph plate; middle cardinal heavy; anterior cardinal thin and not so high as the other two; anterior lateral strong and broadly rounded. Hinge of right valve not exposed. Posterior dorsal edge of right valve channeled posterior to the ligamental groove to receive the corresponding edge of the opposite valve. Pallial sinus beyond the middle of the shell.

Dimensions.—Type specimen: greatest dorsal-ventral height, 54 mm.; greatest anteroposterior length, 59 mm.; diameter of one valve, about 161 mm. Paratype: greatest dorsal-ventral height, 46 mm.; greatest anteroposterior length, 48 mm.

Occurrence.—A very common species in the Agasoma gravidum zone, University of California localities 14, 798, 1315, 189, 1131, etc.

Antigona undosa is of about the same size and is rather close in outline to *A. neglecta;* it differs from the latter in that the anterior end is slightly more produced, the lunule is not so large, the concentric sculpturing is entirely different, the latter species lacking the distinct undulations seen on the former. The hinge plates, also, of the two species differ somewhat in minor details.

Genus MACROCALLISTA Meek

MACROCALLISTA? INCOGNITA, n. sp.

Plate 9, figures 2 and 3

Type specimen 11116, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell medium in size, broadly subovate; beaks rather prominent, anterior to the middle, strongly inturned. Posterior dorsal slope fairly long and straight; anterior slope short, nearly straight; anterior end broadly rounded; posterior end regularly rounded but not so broad as anterior; ventral edge strongly arcuate. Lunule cordate, medium in size, marked off by a well-defined, impressed line, rather strongly pouting medially. No escutcheon, but posterior dorsal margin rather strongly depressed. Surface quite strongly excavated in front of beaks, sculptured by somewhat irregular undulations, which in part may be due to weathering; on and between these undulations are finer incremental lines.

Dimensions.—Length, about 30 mm.; height, 26 mm.; diameter of both valves, 14.5 mm.

Occurrence.—So far only one specimen of this species has been found. University of California locality 1131.

MACROCALLISTA PITTSBURGENSIS Dall

Meretrix (Callista) *pittsburgensis* Dall, Trans. Wagner Inst. Sci., vol. 3, pt. 5, pl. 36, fig. 22; pl. 43, fig. 15, 1903.
Macrocallista pittsburgensis Dall, Trans. Wagner Inst. Sci., vol. 3, pt. 6, p. 1253, 1903.
Macrocallista pittsburgensis Dall, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, p. 581, 1913.
Macrocallista pittsburgensis Dall, Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, p. 28, 1916; Proc. Calif. Acad. Sci., ser. 4, vol. 6, no. 2, pp. 28, 29, 35, 1916.

Macrocallista pittsburgensis Dall is one of the most characteristic species of the Oligocene of the West Coast. The type specimen came from beds along the Nehalem River, near the town of Pittsburg, Oregon; these beds were first referred by Dall to the Oligocene, later to the Tejon (Upper Eocene). The species is also found in the Oligocene of Washington, being listed by Weaver as one of the character istic species of his Molopophorus lincolnensis zone, or Lincoln horizon; it is found in the Kreyenhagen shales to the north of Coalinga and in Oligocene beds near the south end of the San Joaquin Valley in the San Emigdio Hills. It is also found in the Astoria beds to the north of Mount Diablo, at University of California locality 78, where it is associated with *Acila shumardi, Yoldia oregona, Agasoma gravidum, Molopophorus* cf. *biplicatus*, etc.

MACROCALLISTA WEAVERI, n. sp.

Plate 12, figures 4 and 7

Type specimen 11155, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell medium in size, beaks in the anterior fourth strongly inturned and slightly prosogyrous. Posterior slope fairly long, nearly straight; anterior slope short, straight; area anterior to the beaks rather strongly excavated. Ventral margin regularly arcuate; posterior end obliquely subtruncate. Surface sculptured by regularly spaced and rather deeply incised, concentric lines, between which are finer incremental lines. Extending from the beaks to the lower angle of the posterior subtruncate end is a fairly distinct ridge, the area posterior to which is rather strongly depressed. Lunule faint, larger on right valve than on left, marked off by slightly impressed lines. Escutcheon absent. Ligamental groove a little over half the length of the posterior dorsal margin.

Dimensions.—Length, about 33 mm.; height, 22 mm.; greatest diameter, including both valves, 15 mm. Hinge unknown.

Occurrence.—University of California locality 1131.

M. weaveri is of the same general type as *M. pittsburgensis* Dall,[119] which is common in the lower Oligocene of Oregon and Washington.

[119] For original description of *M. pittsburgensis* see Trans. Wagner Inst. Sci., vol. 3, pt. 6, p. 1253; pl. 36, fig. 22; pl. 43, fig. 15, 1903.

It differs from this latter species in the following respects: it is not so long in proportion to the height; it is not so strongly truncated posteriorly, and the lunule is not so sharply defined.

MACROCALLISTA?, sp.

Plate 9, figure 1

Several casts of a species which is apparently new were found at University of California locality 14; the outline is rather elongate, and the beaks fairly conspicuous. The posterior end is rather narrow and acutely rounded; there is no escutcheon; the lunule is not preserved on any of the specimens at hand. The surface is covered by fairly heavy, somewhat irregular lines of growth. The pallial sinus reaches the middle of the shell, is strongly ascending and is bluntly pointed.

Genus PITARIA Römer

PITARIA LORENZANA, n. sp.

Plate 10, figures 2 and 4

Type specimen 11129, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell medium in size, fairly heavy, broadly subelliptical to subovate, somewhat variable in outline. Beaks well forward, prominent, strongly inturned. Anterior dorsal slope steep, on the type specimen being almost at right angles to the anterior part of the ventral edge; anterior end bluntly rounded; posterior dorsal edge long and gently convex; posterior end broadly and regularly rounded. Lunule fairly large, lanceolate, slightly depressed and somewhat pouting along the dorsal edges. Surface of shell covered by rather fine incremental lines, which on unweathered specimens stand up as low but well-defined lamellae. Pallial sinus ample, strongly ascending and pointed in front. Enough of the hinge plate was exposed to show a well-defined anterior lateral in the left valve; this, together with other characters of the shell, appears to place it as belonging to the genus *Pitaria.*

Dimensions.—Length, about 67 mm.; height, 36 mm.; maximum height of posterior and beaks, 46 mm.; diameter of both valves, 33 mm.

Occurrence.—University of California locality 1131.

Pitaria lorenzana is rather similar to *P. dalli* Weaver,[120] a characteristic species of the Lower Oligocene of Washington, the Molopophorus lincolnensis zone as recognized by Weaver. The sculpturing of *P. lorenzana* does not appear to be so lamellose as that of the northern species, but this may possibly be due to the more weathered condition of the specimens at hand; on most of the specimens of the northern form, examined by the writer, the anterior margin is somewhat more produced, the posterior dorsal margin be-

[120] For original description of *Pitaria dalli,* see Weaver, C. E., Univ. Wash. Publ. Geol., vol. 1, no. 1, pl. 1, figs. 1–4, 1916.

hind the ligamental groove slopes down more abruptly to the posterior end; one of the big differences between the two species is the larger angle between the pallial line and the pallial sinus on *P. lorenzana*, the apex of the sinus pointing just a little below the beaks while on *P. dalli* it points to about the middle of the anterior muscle scar.

PITARIA? sp.

Plate 14, figure 8

Several poorly preserved specimens of a species which appears to belong to the genus *Pitaria*, were found at University of California locality 76 at the base of the Kirker formation. The outline of this form, as shown on plate 14, figure 8, differs considerably from that of *P. lorenzana*, found in the San Ramon formation in the vicinity of Walnut Creek; also, the angle between the pallial sinus and the pallial line is less than on this latter species; the concentric sculpturing appears to be more lamellate, but this last character may be due to difference in weathering of the specimens from the different localities.

Genus CALLOCARDIA Adams

CALLOCARDIA (AGRIOPOMA) CALIFORNICA, n. sp.

Plate 11, figures 2, 3, 4 and 11

Type specimen 11107, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell thin, medium in size, broadly ovate and rather strongly ventricose. Beaks fairly prominent, prosogyrous, strongly inturned, situated about three-fourths the distance from the posterior to the anterior end. Anterior end rather strongly produced, subacutely rounded; posterior end broadly subtruncate. Surface smooth except for medium fine, somewhat irregular incremental lines; posteriorly the surface is very strongly depressed, being slightly flattened along the dorsal margin, with the ligament tending to be immersed below the flattened area. Lunule fairly large, lanceolate, marked off by an impressed line; dorsal margin of lunular area strongly pouting. In the left valve the cardinals are thin and entire, the posterior one being the longest and situated close up to the feeble nymph plate; anterior lateral also thin, pyramidal, not situated on a well-defined platform. Posterior cardinal of right valve long, fairly heavy and grooved; the other two cardinals are entire. Adductor scars indistinct; pallial sinus short and rather acutely rounded. Ligamental groove deep and strongly immersed.

Dimensions.—Type specimen: length, 49 mm.; height, 31 mm.; height, measured just posterior to the beaks, 34 mm.; diameter of both valves, 29 mm.

Occurrence.—University of California locality 1131.

The specimens referred to this species were all sent to Dr. W. H. Dall for generic determination; he states that it belongs to the genus *Callocardia*, subgenus *Agriopoma*. According to Dall, this group heretofore has been known only from eastern America and Japan in the Recent state.

Genus CHIONE Megarle von Muhlfeld

CHIONE CRYPTOLINEATA, n. sp.

Plate 5, figures 1, 2, 3 and 4

Type specimen 11178, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell heavy, longer than high, subovate in outline; beaks prominent, strongly inturned. Anterior slope short; posterior slope long, gently convex for a short distance below the beaks, beyond which it is straight. Anterior end rather strongly produced, regularly rounded; posterior end regularly rounded. Lunule large, rather strongly depressed, cordate, pouting, concentrically sculptured by rather fine, sharp, closely crowded lamellae. Escutcheon well defined, depressed a little more than at right angles to the main outer surface of the shell, being more distinct and covered by finer incremental lines on the left valve than on the right. Main surface of shell covered by prominent and fairly equally spaced sharp lamellae which, on the unweathered specimens, are almost two millimeters high. Surface on weathered specimens radially sculptured; these radial ribs are fine and close together and apparently do not extend onto the lunule or escutcheon; margins internally crenulate; the radials are internal and do not show on unweathered specimens. Three cardinals on each valve; on the right valve the two posterior cardinals are strongly bifid; on the left valve the posterior cardinal is long and narrow and situated on top of the nymph plate, the middle cardinal is bifid and the anterior cardinal is higher than the other two. The posterior dorsal edge of the right valve is grooved to receive the corresponding edge of the opposite valve. Pallial sinus short and bluntly rounded.

Dimensions.—Type specimen: greatest dorsal-ventral height, 49 mm.; greatest anteroposterior length, 59 mm.; length of posterior dorsal slope, about 47 mm.; length of anterior dorsal slope, about 16 mm.; greatest diameter of both valves, 19 mm.

Occurrence.—University of California localities 1131, 1686, 14, 1343, etc.

This species is quite distinct from, but in some cases, with poor material, might be mistaken for *C. mediostriata*, which is found in the same horizon. In outline it differs from the latter species in being longer in proportion to the height; the anterior end is more regularly rounded; the lunule is different in that it is pouting and is not so wide; the escutcheonal area is not quite so strongly depressed. The greatest difference between the two species is that on *C. mediostriata* there are four cardinal teeth in the right valve, while on *C. cryptolineata* there are only three. On the right valve of *C. cryptolineata* the anterior cardinal is not so high and is longer than the corresponding tooth on *C. mediostriata*. The posterior cardinal of the left valve of *C. cryptolineata* is situated on top of the nymph plate, while the same tooth on *C. mediostriata* is separated from the nymph plate by a distinct groove, into which fits the fourth posterior cardinal of the right valve.

CHIONE LINEOLATA, n. sp.

Plate 6, figures 1, 2 and 5

Type specimen 11123, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell heavy, medium in size, subtrigonal in outline, longer than high; beaks prominent. Anterior slope short, gently concave; posterior slope long, gently convex. Anterior end evenly rounded; posterior end subangulate; ventral edge gently arcuate. Lunule large, cordate, concentrically sculptured only. Dorsal edge of lunule in right valve slightly convex just below the beaks. Escutcheon well-defined, depressed more than at right angles to the main outer surface of shell; area more distinct and less coarsely sculptured on left valve than on right; margins internally crenulate. Surface of shell covered by heavy, coarse concentric ridges or lamellae which, near the beaks, are rather wide apart but become closely crowded near the ventral edge; surface also sculptured by medium fine, closely crowded, radial ribs which become obsolete on the posterior dorsal margin, and which are probably internal, not showing on unweathered specimens. Hinge plate heavy; ligamental groove deep. Three strong, equally spaced cardinals in right valve, none of which are bifid. On the left valve the posterior cardinal is elongate, fairly prominent and situated on top of nymph plate; the middle cardinal is deeply bifid; anterior cardinal higher than the other two, bluntly pointed. Posterior dorsal edge of right valve below ligamental groove channeled to receive the corresponding edge of the opposite valve.

Dimensions.—Type specimen: greatest dorsal-ventral height, 55 mm.; greatest anteroposterior length, 62 mm.; length of posterior dorsal slope, 53 mm.; length of anterior dorsal slope, about 19 mm.; greatest diameter of one valve, 21 mm.

Occurrence.—University of California locality 1131, about three-fourths of a mile southwest of the town of Walnut Creek.

For a comparison of this species with *C. mediostriata* see the description of the latter species.

C. lineolata rather closely resembles *C. securis* Shumard,[121] a species very common in the Upper Miocene of Oregon and Washington. The anterior end of *C. lineolata* is more strongly produced than on *C. securis,* the ventral edge is not so arcuate, the escutcheonal area is more depressed and sharply defined, and the lunule is somewhat larger. The hinge plate of the right valve of *C. securis,* as figured by Dall, is quite different from that of *C. lineolata.*

CHIONE MEDIOSTRIATA, n. sp.

Plate 5, figures 5 and 6; plate 6, figures 3 and 4

Type specimen 11181, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell heavy, medium in size, cordate; beaks prominent, strongly inturned and prosogyrous. Anterior slope short and slightly concave; posterior slope long and gently convex. Posterior end subangulate to bluntly rounded; anterior end

[121] See description and figure of *C. securis* given by Dall, U. S. Geol. Surv., Prof. paper 59, p. 120, pl. 11, fig. 8; pl. 13, figs. 2, 9, 1909.

regularly rounded. Ventral edge strongly arcuate, sloping more sharply anteriorly. Lunule large, depressed, lanceolate, about as high as wide. Escutcheon long, distinct, depressed a little more than at right angles to the main outer surface of the shell; it is more distinct and less coarsely sculptured, with incremental lines stronger on the left valve than on the right. Surface of shell covered by fairly coarse, somewhat irregularly spaced concentric ridges or lamellae which on unweathered specimens are quite prominent, on weathered specimens, sculptured by fairly fine and narrowly spaced radial ribs which are absent on the escutcheon and for a short distance in front. Ventral and anterior dorsal edges crenulate. Posterior dorsal edge of right valve below the ligamental groove channeled to receive the corresponding edge of the opposite valve. Hinge plate heavy. Ligamental groove deep, medium in length. Four cardinals on the right valve; the posterior cardinal is low, long and narrow and is just in front of the rather indistinct nymph plate; two middle cardinals are bifid, the posterior one being the heavier and longer; anterior cardinal thin, not so high as the middle two and situated on the inside of the anterior dorsal margin; on the left valve the elongate, narrow posterior cardinal is set a little in front of and is separated from the nymph plate by a shallow groove or socket for reception of the posterior cardinal of the opposite valve; anterior cardinal heavy and higher than the other two and bluntly pointed, middle cardinal bifid.

Dimensions.—Type specimen: greatest dorsal-ventral height, 60 mm.; greatest anteroposterior length, 62 mm.; length of posterior dorsal slope, 62 mm.; length of anterior dorsal slope, 16 mm.; diameter of both valves, 39 mm.

Occurrence.—University of California locality 1131, about three-fourth mile south of Walnut Creek in basal beds of Agasoma gravidum zone.

This species somewhat resembles *Chione lineolata,* which is found in the same horizon. It differs, however, in outline, in sculpturing and in the dentition. On the latter the anterior end is more produced, and the posterior end is usually more angulate, the beaks are more prominent, the ventral edge is not so arcuate, the lunule is longer in proportion to the width and is not so depressed. The greatest difference between the two species is in the dental armature; on the right valve of *C. lineolata* there are three cardinals which are entire, while on the right valve of *C. mediostriata* there are four cardinals, the two middle of which are bifid. On the left valve of *C. mediostriata* the posterior cardinal is separated from the nymph plate by a shallow groove, while on the left valve of *C. lineolata* the posterior tooth is on top of the nymph plate. For a comparison of *C. mediostriata* with *C. cryptolineata,* which is also found in the same horizon, see the description of the latter.

Family Tellinidae

Genus TELLINA Linnaeus

TELLINA LORENZOENSIS Arnold

Tellina lorenzoensis Arnold, Proc. U. S. Nat. Mus., vol. 34, no. 1617, p. 367, pl. 33, fig. 1, 1908.

Macoma lorenzoensis Arnold, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, p. 583, 1913.

Tellina lorenzoensis Arnold, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

This is a common species in the Kirker tuffs of the Sobrante Ridge section; it is also very common in the Kirker formation on the north side of Mount Diablo.

TELLINA OREGONENSIS Conrad

Plate 13, figures 1 and 4

1848; Amer. Jour. Conch., vol. 1, p. 152, 1865.

Tellina oregonensis Conrad, Amer. Jour. Sci., ser. 2, vol. 5, p. 432, fig. 5, 1848– Amer. Jour. Conch., vol. 1, p. 152, 1865.

?*Macoma nasuta* Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 93, 1868; not *Macoma nasuta* Conrad, 1837.

Tellina oregonensis Conrad, Dall, U. S. Geol. Surv., Prof. paper no. 59, p. 124, 1909.

Tellina oregonensis Conrad, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, p. 178, 1912.

Tellina oregonensis Conrad, Weaver, Wash., Geol. Surv., Bull. 15, p. 18, 1912.

Tellina oregonensis Conrad, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, pp. 583, 588, 1913.

Tellina oregonensis Conrad, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 3, pp. 15, 18, 1915.

Tellina oregonensis Conrad, Dickerson, Proc. Cal. Acad. Sci., ser. 4, vol. 7, p. 16, pl. 29, fig. 4, 1917.

Tellina oregonensis Conrad apparently has a rather long range for a species of this genus; it extends from the Oligocene into the Upper Miocene; it is very common in the Scutella breweriana beds, Briones formation of Contra Costa County, the fauna of which has a stronger affinity with that of the Upper Miocene than with the fauna of the Lower Miocene; it is common in the *Arca montereyana* zone in Contra Costa County, California, and is reported in the same horizon in Oregon and Washington; it is also found in the Oligocene of Oregon and Washington. The following is Conrad's original description:

Elliptical, thin, much compressed; valves flattened and having regular concentric fine lines; anterior submargin somewhat angulated, margin nearly direct, truncated; beaks rather nearest to the anterior extremity; posterior end acutely rounded.

In the cast, an oblique shallow furrow meets the apex on the posterior side.

Conrad figured a very good specimen of a right valve. The oblique shallow furrow referred to is on the anterior side of the beaks instead of the posterior side; the posterior dorsal margin of the left valve is not so strongly depressed as on the right valve and the posterior end is more rounded.

TELLINA PRAECUTA, n. sp.

Plate 12, figure 13

Type specimen 11166, Coll. Invert. Palae. Univ. Calif., loc. 14

Shell elongate-ovate, strongly rostrate posteriorly; beaks inconspicuous, anterior to the middle of the shell, right valve rather strongly flexed near the posterior end. Posterior dorsal margin long and straight; anterior dorsal margin gently convex, shorter than posterior margin; anterior end regularly rounded; posterior end narrow and truncated; ventral edge long and gently arcuate except near posterior end where it is slightly concave due to the flexure of the valve. Surface sculpturing not well preserved on specimens at hand but enough is seen to show that it is of the same general type as *T. tenuilineata* and *T. idea,* having the same type of depressed posterior margin.

Dimensions.—Length, 36 mm.; height, 19 mm.; length of posterior dorsal edge, 21 mm.; length of anterior dorsal edge, about 15 mm.

Occurrence.—University of California locality 14.

At present the writer has only one specimen of a right valve of this species, and that is a rather imperfect cast; fragments of other specimens have been seen; the form, however, appears to be so distinctive in outline as to be worthy of description.

TELLINA TENUILINEATA, n. sp.

Plate 10, figures 1, 3 and 5

Type specimen 11130, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell subovate in outline, inequivalve; rostrate posteriorly with the posterior end subtruncate; beaks nearly straight; valves slightly flexed to the right near the posterior end; left valve slightly more convex than right; anterior end regularly rounded; ventral edge regularly convex except near the posterior end, where it is slightly concave due to the flexure of the valves. Escutcheon well-defined, elongate, narrow and strongly depressed, wider on the left valve, the wider part being near the middle of the posterior dorsal margin. Ligamental groove deep, shorter than the escutcheon. Lunule small and deeply inset. Surface of right valve covered by fairly fine, regularly spaced, sharp, concentric, raised lines, which are closely crowded together near the beaks, the interspaces becoming wider and more regular toward the ventral edge; on the depressed posterior margin these lines are rather strongly imbricated. A fairly broad, shallow flexure sinus near the posterior dorsal edge, posterior to which the dorsal margin is depressed, the depressed area being separated from the main surface of the shell by a distinct ridge; on the depressed area, posterior to this ridge and extending from near the beak to the posterior end, is a fairly deep sinus. Left valve covered by concentric lines, which are somewhat finer and closer together than on right valve; posterior dorsal margin not so strongly depressed as on right valve. On the depressed margin there is a shallow sinus, which is not separated by a distinct ridge from the surface anterior to it.

Dimensions.—Length, about 44 mm.; height, about 27 mm.

Occurrence.—University of California locality 1131, outcrop in bed of creek about one-half mile south and a little west of the town of Walnut Creek.

T. tenuilineata resembles rather closely *T. idea* Dall,[122] a Recent West Coast species; the two are somewhat different in outline; the beaks of the latter are more conspicuous; the raised concentric lines are somewhat coarser and on the posterior margin they appear to be more strongly imbricated. *T. tenuilineata* lacks the fine radiating lines seen on *T. idea.*

Genus MACOMA Leach

MACOMA, aff. NASUTA Conrad

This species was listed by the writer[123] in a former paper as *Macoma nasuta;* a further study of better material, obtained at the same locality from which it was previously listed, shows that it is a distinct form, the principal characters that distinguish it from *M. nasuta* being that the beaks are possibly more anterior, the posterior dorsal margin is longer and the posterior end more acute. The specimens at hand, representing this form, are so poorly preserved that it does not seem best to give it a specific name; the writer is of the opinion, however, that it may be a new species.

Occurrence.—University of California locality 1900, near the top of the Kirker formation.

Genus METIS H. and A. Adams

METIS ROSTELLATA, n. sp.

Plate 9, figure 7

Type specimen 11120, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell medium in size, ventricose, equivalved, broadly subrostrate posteriorly, broadly rounded in front; beaks rather inconspicuous, situated within the anterior third of the shell. Anterior dorsal edge very short, gently convex and with no angulation or change in slope between it and the rounded anterior end; posterior end narrow, broadly truncate. Surface rather strongly excavated just anterior to the beaks; covered by low, sharp, somewhat irregular lines of growth. Posterior dorsal margin on left valve strongly depressed and separated from main portion of shell by a distinct ridge, which reaches from the beak to the posterior end;

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122 For original description of *Tellina idea,* see Dall, W. H., U. S. Nat. Mus., vol. 14, p. 183, pl. 6, fig. 3; pl. 7, figs. 1, 4, 1891.

123 Clark, B. L., The Neocene section at Kirker Pass, on the north side of Mount Diablo, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, no. 4, p. 51, 1912.

a broad, shallow sinus anterior to this ridge and parallel with it. A good right valve of the species was not obtained but it seems very probable, as on many species of this genus, that on this valve there would be a sinus near and parallel to the posterior dorsal margin, corresponding to the ridge on left valve. Two well-developed cardinals in left valve.

Dimensions.—Length, about 50 mm.; height, about 37 mm.; greatest diameter, about 23 mm.

Occurrence.—University of California locality 1131.

This species is quite unique, differing from most of the other species of this genus in having the beaks so far anterior.

Family Psammobiidae

PSAMMOBIA, aff. EDENTULA (Gabb)

Plate 16, figure 3

A number of specimens of a species of *Psammodia* have been obtained in the San Ramon formation at several localities. All the specimens are too poor to permit of specific determination. The form is close in outline to *P. edentula* Gabb, but appears to differ in some minor respects; the outline differs somewhat from the majority of that species; also, the nymph plate is not so heavy. *P. edentula* (Gabb)[124] is a variable form, especially in outline, and for that reason the writer has hesitated to describe the form from the Agasoma gravidum beds as a new species. He feels, however, that it is very probably a new species and will be differentiated when better material is obtained.

Family Donacidae

Genus DONAX Linnaeus

DONAX sp. indt.

A cast from University of California locality 1314.

Family Solenidae Leach

Genus SOLEN Linnaeus

SOLEN (PLECTOSOLEN) CURTUS Conrad

Plate 10, figure 6

Solen curtus Conrad, Amer. Jour. Sci., ser. 2, vol. 5, p. 433, fig. 14, 1848.

Plectosolen curtus Conrad, Check list Eocene Fossils N. Am., p. 8, no. 239, 1866.

Enses curtus Meek, Check list Miocene Fossils N. Am., p. 12, no. 416, 1864; Conrad, Am. Jour. Conch., vol. 1, p. 152, 1865; Gabb, Geol. Surv. Calif., Palaeontology, p. 116, 1868.

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124 For original description of *Psammobia edentula* (described as *Siliquaria? edentula*), see Geol. Surv. Calif., Palaeontology, vol. 2, p. 53, pl. 15, fig. 11, 1869.

Solen (*Plectosolen*) *curtus* Conrad, Dall, U. S. Geol. Surv., Prof. paper no. 59, p. 129, 1909.

? *Solen curtus* Conrad, Arnold and Hannibal, Proc. Am. Philos. Soc., vol. 52, no. 212, pp. 583, 584.

Solen curtus Conrad, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, pp. 15 and 18, 1915.

Occurrence.—University of California localities 11, 1131, 1312, 2753, etc.

Solen curtus is a much smaller form than the ordinary *Solen;* the anterior end is obliquely rounded and the posterior dorsal margin is slightly concave similar to *S. sicareus* Gould,[125] a common Recent species on the West Coast. *S. curtus* is reported by Arnold and Hannibal (Proc. Amer. Philos. Soc., vol. 52, no. 212, pp. 583–584) as having a range from Oligocene to Recent; the writer doubts very much whether it occurs above the Lower Miocene. It seems probable that the writers referred to have, at least in part, confused *S. curtus* with another species. *S. curtus* is found in the Lower Miocene beds near Bakersfield, California; these beds belong to the Turritella ocoyana zone.

SOLEN GRAVIDUS, n. sp.

Plate 10, figure 7

Type specimen 11133, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell large and rather heavy. Posterior dorsal and ventral edges straight and parallel with each other. Posterior end regularly rounded; anterior end regularly and gently rounded, with highest point of convexity a little below the middle. Shell subangulate at junction of anterior dorsal and ventral edges. In the right valve there is a heavy, bifid, deltoid cardinal; in the left valve the cardinal is heavy and elongate, with the highest point anterior, sloping down rapidly posteriorly. On surface near anterior end there is a narrow, shallow groove or sinus which slants obliquely from beaks to anterior end of ventral edge; the margin between this sinus and the anterior dorsal edge is somewhat variable in width on different specimens; the sinus is also variable in depth. Anterior end of shell thickened internally just back of anterior dorsal edge and in front of sinus.

Dimensions.—Length, 93 mm.; height, 15 mm.; diameter of both valves, about 10 mm.

Occurrence.—University of California localities 1131, 1173, 1213, etc.

There has been a tendency for different workers on the palaeontology of the West Coast to disregard the species of the genus *Solen.* The average published faunal list of Miocene and Pliocene species contains the species *Solen sicareus* Gould. The Solens, like the Naticas, require well-preserved specimens in order to obtain the

[125] For original description of *Solen sicareus* see Proc. Bost. Soc. Nat. Hist., vol. 3, p. 214, 1850. For good redescription see Arnold, Mem. Calif. Acad. Sci., vol. 3, p. 172, 1903.

diagnostic characters. It is questionable whether *S. sicareus* goes below Upper Miocene (San Pablo, Santa Margarita). The species which is most common in the Upper Miocene and Lower Pliocene (San Pablo, Etchegoin) on the West Coast is *S. perrini* B. L. Clark;[126] this appears to be more closely related to *S. rosaceus* Cpr.[127] than to *S. sicareus,* under which name it has been listed a great many times. *S. perrini* differs from *S. rosaceus* in being heavier and the proportion of height to length is greater. The hinge plate of *S. perrini* has not been described.

S. gravidus differs from *S. rosaceus* in that it is heavier; it has a different proportion of height to length, and the anterior end is less oblique; the cardinals of the two species are quite different.

S. gravidus differs from *S. perrini* in the following respects: the anterior end is not so oblique, being more regularly rounded; there is usually more of a margin in front of the sinus on the anterior end.

S. gravidus is very similar in outline to *S. parallelus* Gabb.[128] It differs from this species in that the anterior end is not so obliquely truncated and the anterior margin not so strongly depressed.

There is a Solen in the Lower Miocene beds of Kern River section near Bakersfield which is very similar to, if not identical with, *S. gravidus;* the writer would like, however, to see more and better material before deciding definitely as to its identity with *S. gravidus.*

Family MACTRIDAE

Genus SPISULA Gray

SPISULA OCCIDENTALIS Gabb

Plate 11, figure 1

Hemimactra occidentalis Gabb, Geol. Surv. Calif., Palaeontólogy, vol. 2, p. 54, pl. 15, figs. 13, 13*a*, 1869.

Spisula occidentalis Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Spisula occidentalis Gabb, Packard, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 15, pp. 288–289, pl. 23, figs. 1, 2 and 3, 1916.

This is a very common species in the Agasoma gravidum zone. It is somewhat similar in outline to *S. catenulatus* Conrad, a Recent West Coast species.

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[126] Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 22, p. 477, pl. 44, fig. 2, 1915.

[127] For good description of *Solen rosaceus* see Arnold, Mem. Calif. Acad. Sci., vol. 3, p. 171, 1903.

[128] For original description of *Solen parallelus,* see Geol. Surv. Calif., Palaeontology, vol. 1, pp. 146–147, pl. 22, fig. 117, 1866.

SPISULA RAMONENSIS Packard

Plate 9, figures 4 and 5

Spisula ramonensis Packard, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Spisula albaria ramonensis Packard, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 15, p. 291, pl. 23, fig. 5; pl. 25, figs. 1–2, 1916.

Occurrence.—A very common species in the Agasoma gravidum beds, University of California localities 1131, 1309, etc.; also common in the Oligocene of Oregon and Washington.

This is one of several species which are very close in outline and sculpturing to *S. albaria* Conrad. The exact horizon from which Conrad's species came is not certain. W. H. Dall[129] has redescribed the species, taking as a pleseotype a specimen from the Empire beds of Coos Bay, Oregon, which horizon is, at least approximately, equivalent to what is recognized as Middle Pliocene in California, the same horizon as the Lower Merced and Lower Wildcat. Earl Packard, in his paper on the Mactrinae of the West Coast, has accepted Dall's determination. The writer feels that it is very possible that Dall's determination of *S. albaria* is incorrect. Conrad's type came from near Astoria, Oregon. As far as known, Pliocene beds are not present in that vicinity. Packard has shown that the form from the Monterey of Contra Costa County, *S. selbyensis* Packard, previously listed as *S. albaria,* is distinct, as well as the one from the Agasoma gravidum beds, *S. ramonensis,* though he has listed the latter as a variety of *S. albaria.* It remains to be proven whether the Pliocene species extends down into the Lower Miocene. It is very improbable that it extends into the Oligocene. Both *S. ramonensis* and *S. selbyensis* Packard are very similar in outline and sculpturing to *S. albaria* Conrad, the form recognized by Dall and so common in the Upper Miocene and Pliocene of the West Coast. The range of variation in outline of all three species is so great that many times it is difficult to separate them unless the hinge plates are exposed. Packard has shown that the three species, as shown by the hinge plates, are quite distinct and that one with good material can also see slight differences externally.

SPISULA RAMONENSIS ATTENUATA, n. var.

Plate 9, figure 6

Type specimen 11119, Coll. Invert. Palae. Univ. Calif., loc. 1167

Shell medium in size, longer than high, equivalved, inequilateral; beaks fairly conspicuous, strongly inturned, anterior to middle. Anterior dorsal slope long

[129] U. S. Geol. Surv., Prof. paper no. 59, pp. 130–131, pl. 10, fig. 1, 1909.

and nearly straight; posterior dorsal slope fairly steep and slightly convex. Anterior end strongly produced, rather attenuately rounded; posterior end broadly rounded. Surface smooth except for medium fine, incremental lines. Extending from the beak to the ventral side of the posterior end is a well-marked ridge, posterior to which the surface is depressed rather strongly.

Dimensions.—Length, about 93 mm.; height, about 29 mm.; diameter of both valves, about 18 mm.

Occurrence.—University of California localities 14, 708, 1131 and 1167.

This species is of the same general type as *Spisula albaria* Conrad[130] *Spisula selbyensis* Packard,[131] and *Spisula ramonensis* Packard. The hinge plate of *S. ramonensis* attenuata is not known. The chief basis for separating it from *S. ramonensis*, found in the same horizon, is the more strongly produced anterior end and the more prominent posterior ridge. It appears to be a distinct form and worthy of at least varietal rank.

SPISULA? SAXADOMOIDES, n. sp.

Plate 16, figure 1

Type specimen 11268, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell medium in size, broadly elongate-ovate; beaks fairly prominent, strongly inturned, situated about two-thirds the distance from the posterior to the anterior end; anterior dorsal margin slightly excavated; anterior end rather strongly produced, broadly and regularly rounded; posterior end broadly and regularly rounded; posterior dorsal margin long, nearly straight. Ventral edge gently arcuate. Surface smooth except for incremental lines; anterior and posterior dorsal margins of shell rather strongly pouting, one of the common characteristics of many of the species of this genus. Hinge plate of left valve only imperfectly exposed, showing a small deltoid cardinal with a deep resilifer pit.

Dimensions.—Length, 60 mm.; height, 40 mm.; diameter of both valves, 26 mm.

Occurrence.—University of California localities 52 and 1131.

The outline of this species is very unique, reminding one of a *Saxidomus* rather than of a *Spisula.*

Genus MULINIA Gray

MULINIA?, sp.

Dimensions.—Height, about 90 mm.; length, about 95 mm.

A cast of a large mactroid shell was found at University of California locality 1131. It is referred questionably to the genus *Mulinia,* chiefly because of the thickness, outline and fairly heavy muscle

130 For original description of *Spisula albaria* Conrad, see Amer. Jour. Sci., ser. 2, vol. 5, p. 432, fig. 4, 1878.

131 For original description of *Spisula selbyensis* Packard, see Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 15, pp. 292–293, 1916.

scars. The shell is trigonal in outline, only slightly longer than high; the beaks are fairly prominent and situated anterior to the middle of the shell. The dorsal slopes are steep. There is a very distinct ridge, extending from the beak to the posterior end and parallel with the posterior dorsal margin, the narrow surface between this ridge and the dorsal margin being depressed almost at right angles to the main surface of the shell. Another specimen of a *Mulinia?* was found at University of California locality 1309; the exterior of this specimen was very poorly preserved but the hinge plate was exposed, showing Mulinia-like character; it seems very likely that it belongs to the same species as that found at the other locality.

Casts of a large mactroid shell, very close in outline to the specimens referred to above, were found at University of California locality 78, on the north side of Mount Diablo in the basal beds of the Pittsburg tuff; however, one cannot be certain that these specimens belong to the same species as those from the other localities.

Family Myacidae

Genus MYA Linnaeus

MYA (CRYPTOMYA) INCOGNITA, n. sp.

Plate 11, figure 8; plate 14, figure 4

Type specimen 11114, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, thin, subquadrate in outline; beaks near the middle, rather conspicuous. Posterior dorsal slope nearly straight, usually not so long as anterior slope, which is gently convex; posterior end obliquely truncated, on some specimens gaping rather strongly. Ventral edge, in the middle, gently convex to nearly straight, sloping up rather strongly near the ends. Surface smooth except for rather fine incremental lines. On one specimen the chondrophore of the left valve was exposed; it is small with two distinct, fairly heavy ridges posterior to resilium pit. The anterior of these two ridges is the raised posterior margin of resilium pit; the posterior ridge extends out somewhat beyond the platform of chondrophore as on *Mya arenaria*. Pallial sinus apparently absent.

Dimensions.—Type specimen: length, 10.5 mm.; height, 6.5 mm.; diameter of one valve, about 2 mm.

Occurrence.—University of California locality 1131.

M. incognita is very similar to *M. californica* Conrad.[132] All the specimens at hand of the former species are somewhat smaller than the average size of the latter; outside of this, if it were not for the hinge plate, it would be hard to distinguish the two species; on the

[132] For original description and figure of *Mya californica* Conrad [originally described as *Sphaenia californica*], see Jour. Phila. Acad. Nat. Sci., vol. 7, p. 234, pl. 17, fig. 11, 1856.

latter the hinge plate is heavier, the resilium pit is larger and not so deep and well-defined; also there is only one well-defined ridge posterior to resilium pit and it does not extend out beyond the edge of platform of chondrophore as on *M. incognita.*

M. incognita somewhat resembles in outline *Mya* (*Cryptomya*) *oregonensis* Dall,[133] from which it differs in being more obliquely and strongly truncated; the two valves of *M. incognita* are equal, while Dall describes *M. oregonensis* as being "moderately unequivalve."

Family Saxicavidae

Genus PANOPE Menard

PANOPE cf. ESTRELLANA Conrad

Glycimeris estrellana Conrad, Pacific Railroad Rep., vol. 7, p. 194, pl. 7, fig. 5, 1857.

Panopea estrellana Conrad, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, p. 173, 1912.

Panope estrellana Conrad, Anderson and Martin, Proc. Calif. Acad. Sci., ser. 4, vol. 4, p. 42, 1914.

Panope estrellana Conrad, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

The type of *Panope estrellana* came from the southern part of the state. It is not known for a certainty whether it came from the Lower or Upper Miocene of that region. The Recent species, *P. generosa* Gould,[134] is rather variable in outline and sculpturing; this is also true of the form found in the Lower Miocene and Oligocene, referred to here as *P. estrellana.* Some authors have concluded that the variations of the Recent and Oligocene-Lower Miocene forms are so great that they can not be separated as distinct species. After examining a considerable number of specimens from the Lower Miocene and the Oligocene and of the Recent, the writer believes that the Oligocene-Lower Miocene form is distinct; he does not feel certain, however, that the form described as *Mya abrupta* by Conrad and placed as a synonym of *Panope estrellana* by Dall is not a distinct species. Possibly when good hinge plates are exposed of specimens from both the Oligocene and Miocene, specific differences will be found between them.

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133 For original description of *Mya oregonensis* see U. S. Geol. Surv., Prof. paper no. 59, pp. 132–133, pl. 11, fig. 4, 1909.

134 For original description of *Panope generosa,* see Proc. Bost. Soc. Nat. Hist., vol. 3, p. 215, 1850; for good redescription and discussion see Arnold, Mem. Calif. Acad. Sci., vol. 3, p. 182, 1903.

The most important differences between *P.* cf. *estrellana* and *P. generosa* appear to be that the former is somewhat longer in proportion to the height and has less conspicuous beaks. The posterior dorsal edge on *P.* cf. *estrellana* is straight, while on *P. generosa* it is usually concave; on *P.* cf. *estrellana* there is a wide, shallow sinus, which extends from the beaks to the lower side of the truncate posterior end; this is usually absent on *P. generosa,* though appearing on some specimens.

The writer exposed an imperfect hinge of the right valve of a specimen of *P.* cf. *estrellana* from the Agasoma gravidum beds, apparently enough to show that there are specific differences between it and *P. generosa.* It is very possible that when this form from the Oligocene and Lower Miocene is compared with the type it will be found to be a new species.

Family PHOLADIDAE

Genus PHOLADIDEA Goodall

PHOLADIDEA aff. PENITA Conrad

Poorly preserved specimens of *Pholadidea* were found at locality 1131 extending from basal Oligocene beds into beds that are presumably Tejon, though no Tejon fossils were found at this locality. The species is close to *Pholadidea penita* Conrad[135] from which it appears to differ somewhat in outline; the sculpturing is very close. It does not seem best, on account of the poorness of the preservation of the specimens at hand, to describe this form as a new species; the writer feels, however, that with better material it may be found to be new.

Family TEREDINIDAE

Genus TEREDO Linnaeus

TEREDO sp. indt.

Fossil wood was found at University of California locality 2753, full of Teredo borings.

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[135] For original description of *Pholadidea penita,* see Jour. Phila. Acad. Nat. Sci., vol. 7, p. 237, pl. 18, fig. 7, 1837; also for good description see Arnold, Mem. Calif. Acad. Sci., vol. 3, pp. 184–185, 1903.

Class GASTROPODA

Family TROCHIDAE

Genus CALLIOSTOMA Swains

CALLIOSTOMA LAWSONI, n. sp.

Plate 22, figures 14, 17 and 18

Type specimen 11231, Coll. Invert. Palae. Univ. Calif., loc. 331

Shell medium in size, thin; spire acute, higher than body whorl. Whorls seven or eight, angulate; body whorl angulated at the base and again a little posterior to the middle of the shell; sides of whorls, below the upper angulation, flat; on body whorl almost at right angles to the nearly flat base. Surface above the upper angle subtabulate, sloping obliquely to the suture. Sutures channeled, bounded anteriorly by a fairly distinct nodose collar. Sides of whorls, including tabulate areas, covered by medium narrow, nodose, spiral ribs with interspaces somewhat wider than the ribs; three nodose spiral ribs, including the one on the angulation and the one forming the collar next to the suture, on the subtabulate portion of the body whorl and of the whorls of the spire, a small, unnodose interrib being included in each interspace; the minor spiral ribs on the tabulate areas of the larger specimens become heavier and on some specimens are not easily distinguished from the major spiral ribs; usually only one major nodose rib is visible on the sides of the whorls of the spire below the angulation, though on some specimens the second one next to the suture may be seen; two major spiral ribs on the sides of the body whorl, one about half way between the upper angulation and the base, the other on the angulation at the base; both on the sides of the whorls of the spire and on the sides of the body whorl, there are minor, unnodose, spiral ribs in the interspaces between the major spiral ribbing, sometimes only one, sometimes two or three in each interspace; usually the larger number is found on the sides of the body whorl; base sculptured by eight or nine granulose, fairly heavy, but somewhat variable, spiral ribs. Shell imperforate; apparently no callus in umbilical region, if so, very small.

Dimensions.—Type specimen: height, 22.5 mm.; greatest width of body whorl, about 25 mm.; height of spire, about 8.5 mm.

Occurrence.—University of California localities 30, 331, 1131, 1311, etc.

Family PYRAMIDELLIDAE

Genus TURBONILLA Risso

TURBONILLA sp.

An impression of a *Turbonilla* was found in the same piece of sandstone, from which the cast of *Epitonium ventricosum* was obtained, University of California locality 1165. A fairly good wax cast was made of the *Turbonilla;* however, it is not complete enough to warrant its description as a new species, the body whorl as well as the tip of the spire being gone. The species is of the same general type as *Turbonilla* (*Pyrogiscus*) *grippi* Bartsch,[136] a Recent West Coast species. The ribs of the former are a little heavier and possibly the body whorl is a little more ventricose.

Family Epitonidae

Genus EPITONIUM Bolten

EPITONIUM PINOLENSIS, n. sp.

Plate 20, figure 16

Type specimen 11273, Coll. Invert. Palae. Univ. Calif., loc. 3055

Shell medium in size, turreted; apex acute; whorls strongly and regularly convex; sutures strongly depressed; number of whorls seven or eight. Surface convered by about twenty-five to twenty-eight fine, longitudinal ribs, with interspaces somewhat wider than the width of the ribs; surface of each whorl also sculptured by about six spiral ribs, with interspaces nearly twice the width of the ribs; body whorl rounded at junction of side to base; on the type specimen the posterior two or three spiral ribs are nearly obsolete. Aperture not exposed.

Occurrence.—University of California localities 3051 and 3055.

EPITONIUM VENTRICOSUM, n. sp.

Plate 23, figure 14

Type specimen 11240, Coll. Invert. Palae. Univ. Calif., loc. 165

Shell large, with six or seven whorls which are strongly and regularly convex; sutures depressed. Spire high, acute; body whorl strongly ventricose, about half the height of the shell. Surface sculptured by about twelve heavy, rounded, continuous varices. Base of body whorl broad, depressed in umbilical region. Aperture covered by matrix.

Dimensions.—Type specimen: height, about 45 mm.; height of body whorl, 22 mm.; greatest diameter of body whorl, 31 mm.

This species appears to be quite unique, the body whorl being larger and more ventricose than on any of the Recent or fossil species of the same genus on this coast. The type is a wax mould taken from a very well preserved impression in the rock.

EPITONIUM, sp. indt.

Plate 21, figure 8

Shell medium in size; apex acute; whorls regularly convex, seven or eight in number; sutures depressed, apparently a fairly well-marked sutural band at the base of each whorl. Surface covered by about twelve distinct rounded varices, with interspaces averaging about as wide as the varices. On the penultimate whorls of the spire of the type, four or five spiral ribs can be discerned between the varices; undoubtedly the whole surface of the shell was covered by spiral ribs. Aperture not exposed.

The specimen figured is a wax cast from University of California locality 3055.

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136 For original description of *Turbonilla grippi*, see Proc. U. S. Nat. Mus., vol. 42, p. 270, pl. 36, fig. 9, 1912.

Family SOLARIIDAE

Genus SOLARIUM Lamarck

SOLARIUM LORENZOENSIS (Arnold)

Architectonica lorenzoensis Arnold. Proc. U. S. Nat. Mus., vol. 34, p. 374, pl. 33, fig. 10, 1908.

Occurrence.—Found at University of California locality 3051, at base of Kirker formation; associated with *Acila gettysburgensis, Solen gravidus, Tellina lorenzoensis, Agasoma gravidum, Pseudoperissolax merriami,* etc.

Family CAPULIDAE

Genus CALYPTRAEA Lamarck

CALYPTRAEA (GALERUS) cf. EXCENTRICA (Gabb)

? Galerus excentricus Gabb, Geol. Surv. Calif., Palaeontology, vol. 1, p. 136, pl. 20, fig. 95; pl. 29, fig. 232*a*, 1857.

Calyptrae excentrica Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

CALYPTRAEA RADIANS (Lamarck)

Crepidula (*Trochita*) *radians* Lamarck, Histoire naturelle des Animaux sans vertébrés, vol. 7, p. 626, 1818–1822.

Trochita radians Lamarck, Reeve, Conchologia Iconica, vol. 11, Monograph on the genus *Trochita,* pl. 1, figs. 3*a* and 3*b*, 1859.

Calyptrae radians Lamarck, Tyron, Man. of Conch., vol. 8, p. 121, pl. 35, figs. 84, 88, 1886.

Trochita radians Lamarck, Arnold, U. S. Geol. Surv., Bull. 322, p. 60, pl. 21, fig. 1, 1907.

This is one of the few Recent species found in the Agasoma gravidum zone. It is very common at University of California locality 1131.

Genus CREPIDULA Lamarck

CREPIDULA PRAERUPTA Conrad

Crepidula praerupta Conrad, Geol. U. S. Expl. Exp., p. 727, pl. 19, figs. 9, 9*a*, 1849.

Crypta praerupta Conrad, Amer. Jour. Conch., vol. 1, p. 151, 1865.

? Crepidula praerupta Conrad, Anderson, Proc. Calif. Acad. Sci., ser. 4, vol. 2, no. 2, p. 204, pl. 16, figs. 68, 69, 1905.

Crepidula praerupta Conrad, Dall, U. S. Geol. Surv., Prof. paper no. 59, p. 83, pl. 7, fig. 8, 1909.

Crepidula praerupta Conrad, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, pp. 476, 583, 588, 1913.

Crepidula praerupta Conrad, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

The form referred to *Crepidula praerupta* from the Agasoma gravidum beds was determined purely on external outline; the septum of this species is unknown, and it is very possible that two or more species have been listed by different writers under this name.

Crepidula praerupta is reported in the Miocene of Coos Bay, Oregon. Conrad's type came from near Astoria and was obtained from either the Oligocene or Miocene of that region. Arnold and Hannibal have reported *Crepidula praerupta* from the Oligocene of Vancouver Island and Oregon. They have also reported it from the Lower Miocene of Oregon and Washington.

CREPIDULA ROSTRALIS Conrad

Crepidula? Conrad, Geol. U. S. Expl. Exp., pl. 19, figs. 11*a*, 11*b*, 1849.
Crypta rostralis Conrad, Amer. Jour. Conch., vol. 1, p. 151, 1865.
Crepidula rostralis Conrad, Dall, U. S. Geol. Surv., Prof. paper no. 59, p. 83, 1909.

Family Naticidae

Genus NATICA Scopoli

NATICA (AMPULLINA) GABBI, n. sp.

Plate 19, figures 12, 14 and 15

Type specimen 11252, Coll. Invert. Palae. Univ. Calif, loc. 1311

Shell small to medium in size, globose; spire low; apex acute; sutures marked by a distinct impressed line. Number of whorls five; whorls of spire gently convex; on the body whorl the convexity is the greatest just below the suture, while the sides of the whorl are only gently convex. On some of the specimens, on the body whorl just below the suture there is a fairly well-defined, narrow tabulation; this appears to be due to weathering. Surface smooth except for fine lines of growth. Base of body whorl rather narrow and strongly produced anteriorly. Aperture semilunate; inner lip reflexed anteriorly, the reflexed portion extending up to and nearly covering the umbilicus; here it is somewhat thicker than anteriorly and might be considered as a part of the callus. On a few specimens, posterior to the umbilicus the base of the body whorl is covered by a thin wash of callus. Umbilicus subperforate.

Dimensions.—Type specimen: height, 11 mm.; height of body whorl, 9 mm.; maximum width of body whorl, 11 mm.

Occurrence.—University of California localities 14, 1131, 1311, 1309, etc Type specimen from locality 1131; paratype from locality 1309.

NATICA (EUSPIRA) RAMONENSIS, n. sp.

Plate 19, figure 16

Type specimen 11257, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell medium in size, subovate; spire low; body whorl large, a little over three-fourths the height of the shell, subtabulate just below the suture. Number of whorls five, with sides gently convex. Sutures appressed. Surface of shell smooth except for lines of growth. Base of body whorl narrow; aperture semilunate, rather narrow, just strongly produced anteriorly; inner lip covered by a heavy callus which is broad and flat posteriorly, narrowing rapidly in the region of the umbilicus which is almost covered by a callus. The callus is quite similar to that of *N. pallida* Broderip,[137] a Recent West Coast species.

Dimensions.—Height, about 16 mm.; height of spire, 3 mm.; greatest width of body whorl, 12 mm.

Occurrence.—University of California locality 1131.

NATICA (NEVERITA) RECLUZIANA Petit

Natica recluziana Petit, Deshayes, Mag. de Zool., Mollusca, pp. 3, 7, 1841.

Natica recluziana Petit, Tyron, Man. Conch., vol. 8, p. 34, pl. 12, fig. 1, 1886.

Neverita recluziana Petit, Adams, H. and A., Gen. Rec. Moll., vol. 1, p. 208, 1853.

Neverita recluziana Petit, Carpenter, Brit. Assn. Rep., p. 661, 1863.

Neverita recluziana Deshayes, Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 77, 1869.

Neverita recluziana Petit, Cooper, 7th Ann. Rep. Calif. St. Min. Bur., p. 254, 1888.

Neverita recluziana Petit, *in* Keep, *in* West Coast Shells, p. 46, fig. 26, 1892.

Neverita recluziana Petit, Williamson, Proc. U. S. Nat. Mus., vol. 15, p. 211, 1892.

Neverita recluziana Deshayes, Dall, Trans. Wagner Inst. Sci., vol. 3, pt. 2, p. 369, 1892.

Polynices (*Neverita*) *recluziana* Petit, Arnold, Mem. Calif. Acad. Sci., vol. 3, p. 314, 1903.

Neverita recluziana Petit, Arnold, U. S. Geol. Surv., Bull. 309, pp. 25, 28, pl. 38, fig. 6, 1907.

Neverita recluziana Petit, Arnold and Anderson, U. S. Geol. Surv., Bull. 322, p. 59, pl. 21, figs. 14*a*, 14*b*, 15, 16, 1907.

Neverita recluziana Petit, Arnold, U. S. Geol. Surv., Bull. 396, p. 31, pl. 20, fig. 2, 1909.

Neverita recluziana Petit, Weaver, Univ. Calif. Publ., Bull. Dept. Geol., vol. 5, no. 16, p. 265, 1909.

Neverita recluziana Petit, Arnold, U. S. Geol. Surv., Bull. 398, p. 130, pl. 42, fig. 2, 1910.

Polynices recluziana Petit, Keep, *in* West Coast Shells, p. 212, fig. 205, 1911 ed.

Neverita recluziana Petit, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, p. 182, 1912.

Natica (*Neverita*) *recluziana* Petit, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 22, p. 423, 1915.

Natica (*Neverita*) *recluziana* Petit, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Occurrence.—A very common species in the lower beds of the San Ramon formation.

Natica recluziana Petit is a variable species; two of the Recent varieties that have been described are *N. recluziana alta* Arnold and

[137] For description and figures of *N. pallida*, see Tryon, Man. Conch., vol. 8, p. 37, pl. 14, fig. 2626; pl. 13, fig. 15; pl. 9, figs. 76, 78, 1886.

N. recluziana imperforata Stearns. Besides these two, there are a number of others that might be equally well described.

The specimens of *N. recluziana* from the Agasoma gravidum beds apparently show as much variation as those of the Recent. Nearly all the Recent varieties are found in these beds, as well as several forms which have not been found in the Recent. For example, there is one variety, the shell of which is apparently lower than any of the Recent forms, and another, the body of which is more rounded than that of any of the Recent varieties. Neither of these has been described, as they apparently grade into typical forms. One of the species described in this paper, which is considered as a variety of *N. recluziana*, is *N. recluziana andersoni*.

NATICA (NEVERITA) RECLUZIANA ANDERSONI, n. var.

Plate 20, figures 3, 10, 11 and 12

Type specimen 11212, Coll. Invert. Palae. Univ. Calif., loc. 1131

? *Natica inezana* Conrad, Pacific Railroad Rep., vol. 7, p. 195, pl. 10, figs. 5, 6, 1857.

Neverita callosa Anderson and Martin; not *Natica callosa* Gabb, Proc. Calif. Acad. Sci., ser. 4, vol. 4, p. 43, 1914.

Shell fairly large for this genus, somewhat variable in outline; spire low; apex acute. Number of whorls to spire five or six; sutures rather strongly appressed. Body whorl over three-fourths the height of the shell, with sides somewhat flattened and usually with an indistinct shoulder a little below the suture, giving to that portion of the shell a broadly subtabulate appearance; base rather broad; aperture ovate; inner lip and posterior part of base covered by a broad callus, usually with a well-marked groove anterior to the middle and extending from the outer edge of the callus toward and almost at right angles to the inner lip. The callus is very similar to that seen on *N. recluziana* Petit, of which this form is described as a subspecies, and is just as variable; on some specimens the umbilicus is open anterior to the callus, while on others the callus covers the entire umbilical area.

Dimensions.—Type specimen: height, about 32 mm.; height of body whorl, 27 mm.; maximum width of body whorl, 33.5 mm. Paratype: height, about 39 mm.; height of body whorl, 34 mm.; maximum width of body whorl, 41 mm.

Occurrence.—Type found in the Agasoma gravidum beds, University of California locality 1131; paratype from east of Bakersfield in the Temblor (Middle Miocene), University of California locality 2715, in a collection made by Clarence Moody; here it is very abundant. This form is also found in the collections of the Unversity of California as follows: from the Santa Margarita (Upper Miocene), Clark, University of California locality 2283, in the Lower Fernando (Pliocene), English, University of California locality 1735, and in the type section of the Vaqueros (Lower Miocene), Vaqueros Valley, Monterey County, California.

Named in honor of F. M. Anderson, formerly Curator of Palaeontology in the California Academy of Sciences at San Francisco.

N. recluziana andersoni differs from the typical *N. recluziana* in that the body whorl is broader posteriorly, the sides of the whorl being more nearly perpendicular to the base, and flatter; also, in the presence of the subtabulate, depressed area just below the suture. On most of the specimens examined, the callus does not seem to be so heavy posteriorly as on the typical *N. recluziana.* In other respects the two species are very similar.

N. recluziana andersoni is apparently a direct offshoot of *N. recluziana* or vice versa, both appearing first in the Oligocene; during Lower and Middle Miocene times it apparently became a distinct form, for in these horizons the typical *N. recluziana* is very scarce; possibly during this time the two lived in different environments. The typical *N. recluziana* has continued to live up to the present day, the other form having become extinct.

N. recluziana andersoni may be the same as Conrad's species, *N. ocoyana,* which comes from Ocoya Creek, California, where it is associated with a typical Monterey fauna. Conrad's description is very meagre and his figures poor, so much so that it is impossible to make a specific determination from them. The fact that there are at least two species of *Natica* in the fauna from Ocoya Creek beds would make it unsafe to determine this species as *N. ocoyana* on the basis that the type came from the same horizon. W. H. Dall lists *N. ocoyana* as a questionable synonym of *N. inezana,* the type of which came from the San Inez Mountains, California. Certainly *N. recluziana andersoni*[138] is not the same as what Dall has determined as *N. inezana* from Coos Bay, Oregon. He says of this form: ''The shell from the Miocene of Coos Bay, which I have referred to *N. inezana,* however, has the open part of the umbilicus behind the umbilical and to the left of it, with no dividing sulcus, and by these characters can be recognized at a glance.'' The umbilical opening, when present on *N. recluziana andersoni,* as on *N. recluziana,* is always anterior to the callus.

Genus SINUM Bolten

SINUM SCOPULOSUM Conrad

Plate 22, figure 8

Sigaretus scopulosus Conrad, U. S. Expl. Exp., Geol., Appendix, p. 727, pl. 19, figs. 6, 6*a* only, 1849.

Catinus scopulosus Conrad, Amer. Jour. Conch., vol. 1, p. 151, 1865.

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[138] For discussion by Dall, see U. S. Geol. Surv., Prof. paper no. 59, p. 88, 1909.

Sinum scopulosum Conrad, Meek, Smithson. Check list Miocene Fossils N. Am., p. 32, 1864.

Sinum scopulosum Conrad, Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 114, 1868.

Sinum planicostum Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, pp. 49, 78, pl. 14, fig. 6, 1868.

Sigaretus scopulosus Conrad, Anderson, Proc. Calif. Acad. Sci., ser. 3, vol. 2, p. 188, pl. 16, figs. 72, 73, 1905.

Sinum scopulosum Conrad, Dall, U. S. Geol. Surv., Prof. paper no. 59, pp. 91–92, pl. 4, fig. 10; pl. 5, fig. 8, 1909.

Sigaretus scopulosus Conrad, Anderson, Proc. Calif. Acad. Sci., ser. 4, vol. 3, p. 100, 1911.

Sigaretus scopulosus Conrad, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, p. 176, 1912.

Sinum scopulosum Conrad, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, pp. 584, 588, 1913.

Sigaretus scopulosus Conrad, Anderson and Martin, Proc. Calif. Acad. Sci., ser. 4, vol. 4, p. 43, 1914.

Sinum scopulosum Conrad, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Occurrence.—University of California locality 14, 1131, etc.

Family Turritellidae

Genus TURRITELLA Lamarck

TURRITELLA DIVERSILINEATA Merriam

Plate 22, figure 5

Turritella diversilineata Merriam, Nautilus, vol. 11, p. 65, 1897.

Turritella blakeleyensis Weaver, Wash. State Geol. Surv., Bull. 15, p. 72, pl. 6, figs. 64, 67; pl. 11, fig. 85, 1912.

Turritella newcombei Arnold and Hannibal, in part, Proc. Amer. Philos. Soc., vol. 52, pp. 581, 583, 1913.

The following is J. C. Merriam's original description of *T. diversilineata:*

Shell medium in size. The imperfect type specimen shows seven flattened whorls, which are strongly beveled below. Flattened sides ornamented by five revolving ribs, of which the lowest, standing on the angle of the whorl, is much stronger than the others. On some of the whorls there are indications of revolving sculpture on the beveled surface between the lowest rib and the suture. Locality, Carmanah Point, Vancouver Island.

This species is very common in Oregon and Washington; it is found on Vancouver Island at Carmanah Point, from which locality Merriam obtained the type specimen. It is common in the Blakely beds, as described by C. E. Weaver, in the region of Puget Sound.

T. porterensis Weaver[139] is very close to this species; the typical *T. porterensis* differs from the typical *T. diversilineata* in that the

[139] For original description of *T. porterensis,* see Weaver, C. E., Wash. State Geol. Surv., Bull. 15, p. 73, pl. 11, figs. 83, 84, 1912.

sides of the whorls are more convex and are not so perpendicular, each whorl sloping in more obliquely toward the axis. The sculpturing of the two species appears to be identical, except that on the latter the spiral ribbing tends to be heavier; undoubtedly they are closely related species.

TURRITELLA PORTERENSIS Weaver

Turritella porterensis Weaver, Wash. State Geol. Surv., vol. 52, p. 73, pl. 11, figs. 83, 84, 1912.

Turritelli newcombei Arnold and Hannibal, in part, Proc. Amer. Philos. Soc., vol. 52, p. 581, 1913.

Turritella porterensis Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, pp. 5, 30, 1916; Calif. Acad. Sci., ser. 4, vol. 6, no. 2, pp. 28 and 40, 1916.

Occurrence.—Found at University of California locality 3051.

TURRITELLA PORTERENSIS SOBRANTENSIS, n. var.

Plate 22, figure 1

Type specimen 11269, Coll. Invert. Palae. Univ. Calif., loc. 3051

Turritella porterensis Clark, not Weaver. Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Shell medium in size; whorls about ten; sides of whorls flat, sloping slightly inwards; sutures impressed. A narrow depressed area or groove at the base of each whorl, in which may usually be seen a spiral riblet; sides of whorls sculptured by six or seven narrow but prominent ribs, separated by interspaces about equal to the ribs.

Occurrence.—University of California localities 14, 215 and 1131.

The details of the sculpturing of this form are identical with that of *T. porterensis* Weaver. Weaver does not describe the riblet in the depressed area at the base of each whorl but it occurs on many of the specimens of that species from the type locality. The main difference between the species and the variety is that on the species there is a slight convexity near the base of each whorl; this is described by Weaver as being a broad angulation; on the variety the sides of the whorls are flat down to the depressed area. On some specimens of *T. porterensis* the convexity of the whorls, as described above, is almost obsolete.

Family Cerithiidae

Genus POTOMIDES Brongt

POTOMIDES (CERITHIDEA) BRANNERI, n. sp.

Plate 22, figures 6, 13 and 16

Type specimen 11229, Coll. Invert. Palae. Univ. Calif., loc. 2754

Shell medium in size, fairly heavy. Spire high; number of whorls nine or ten; sutures slightly depressed, marked by a well-defined, impressed line; whorls only slightly convex. Surface of shell sculptured by about thirteen or fourteen irregular, rounded, longitudinal ribs, which vary considerably in prominence; on some specimens they become obsolete on the body whorl and sometimes on the penultimate whorl. Surface also covered by numerous fine, spiral ribs, the interspaces between which vary considerably in width, being usually narrower than the tops of the ribs, which also vary in width. On whorls of spire about twelve, and on body whorl about twenty to twenty-three of the spiral ribs. Base of body whorl regularly rounded, the spiral ribs extending down onto it. Aperture ovate in outline. Outer lip thin; inner lip incrusted. Canal short, straight but well-defined.

Dimensions.—Type specimen: height, about 20 mm.; height of body whorl, about 7 mm.; maximum width of body whorl, about 7 mm.

Named in honor of Dr. J. C. Branner, ex-President of Leland Stanford Junior University.

Occurrence.—University of California localities 52, 2754, etc.

Family VERMICULARIIDAE

Genus VERMICULARIA

VERMICULARIA?, sp.

At several localities in the vicinity of Kirker Creek, to the north of Mount Diablo, thin lentils of blue-gray, medium fine, tuffaceous sandstone are found near the top of the tuff member of the Kirker formation. In this sandstone are numerous casts of small tests of what appear to be *Vermicularia;* the greatest diameter of any of these is not much over a millimeter, the greatest length being about one and a half centimeters.

Family DOLIIDAE

Genus FICUS Bolten

FICUS PYRIFORMIS Gabb

Ficus pyriformis Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 48, pl. 14, fig. 4, 1868.

Ficus pyriformis Gabb, Arnold, U. S. Geol. Surv., Bull. 396, p. 18, 1911.

Ficus pyriformis Gabb, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 166, 175, 1912.

Ficus pyriformis Gabb, English, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 10, p. 246, pl. 25, fig. 1, 1914.

The type of this species is reported by Gabb as coming from the Miocene near Martinez; it is possible that it came from either the Monterey or the Agasoma gravidum beds. The species is reported in other parts of the state as being found in the Temblor horizon. It is found in the Agasoma gravidum beds at Walnut Creek, University of California locality 1131, also at University of California locality 14.

Family Nyctilochidae

Genus BURSA Bolten

BURSA MATHEWSONII (Gabb)

Plate 20, figures 1 and 2

Ranella mathewsonii Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 8, pl. 2, fig. 13, 1868.

Ranella mathewsonii Gabb, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 176, 179, 1912.

Bursa mathewsonii (Gabb), Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Shell heavy, robust, medium in size to fairly large; spire high; tops of all specimens examined broken but probably with not more than seven, possibly eight, whorls; sutures depressed. Surface sculptured by about fourteen or fifteen longitudinal, rather coarse, rounded ribs, which are nodose, due to the fact that they are crossed by spiral ribbing which, on the smaller specimens, is not quite so heavy as the longitudinal ribbing, but on the larger specimens this spiral ribbing may become the more prominent. Interspaces between the spiral ribbing slightly wider than the tops of the ribs, and in each interspace there is a narrow, spiral riblet. On the whorls of the spire there are four of these major spiral ribs; on the body whorl there are nine or ten. On the surface of the shell there are two fairly strong, continuous, rope-like varices, one of which is usually close to the outer lip, the other on the opposite side of the whorl. Mouth ovate in outline· inner lip incrusted; canal short and rather abruptly recurved.

Dimensions.—Pleseotype: height, about 15 mm.; height of body whorl, about 10 mm.; maximum width of body whorl, about 10 mm.

Occurrence.—University of California localities 1131 and 2754.

Family Columbellidae

Genus COLUMBELLA Lamarck

COLUMBELLA (MITRELLA) TENUILINEATA, n. sp.

Plate 22, figures 2 and 3

Type specimen 11221, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, fusiform; spire fairly high; apex acute. Number of whorls six or seven; body whorl higher than wide, about half the height of the shell; sutures marked by a depressed line. Sides of whorls gently convex; base of body whorl rounded, the whorl narrowing rapidly toward the anterior end of the canal. Surface of shell sculptured by medium fine, spiral ribs, with interspaces which appear as narrow, incised lines; on the body whorl are about eighteen, and on the whorls of the spire six or seven of the spiral ribs, which tend to be nodose due to the fact that they are crossed by fine longitudinal ribbing. As counted on the body whorl there are at least thirty of the fine longitudinal ribs, the interspaces between which are approximately equal to the width of the ribs. The longitudinal ribbing tends to become obsolete on the body whorl and, on some specimens, even on the lower whorls of the spire. Aperture narrow, elongate-subovate; outer lip thin, denticulate internally; inner lip not incrusted. Canal short, narrow and straight.

Dimensions.—Height, 4 mm.; height of body whorl, 2.25 mm.; greatest width of body whorl, 2 mm.

Occurrence.—University of California locality 1131.

Genus AMPHISSA H. and A. Adams

AMPHISSA PULCHRILINEATA, n. sp.

Plate 21, figures 5 and 6

Type specimen 11276, Coll. Invert. Palae. Univ. Calif., loc. 3055

Shell medium in size; apex acute; whorls rather strongly and regularly convex; sutures depressed; number of whorls six or seven; body whorl only a little over half the height of the shell. Surface sculptured by rather fine longitudinal and spiral ribbing, the former being considerably the heavier and separated by interspaces somewhat wider than the ribs, about twenty in number; on the spire seven, and on the body whorl about fourteen of the spiral ribs, separated by interspaces which average about twice the width of the ribs. Canal short, straight. Convexity of body whorl between base and sides rather sharp; on some specimens there is almost an angulation along this line. Aperture not exposed.

Dimensions.—Height, about 15 mm.; height of body whorl, 8 mm.; greatest diameter of body whorl, 7 mm.

Occurrence.—This species has been found only at the type locality, which is in the Concord formation above the Kirker tuff beds.

Family Nassidae

Genus MOLOPOPHORUS Gabb

MOLOPOPHORUS BIPLICATUS (Gabb)

Plate 20, figures 4, 6 and 8

Cuma biplicata Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 9, pl. 2, fig. 14, 1868; also p. 75, 1868.

Cuma biplicata Gabb, Arnold, U. S. Geol. Surv., Prof. paper no. 47, p. 19, 1906.

Cuma biplicata Gabb, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 165, 175, 1912.

Molopophorus biplicatus Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Molopophorus gabbi Dall, Clark, *op. cit.*, pp. 15, 18.

This species is very similar to *Molopophorus gabbi* Dall, described from the Lower Oligocene of Oregon. The two species are undoubtedly very closely related; the details of their sculpturing are practically identical; there is a little difference in outline, *M. biplicatus* being slightly more excavated below the collar on the body whorl. For the reason that there can be very little doubt but that the species are very closely related genetically, the writer proposes to consider *M. gabbi* as a subspecies of *M. biplicatus.*

Family Buccinidae

Genus SEARLESIA Harmer

SEARLESIA DALLI, n. sp.

Plate 20, figures 5, 9 and 15

Type specimen 11215, Coll. Invert. Palae. Univ. Calif., loc. 2754

Shell medium in size, rather heavy; spire fairly high; number of whorls five or six; apex acute; sutures impressed, the surface of each whorl just below the suture being slightly concave, giving it a collar-like effect. Sides of whorls convex; body whorl rather ventricose, about two-thirds the height of the shell. Whorls covered by numerous, spiral ribs and riblets; interspaces between ribs somewhat variable, averaging less in width than the tops of the ribs; there is a well-defined riblet in most of the interspaces. On lower whorls of spire there are about nine or ten, and on body whorl from twenty to twenty-five spiral ribs. Surface also sculptured by about sixteen longitudinal, rounded ribs; on whorls of spire these begin a little below the upper suture and extend to the suture in front; longitudinal ribbing on body whorl obsolete except on the immature specimens. Aperture semilunate; outer lip thin; inner lip incrusted. Columella subperforate; canal short, slightly recurved.

Occurrence.—University of California localities 14, 217, 1131 and 2754.

Named in honor of Dr. W. H. Dall of the Smithsonian Institution.

This species appears to be of the same general type as *Serlesia dira* (Reeve)[140] = *Chrysodomus dirus* (Reeve). It is rather common in the San Ramon formation but so far no perfect specimens have been obtained.

Genus CHRYSODOMUS Swains

CHRYSODOMUS? PULCHERRIMUS, n. sp.

Plate 22, figure 4

Type specimen 11222, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell rather small; spire acute, with five or six whorls; sutures depressed. Sides of whorls regularly convex; body whorl strongly and regularly ventricose, nearly two-thirds the height of the shell. Surface sculptured by numerous, rather finely nodose, spiral ribs, the interspaces between which on the body whorl may be a little wider than the ribs, while on whorls of spire they are narrower; a nodose spiral riblet in each interspace on upper part of body whorl; these are not in evidence on whorls of spire. On body whorl are about twelve to fourteen, and on whorls of spire four or five of major spiral ribs. The shell has the appearance of being sculptured by numerous fine longitudinal ribs; this, however, is due to the fact that the nodes on the different spiral ribs are in line. Aperture elongate-ovate; outer lip sharp; inner lip not incrusted. Canal medium in length, imperforate, slightly recurved.

Dimensions.—Height, 8+ mm.; height of body whorl, 6+ mm.; maximum width of body whorl, 5 mm.

Occurrence.—University of California localities 1131 and 2754.

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[140] For original description of *Searlesia dira,* see Reeve, L. A., *Conchologia* Iconica, vol. 3, Monograph of genus *Buccinum,* opposite plate 12, figure 92, 1846.

Family Muricidae Tryon

Genus MUREX Linnaeus

MUREX (OCINEBRA) SOBRANTENSIS, n. sp.

Plate 23, figure 3

Type specimen 11234, Coll. Invert. Palae. Univ. Calif., loc. 1164

Shell heavy, medium in size, fusiform; number of whorls five or six; spire acute. Body whorl about two-thirds the height of shell; sutures obscurely appressed. Whorls strongly and regularly convex. Surface sculptured by about ten longitudinal, rounded ribs or frills, which extend entirely across the whorls of spire but not onto the anterior end of body whorl. Surface also covered by medium coarse, spiral ribs, the alternate ribs being the stronger except on anterior end of body whorl where ribs are about equal in prominence; interspaces between ribs very narrow. On the body whorl are about twenty-five, and on the spire about ten of these spiral ribs. Canal fairly long for this genus; anterior end broad. Aperture not exposed.

Dimensions.—Type specimen: height of shell, about 26 mm.; height of body whorl, 20 mm.; greatest width of body whorl, 11 mm.

Occurrence.—University of California localities 127 and 1164. Type, a wax impression.

This species somewhat resembles *Murex dalli* B. L. Clark,[141] a species found in the San Pablo Group. Both have about the same number of transverse ridges and the spiral sculpturing is quite similar. The latter species differs from the former in that the spire is higher, the body whorl is not so ventricose, the anterior end of the canal is more attenuate, being cut off more obliquely in the region of the imperforate umbilicus. Probably the most striking difference between the two species is that the sutures on *M. sobrantensis* are appressed, while on *M. dalli* they are depressed.

M. sobrantensis also resembles *M. topangensis* Arnold,[142] a species common in the Monterey horizon in the southern part of the state. The whorls on the latter species are angulated and subtabulate above the sutures; on *M. sobrantensis* the whorls are regularly convex. Also, on *M. topangensis* there are fewer longitudinal ridges or frills, the frills being more sharp and crested.

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[141] For original description see Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 2, p. 501, pl. 67, figs. 4, 9, 1915.

[142] For original description of *Murex topangensis*, see Proc. Nat. Mus., vol. 32, pl. 43, fig. 4, 1907.

Family Thaisidae

Genus THAIS Bolten

THAIS PACKI, n. sp.

Plate 19, figures 2 and 13

Type specimen 11246, Coll. Invert. Palae., Univ. Calif., loc. 1309

Shell heavy, medium in size; whorls five; spire acute; sutures slightly depressed; body whorl strongly and regularly convex, nearly three-fourths the height of shell; whorls of spire only slightly convex. Surface of shell sculptured by heavy, flat-topped ribs, separated by much narrower interspaces. Spiral ribs on body whorl about sixteen and on whorls of spire usually five. Mouth elongate-ovate; outer lip thickened internally. About ten elongate teeth on inner margin of outer lip; these reach from the thickened inner portion to the outer edge; inner lip slightly depressed, incrusted. Umbilicus subperforate; canal short, straight, deep and narrow.

Dimensions.—Type specimen: height of shell, 35 mm.; height of body whorl, 25 mm.; greatest width of body whorl, 24 mm.

Named in honor of R. M. Pack, palaeontologist on the United States Geological Survey.

Occurrence.—University of California localities 14, 52, 1131, 1309, 1343, etc.

This species superficially resembles *T. lima* Martyn,[143] a common and variable species on the West Coast, from which it differs in the character of the spiral ribs and in the denticulations on the inner margin of the outer lip; also the shell is heavier. It differs in the same respects from *T. precursor* Dall,[144] a form from the Pliocene of Coos Bay, Oregon.

Family Fusidae

Genus FUSINUS

FUSINUS (PRISCOFUSUS) HECOXI Arnold

Plate 22, figure 7

Fusus hecoxi Arnold, Proc. Nat. Mus., vol. 34, p. 371, pl. 33, fig. 8, 1908.
Fusinus (*Priscofusus*) *hecoxi* Arnold, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

The aperture and canal on Arnold's type were missing. The specimen here figured shows the aperture to be elongate-ovate; the inner lip is rather heavily incrusted and the canal narrow, slender, fairly long, and straight except near the anterior end, where it is slightly recurved.

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143 For description and figures of *Thais lima*, see Tryon, Manual of Conchology, vol. 2, p. 175, pl. 53, figs. 156, 158, 159, 161, 1880.

144 For original description of *Thais precursor*, see U. S. Geol. Surv., Prof. paper no. 59, p. 51, pl. 4, fig. 4, 1909.

Fusinus hecoxi is closely related to *Fusinus chehalisensis* (Weaver).[145] The species, listed by Arnold and Hannibal[146] as *Priscofusus hecoxi* from the San Lorenzo horizon of their Astoria series, is *Fusinus chehalisensis* (Weaver). Weaver, in a recent paper, threw out his own species, *F. chehalisensis,* described by him as a *Drillia,* and placed it as a synonym of Arnold's species, *F. hecoxi,* listing it, however, under the genus Drillia rather than Fusinus. The form, described by Weaver as *Drillia chehalisensis* and listed here as *Fusinus chehalisensis,* which form is common in the Lower Oligocene of Oregon and Washington, is very distinct from *F. hecoxi* Arnold. The spire is higher, the canal shorter and the area below the suture of the body whorl more strongly depressed. On *F. chehalisensis* the longitudinal sculpturing consists of broad longitudinal ribs, which, on each rib, begin just below the appressed collar and extend almost, if not quite, to the suture in front. On *F. hecoxi,* well-defined nodes near the middle of each whorl take the place of the longitudinal ribs seen on the other species.

FUSINUS (EXILIA) LINCOLNENSIS (Weaver)

Plate 23, figure 10

Exilia lincolnensis Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, pp. 51–52, pl. 4, figs. 49–50, 1916.

The specimen of *Fusinus lincolnensis,* figured in this paper, was found by John Ruckman near the top of what is known as the white shale in the East field, about fifteen miles north of Coalinga. These beds, in a recent paper by Robert Anderson and Robert W. Pack,[147] were given the name of Kreyenhagen shale and provisionally placed in the Oligocene. Previous to this they had been referred to by Arnold and Anderson[148] as questionably Eocene. The following species were found associated with *Fusinus lincolnensis* in these beds: *Macrocallista* cf. *pittsburgensis* Dall, *Pecten peckhami* Gabb and *Leda lincolnensis* Weaver. *F. lincolnensis* is found in a collection at the University of California from the type section of the San Lorenzo.

145 For original description of *Fusinus chehalisensis,* see Wash. State Geol. Surv., Bull. 15, p. 78, pl. 6, figs. 65, 66, 1912.

146 Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, p. 581, 1913.

147 Anderson, Robert, and Pack, Robert W., Geology and oil resources of the west border of the San Joaquin Valley, north of Coalinga, U. S. Geol. Surv., Bull. 603, pp. 76–78, 1915.

148 Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga District, U. S. Geol. Surv., Bull. 398, pp. 73–74, 1910; also, Arnold, Ralph, Palaeontology of the Coalinga District, U. S. Geol. Surv., Bull. 396, p. 00, 1909.

It is common in the Oligocene of Oregon and Washington, where it is associated with *Cardium lorenzanum* Arnold, *Macrocallista pittsburgensis* Dall, *Leda lincolnensis* Weaver, *Agasoma gravidum columbianum* Anderson and Martin. It is found in the San Ramon formation to the south of Walnut Creek, at University of California locality 1131; here it is associated with a typical Agasoma gravidum fauna.

FUSINUS (EXILIA) PINOLIANUS, n. sp.

Plate 21, figure 2

Type specimen 11274, Coll. Invert. Palae. Univ. Calif., loc. 3055

Shell tall, slender, medium in size; spire high, acute; whorls five or six; body whorl, including canal, a little over half the height of the shell; whorls rather strongly convex, with sutures deeply depressed. Surface sculptured by about eighteen narrow, rounded, longitudinal ribs, with interspaces not much wider than the ribs; surface also covered by numerous fine spiral ribs, with interspaces usually about twice as wide as the ribs; on the penultimate whorl there are seven, and on the body whorl about twenty of these spiral ribs. Aperture not exposed. Canal straight; anterior end broken on all specimens at hand.

Dimensions.—Height, about 13 mm.; height of spire, 5 mm.; width of body whorl, about 4.5 mm.

PERSE, new genus[149]

Shell fusiform, with a medium high spire; sutures appressed; upper part of each whorl depressed into a fairly broad collar, which is most distinct on the body whorl. Canal medium in length, straight to slightly curved, narrow anteriorly; surface sculptured by spiral ribs and usually with well-developed longitudinal ribs or nodes.

There are several species which appear to fall within the genus described above. The type of the genus, *Perse corrugatum*, is described below. *Hemifusus washingtoniana* Weaver,[150] described from the Tejon of Washington and listed by Weaver from the lower Oligocene of that region, also belongs to this genus. There is still another species in the Oligocene of Oregon which has not been described that belongs to this genus.

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[149] Credit is due to Harold Hannibal for first discerning that the genus here described is new. His observations were based on the form described by Weaver as *Hemifusus washingtoniana.* As Hannibal does not intend to describe the genus and as the species described below from the San Lorenzo Group of the Mount Diablo region falls within this genus, it seems best for the writer to describe it.

[150] For original description of *Hemifusus washingtoniana*, see Weaver, C. E., Wash. State Geol. Surv., Bull. 15, pp. 46–47, pl. 2, figs. 11, 12, 1912.

PERSE CORRUGATUM, n. sp.

Plate 23, figure 2

Type specimen 11233, Coll. Invert. Palae. Univ. Calif., loc. 2754

Shell fusiform, medium in size; spire medium in height, acute; sutures appressed, with a fairly broad, appressed collar, as described in the description of the genus. Body whorl strongly convex, a little below the collar, sloping down very rapidly to the canal; whorls of spire gently convex below the collar. Surface sculptured by fairly heavy spiral ribs, with interspaces averaging about the width of the ribs; on each whorl of the spire there are about ten or twelve, and on the body whorl about thirty of the spiral ribs. Surface also covered by ten or eleven fairly heavy, broad, rounded, longitudinal ribs, which, on the whorls of spire, begin just below the depressed collar and extend down to the suture; on the body whorl they extend from just below the appressed collar to a little below the line of highest convexity. Aperture elongate-ovate; canal straight, medium in length, narrow anteriorly; outer lip thin; inner lip smooth.

Perse corrugatum is very close to a species in the Oligocene of Washington, found at both the Lincoln and Porter localities, and which is listed by Weaver as *Hemifusus washingtoniana;* this last species, which belongs to the genus *Perse,* was described by Weaver from the Tejon (Upper Eocene). The form in the Oligocene, listed as this species, is possibly distinct from the Eocene species; the writer does not have enough material of the latter to be certain of this, but certainly Weaver's type, as figured by him, is different from the common Oligocene form in the Lincoln and Porter beds. This last form, which the writer believes to be very probably a new species, is very similar to *Perse corrugatum;* the spire of the former species is somewhat lower, the spiral sculpturing is more irregular and the longitudinal ribs are more nodose, due to the fact that the spiral ribbing which passes over them is somewhat heavier, and the canal is possibly a little longer.

PSEUDOPERISSOLAX, n. genus

Shell medium to fairly large in size; body whorl biangulate, with a well-defined shoulder or tabulation above the posterior angle; the sides of the whorl between the two angulations are vertical or nearly so. Surface usually sculptured by fairly fine spiral striations or ribs. Canal long, straight, rather narrow. Columellar axis straight.

The writer has taken *Perissolax blakei* Conrad[151] for the type of this genus. Conrad's type was not a perfect specimen; he referred the pieces to Busycon?. Gabb[152] later figured a perfect specimen of this species and referred it to the genus Perissolax.

[151] For Conrad's original description of *Busycon? blakei,* see Pacific Railroad Rep., vol. 5, p. 322, pl. 2, fig. 13, 1855.

[152] For Gabb's description of *Perissolax blakei* Conrad, see Geol. Surv. Calif., Palaeontology, vol. 1, p. 92, pl. 21, fig. 110, 1864.

Pseudoperissolax differs from the typical Perissolax, as described by Gabb,[153] in having a higher spire and an entirely different kind of sculpture. Undoubtedly several different genera have been included under the name Perissolax.

The genus *Pseudoperissolax* differs from the genus *Busycon* principally in the canal, which is more slender, the aperture narrower; it lacks plication and infolding found on the inner lip of *Busycon;* also the biangulate character of the body whorl of the genus *Pseudoperissolax* distinguishes it from *Busycon.*

Genus PSEUDOPERISSOLAX, n. genus

PSEUDOPERISSOLAX MERRIAMI, n. sp.

Plate 21, figure 4; plate 22, figures 10 and 15

Type specimen 11161, Coll. Invert. Palae. Univ. Calif., loc. 2033

Shell fusiform; apex acute; number of whorls seven or eight; sutures apparently slightly channeled. Body whorl fairly large, biangulate; only upper angle shows on whorls of spire; each whorl broadly subtabulate posteriorly between angle and suture, the subtabulate area sloping up obliquely to suture; whorls of spire below subtabulate area straight, also straight on body whorl down to anterior angulation, below which surface slopes in very rapidly to canal. Thirteen or fourteen blunt but rather prominent nodes on each angulation of body whorl; surface also covered by numerous fine, closely crowded, spiral ribs, every other rib being slightly heavier than the one between. Canal straight, fairly long.

Dimensions.—Height, about 47 mm.; greatest width of body whorl, about 17 mm.

Occurrence.—On the north side of Mount Diablo in tuff beds just below the San Pablo, associated with *Acila gettysburgensis* Reagan, *Mallelia packardi,* n. sp., and *Cardium lorenzoanum* Arnold.

Pseudoperissolax merriami is closely related to *P. blakei* Gabb,[154] a characteristic species of the Tejon, the sculpturing and general outline being very similar. *P. merriami* differs from *P. blakei* in that the spire is higher, the angulations on the body whorl are farther apart, and there are fewer nodes on the angles. The spiral ribbing on *P. blakei* appears to be the coarser, and the canal is apparently more elongate and slender. It should be remembered, however, that the anterior portion of the canal on the specimen from the Oligocene is broken.

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[153] For Gabb's original description of *Perissolax,* see Synopsis of the Mollusca of the Cretaceous formation, including the geographical and stratigraphical range and synonymy, Proc. Amer. Philos. Soc., vol. 8, p. 122, March, 1861.

[154] For original description of *Perissolax blakei,* see Pacific Railroad Rep., vol. 5, p. 322, pl. 2, fig. 13, 1855. For good redescription of the species, see Gabb, W. M., Geol. Surv. Calif., Palaeontology, vol. 1, p. 92, pl. 21, fig. 110, 1864.

PSEUDOPERISSOLAX?, sp. indt.

Several imperfect specimens of a species, which appears to belong to the genus *Pseudoperissolax,* were found near the upper part of the San Lorenzo beds on the north side of Mount Diablo at University of California localities 2038 and 3081. All the specimens at hand are casts; good material, showing the upper whorls of the spire and aperture, was not obtained. The body whorl is biangulate, with a fairly broad, slightly upward sloping tabulation between the suture and the upper angulation; about twelve rather sharp nodes on each angulation; these, on some specimens, merge into faint longitudinal ribs extending from the suture to the lower angulation; only one of the angulations shows on the whorls of the spire. Surface also sculptured by fairly coarse spiral ribbing; every alternate spiral rib is heavier than the one in between. Interspaces slightly wider than the narrower ribbing on body whorl; three or four spiral ribs between the upper angulation and the suture; seven or eight between the angulations. Canal straight, fairly long.

Genus AGASOMA Gabb

AGASOMA ACUMINATUM Anderson and Martin

Plate 22, figures 11 and 19

Agasoma acuminatum Anderson and Martin, Proc. Calif. Acad. Sci., ser. 4, vol. 4, p. 73, pl. 5, figs. 4*a*, 4*b*, 1914.

Agasoma acuminatum Anderson and Martin, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

This species appears to be one of the most important markers of the Oligocene of the West Coast. It is found in the Sooke beds of Vancouver Island and is also common in Oregon, the type coming from about ten miles northwest of Scappoose, Oregon.

AGASOMA GRAVIDUM Gabb

Plate 19, figures 1, 3 and 5

Clavella gravida Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 4, 1866.

Agasoma gravida Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 46, pl. 1, fig. 6, 1869.

Agasoma gravida Gabb, Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, no. 16, pp. 378, 380, 381, 1904.

Agasoma gravidum Gabb, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 165, 175, 178, 1912.

Clavella gravida Gabb(?), Dall, 17th Ann. Rep. U. S. Geol. Surv., pt. 1, p. 467, 1895.

Clavella gravida Gabb?, Dall, U. S. Geol. Surv., Bull. 590, p. 23, 1914.
Agasoma gravidum Gabb, English, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 10, pp. 244, 251, pl. 25, figs. 7, 8, 1914.
Agasoma gravidum Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, pp. 15, 18–20, 1915.

Agasoma gravidum is very closely related to *A. columbianum* Anderson and Martin.[155] The sculpturing of the two forms is nearly identical; both vary considerably in the prominence of the nodes, the heaviness of the collar and the distance between the first row of nodes and the collar. On the majority of the specimens of *A. columbianum*, which the writer has seen, the collar is heavier, there is a deeper excavation just below the collar, and the first row of nodes is situated farther away from the collar than on *A. gravidum*. On *A. columbianum* there is a tendency for the third row of nodes below the collar to be nearly obsolete; on the majority of specimens of *A. gravidum*, this row is well developed; the species varies, however, in this respect for on some specimens the third row is nearly obsolete; this appears to be so on the type as figured by Gabb, who mentions the fact of its variability. The two forms are so similar and their variability so great that the writer prefers to consider *A. columbianum* as a subspecies of *A. gravidum*.

AGASOMA GRAVIDUM MULTINODOSUM, n. var.

Plate 23, figure 5

Type specimen 11266, Coll. Invert. Palae. Univ. Calif., loc. 2754

This form was found at a number of localities associated with the typical *Agasoma gravidum*, from which it differs in the following respects: The body whorl is somewhat broader in proportion to the height of the shell; the nodes are more numerous; the three rows of nodes on the body whorl are connected by faint longitudinal ribs; the anterior row of these nodes is almost obsolete; the spiral ribbing anterior to this row is heavier than on the typical *A. gravidum*.

Genus CLAVELLA Swains

CLAVELLA CALIFORNICA, n. sp.

Plate 23, figure 8

Type specimen 11238, Coll. Invert. Palae. Univ. Calif., loc. 76

Shell medium in size; spire high, acute; number of whorls seven or eight. Sutures slightly depresed, with a well-defined, narrow tabulation which is about

[155] Proc. Calif. Acad. Sci., ser. 4, vol. 4, p. 73, pl. 5, figs. 6*a*, 6*b*, 1914.

at right angles to the sides of the whorls; this angulation stands out rather prominently, giving the upper part of each whorl a collar-like appearance. Sides of whorls slightly concave a little below the angulation on the body whorl; below this concavity the surface swells out rather strongly; anterior to this it slopes down obliquely to the canal. Surface covered by numerous spiral ribs, with interspaces about as wide as ribs. On all the specimens at hand, this ribbing is faint to obsolete on whorls of spire and on larger part of body whorl, but on anterior end of body whorl it is rather strong. The faintness of the ribbing is due, at least in part, to poor preservation and it is not unlikely that other specimens may be found, on which it is fairly heavy over all or most of the shell. Outer lip thin; inner lip not exposed. Canal straight, medium in length.

Dimensions.—Length, about 18 mm.; canal broken; height of spire, 7 mm.; greatest width of body whorl, about 8 mm.

Occurrence.—University of California locality 76.

This form is of somewhat the same general type as *Clavella sinuata* Gabb,[156] from which it differs quite decidedly in the shape of the body whorl and in minor details of sculpturing. Gabb, in his original description of *Clavella sinuata,* determined it to belong to the genus *Clavella* Swainson; in the second part of the same volume he described a new genus, *Agasoma,* the type of which is *A. gravidum.* He included his species *Clavella sinuata* in that genus. The writer believes that Gabb's original determination of the generic character of this species was more nearly correct than the last; it corresponds more closely to Swainson's genus, *Clavella,*[158] than to the type represented by *Agasoma gravidum.*

Family Volutidae

Genus MIOPLEIONA Dall

MIOPLEIONA sp.

Plate 23, figure 13

Shell large, fusiform; spire broken on type and not known from other specimen. Sutures appressed; body whorl large, about twice as long as wide. Surface of whorls gently convex, covered by numerous medium fine, longitudinal, irregular undulations, which should possibly be considered as irregular lines of growth rather than axial ribbing. Surface otherwise smooth. Aperture elongate, elliptical; outer lip thin; pillar straight; one fairly prominent pillar-plate observable.

Occurrence.—University of California locality 1156. Only one imperfect specimen of the form described above was found. It occurs in the same horizon with *M. indurata,* from which it is apparently, though not certainly, distinct.

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156 For description of *Clavella sinuata* Gabb, see Geol. Surv. Calif., Palaeontology, vol. 2, p. 5, pl. 1, fig. 7, 1866.

158 The type of Swainson's *Clavella* is *C. serotina* Hinds. See Tryon, Structural and systematic conchology, vol. 2, p. 129, pl. 47, fig. 83, 1883.

MIOPLEIONA INDURATA (Conrad)

Rostellaria indurata Conrad, U. S. Expl. Exp., p. 727, 1849.

Miopleiona indurata (Conrad), Dall, U. S. Geol. Surv., Prof. paper no. 59, p. 35, pl. 18, figs. 5, 6, 1909.

Miopleiona indurata (Conrad), Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, pp. 6, 30, 1916; Calif. Acad. Sci., ser. 4, vol. 6, no. 2, pp. 31, 39, 1916; also no. 3, p. 51, 1916.

Occurrence.—University of California locality 3051; associated with *Acila gettysburgensis, Tellina lorenzoensis, Agasoma gravidum* var., *Fusinus hecoxi, Turritella porterensis, Schizaster californica,* etc.

Family OLIVIDAE

Genus OLIVELLA Swainson

OLIVELLA QUADRIPLICATA, n. sp.

Plate 19, figures 10 and 17

Type specimen 11251, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, solid, subovate; spire less than one-third of height; whorls five, smooth, gently convex. Sutures narrowly channeled. Aperture long and narrow; outer lip thin; pillar short, slightly twisted, with a strong pillar-plate, near the lower end of which is an oblique, fairly deep groove; above this groove there are four or five medium fine plications, with one heavier plication below the groove.

Dimensions.—Height, about 10 mm.; height of body whorl, 7.5 mm.; greatest width of body whorl, 5 mm.

Occurrence.—University of California localities 1131, 1173, 1343, 2754, etc.

Genus ANCILLA Lamarck

ANCILLA FISHII Gabb

Plate 19, figures 4, 6–9 and 11

Ancillaria fishii Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 9, pl. 2, fig. 15, 1866.

Bullia buccinoides Merriam, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 1, p. 179, 1899.

Ancillaria fishii Gabb, Smith, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 175, 179, 1912.

Ancillaria fishii Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Ancilla fishii is rather variable in outline, due in part to the heavy callus growth which many times almost completely covers the shell.

Genus BULLIA Gray

BULLIA BUCCINOIDES Merriam

Bullia buccinoides Merriam. Proc. Calif. Acad. Sci., ser. 3, vol. 1, no. 6, p. 179, pl. 23, fig. 5, 1898.

Bullia buccinoides Merriam, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, p. 576, 1913.

This is one of the common species from the Sooke beds (Oligocene) of Vancouver Island, where it is found associated with *Agasoma acuminatum* Anderson and Martin, and *Mytilus mathewsonii* Gabb. It is also found in the beds along the Pittsburg bluffs of Nehalem River near the town of Pittsburg, Oregon, where it is associated with *Spisula ramonensis, Solen curtus, Solen gravidus, Thracia condoni, Agasoma gravidum columbianum, Molopophorus gabbi,* etc.

Bullia buccinoides is rather common in the Agasoma gravidum beds. In almost every locality, it is found associated with *Ancilla fishii* (Gabb), with which species it was formerly confused; it differs from the latter in having a more ventricose body whorl, it is usually larger and lacks the callus growth which generally covers the spire and sutures of *A. fishii.*

Family Cancellariidae

Genus CANCELLARIA Lamarck

CANCELLARIA RAMONENSIS, n. sp.

Plate 23, figure 7

Type specimen 11237, Coll. Invert. Palae. Univ. Calif., loc. 1131

Cancellaria condoni Anderson, in part, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 2, no. 2, pl. 15, fig. 50, not fig. 49, which is the type of *C. condoni.*

Cancellaria dalliana Anderson, Anderson and Martin, in part, Proc. Calif. Acad. Sci., ser. 4, vol. 4, pl. 8, fig. 1*a*, not figs. 1*b*, 1*c*, and 1*d*, which are the typical forms of *C. dalliana* Anderson.

Shell medium in size, fairly heavy; spire high, acute, with six or seven whorls; body whorl rather broad, about half the height of the shell; sutures slightly impressed. Whorls angulated below the suture, with a fairly broad, rather strongly tabulated area between the angulation and the suture; as a rule the surface of this area slopes slightly up to the suture. Sides of whorls below angulation nearly straight except the body whorl near the anterior end, where it is gently convex. Surface sculptured by ten or eleven fairly prominent, rounded longitudinal ribs, which are rather obscure on the tabulate area but extend well to the anterior end of body whorl and usually are more prominent at the angulation of the whorls, where, on some specimens, they are produced as short, blunt spines. Surface also covered by fairly coarse, spiral ribbing. On whorls of spire below angulation there are about five, on tabulate area four or five, and on body whorl below angulation from eleven to thirteen of these spiral ribs. The interspaces between the spiral ribs, just described, average about twice the width of tops of ribs. In most of interspaces a well-defined spiral riblet may be discerned. Aperture subovate to subquadrate; outer lip thin; inner lip heavily incrusted. Columellar plications well defined. Canal short, slightly recurved. Umbilicus subperforate.

Dimensions.—Type specimen: height, about 26 mm.; height of body whorl, about 15 mm.; maximum width of body whorl, about 17 mm.

Occurrence.—University of California localities 14, 52, 1131, 1309, etc.

Named in honor of F. M. Anderson.

This species appears to be close if not identical to a species found in the Temblor beds (Lower Miocene) in the vicinity of Bakersfield, California, which is associated with *Cancellaria condoni* Anderson and *Cancellaria dalliana* Anderson. It is a fairly common species in the Agasoma gravidum beds.

CANCELLARIA SOBRANTENSIS, n. sp.

Plate 23, figure 6

Type specimen 11238, Coll. Invert. Palae. Univ. Calif., loc. 2754

Shell medium in height; spire fairly high, with five or six whorls; sutures depressed; whorls gently convex except in the vicinity of the suture where they are strongly tabulated; narrow tabulated area practically at right angles to sides of whorl. Surface sculptured by medium coarse, spiral ribbing, the interspaces between which average about the width of the ribs. On the whorls of the spire, below tabulate area, there are five or six, and on the body whorl twelve or thirteen of the spiral ribs. Surface of whorls also covered by about sixteen narrow, rounded, longitudinal ribs, which become obsolete on anterior end of body whorl. Aperture elongate-ovate; outer lip thin; inner lip heavily incrusted. Canal short and straight; umbilicus subperforate. Only the type of this species is known.

Dimensions.—Height, about 20 mm.; height of body whorl, 15 mm.; maximum width of body whorl, about 11 mm.

Occurrence.—University of California locality 2754.

CANCELLARIA, sp. A

Plate 23, figure 9

An imperfect specimen of a *Cancellaria* was found at University of California locality 14, which appears to be a distinct form. The whorls are angulated but are rather strongly convex just below the suture. The surface is sculptured by about eight longitudinal ribs; these are crossed by rather fine, spiral ribs, which are about as wide as the interspaces between them. Aperture broadly subovate; canal short.

CANCELLARIA?, sp. B

Plate 21, figure 1

A few imperfect casts of a species were found at University of California locality 3053, which appear to be referable to the genus Cancellaria. A drawing of one of these is shown on plate 19, figure 1. The material is too poor for specific determination; apparently, however, it is a distinct form.

Family Acteonidae

Genus ACTEON Montf.

ACTAEON KIRKERENSIS, n. sp.

Plate 22, figure 9

Type specimen 11254, Coll. Invert. Palae. Univ. Calif., loc. 76

Shell fairly large for this genus; spire acute; number of whorls seven, with sides gently concave; body whorl large and rather ventricose; sutures distinct and narrowly channeled. Surface of shell sculptured by numerous spiral ribs with interspaces about as wide as the ribs; four or five spiral ribs on each whorl of spire, and about twenty-three on body whorl. Aperture elongate-ovate; columella area with the typical depression-fold of this genus.

Dimensions.—Height, about 12 mm.; height of spire, about 4.5 mm.; greatest width of body whorl, 8 mm.

Occurrence.—University of California locality 78.

This form appears to be distinct from any of the known species of this genus. The species that it seems to resemble the most is *Aceton traskii* Stearns,[158] from which it differs in being heavier and broader in proportion to the height, the body whorl being more ventricose and the interspaces between the spiral ribs broader.

Family Scaphandridae

Genus CYLICHNA Lovin

CYLICHNA RAMONENSIS, n. sp.

Plate 20, figure 7

Type specimen 11218, Coll. Invert. Palae. Univ. Calif., loc. 1131

Shell small, elongate, cylindrical; spire concealed. Sides of whorl smooth; aperture narrow, elongate, broadening rather rapidly near the anterior end; margin of outer lip produced rather strongly posteriorly; single columellar plate or plication well developed on lower edge of inner lip.

Dimensions.—Height, 5 mm.; width, 2 mm.

Occurrence.—University of California locality 1131.

This species resembles quite closely in outline *Cylichna alba* (Brown), a Recent West Coast species. It differs in not being so large, the apex is more shrunken and the outer lip more strongly produced posteriorly. The surface of *C. alba*[159] is covered by fine spiral lines; apparently the surface of *C. ramonensis* is smooth.

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[158] For original description see Nautilus, vol. 11, no. 2, p. 14, 1897.

[159] For good description and figure of *Cylichna alba* (Brown), Arnold, see Mem. Calif. Acad. Sci., vol. 3, p. 192, pl. 10, fig. 18, 1903.

Genus SCAPHANDER Montfort

SCAPHANDER sp.

Several poorly preserved specimens of a species of Scaphander were found at University of California locality 2033, in the tuff member of the Kirker formation. These are generically but not specifically determinable.

Family Turritidae

Genus TURRIS Bolten

TURRIS ALTUSCOLLUS, n. sp.

Plate 23, figure 1

Type specimen 11232, Coll. Invert. Palae. Univ. Calif., loc. 1131.

Shell fusiform, medium in size; spire high, acute, with five or six whorls; apex broken on all specimens observed. Sutures strongly appressed, the upper part of each whorl being appressed into a fairly broad, distinct collar. Surface sculptured by numerous spiral, granular ribs and riblets; on whorls of spire there are nine or ten, and on body whorl about twenty-five to twenty-eight of the spiral ribs. On body whorl there are three spiral riblets in each interspace, two of which are situated up close to the sides of the ribs and one in the middle of the interspace; on the whorls of the spire, only the medium riblet is distinct. Surface of whorls also sculptured by ten or eleven elongate, rounded nodes; on the whorls of the spire these begin just below the depressed area of the collar extending to the suture below; on the body whorl, they extend only a little below the line of greatest convexity. Aperture elongate-ovate; outer lip thin; inner lip rather heavily incrusted; lower end of canal broken.

So far only one specimen of this species has been obtained.

Occurrence.—University of California locality 1131.

TURRIS (PLEUROTOMA) NOMLANDI, n. sp.

Plate 21, figure 7

Type specimen 11275, Coll. Invert. Palae. Univ. Calif., loc. 3055

Shell fairly large for this genus, fusiform; spire acute; sutures rather strongly appressed; number of whorls six. Surface covered by numerous fine spiral ribs which are somewhat irregular in prominence, the interspaces averaging less than the width of the ribs; on the body whorl there is a tendency for every other spiral rib to be heavier than the one between; on the penultimate whorl twelve, and on the body whorl over thirty of the spiral ribs. Surface also sculptured by nine or ten prominent, rounded longitudinal ribs; these are indistinct on the appressed area just below the suture, but on the whorls of the spire they extend to the suture below, being the most prominent near the middle of the whorl; on the body whorl, just below the appressed area, they become so prominent as to form fairly distinct nodes, giving this portion of the shell a subangulate appearance. The sides of the whorl slope very rapidly and evenly from this line of subangulation down almost to the anterior end. Canal straight, short; aperture not exposed.

Dimensions.—Height, about 26 mm.; height of body whorl, 15.5 mm.; greatest diameter of body whorl, 11 mm.

Occurrence.—So far this species has been found only at the type locality. Several good impressions were obtained; the type is a wax cast made from one of these. Associated with *Acila gettysburgensis, Tellina lorenzoensis, Fusinus hecoxi, Pseudoperissolax merriami, Strepsidura* cf. *californica, Turris perissolaxoides*, etc.

TURRIS (PLEUROTOMA) PERISSOLAXOIDES (Arnold)

Pleurotoma perissolaxoides Arnold, Proc. U. S. Nat. Mus., vol. 34, p. 368, pl. 33, fig. 13, 1908.

Turris perissolaxoides Arnold, Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, p. 30, 1916.

Occurrence.—University of California locality 3051, between Pinole and Bear Creek on north side of Sobrante anticline, about fifty feet below Kirker tuff member. Associated with *Acila gettysburgensis, Tellina lorenzoensis, Calliostoma lawsoni, Fusinus hecoxi, Pseudoperissolax merriami, Strepsidura* cf. *californica*, etc.

TURRIS (PLEUROTOMA) THURSTONENSIS Weaver

Plate 23, figures 11 and 12

Turris thurstonensis Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, p. 54, pl. 5, figs. 79, 80, 1916.

This is one of the few highly ornamented gastropods common to the Lower Oligocene, Molopophorus lincolnensis zone as described by Weaver, and the Agasoma gravidum beds. At the type locality it is found associated with *Exilia lincolnensis* Weaver. These two species are also found associated in the same beds in the San Ramon formation, University of California locality 1131.

Class SCAPHOPODA

Family DENTALIIDAE

Genus DENTALIUM Linnaeus

DENTALIUM PETRICOLA Dall

Teredo substriata Conrad, Geol. U. S. Expl. Exp., vol. 10, Geol., p. 728, pl. 20, figs. 7 and 7*b* only, 1849.

Dentalium petricola Dall, n. nom., U. S. Geol. Surv., Prof. paper no. 59, p. 136, 1909.

A common species in both the Oligocene and Lower Miocene.

DENTALIUM CONRADI Dall

Teredo substriatum Conrad, Geol. U. S. Explor. Exped., vol. 10, Geol., p. 728, pl. 20, fig. 7*a* only, 1849.

Dentalium substriatum Conrad, Carpenter, Rep. Brit. Assoc. Adv. Sci., p. 367, 1856.

Dentalium substriatum Conrad, Amer. Jour. Conch., vol. 1, p. 151, 1865.

Dentalium substriatum Conrad, Gabb, Geol. Surv. Calif., Palaeontology, vol. 2, p. 115, 1868.

Dentalium conradi Dall, n. nom., U. S. Geol. Surv., Prof. paper no. 59, p. 136, 1909.

Dentalium conradi Dall, Arnold and Hannibal, Proc. Amer. Philos. Soc., vol. 52, no. 212, pp. 581, 583, 584, 588, 1913.

Dentalium conradi Dall, Weaver, Univ. Wash. Publ. Geol., vol. 1, no. 1, p. 30, 1916; Calif. Acad. Sci., ser. 4, vol. 6, no. 2, p. 37; also no. 3, p. 51, 1916.

Dentalium conradi is a common species in both the Oligocene and Lower Miocene of the West Coast.

DENTALIUM RADIOLINEATA, n. sp.

Plate 22, figure 12

Type specimen 11227, Coll. Invert. Palae. Univ. Calif., loc. 1131.

Shell medium in size, gently curved, cross-section circular; apex slender, not notched. Surface covered by about sixteen fairly heavy, radiating ribs with interspaces considerably wider than the ribs. On the smaller specimens the radiating ribs cover the entire shell; on large specimens, however, they become faint or obsolete near anterior end.

Occurrence.—University of California localities 1131, 1173, 1631.

DENTALIUM RADIOLINEATA SOBRANTENSIS, n. var.

Plate 14, figures 9 and 10

Type specimen 11261, Coll. Invert. Palae. Univ. Calif., loc. 1173

Dentalium cf. *stramineum* Gabb, Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Occurrence.—University of California locality 1173.

A couple of specimens were found at University of California locality 1173, which the writer in a previous paper referred to *D.* cf. *stramineum.* Further study shows that this should probably be considered a variety of *D. radiolineatum,* n. sp., from which it differs in the presence of a less prominent interrib between the longitudinal ribs; also, the surface, on the more unweathered portions of the shell, is covered with very fine longitudinal striations, which are on both the ribs and the interspaces. This last character is observable only on exceptionally unweathered specimens and it may very possibly be found to be a characteristic of the typical *D. radiolineatum.*

Class AMPHINEURA

Plate 14, figure 2

An anterior plate of a chiton was found at University of California locality 1131. The form has not been determined either generically or specifically.

Subkingdom **VERMES**

Class ANNELLIDAE

Order Polychaeta

Genus SERPULA Linnaeus

SERPULA RECTIFORMIS, n. sp.

Plate 24, figures 1 and 2

Type specimen 11262, Coll. Invert. Palae. Univ. Calif., loc. 52

A mass of straight or nearly straight calcareous circular tubes, which have a diameter of from 2 to 3 mm. The tubes are long and wherever they touch each other they are cemented together. A tube may be cemented to another tube along part of its length and be free from it along the remaining portion; thus, the tubes, compactly massed, weave in and out among themselves to some extent but in general they all lie more or less parallel. They are somewhat smaller at one end than at the other. The small ends of the tubes are all on the same side of the block, this side evidently being the base of the colony. Surface of tubes finely striated longitudinally.

Occurrence.—University of California locality 52.

Subkingdom **CEPHALOPODA**

Subclass TETRABRANCHIATA

Family Clydonautilidae

Genus ATURIA Brown

ATURIA sp.

Plate 17, figure 1

Up to the present time only one specimen of the genus Aturia has been found in the Agasoma gravidum beds of Contra Costa County; it is very imperfect and not determinable specifically. A good cross-section, however, is exposed, showing the siphonal funnels reaching from one septum to the other, so characteristic of this genus.

Collected by John Buwalda at University of California locality 1173; found associated with *Dosinia mathewsonii, Agasoma gravidum, Molopophorus biplicatus,* etc.

Phylum ECHINODERMATA

Class ECHINOIDEA

Family Strongylocentrotidae

Genus STRONGYLOCENTROTUS Brandt

STRONGYLOCENTROTUS? sp.

Spines, which appear to be referable to this genus, are rather common at University of California locality 1131. No good specimens of the test have as yet been found.

Family SPATANGIDAE

Genus SCHIZASTER Agassiz

SCHIZASTER CALIFORNICA Weaver

Plate 17, figure 2

Linthia? californica Weaver, Univ. Calif. Publ., Bull. Dept. Geol., vol. 5, no. 17, pp. 272, 274, pl. 21, fig. 2, 1908.

Brissopsis californica Weaver, Stefanini, Boll. Soc. Geol. Ital., vol. 30, p. 705, 1911.

Linthia californica Weaver, B. L. Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1915.

Linthia californica Weaver, Clark and Twitchell, U. S. Geol. Surv., Monograph 54, pp. 214–215, pl. 98, fig. 4, 1915.

This species is common at University of California locality 2755, which appears to be the locality from which Weaver obtained his type specimen. Some of the species found associated with it are *Leda rostellata, Glycimeris tenuimbricata, Agasoma gravidum,* etc. It was at this locality that an imperfect specimen of an Archeocyathus (one of the modern cup corals) was found, also found at localities 3051 and 3055, associated with a typical San Lorenzo fauna.

Order ZYGOPHIUROIDA

Class OPHIUROIDEA

Family AMPHIURIDAE

Genus AMPHIURA

AMPHIURA? sp.

A fragmentary specimen, apparently belonging to the genus *Amphiura,* was found in the diatomaceous shale of the Markley formation, University of California locality 3080.

Subkingdom **COELENTERATA**

Class ANTHOZOA

Subclass HEXACORALLA

Family TURBINOLIDAE

Genus THROCHOCYATHUS Milne-Edwards and Haime

TROCHOCYATHUS sp. indt.

A cross-section of a poorly preserved specimen, referable to this genus, was found at University of California locality 2755. The specimen is determinable generically but is not sufficiently well-preserved to warrant a description as a new species.

Family Eupsammidae

Genus DENDROPHYLLIA

DENDROPHYLLIA CALIFORNIANA Nomland

Dendrophyllia californiana Nomland, Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, no. 13, pp. 188, 189, 1917.

The type of this species came from the basal beds of the San Ramon formation; outcrops in creek bed about one-half mile south of the town of Walnut Creek, University of California locality 1131.

Family Fungidae

Genus SIDERASTREA Blainville

SIDERASTREA CLARKI Nomland

Siderastrea n. sp. Clark, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 2, p. 15, 1912.

Siderastrea clarki Nomland, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 5, p. 65, 1916.

Type obtained from University of California locality 1131.

Subkingdom **ARTHROPODA**

Class CRUSTACEA

Superorder CIRRIPEDIA

Genus BALANUS Linné

BALANUS sp.

Plate 20, figures 13 and 14

At least two distinct species of *Cirripedia* belonging to the genus *Balanus* were determined by the writer; both are from the San Ramon formation. The material at hand is rather poor and no opercular valves have been found. The two best specimens are figured as indicated above.

EXPLANATION OF PLATE 5

Fig. 1. *Chione cryptolineata*, n. sp. Type, no. 11178, Coll. Invert. Palae. Univ. Calif., loc. 1131. View of right valve, natural size.

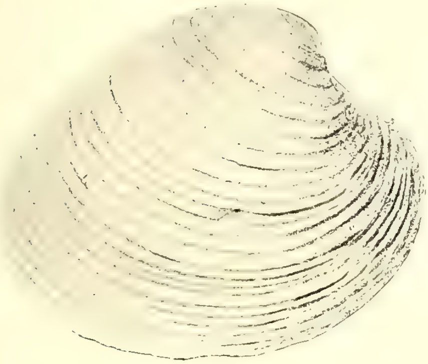
Fig. 2. *Chione cryptolineata.* Same specimen as fig. 1, showing dorsal view.

Fig. 3. *Chione cryptolineata*, n. sp. No. 11179, Coll. Invert Palae. Univ. Calif., loc. 1131. Hinge of right valve, natural size.

Fig. 4. *Chione cryptolineata*, n. sp. No. 11180, Coll. Invert. Palae. Univ. Calif., loc. 1131. Hinge of left valve, natural size.

Fig. 5. *Chione mediostriata*, n. sp. Type, no. 11181, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 6. *Chione mediostriata*, n. sp. No. 11182, Coll. Invert. Palae. Univ. Calif., loc. 1343. Natural size.



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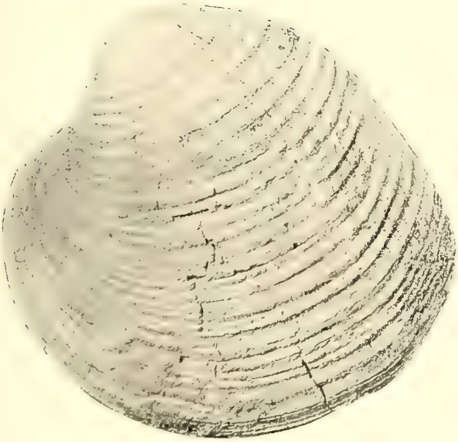

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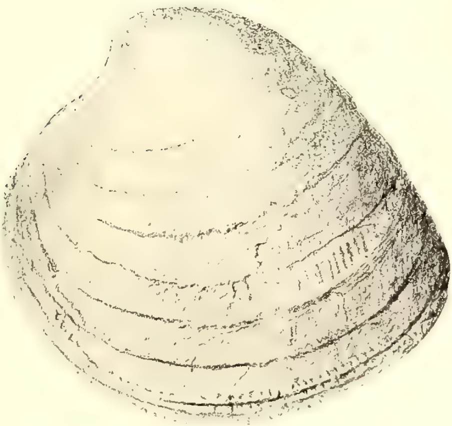

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EXPLANATION OF PLATE 6

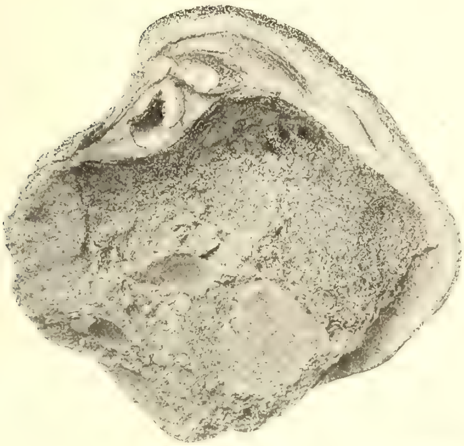
Fig. 1. *Chione lineolata*, n. sp. Type, no. 11123, Coll. Invert. Palae. Univ. Calif., loc. 1131. View of hinge of right valve; the posterior cardinal was broken in preparation.

Fig. 2. *Chione lineolata*, n. sp. External view of same specimen as fig. 1. Natural size.

Fig. 3. *Chione mediostriata*, n. sp. No. 11124, Coll. Invert. Palae. Univ. Calif., loc. 1131. View of hinge of right valve, natural size.

Fig. 4. *Chione mediostriata*, n. sp. No. 11125, Coll. Invert. Palae. Univ. Calif., loc. 1131. View of hinge of left valve, natural size.

Fig. 5. *Chione lineolata*, n. sp. No. 11126, Coll. Invert. Palae. Univ. Calif., loc. 1131. View of hinge of left valve, natural size.



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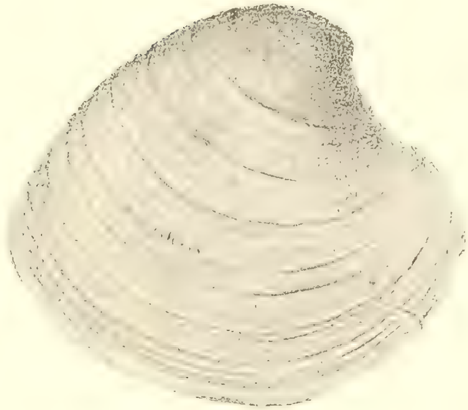

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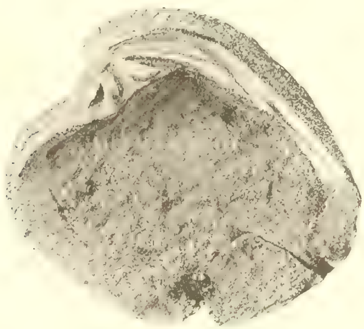

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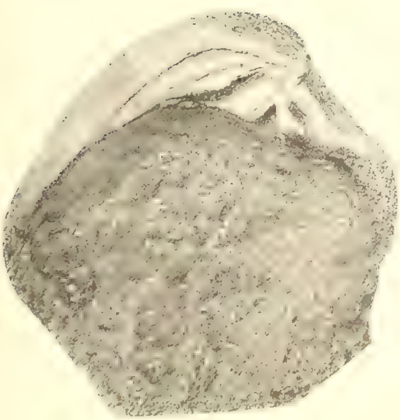

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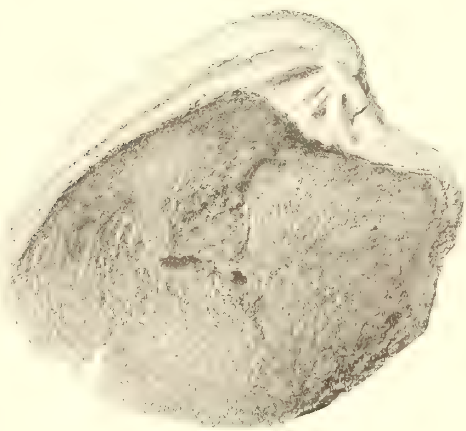

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EXPLANATION OF PLATE 7

Fig. 1. *Dosinia mathewsonii* Gabb. No. 11145, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 2. *Dosinia mathewsonii* Gabb. Same specimen as fig. 1, showing dorsal view. Natural size.

Fig. 3. *Dosinia* (*Docinidia*) *whitneyii* Gabb. No. 11146, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.

Fig. 4. *Dosinia* (*Docinidia*) *whitneyii* Gabb. Same specimen as fig. 3, showing dorsal view. Natural size.

Fig. 5. *Dosinia mathewsoni* Gabb. No. 11149, Coll. Invert. Palae. Univ. Calif., loc. 1131. Hinge of right valve, natural size.

Fig. 6. *Dosinia mathewsonii* Gabb. No. 11148, Coll. Invert. Palae. Univ. Calif., loc. 1131. Hinge of left valve, natural size.

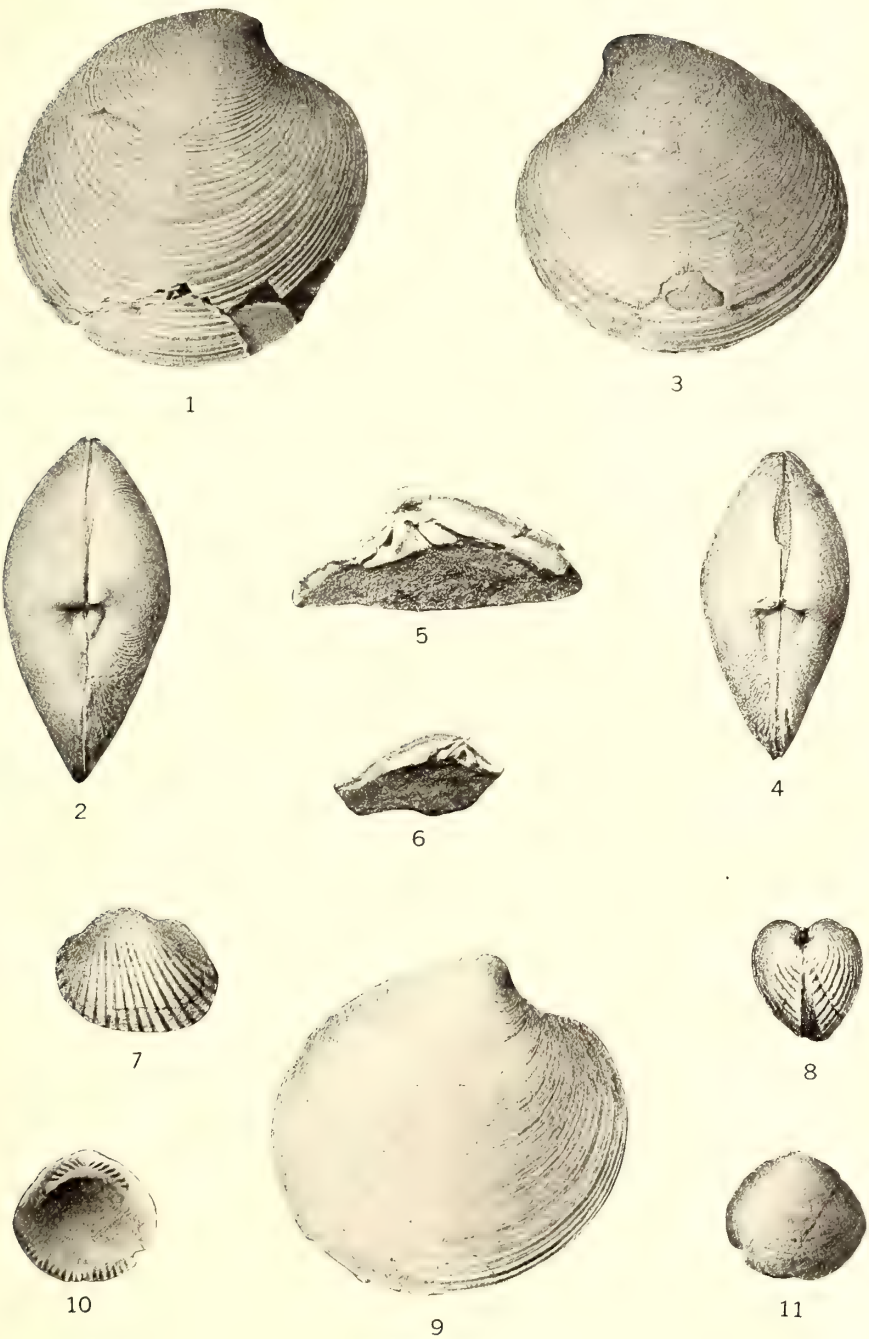
Fig. 7. *Arca* (*Scapharca*) *mediaimpressa,* n. sp. No. 11172, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size—a rather large specimen for this species.

Fig. 8. *Arca* (*Scapharca*) *mediaimpressa,* n. sp. An anterior view of the same specimen as fig. 7.

Fig. 9. *Dosinia mathewsonii* Gabb. No. 11173, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 10. *Glycimeris buwaldi,* n. sp. Type, no. 11150, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 11. *Glycimeris buwaldi,* n. sp. Same specimen as fig. 10, exterior view. Approximately twice natural size.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EXPLANATION OF PLATE 8

Fig. 1. *Antigona* (*Ventricola*) *undosa*, n. sp. Type, no. 11134, Coll. Invert. Palae. Univ. Calif., loc. 14. Right valve, natural size.

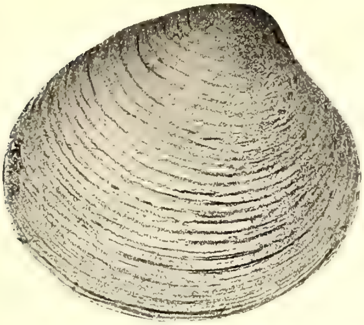
Fig. 2. *Antigona* (*Ventricola*) *undosa*, n. sp. Same specimen as fig. 1, view of dorsal areas, natural size.

Fig. 3. *Antigona* (*Artena*) *neglecta*, n. sp. Type, no. 11135, Coll. Invert. Palae. Univ. Calif., loc. 14. Left valve, natural size.

Fig. 4. *Antigona* (*Artena*) *neglecta*, n. sp. Same specimen as fig. 3, showing anterior view. Natural size.

Fig. 5. *Antigona* (*Ventricola*) *undosa*, n. sp. No. 11136, Coll. Invert. Palae. Univ. Calif., loc. 14. Right valve, natural size. The heavy concentric undulations are better preserved on this specimen than on the one shown in fig. 1.

Fig. 6. *Antigona* (*Artena*) *neglecta*, n. sp. No. 11138, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.



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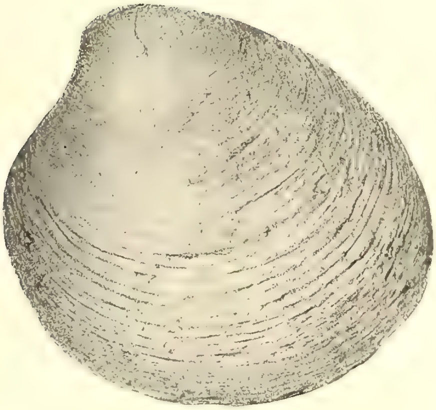

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EXPLANATION OF PLATE 9

Fig. 1. *Macrocallista* sp.? An internal mould. No. 11156, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.

Fig. 2. *Macrocallista? incognita,* n. sp. Type, no. 11116, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 3. *Macrocallista? incognita,* n. sp. Same specimen as fig. 2, view showing dorsal areas. Natural size.

Fig. 4. *Spisula ramonensis* Packard. Type, no. 11118, Coll. Invert. Palae. Univ. Calif., loc. 1687. Natural size.

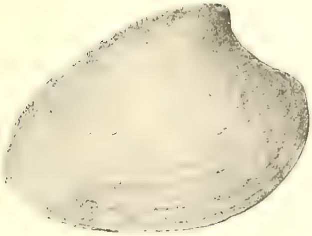
Fig. 5. *Spisula ramonensis* Packard. An exterior cast of left valve. No. 11117, Coll. Invert. Palae. Univ. Calif., loc. 1458. Natural size.

Fig. 6. *Spisula ramonensis attenuata,* n. var. Type, no. 11119, Coll. Invert. Palae. Univ. Calif., loc. 1167. Natural size.

Fig. 7. *Metis rostellata,* n. sp. Imperfect specimen of left valve, no. 11120, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 8. *Modiolus kirkerensis,* n. sp. Type, no. 11121, Coll. Invert. Palae. Univ. Calif., loc. 3081. Natural size.

Fig. 9. *Modiolus pittsburgensis,* n. sp. Type, no. 11122, Coll. Invert. Palae. Univ. Calif., loc. 1895. Natural size.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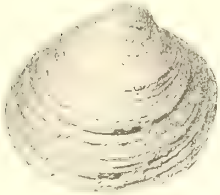
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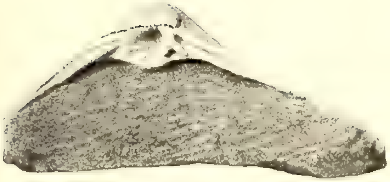
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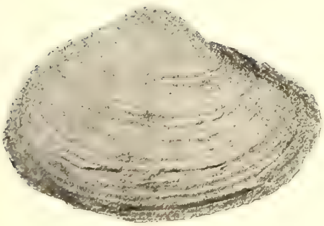
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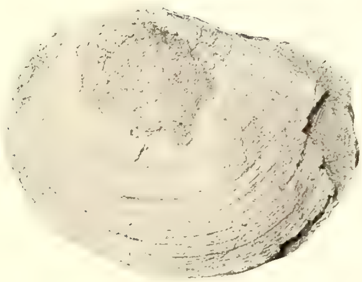
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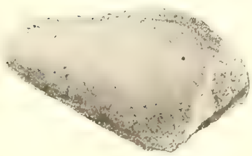
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EXPLANATION OF PLATE 10

Fig. 1. *Tellina tenuilineata,* n. sp. A plaster-of-paris mould from an impression in the rock. No. 11128, Coll. Invert. Palae. Univ. Calif., loc. 1175. Natural size.

Fig. 2. *Pitaria lorenzana,* n. sp. Type, no. 11129, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

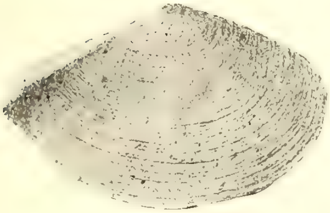
Fig. 3. *Tellina tenuilineata,* n. sp. Type, no. 11130, Coll. Invert. Palae. Univ. Calif., loc. 1131. View of right valve, with posterior end broken, natural size.

Fig. 4. *Pitaria lorenzana,* n. sp. Same specimen as fig. 2, showing view of dorsal areas, natural size.

Fig. 5. *Tellina tenuilineata,* n. sp. An imperfect specimen showing the posterior half of a right valve. No. 11131, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 6. *Solen* (*Plectosolen*) *curtus* Conrad. No. 11132, Coll. Invert Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 7. *Solen gravidus,* n. sp. Type, no. 11133, Coll. Invert. Palae. Univ. Calif., loc. 1131. Left valve, natural size.



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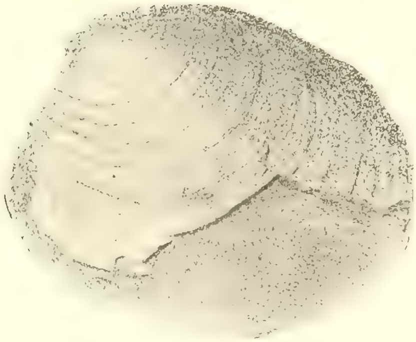

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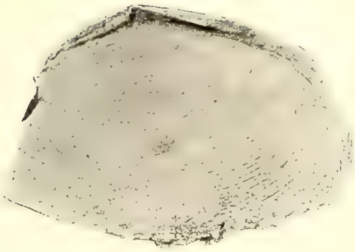

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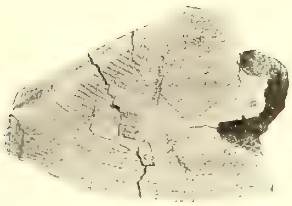

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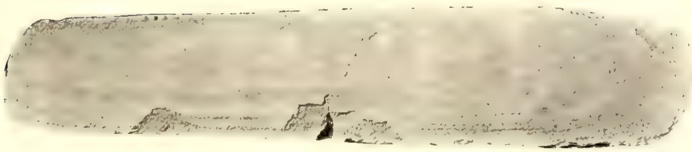

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EXPLANATION OF PLATE 11

Fig. 1. *Spisula occidentalis* Gabb. View of right valve, no. 11106, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 2. *Callocardia* (*Agriopoma*) *californica,* n. sp. Type, no. 11107, Coll. Invert. Palae. Univ. Calif., loc. 1131. Left valve, natural size.

Fig. 3. *Callocardia* (*Agriopoma*) *californica,* n. sp. Same specimen as fig. 2, showing dorsal areas, natural size.

Fig. 4. *Callocardia* (*Agriopoma*) *californica,* n. sp. No. 11108, Coll. Invert. Palae. Univ. Calif., loc. 1131. Left valve, natural size.

Fig. 5. *Leda pulchrisinuosa,* n. sp. Type, no. 11109, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size; view showing dorsal areas.

Fig. 6. *Leda pulchrisinuosa,* n. sp. Same specimen as fig. 5, showing left valve. Approximately twice natural size.

Fig. 7. *Pandora acutirostrata,* n. sp. View of imperfect specimen of left valve. No. 11112, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 8. *Mya* (*Cryptomya*) *incognita,* n. sp. Type, no. 11114, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

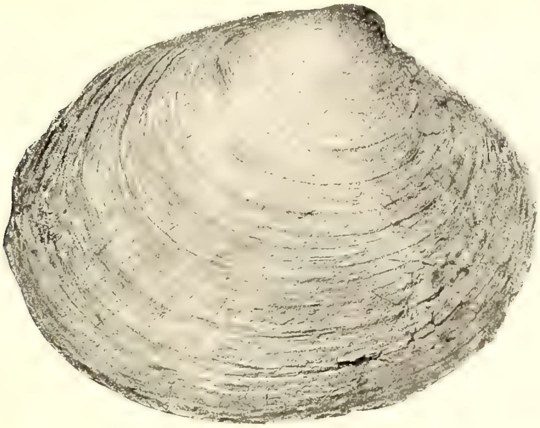
Fig. 9. *Pandora acutirostrata,* n. sp. Type, no. 11111, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 10. *Yoldia cooperi tenuissima,* n. var. Type, no. 11110, Coll. Invert. Palae. Univ. Calif., loc. 798. Natural size.

Fig. 11. *Callocardia* (*Agriopoma*) *californica,* n. sp. View of hinge of left valve. No. 11113, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 12. *Thracia condoni* Dall. An immature individual; specimens are usually much larger than this. No. 11277, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 13. *Pandora acutirostrata,* n. sp. No. 11289, Coll. Invert. Palae. Univ. Calif., loc. 1131.



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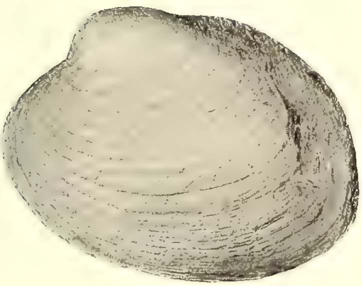

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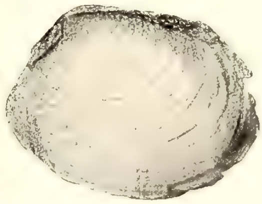

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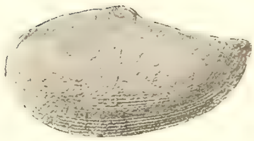

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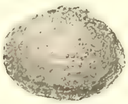

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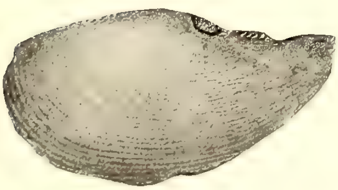

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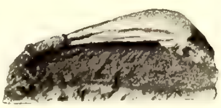

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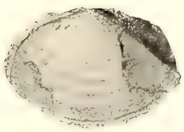

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EXPLANATION OF PLATE 12

Fig. 1. *Mytilus arnoldi*, n. sp. Type, no. 11153, Coll. Invert. Palae. Univ. Calif., loc. 78. Natural size.

Fig. 2. *Thracia condoni* Dall. No. 11168, Coll. Invert. Palae. Univ. Calif., loc. 517. Natural size.

Fig. 3. *Malletia packardi*, n. sp. Type, no. 11154, Coll. Invert. Palae. Univ. Calif., loc. 2033. Natural size.

Fig. 4. *Macrocallista weaveri*, n. sp. Type, view showing dorsal areas, no. 11155, Coll. Invert. Palae. Univ. Calif., loc. 1134. Natural size.

Fig. 5. *Cardium kirkerensis*, n. sp. Type, a wax cast, no. 11165, Coll. Invert. Palae. Univ. Calif., loc. 2033. Natural size.

Fig. 6. *Diplodonta stephensoni*, n. sp. Type, no. 11171, Coll. Invert. Palae. Univ. Calif., loc. 1131.

Fig. 7. *Macrocallista weaveri*, n. sp. Same specimen as fig. 4, lateral view of left valve, natural size.

Fig. 8. *Yoldia cooperi tenuissima*, n. var. An immature individual. No. 00000, Coll. Invert Palae. Univ. Calif., loc. 1309. Natural size.

Fig. 9. *Leda ramonensis*, n. sp. Type, no. 11167, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

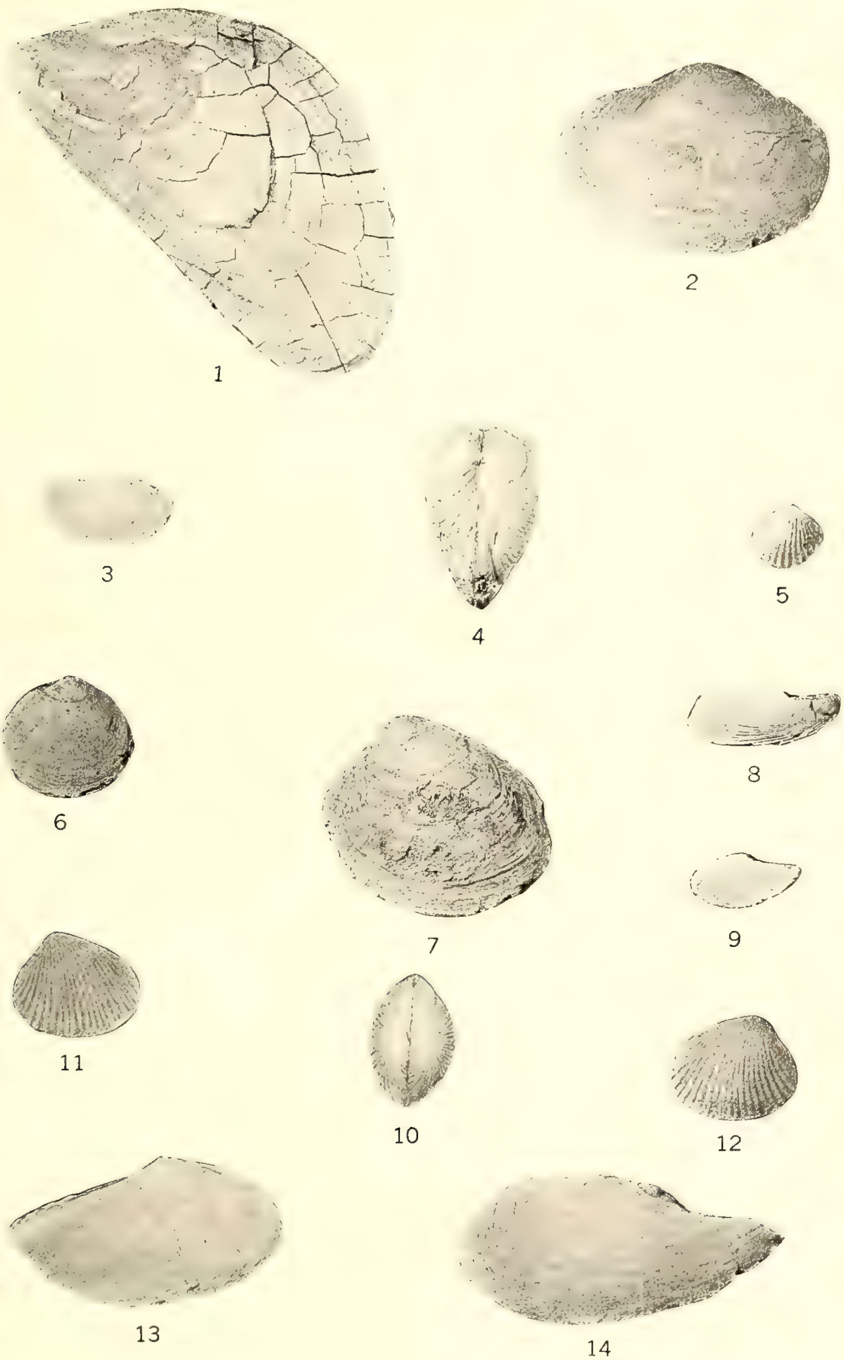
Fig. 10. *Nucula? bifida*, n. sp. Type, view of dorsal areas, no. 11184, Coll. Invert. Palae. Univ. Calif., loc. 331. Approximately three times natural size.

Fig. 11. *Nucula? bifida*, n. sp. Lateral view of left valve of same specimen as figs. 10 and 11; approximately twice natural size.

Fig. 12. *Nucula? bifida*, n. sp. Lateral view of right valve of same specimen as figs. 10 and 11; approximately twice natural size.

Fig. 13. *Tellina praecuta*, n. sp. Type, no. 11166, Coll. Invert. Palae. Univ. Calif., loc. 14. An interior cast, natural size. The external ribbing is very similar to that of *Tellina tenuilineata*, n. sp.

Fig. 14. *Yoldia cooperi tenuissima*, n. var. No. 11163, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.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EXPLANATION OF PLATE 13

Fig. 1. *Tellina oregonensis* Conrad. No. 11191, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.

Fig. 2. *Nucula postangulata,* n. sp. No. 11194, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 3. *Acila muta markleyensis,* n. var. Type, no. 11195, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 4. *Tellina oregonensis* Conrad. A very well preserved specimen of left valve, no. 11192, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 5. *Nucula postangulata,* n. sp. Type, no. 11260, Coll. Invert. Palae. Univ. Calif., loc. 2754. Approximately twice natural size.

Fig. 6. *Acila muta,* n. sp. Type no. 11196, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 7. *Acila shumardi* Dall. Posterior view showing escutcheon; specimen from the California Academy of Sciences collection, obtained from the type locality, from which the type of this species came, on the bluffs along the Nehalem River, near the town of Pittsburg, Oregon. Natural size.

Fig. 8. *Acila shumardi* Dall. Lateral view of right valve of same specimen as fig. 7. Natural size.

Fig. 9. *Acila gettysburgensis* Reagan. Left valve of specimen collected by Professor C. E. Weaver. Natural size.

Fig. 10. *Cyathodonta weaveri,* n. sp. No. 11193, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 11. *Cardium dickersoni.* No. 11198, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 12. *Acila muta,* n. sp. A small specimen enlarged about twice natural size. No. 11199, Coll. Invert. Palae. Univ. Calif., loc. 1131.

Fig. 13. *Acila muta,* n. sp. No. 11200, Coll. Invert. Palae. Univ. Calif., loc. 199. Natural size.

Fig. 14. *Pecten (Pseudomuseum) alterlineatus,* n. sp. Type, no. 11202, Coll. Invert. Palae. Univ. Calif., loc. 1131. Nearly twice natural size.

Fig. 15. *Pecten (Pseudomuseum) alterlineatus,* n. sp. No. 11203, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

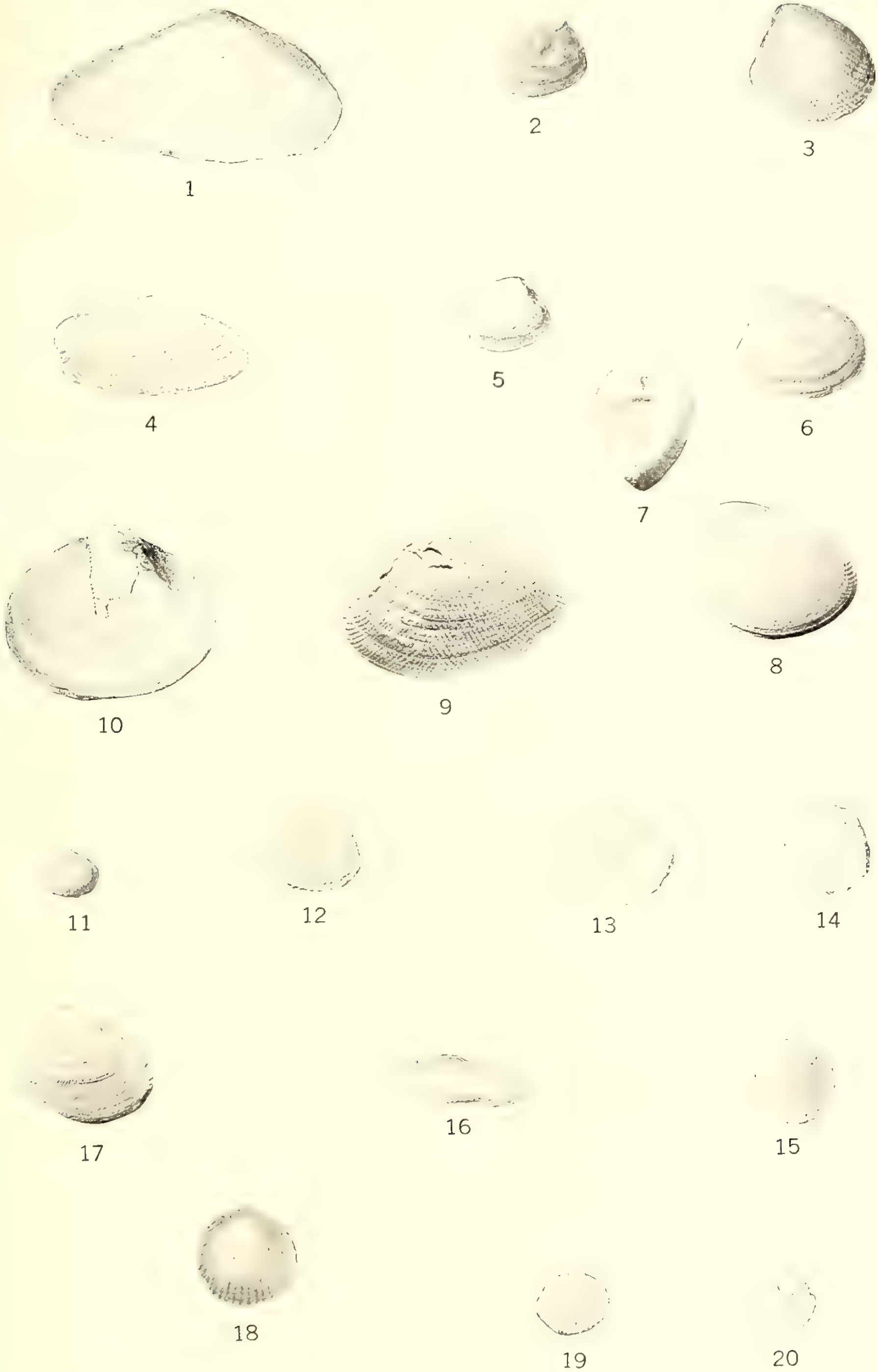
Fig. 18. *Cardium dickersoni,* n. sp. Type, no. 11207, Coll. Invert. Palae. Univ. Calif., loc. 2755. Natural size.

Fig. 17. *Acila shumardi* Dall. No. 11207, Coll. Invert. Palae. Univ. Calif., loc. 78. Natural size.

Fig. 18. *Cardium dickersoni,* n. sp. Type, no. 11207, Coll. Invert. Palae. Univ. Calif., loc. 1131. Three times natural size.

Fig. 19. *Anomia inconspicua,* n. sp. Type, a left valve, no. 11205, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 20. *Anomia inconspicua.* A right valve, showing large unclosed byssal sinus. No. 11204, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.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EXPLANATION OF PLATE 14

Fig. 1. *Cyathodonta weaveri*, n. sp. Type no. 11131, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.

Fig. 2. An anterior plate of a chiton from Univ. Calif., loc. 1131.

Fig. 3. *Donax* sp. indt. No. 11278, Coll. Invert. Palae. Univ. Calif., loc. 1314. Natural size.

Fig. 4. *Mya (Cryptomya) incognita*, n. sp. No. 11114, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 5. *Malletia packardi*, n. sp. No. 11279, Coll. Invert. Palae. Univ. Calif., loc. 3080. A wax cast from the diatomaceous shale of the Markley formation, natural size.

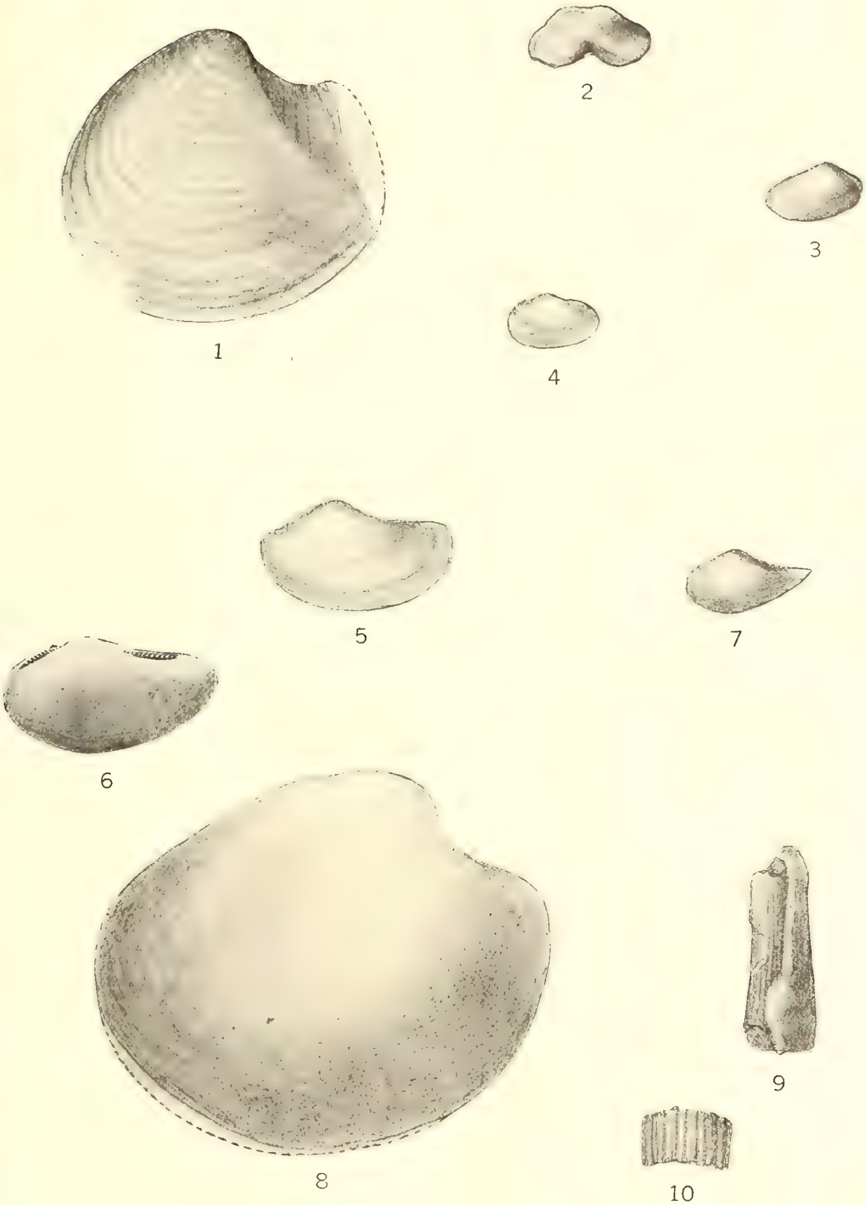
Fig. 6. *Malletia packardi*, n. sp. No. 11280, Coll. Invert. Palae. Univ. Calif., loc. 3081; natural size; an internal cast from the diatomaceous shale of the Markley formation.

Fig. 7. *Leda markleyensis*, n. sp. Type, no. 11272, Coll. Invert. Palae. Univ. Calif., loc. 3081. Natural size.

Fig. 8. *Pitaria?* sp. No. 11281, Coll. Invert. Palae. Univ. Calif., loc. 78. Natural size.

Fig. 9. *Dentalium radiolineata sobrantensis*, n. var. No. 11261, Coll. Invert. Palae. Univ. Calif., loc. 1173.

Fig. 10. *Dentalium radiolineata sobrantensis*, n. var. A detail of surface of surface of same specimen as fig. 9.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EXPLANATION OF PLATE 15

Fig. 1. *Pecten* (*Chlamys?*) *gabbi*, n. sp. Type, a left valve, no. 11138, Coll. Invert. Palae. Univ. Calif., loc. 1311. Natural size.

Fig. 2. *Pecten* (*Chlamys?*) *gabbi*, n. sp. A right valve, no. 11139, Coll. Invert. Palae. Univ. Calif., loc. 1311. Natural size.

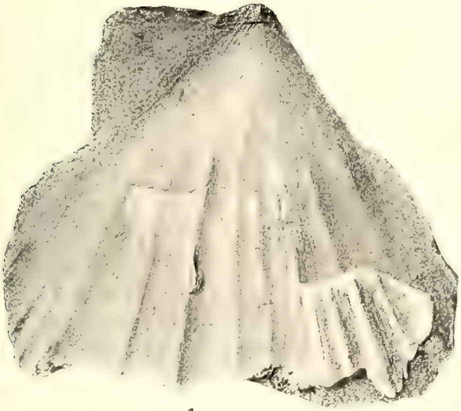
Fig. 3. *Periploma undulata*, n. sp. No. 11140, Coll. Invert Palae. Univ. Calif., loc. 1309. A right valve, natural size.

Fig. 4. *Periploma undulata*. Type, no. 11141, Coll. Invert. Palae. Univ. Calif., loc. 1309. A left valve, natural size.

Fig. 5. *Antigona* (*Artena*) *mathewsonii* (Gabb). Hinge of left valve, no. 11142, Coll. Invert. Palae. Univ. Calif., loc. 1131.

Fig. 6. *Antigona* (*Artena*) *mathewsonii* Gabb. A specimen from the collection of the old state survey, labeled *Chione mathewsonii*, from near Martinez. A left valve, no. 11143, Coll. Invert. Palae. Univ. Calif., loc. 4. Natural size.

Fig. 7. *Antigona mathewsonii* Gabb. No. 11144, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.



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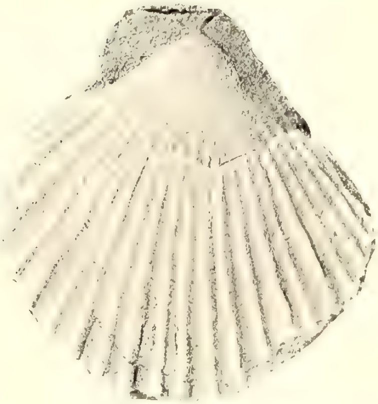

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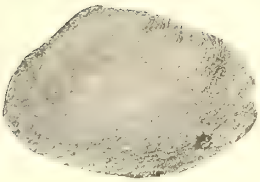

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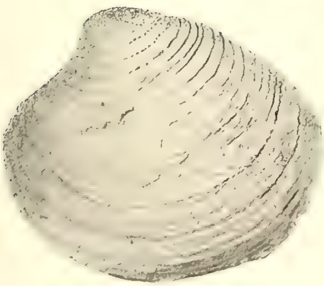

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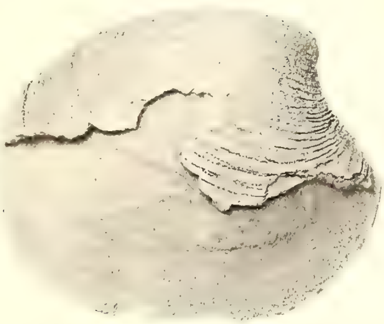

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EXPLANATION OF PLATE 16

Fig. 1. *Spisula? saxidomoides*, n. sp. Type, no. 11268, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 2. *Arca submontereyana*, n. sp. Type, no. 11186, Coll. Invert. Palae. Univ. Calif., loc. 52. Natural size.

Fig. 3. *Psammobia* aff. *edentula* Gabb. No. 11187, Coll. Invert. Palae. Univ. Calif., loc. 1311. Natural size.

Fig. 4. *Glycimeris tenuimbricata*, n. sp. No. 11185, Coll. Invert. Palae. Univ. Calif., loc. 1173. Natural size.

Fig. 5. *Arca (Scapharca) mediaimpressa*, n. sp. Type, no. 11174, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

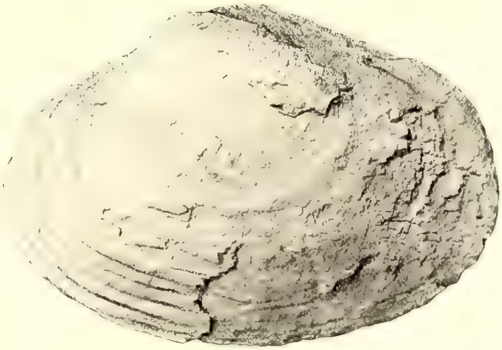
Fig. 6. *Arca (Scapharca) mediaimpressa*, n. sp. Hinge view of same specimen as fig. 5; approximately twice natural size.

Fig. 7. *Arca (Scapharca) mediaimpressa*, n. sp. No. 11189, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately three times natural size.

Fig. 8. *Glycimeris tenuimbricata*, n. sp. Type, no. 11183, Coll. Invert. Palae. Univ. Calif., loc. 1131. Hinge view of somewhat eroded specimen, natural size.

Fig. 9. *Glycimeris tenuimbricata*, n. sp. External view of same specimen as fig. 8, natural size.

Fig. 10. *Glycimeris tenuimbricata*, n. sp. No. 11188, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.



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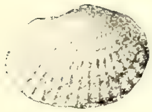

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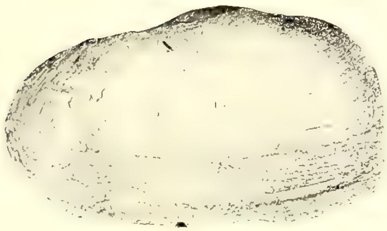

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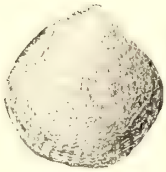

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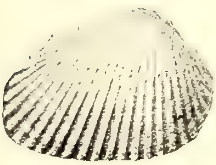

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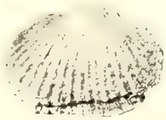

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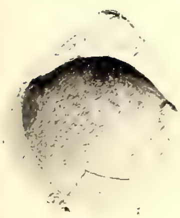

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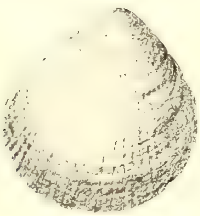

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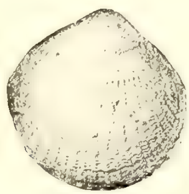

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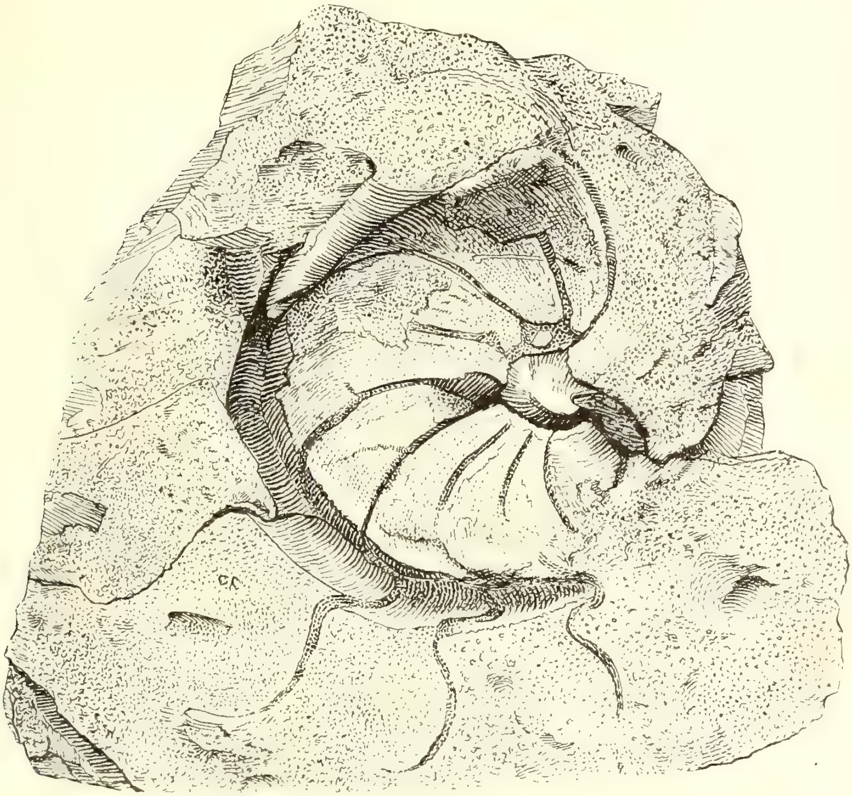
EXPLANATION OF PLATE 17

Fig. 1. *Aturia* sp. No. 11258, Coll. Invert. Palae. Univ. Calif., loc. 1173. A cross-section showing the long funnels reaching from one septum to the other and somewhat beyond; this is characteristic of this genus.

Fig. 2. *Schizaster californica* Weaver. No. 11259, Coll. Invert. Palae. Univ. Calif., loc. 2755. Natural size.



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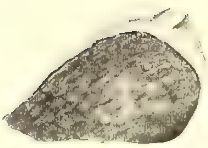
EXPLANATION OF PLATE 18

Fig. 1. *Mytilus* (*Mytiloconcha*) *mathewsonii* Gabb. Type, taken from Gabb's figure in Geol. Surv. Calif., Palaeontology, vol. 2, sec. 1, p. 30, pl. 8, fig. 51, 1866. Natural size.

Fig. 2. *Mytilus* (*Mytiloconcha*) *mathewsonii* Gabb. View of hinge, showing characteristic groove under the beak of subgenus Mytiloconcha. No. 11282, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.



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EXPLANATION OF PLATE 19

Fig. 1. *Agasoma gravidum* Gabb. No. 11245, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.

Fig. 2. *Thais packi*, n. sp. Type, no. 11246, Coll. Invert. Palae. Univ. Calif., loc. 1309. Natural size.

Fig. 3. *Agasoma gravidum* Gabb. No. 11247, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.

Fig. 4. *Ancilla fishii* Gabb. No. 11248, Coll. Invert. Palae. Univ. Calif., loc. 1132. Natural size.

Fig. 5. *Agasoma gravidum* Gabb. No. 11283, Coll. Invert. Palae. Univ. Calif., loc. 14. Enlarged nearly 1.5 times natural sizes.

Fig. 6. *Ancilla fishii* Gabb. No. 11250, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 7. *Ancilla fishii* Gabb. No. 11253, Coll. Invert. Palae. Univ. Calif., loc. 52. Natural size.

Fig. 8. *Ancilla fishii* Gabb. No. 11249, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 9. *Ancilla fishii* Gabb. Same specimen as fig. 6. Natural size.

Fig. 10. *Olivella quadriplicata*, n. sp. Type, no. 11251, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 11. *Ancilla fishii* Gabb. No. 11160, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 12. *Natica (ampullina) gabbi*, n. sp. No. 11250, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

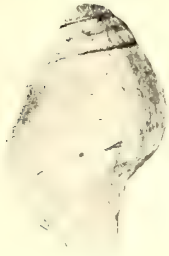
Fig. 13. *Thais packi*, n. sp. Same specimen as fig. 2. Natural size.

Fig. 14. *Natica (Ampullina) gabbi*, n. sp. No. 11255, Coll. Invert. Palae. Univ. Calif., loc. 1309. Approximately twice natural size.

Fig. 15. *Natica (ampullina) gabbi*, n. sp. Type, no. 11252, Coll. Invert. Palae. Univ. Calif., loc. 1311. Approximately twice natural size.

Fig. 16. *Natica (Euspira) ramonensis*, n. sp. Type, no. 11257, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 17. *Olivella quadriplicata*, n. sp. No. 11256, Coll. Invert. Palae. Univ. Calif., loc. 14. Approximately twice natural size.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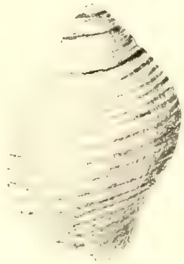
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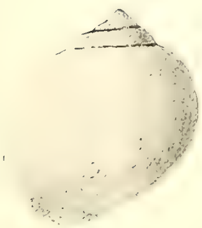
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EXPLANATION OF PLATE 20

Fig. 1. *Bursa mathewsonii* (Gabb). No. 11209, Coll. Invert Palae. Univ. Calif., loc. 1173. Natural size.

Fig. 2. *Bursa mathewsonii* (Gabb). No. 11210, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 3. *Natica* (*Neverita*) *recluziana andersoni*, n. var. No. 11211, Coll. Invert. Palae. Univ. Calif., loc. 2713. Natural size.

Fig. 4. *Molopophorus biplicatus* (Gabb). No. 11158, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 5. *Searlesia dalli*, n. sp. No. 11214, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 6. *Molopophorus biplicatus* (Gabb). No. 11152, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 7. *Cylichna ramonensis*, n. sp. Type, no. 11218, Coll. Invert. Palae. Univ. Calif., loc. 1131. Nearly three times natural size.

Fig. 8. *Molopophorus biplicatus* (Gabb). Same specimen as fig. 4, natural size.

Fig. 9. *Searlesia dalli*, n. sp. No. 11214, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 10. *Natica* (*Neverita*) *recluziana andersoni*, n. var. Type, no. 11212, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 11. *Natica* (*Neverita*) *recluziana andersoni*, n. var. Same specimen as fig. 10. Natural size.

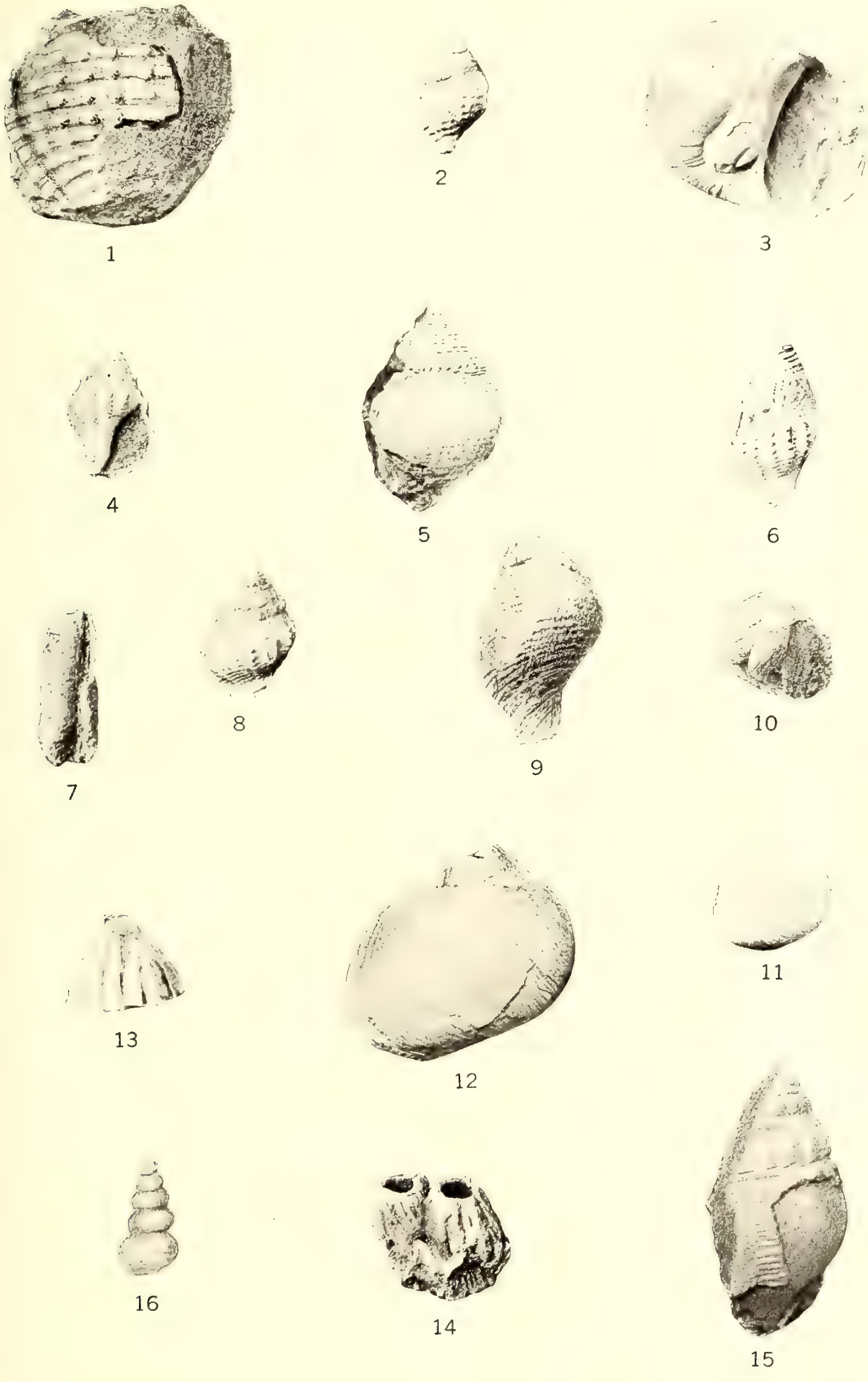
Fig. 12. *Natica* (*Neverita*) *recluziana andersoni*, n. var. Same specimen as fig. 3. Natural size.

Fig. 13. *Balanus* sp. A. No. 11213, Coll. Invert. Palae. Univ. Calif., loc. 1162. Natural size.

Fig. 14. *Balanus* sp. B. No. 11216, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 15. *Searlesia dalli*, n. sp. Type, no. 11215, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 16. *Epitonium pinolensis*, n. sp. Type, no. 11273, Coll. Invert. Palae. Univ. Calif., loc. 3055. Natural size.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EXPLANATION OF PLATE 21

Fig. 1. *Cancellaria* sp. B. No. 11284, Coll. Invert. Palae. Univ. Calif., loc. 3051. Natural size.

Fig. 2. *Fusinus* (*Exilia*) *pinolianus*, n. sp. Type, no. 11274, Coll. Invert. Palae. Univ. Calif., loc. 3055. Natural size.

Fig. 3. *Turris* sp.? No. 11285, Coll. Invert. Palae. Univ. Calif., loc. 3051. A wax cast, natural size.

Fig. 4. *Pseudoperissolax merriami*, n. sp. No. 11286, Coll. Invert. Palae. Univ. Calif., loc. 3055.

Fig. 5. *Amphissa pulchrilineata*, n. sp. Type, no. 11276, Coll. Invert. Palae. Univ. Calif., loc. 3055. Natural size.

Fig. 6. *Amphissa pulchrilineata*, n. sp. From a wax cast. No. 11287, Coll. Invert. Palae. Univ. Calif., loc. 3055. Natural size.

Fig. 7. *Turris* (*Pleurotoma*) *nomlandi*, n. sp. No. 11275, Coll. Invert. Palae. Univ. Calif., loc. 3055. Natural size.

Fig. 8. *Epitonium* sp.? No. 11288, Coll. Invert Palae. Univ. Calif., loc. 3055. Natural size.

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EXPLANATION OF PLATE 22

Fig. 1. *Turritella porterensis sobrantensis,* n. var. Type, no. 11269, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 2. *Columbella* (*Mitrella*) *tenuilineata,* n. sp. Type, no. 11221, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 3. *Columbella* (*Mitrella*) *tenuilineata,* n. sp. Same specimen as fig. 2, approximately twice natural size.

Fig. 4. *Chrysodomus? pulchrissimus,* n. sp. Type, no. 11222, Coll. Invert. Palae. Univ. Calif., loc. 1131. Approximately twice natural size.

Fig. 5. *Turritella diversilineata* Merriam. Type, no. 11224, Coll. Invert. Palae. Univ. Calif. From Carmanah Point, Vancouver Island.

Fig. 6. *Potomides* (*Cerithidea*) *branneri,* n. sp. No. 11225, Coll. Invert. Palae. Univ. Calif., loc. 52. Natural size.

Fig. 7. *Fusinus* (*Priscofusus*) *hecoxi* Arnold. No. 11226, Coll. Invert. Palae. Univ. Calif., loc. 1131, Natural size.

Fig. 8. *Sinum scopulosum* (Conrad). No. 11259, Coll. Invert. Palae. Univ. Calif., loc. 3. Natural size.

Fig. 9. *Actaeon kirkerensis,* n. sp. Type, no. 11254, Coll. Invert. Palae. Univ. Calif., loc. 76. Natural size.

Fig. 10. *Pseudoperissolax merriami,* n. sp. Type, no. 11161, Coll. Invert. Palae. Univ. Calif., loc. 2033. Natural size.

Fig. 11. *Agasoma acuminatum* Anderson and Martin. No. 11239, Coll. Invert. Palae. Univ. Calif., loc. 1310. Natural size.

Fig. 12. *Dentalium radiolineata,* n. sp. Type, no. 11227, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 13. *Potomides* (*Cerithidea*) *branneri,* n. sp. No. 11230, Coll. Invert. Palae. Univ. Calif., loc. 52. Approximately twice natural size.

Fig. 14. *Calliostoma lawsoni,* n. sp. No. 11228, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

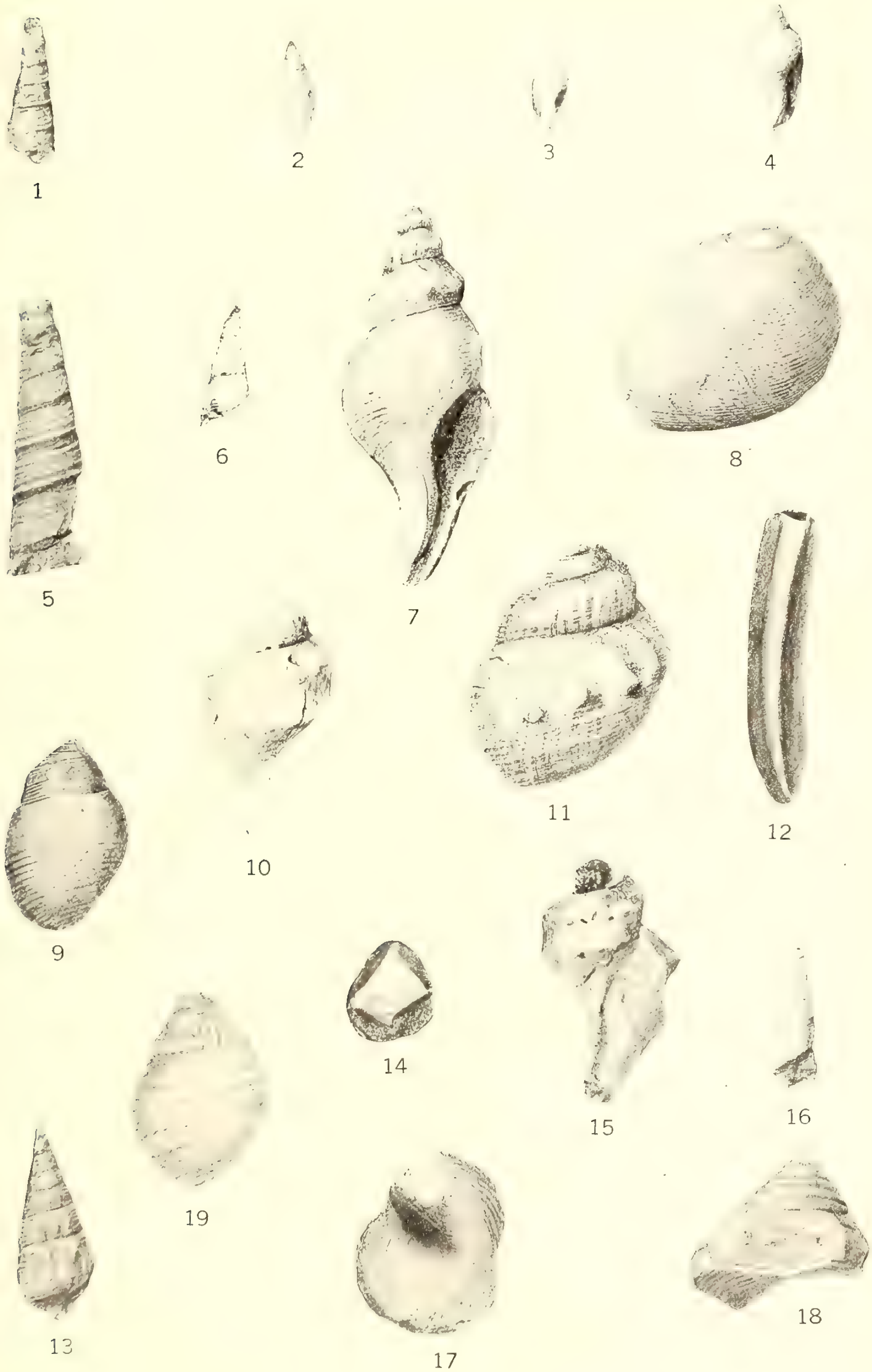
Fig. 15. *Pseudoperissolax merriami,* n. sp. Same specimen as fig. 10, natural size.

Fig. 16. *Potomides* (*Cerithidea*) *branneri,* n. sp. Type, no. 11229, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 17. *Calliostoma lawsoni,* n. sp. Type, no. 11231, Coll. Invert. Palae. Univ. Calif., loc. 331. Natural size.

Fig. 18. *Calliostoma lawsoni,* n. sp. Same specimen as fig. 17, natural size.

Fig. 19. *Agasoma gravidum* Anderson and Martin. Natural size.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EXPLANATION OF PLATE 23

Fig. 1. *Turris altuscollus*, n. sp. Type, no. 11232, Coll. Invert. Palae. Calif., loc. 1131. Natural size.

Fig. 2. *Perse corrugatum*, n. sp. Type, no. 11233, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 3. *Murex (Ocinebra) sobrantensis*, n. sp. Type, from a wax cast, no. 11234, Coll. Invert. Palae. Univ. Calif., loc. 1164. Natural size.

Fig. 4. *Cancellaria andersoni*, n. sp. No. 11235, Coll. Invert. Palae. Univ. Calif., loc. 1309. Natural size.

Fig. 5. *Agasoma gravidum multinodosum*, n. var. Type, no. 11266, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 6. *Cancellaria sobrantensis*, n. sp. Type, no. 11238, Coll. Invert. Palae. Univ. Calif., loc. 2754. Natural size.

Fig. 7. *Cancellaria Ramonensis*, n. sp. Type, no. 11237, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 8. Clavella californica, n. sp. Type, no. 11238, Coll. Invert. Palae. Univ. Calif., loc. 76. Natural size.

Fig. 9. *Cancellaria* sp. A. No. 11241, Coll. Invert. Palae. Univ. Calif., loc. 14. Natural size.

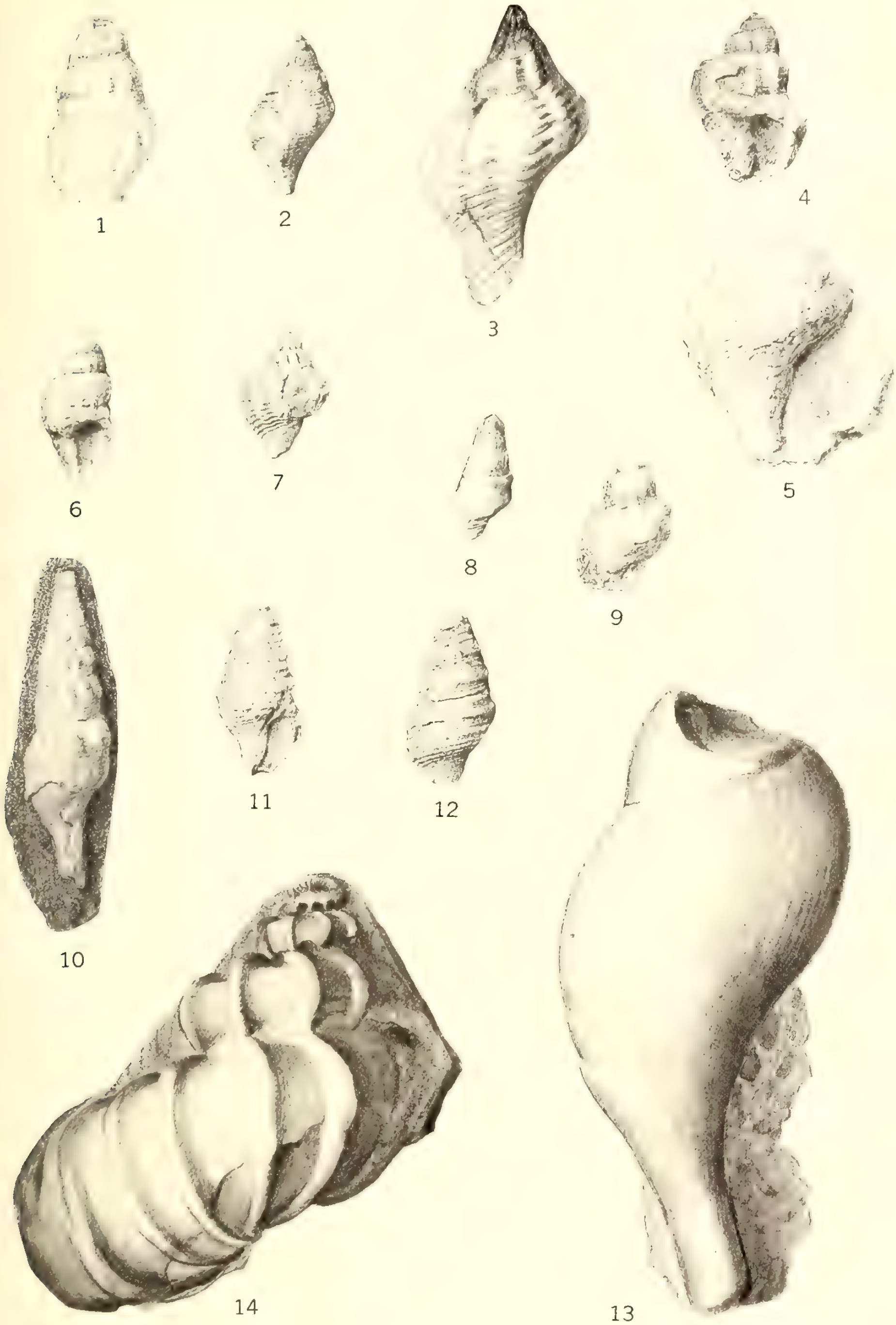
Fig. 10. *Fusinus (Exilia) lincolnensis* (Weaver). No. 11242, Coll. Invert. Palae. Univ. Calif. From near the top of the Kreyenhagen formation to the north of Coalinga. Natural size.

Fig. 11. *Turris (Pleurotoma) thurstonensis* Weaver. Type, no. 11243, Coll. Invert. Palae. Univ. Calif., loc. 1131. Natural size.

Fig. 12. *Turris (Pleurotoma) thurstonensis* Weaver. Same specimen as fig. 11, natural size.

Fig. 13. *Miopleiona* sp. No. 11244, Coll. Invert. Palae. Univ. Calif., loc. 1165. Natural size.

Fig. 14. *Epitonium ventricosum*, n. sp. Type, a wax cast, no. 11240, Coll. Invert. Palae. Univ. Calif., loc. 1165. Natural size.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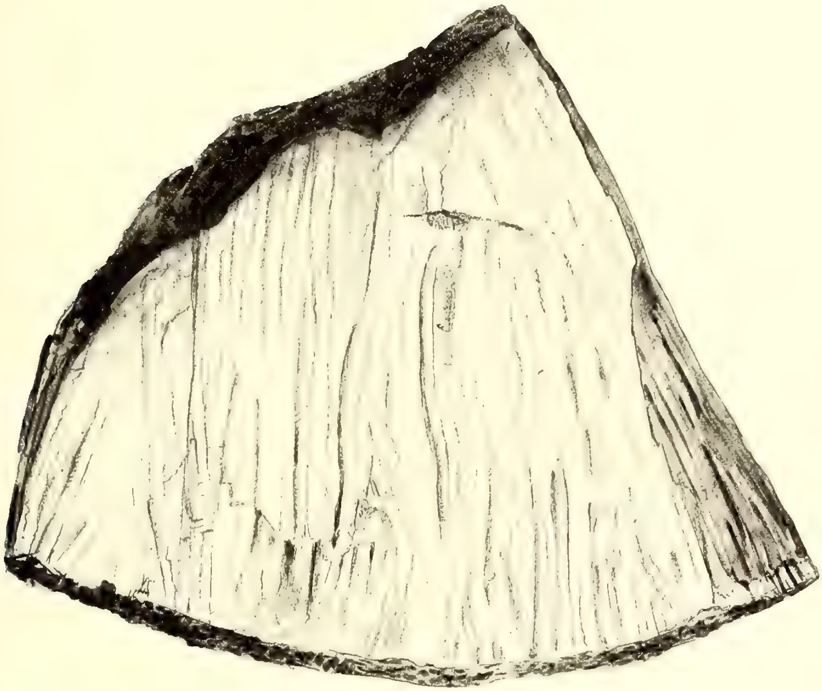
EXPLANATION OF PLATE 24

Fig. 1. *Serpula rectiformis,* n. sp. Type, no. 11262, Coll. Invert. Palae. Univ. Calif., loc. 52. Natural size, a detail of one end.

Fig. 2. *Serpula rectiformis,* n. sp. Same specimen as fig. 1; a side view, natural size.



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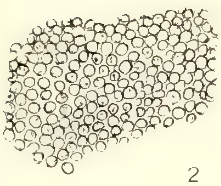

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BULLETIN OF THE DEPARTMENT OF
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Vol. 11, No. 3, pp. 235-432, 16 text-figures, plates 25-36   December 23, 1918

THE RADIOLARIAN CHERTS OF THE FRANCISCAN GROUP

BY
E. F. DAVIS

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

The Franciscan group contains several remarkable lithologic types, of which the most interesting are probably the radiolarian cherts. These rocks are seen throughout the Coast Ranges of California and have aroused the interest and excited the curiosity of geological workers from the earliest explorations of the state down to the present time. The opportunities for the study of these rocks in the region around the Bay of San Francisco are excellent. Not only are they exposed in many road cuttings and quarry sections on the San Francisco and Marin Peninsulas, but they may also be examined in numerous sea cliffs. The visitor to San Francisco may inspect these rocks with little effort at several places within the city, notably in Golden Gate Park and on the Twin Peaks Boulevard.

The present paper presents the results of an investigation undertaken primarily for the purpose of determining the origin of the radiolarian cherts. During the progress of the work a study was made of the bedded cherts of the Monterey group, which are, in certain respects, similar to the Franciscan cherts.

The writer would make grateful acknowledgement of his obligation to Professor Andrew C. Lawson for numerous suggestions and much friendly criticism during the progress of the investigation and the preparation of the manuscript. He is similarly indebted to Professor George D. Louderback, who originally suggested the problem to him.

THE FRANCISCAN GROUP

Rocks of the Franciscan group are found throughout the California Coast Ranges, extending from the Santa Ynez Mountains northward into Humboldt County. Further north they appear again in the southern end of the Oregon Coast Ranges and also in the Olympic Mountains of Washington. The total extent of the Franciscan terrane along the Pacific Coast is, therefore, in the neighborhood of 1000 miles.

Over this great extent it shows a striking uniformity. It comprises several unusual rock types the peculiarities of which, even to minute details, persist throughout.

The sedimentary portion comprises arkose sandstones, radiolarian cherts and foraminiferal limestones with subordinate shale and conglomerate. Estimates of its thickness range from 5000 to 20,000 feet.

The sandstone, which makes up the greater part of the sedimentary portion, is a massive, firmly cemented rock, breaking like quartzite through the grains as well as through the cement. It is pale bluish to greenish in color when fresh, but disintegrates easily when exposed to the action of the weather. The constituent grains are very angular and comprise notable amounts of feldspar and ferromagnesian minerals. The sandstone contains small lenses of conglomerate and there is some admixture of shale. Fossils are extremely rare and the formation appears to have been, in large part, a continental deposit laid down by aggrading streams in an arid region.[1]

The limestone formation (Calera limestone) is of limited thickness, being sixty feet thick on the San Francisco Peninsula. Limestone may occur in lenses in the sandstone. It is usually white to gray in color, but is sometimes dark and fetid. It contains numerous foraminiferal shells. There is considerable chert in the limestone in the form of nodules, patchy lenses and blanket-like masses.

The strata are cut by numerous masses of basic igneous rocks of several types. Basalts and diabases, showing an ellipsoidal or pillow structure are common. These are unquestionably intrusive into the Franciscan sediments at many places in the California Coast Ranges. At other localities pillow basalts show no evidence of intrusive action and represent contemporaneous lava flows. Associated with the pillow basalts, are various basic rocks without pillow structure. These

[1] Davis, E. F., The Franciscan Sandstone, Univ. Calif. Publ., Bull. Dept. Geol., vol. 11, pp. 1–44, 1918.

occur as intrusive masses and also as lava flows interbedded with sandstones or cherts. Intrusive bodies of peridotite, now altered to serpentine, form a conspicuous part of the Franciscan terrane, and with these are intimately associated gabbros, pyroxenites and related rocks.

In the vicinity of intrusive masses of pillow basalt or serpentine there are at many places small irregular areas of metamorphic rocks produced by the contact action of the intrusives. These include glaucophane and crocidolite schists, mica schists, lawsonite schists, actinolite schists, garnetiferous schists, and many other varieties. The schists containing blue soda amphiboles are the most characteristic and are very common. In addition to glaucophane and crocidolite, several other blue amphiboles are found in these rocks. It is customary to speak of them in a general way as "glaucophane schists."

THE RADIOLARIAN CHERTS OF THE FRANCISCAN GROUP

The sandstone of the Franciscan group is, in the region around San Francisco Bay,[2] divided into three formations by the presence of two horizons of radiolarian chert. The following tabulation will indicate the disposition of these formations:

Bonita sandstone	1400+ feet
Ingleside chert	530 "
Marin sandstone	1000 "
Sausalito chert	900 "
Cahil sandstone	2000 "
Calera limestone member	60 "
Cahil sandstone	500+ "

Base not known.

It is not possible to separate the two chert formations lithologically; they can be distinguished only by stratigraphic relations and a description of the varieties of chert in one formation will apply equally well to the varieties found in the other.

[2] Lawson, A. C., San Francisco Folio, U. S. Geol. Surv. Folio no. 193, 1914.

Nature of Contacts Between Chert and Sandstone

In mapping, it is usually easy to distinguish the line of contact. The sandstone generally weathers easily, giving rise to soil with smooth, grassy slopes. The chert areas even on gentle slopes are usually covered with a thinner and poorer soil in which are embedded large numbers of chert fragments; where the chert is massive there are numerous bold outcrops. As a rule there is a thickness of several feet of shale between the sandstone and the chert. This shale is soft and easily affected by the weather, so that it presents no outcrops. Readjustments between the two formations in this zone of soft rock have, in many instances, caused the shale to be greatly sheared and disturbed. Owing to these circumstances one finds the best sections across the contact in artificial cuttings or in cliff sections along the coast.

Near the end of the Twenty-fourth and Hoffman street-car line in San Francisco a section exposed in the side of a street-cut shows the nature of one of these contacts. Here the Ingleside chert rests upon the Marin sandstone. The sandstone at the base of the section is of the ordinary type found in the Franciscan. This passes gradually into a soft gray shale about four feet thick. Above this is a six-inch bed which resembles a greatly altered tuff. Above this are radiolarian cherts of the usual kind.

At Rock Ridge Quarry in Oakland, the contact of the Sausalito chert and the Cahil sandstone is well exposed in the east wall of the old quarry. At the base, there is a sandstone rather rich in carbonaceous material, which passes gradually into a gray shale of the ordinary variety, about a foot thick. Above this is a fine grained, green shale quite different from the gray shale beneath and exactly like the green shales interbedded with some of the green radiolarian cherts. The contact between the green and the gray shale is sharply marked and the two may be easily separated with the point of a pick. The green shale passes up into a red shale of the type found interbedded with red radiolarian cherts. The change from the green shale to the red shale occurs within an inch or two and consists simply in a gradual transition in color. The red and green shales together make up about two feet of the section, there being about a foot of each. The red and green shales differ from the underlying gray shale in that they are finer grained, more compact and a trifle harder. Immediately above the red shale there are red radiolarian cherts consisting of alternating bands of chert and shale, having a total thickness of four to four and a half feet. Above the cherts is a bed of fine red shale, one to two feet thick, identical with the red shale below. This bed is disturbed somewhat by a flow of pillow basalt which rests above it.

On the east side of Red Rock Island, in San Francisco Bay, there is a contact between chert and sandstone. It has been intruded by igneous rock and somewhat broken, but there are several feet of gray shale between the sandstone and the chert at this place.

At Fort Baker in Marin County, a contact is exposed in the military road, which shows several feet of shale between the sandstone and the chert.

On the Twin Peaks Boulevard in San Francisco, just across from the reservoir, a contact of chert and sandstone has been exposed in the road cut. Here the shearing has been so great that the relations are not very clear. The shale between the two formations is rather thick—probably fifteen to twenty feet—and for the most part it is very fine grained and unlike ordinary shale.

In Perkins Creek on the north side of Mount Diablo, a more abrupt contact may be seen. The cherts are dark gray to pale pink in color. Between the cherts and the sandstone are five inches of fine grained gray shale which represents the extent of the sedimentation between the sandstone and the chert.

Fairbanks[3] has described abrupt changes of sandstone to chert in certain sections in the San Luis quadrangle.

Occurrence of Chert in Lenses

Beside the larger areas already mentioned, which mark out definite horizons and constitute distinct formations, there are great numbers of smaller bodies of chert exposed in the Franciscan terrane. These appear as patches, irregularly distributed through the sandstone. The cherts in these smaller masses are in every way like the cherts of the larger formations. The size of these bodies varies considerably. Some are fairly large, covering several acres, while many are small and cover only a few square yards. Around these outcrops the soil indicates the presence of sandstone. These isolated masses are very numerous in certain regions. South of San Francisco, in the southern

[3] Fairbanks, H. W., San Luis Folio, U. S. Geol. Surv. Folio no. 101, 1904.

end of the San Mateo quadrangle, this sporadic distribution of isolated chert masses in sandstone is quite marked. The mapping shows scores of small isolated areas of chert within sandstone. In the area around Mount Tamalpais there is no horizon of chert persistent enough to be mapped as a definite formation, but there are many lenslike masses scattered through the sandstone.

This peculiar tendency to lenslike distribution has been noted by many geologists who have studied the radiolarian cherts. Professor Lawson described it in his first report on the San Francisco Peninsula.[4] Ransome found the same distribution at Angel Island,[5] where there are numerous small, isolated masses of chert within the sandstone. In the Santa Cruz Folio,[6] the statement is made that the Franciscan cherts of the Santa Cruz quadrangle occur in lenses. Smith has described the occurrence of lenses of radiolarian cherts in the Philippine Islands. Perhaps the most extreme case of this lenticular occurrence of radiolarian chert is found in the San Luis quadrangle. Fairbanks[7] mapped and described the radiolarian cherts of that area as being altogether in the form of discontinuous lenses. The map shows a large number of small lenses in the sandstone. These are described as reaching a maximum thickness of 100 feet. It is stated that occasionally an individual outcrop may be traced for a mile or more, but most of them are much shorter. It is suggested that some of them may be continuous for longer distances but are not traceable on account of the narrow outcrop. The number of lenses in a given stratigraphic section varies from place to place. In one locality six lenses occur in about 2000 feet of strata.

In spite of the suggestive distribution of these isolated patches, when they are actually examined in the field one feels that there may be room for doubt in interpreting all of them as lenses, deposited as such and surrounded by sandstone. The doubts are somewhat increased when one remembers that in Scotland,[8] where occurrences of radiolarian chert were studied with much care and in the greatest detail, no mention is made of lenslike bodies of this sort.

[4] Lawson, A. C., Sketch of the Geology of the San Francisco Peninsula, 15th Ann. Rep. U. S. Geol. Surv., pp. 401–476, 1895.

[5] Ransome, F. L., The Geology of Angel Island, Univ. Calif. Bull. Dept. Geol., vol. 1, pp. 193–240, 1894.

[6] Branner, Newsom and Arnold, U. S. Geol. Surv. Folio no. 163, 1909.

[7] Fairbanks, *op. cit.*

[8] The Silurian Rocks of Britain. I, Scotland, Mem. Geol. Surv. United Kingdom, 1899.

There are perhaps three interpretations which could be put upon these small isolated areas of chert:

1. They may be exactly what they appear to be—local depositions of chert in lenses which were finally surrounded and buried by the accumulation of sandstone.

2. They may be merely residuals of erosion, left as a result of the removal of an overlying body of chert.

3. They may represent small blocks which have been let down into or thrust out upon the sandstone by faults.

It is very difficult in certain instances to be sure of the correct interpretation. This uncertainty is brought about by the lack of good exposures in which to observe the nature of the contact of the sandstone and the chert, and by the lack of bedding planes over large areas of the sandstone. That some of these isolated outcrops are due to faulting is unquestionable, since fault contacts may be seen. Fairbanks[9] believed, at one time, that the apparent lenslike distribution was due to intense crushing and faulting of the Franciscan, causing the chert to appear at many points in separated areas. This would require an immense amount of minor faulting, and as Professor Lawson pointed out in objection, the disturbance of the earlier formations of the Coast Ranges has certainly not been so great as this. At a later time, writing in the San Luis Folio, Fairbanks specifically states that the cherts of the San Luis quadrangle occur in lenses. The second explanation would undoubtedly prove to be true in some instances.

While the two explanations above suggested—faulting and differential erosion—are surely correct in certain instances, it seems improbable that all the minor areas of chert can be explained in this way. In localities where these lenses are quite numerous, as in the San Luis quadrangle, their explanation by faulting would involve an extremely complicated system of cross faults, which is not borne out by the general character of the Franciscan where well exposed. In the region south of San Francisco, the mapping of the lines of contact between the larger chert formation and the sandstone shows that there is none of this intricate cross faulting in that area. Yet in that region there are great numbers of small isolated areas of chert in addition to the larger body.

To explain them all as due to a combination of infolding and erosion would be incorrect. In many of these small masses, the dip

[9] Fairbanks, Bull. Geol. Soc. Am., vol. 6, p. 85, 1894.

of the bedding of the cherts is nearly vertical and this relation is found everywhere across the outcrop of the lens. In order to explain these uniform steep dips in the small chert masses by the hypothesis of infolding, it would be necessary to assume that the folds were of the nature of very closely appressed anticlines or synclines. Nothing in the Franciscan justifies this assumption. While the cherts themselves are often intensely contorted, this is due to incompetence of the cherts and the consequent local readjustments within their mass. The contact planes between the larger formations of chert and sandstone, as revealed by field mapping, show absolutely no sign of such close folding. Where sandstone is bedded with shale a similar condition is found. While the dips may be steep there is no evidence of the intense plication required by the hypothesis under discussion.

Moreover, small lenses of radiolarian chert with dimensions of only a few feet are sometimes exposed in sections. On Mount Tamalpais an instance of this sort may be seen on the curve of the railroad near the saddle between the two summits. Here a small lens of radiolarian chert showing shale partings is exposed in the side of the railroad cut. It is not over five feet in diameter and is entirely surrounded by sandstone.

In the quarry across from the cemetery in the region of the Claremont Country Club, in Piedmont, there is a sandstone-chert contact. A few feet above the top of the main chert body and entirely separated from it there are lenticular bodies of rather massive chert, embedded in the sandstone.

Roderick Crandall[10] has described such an occurrence in San Francisco:

> Besides the large areas of jasper, there are small areas in various places throughout the Coast Ranges that do not seem to belong to the main beds. These may possibly be erosion remnants left by the removal of the larger masses, or it may be that the organisms forming the jaspers survive in colonies that form small lens-shaped masses. This latter suggestion receives support by evidence found at a place in the cliffs near Golden Gate Strait, where about six or eight inches of jasper appears in the sandstone several feet below the bottom jasper beds. The small bed appears to show the arrival of the first condition that allowed the development of the organisms followed by a period of slight change with sandstone and final settling down to the quiet conditions in which the larger deposits were laid down.

[10] Geology of the San Francisco Peninsula, Proc. Am. Philos. Soc., vol. 46, p. 48, 1907.

Bedding of the Cherts

TWO TYPES OF CHERT

The Franciscan cherts vary somewhat in their nature, but they may be separated into two main types according to the relative proportion of shaly material which they contain.

Cherts of the well bedded type consist of layers of chert alternating with shale. The layers of chert usually range in thickness from half an inch to three inches. They are rarely less than a quarter of an inch thick and sometimes reach a thickness of a foot or more. The average thickness is about two inches. The shale partings vary from mere films up to beds three or four inches thick. The usual range of thickness of shale in well bedded cherts is between one-eighth inch and one inch. The average thickness of the shale partings in the well bedded varieties is between one-quarter and half an inch. Occasionally much thicker bedding is seen; in rare cases the chert beds may be eighteen to twenty-four inches thick while the shale partings are six to eighteen inches thick.

The separation between the chert and shale is clean cut; there is no gradation between them. In some sections of well bedded cherts, hundreds of separate beds are visible in rhythmic alternation (plate 25A and plate 26A). Generally the well bedded varieties are red, or brownish red, in color. Less commonly they are green, black, white, yellow-gray, or rarely purple. Almost invariably the color of the shale is the same as that of the associated cherts.

The massive type of chert differs from the well bedded type in that the shale partings are very thin. Usually the massive cherts are white or gray, and the shale which is present in the partings is pale gray in color. Occasionally a red chert with thin films of red shale shows this massive character, but such occurrences are not common; the red cherts are usually well bedded. The thickness of separate layers of chert in the massive type is about the same as in the well bedded type.

The massive cherts stand up in bold outcrops, and in the areas occupied by them, large isolated blocks of rock appear ranging up to ten feet in diameter, while locally, where they have not been greatly fractured, the outcrops present high, steep cliffs. The well bedded cherts with thick shale partings, on the other hand, seldom outcrop boldly. One may go over considerable areas of chert without finding any well developed beds of shale exposed in natural outcrops. While the slopes underlain by this type of chert may be steep, they are usually smooth and free from large rock masses. In order to get good exposures of well bedded cherts it is usually necessary to seek artificial cuts or sea-cliffs, or look in the trenches of streams which are rapidly cutting downward.

Massive chert may occur as lenses within a formation of well bedded chert, so that one gets prominent outcrops of the former in areas over which there are otherwise no outcrops, but in which the presence of well bedded chert is indicated by the angular fragments in the soil.

CONTORTION OF CHERTS

The well bedded varieties of chert, and occasionally the more massive varieties, are often greatly disturbed, showing intricate plications. Since the associated sandstones are not thus folded it would appear that during the deformation of the Franciscan group there had been a considerable localization of movement in the chert formations. The presence of many bands of shale makes the chert incompetent and susceptible to folding. Plate 25A shows the character of this deformation.

BRECCIATION OF CHERTS

Some of the cherts are traversed by numbers of fissures, so that they break into a great number of little splinters. Others are traversed in all directions by lines of slight discoloration, and it appears probable that these lines represent former fissures in the chert which have been recemented.

In some places, the deformation of the chert has been more rapid or more intense, so that large masses of chert have been brecciated and the bedding entirely obliterated. Often these chert breccias are recemented so that the rock is nearly as strong as an ordinary chert. Near faults, the brecciation has, in some cases, been so intense that the component particles are too fine to be seen with the eye, giving a very fine grained rock with an irregular granular fracture. In some places the brecciated chert is white, earthy in appearance, and crumbles under the hammer instead of breaking into blocks.

MINOR IRREGULARITIES IN BEDDING

When one looks at a section of well bedded, red chert, he gets the impression that the individual beds of chert and shale are persistent. In many instances they are so for limited distances, and it is sometimes possible to trace a single bed of chert, in an outcrop, for as much as thirty feet. However, when chert beds are examined in detail, it is found that they are not so continuous as they seem at first sight. The bedding is often interrupted by numbers of cross faults of small throw and it shows a variety of other irregularities. Since it is believed that these irregularities cast light on the question of the genesis of the chert, they will be described in some detail.

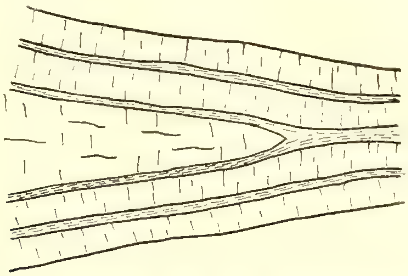

Fig. 1. Beginning of a lens of massive chert.

At various places throughout well bedded cherts there are lenticular masses of chert of considerably greater thickness than the adjacent beds, ranging from one to eight feet in thickness and in length from five to thirty feet. They are usually lighter in color than the enclosing thin bedded cherts. Figure 1 indicates the beginning of a lens of

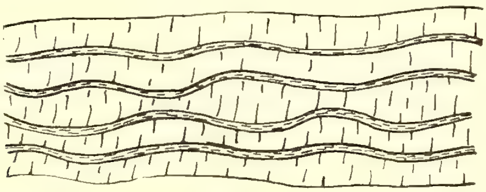

Fig. 2. Pinching and swelling of beds of chert.

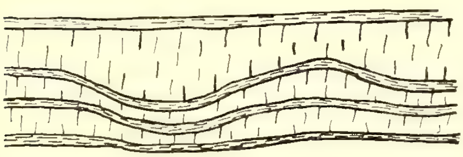

Fig. 3. Pinching and swelling of beds of chert, showing manner in which irregularities in thickness are compensated.

this sort, showing the way in which the surrounding beds accommodate themselves to it.

A very common feature is the pinching and swelling of chert beds; it may be seen in almost any section of the chert and is illustrated in figures 2 and 3 and plates 25B, 27A, B, and 28A. The usual range of pinching and swelling is indicated by the illustrations.

In this pinching and swelling, the thickening of one bed is quickly compensated by the thinning of adjacent beds. In this way, beds which show noticeable thickening and thinning may lie between beds which are evenly bounded and uniform in thickness. The pinching and swelling is not due to thickening and thinning of the beds in folding. This is shown by the fact that the thick parts and the thin parts have, as a rule, no regular distribution, and show no relation to the axes of folding. Pinching and swelling occurs in beds which are not greatly contorted. There is some thickening and thinning in folds, but the greater part of the variation in thickness does not have this origin.

Another peculiarity of bedding is the occurrence of rounded knobs on the surface of the chert beds (center of plate 27A). The chert may have a fairly uniform thickness over an area of a few square feet, but at one point there is a piling up of the chert substance in a small mound or knob. The nature of the chert in the knob is exactly like that of the rest of the bed, so that the cause of the swelling is not due to differences in material. In this respect these knobs are distinct from certain concretionary masses found in the cherts. The knob is limited to a single bed, and its irregularity is quickly compensated by variations in the beds above. These knobs are very common in the well bedded cherts. Their dimensions are generally not very large; the whole knob may have an area much less than a square foot, and the increase in thickness may be as much as two inches. Figure 4 shows a case where a thin shale parting disappears when it runs into a knob of this sort. This figure illustrates a case where the knob affects both the top and bottom of the bed. Often only one side is affected.

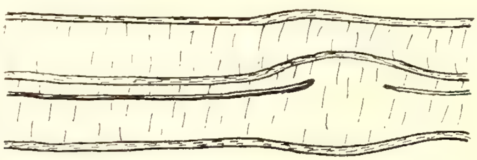

Fig. 4. Termination of shale parting at a place of unusual thickness in a chert bed.

The cherts sometimes occur in short lenses and in nodules, some of which are unusually thick (figures 5–7). These occasionally are two feet in horizontal dimensions and as much as six inches thick. The adjacent beds curve around such large masses, but by variations in thickness of adjacent beds of chert and shale, the disturbance in bedding dies out quickly. In some instances, a chert bed may die

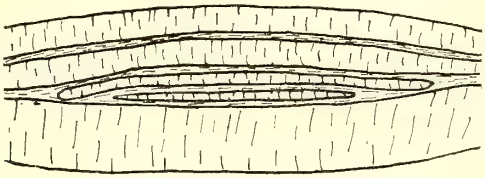

Fig. 5. Occurrence of minor lenses of chert.

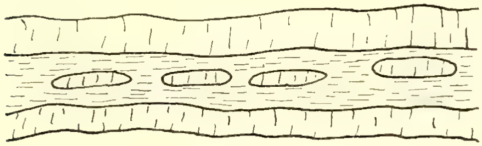

Fig. 6. Occurrence of chert in a chain of nodules.

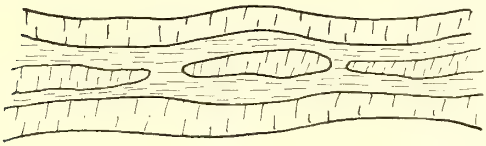

Fig. 7. Nodule of chert lying between ends of two beds.

away for a short distance, and its place may be taken by a little chain of separated chert nodules. In other cases a chert layer simply ends, and the shale partings on either side come together again as shown in figure 8. These occurrences illustrated in this last figure are ex-

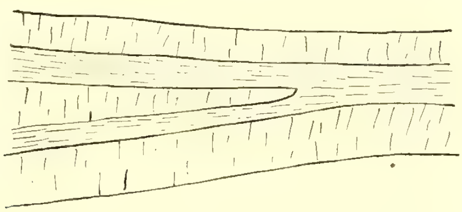

Fig. 8. Termination of a chert bed.

tremely common and may be found by careful examination of almost any section of the chert. In some places, large numbers of lenslike masses having the relations illustrated in figure 9 and plate 28B, may be observed in a section having an area of only a few square feet. The terminations are not always wedgelike, as indicated in some of the figures, but are frequently rather blunt with rounded ends, as shown in plate 28B.

The terminations of beds in the manner indicated in the illustrations are not limited to the chert layers. The shales often terminate in the same manner, so that two bands of chert come together and unite in a single layer (plates 26A, 27A and B). As a rule, in the Franciscan cherts, it is more common for the cherts to show this wedging-out than for the shales to show it. This is a point of contrast with the Monterey cherts. In the Monterey cherts the terminations of shale are rather common, being found about as often as wedge-like terminations of chert beds.

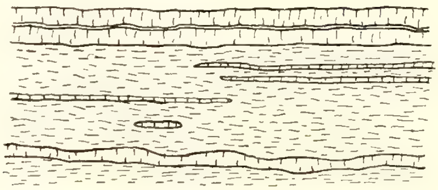

Fig. 9. Minor lenses and nodules of chert in a thick bed of shale.

Some beds of chert show thin, lenslike strips of shaly material included entirely within the mass of the chert, and (plate 25B) occasionally the separation between the included shaly layers and the adjacent chert is not sharp but is in the nature of a transition. They differ in this way from the shale partings between beds of chert which, as already stated, are always sharp and clean cut.

In certain instances one may find very thin ribs of chert in the shale partings between two chert beds of ordinary dimensions. These are not persistent, but die away quickly when traced for a few inches or a few feet.

CONCRETIONARY CHERTS

The radiolarian cherts show, rarely, a kind of structure which, for want of a better term, will be referred to as "concretionary." In the Santa Ynez Mountains concretionary cherts of this sort are found at two points, one in Aleso Cañon and the other at Red Rock on the San Marcos ranch. Structures of this type are also found in the outcrops of chert on Arch Street in North Berkeley. Here and in Aleso Cañon the concretions occur in red chert which is rather massive and does not show well developed shale partings. At Red Rock the concretions are found in well bedded red chert. At all these places the concretions are very abundant.

They stand out on exposed surfaces. The chert in which they are found appears to be of the normal red type, containing numerous radiolaria. The form of the concretions is ellipsoidal or irregular, showing subangular boundaries with rounded corners. Some occur in the form of elongated masses, which may be regular or extremely irregular. The photographs on plate 29 show a few of these concretions. Plate 29A is a fractured surface on which some of the concretions are revealed in section.

Occasionally concretions are found in chert which is banded with manganese oxide. In this case the bands may show a deflection around the periphery of the concretions, or the bands may abut upon the borders of the concretion.

The concretions in North Berkeley are often separated from the matrix which contains them by a coating of soft red shale, identical with the red shale which ordinarily forms the partings between the beds of chert. Many concretions at this locality, however, do not show this rim of red shale. In the occurrences in the Santa Ynez Mountains, red shale was not noticed surrounding the concretions. There, a thin layer of manganese oxide may surround the concretion. In many cases, there is no coating of different material around the concretion, but it is differentiated from the matrix by color or physical nature of its substance.

The material of the concretions is found to be much like that of ordinary radiolarian cherts. The principal difference between the concretion and the matrix is usually in color. The color of the concretion may be red, yellowish, pink or white. Often it is pale pink in color, showing irregular streaks of red or white material. One or two instances are found where a single band of different color appears within the concretion nearly concentric with its center. Usually there is not the slightest indication of regularity in these streakings. Some concretions consist of material nearly white in color and somewhat more granular than ordinary chert, and containing scattered grains and streaks of manganese oxide.

Petrographic Features of the Radiolarian Cherts

Chert, according to Van Hise,[11] is a general term used to include all forms of finely crystalline, non-fragmental silica, including opaline, semicrystalline and completely crystalline varieties. It is dis-

[11] A Treatise on Metamorphism, U. S. Geol. Surv. Monograph 47, 1904.

tinguished from quartzite in that it is non-clastic. The term, chert, includes both organic and chemical deposits. The definition would include the true jaspers, which consist of finely crystalline quartz, stained with iron oxide.

The Franciscan cherts show many variations in lithologic nature. They are composed of several forms of silica—both amorphous and crystalline. They show numerous variations in color and in general appearance. The most common variety is the red to brownish-red chert which is well bedded with shale. Beside these red cherts there are very often found green, gray and white varieties. Yellow, brown, black, purple, blue and clear colorless varieties are also encountered.

THE RED CHERTS

Typical Red Cherts. The typical red cherts, which are the most common variety, may be described as deep brownish-red in color, showing a smooth conchoidal fracture and breaking with sharp edges. Occasionally the fracture is irregular or hackly. The luster is dull vitreous, inclining to waxy. The rock is dense and compact in texture and is rather hard, ranging between six and seven of the ordinary scale of hardness. Within the red siliceous matrix there are darker spots of clear silica, barely perceptible to the naked eye, which represent the remains of radiolaria. Rarely these spots are white and stand out very distinctly from the matrix. In any case the spots are better seen when the surface of the rock is moistened. With a hand-lens, the spots are ordinarily quite distinct and, in a few specimens, it is possible to make out some of the structures of the radiolaria.

Generally the cherts are thin bedded and this fact in conjunction with the prevalence of jointing, causes them to break down into small fragments. Exceptional specimens from thicker beds are massive and do not break up in this way. Spear-heads, brought from the region of Humboldt Bay in northern California, made by Indians from fragments of red chert, are eight inches long. Occasionally one may find in creek beds, solid blocks of red chert having diameters between six inches and a foot.

In thin section, the red chert is seen to consist of a very fine grained siliceous matrix, colored by disseminated grains of red iron oxide. In this red, semitranslucent to opaque matrix there are minute areas of clear silica usually circular or elliptical in outline. These clear spaces represent the radiolaria, and when the rock has not been too much changed by crystallization of the matrix, they show distinctly the spines, characteristic outlines, and in a few cases, even the internal lattice structure of these organisms.

In most instances, the matrix of the rock consists of a microgranular aggregate of chalcedonic silica. Each separate grain shows a fibrous wavy extinction, the direction of which is different from that in adjoining grains. The grains appear to interlock in a fine mosaic. Lying between these grains, and included in them, are numerous specks of red iron oxide, which give the matrix a deep red color. In some instances this material is so abundant that the matrix is practically opaque and appears as a dark red translucent mass in which no detail is observable. Occasionally the matrix consists of quartz grains without fibrous crystallization. While the matrix, in most of the thin sections examined by the writer, consists entirely of anisotropic silica of the kind described above, there were a few in which the matrix is not crystalline but amorphous. One section examined was almost entirely isotropic, showing only here and there a minute grain of polarizing material. Several others showed considerable irregular areas of polarizing silica with residual patches of isotropic material.

These facts, with their probable meaning, have been well described by Professor Lawson,[12] in the following words:

> If a selected series of thin sections of these cherts is viewed under the microscope they present a gradation from those that are composed almost wholly of amorphous or isotropic silica to those that are a holocrystalline aggregate of quartz granules. The most isotropic sections, however, exhibit numerous minute scattered points that polarize light and that cannot be sharply separated, even by the highest powers, from the isotropic base. These points are not inclusions; they are centers of incipient crystallization in the amorphous rock, corresponding to the products of devitrification in glass. In other sections these centers of crystallization are much more thickly crowded and well-defined areas composed of interlocking granules of quartz appear, interlocking also with the isotropic base. The actual boundaries of these areas can be made out only with difficulty and uncertainty, owing to the fact that the quartz grains are under molecular strain, which produces undulatory extinction as the stage is revolved between crossed nicols. In still other sections these areas coalesce and the proportion of amorphous base to the whole rock is very small. Finally, some sections show a holocrystalline aggregate of interlocking quartz grains. Most of the grains are under molecular strain, as is shown by undulatory extinction, and somewhat resemble chalcedony. The discrimination between the amorphous and the crystalline silica is easy in those varieties of the rock that contain little iron-ore pigment but becomes more difficult as the abundance of the obscuring pigment increases. The gradation thus observed in a series of thin sections prepared from specimens taken at random seems clearly to be a gradation in time and not merely a gradation in space.

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[12] Lawson, San Francisco Folio, *op. cit.*, p. 5.

It indicates different stages of a process of crystallization in a solid amorphous mass. If this be granted there seems to be no good ground for doubting that in general the holocrystalline cherts, or jaspers, were originally amorphous silica, and that they have reached their present form by a process of crystallization quite analagous to that of devitrification in volcanic rocks.

Diller has described similar sections from some of the radiolarian cherts of the Port Orford quadrangle in Oregon, in which the matrix contains much amorphous silica. He, also, regards this as proof that the cherts were originally composed of amorphous silica which has undergone a process of crystallization.

It is extremely interesting to find that the cherts which show this isotropic matrix are rather hard—ranging from 6 to 7. The suggestion is strong that we have here a new mineral form of silica. This was noted by Professor Lawson[13] in his report on the Geology of the San Francisco Peninsula:

What is the mineralogical character of the amorphous silica? It is clearly not any one of the numerous cryptocrystalline varieties of silica. It is perfectly isotropic. If we refer to the books we find that opal is the only variety of silica which is strictly amorphous. But this differs from opal. A fragment of chert that showed a large proportion of isotropic base was found to scratch quartz distinctly with comparative ease. It has a specific gravity of 2.628, and although it yielded a little water in the closed tube, the amount of water was notably less than that derived from a corresponding quantity of common opal. We thus seem to have a condition of slightly hydrous amorphous silica much harder and much heavier than opal.

The present writer found a somewhat similar variety of silica in examining a specimen of chert brought from lake beds in the Great Basin. This chert was hard enough to scratch steel but powdered fragments of it were perfectly isotropic. The index of refraction was about 1.535.

The transparent areas, which represent the radiolaria, are usually free from iron oxide, and are the casts of originally hollow skeletons. These areas often show the external form of the organism, and in many instances portions of the delicate spines are preserved. In a few cases nearly perfect skeletons are found (plate 30). In looking over a suite of slides, one may see all degrees of preservation from nearly perfect fossils down to those in which the outlines can be made out with difficulty, and in which only the remnants of spines and external forms are preserved. In the extreme cases only irregu-

13 15th Ann. Rep. U. S. Geol. Surv., p. 423, 1895.

lar transparent spots can be seen in the iron stained matrix of the rock; these represent the nearly obliterated radiolarians.

On examining these transparent areas between crossed nicols, they present a strong contrast with the matrix, aside from the fact that they are free from iron oxide. They generally consist of chalcedony in which the fibrous structure is well developed, showing a negative elongation. In some instances the whole mass is a single spherulite of chalcedony in which the fibers all radiate from one common center. In many instances the areas may be divided into two or three definite sectors in each of which the fibers radiate from a single center. On rotating the stage, the characteristic black cross will be seen in each of these sectors. Occasionally the clear area is made up of an aggregate of fine grains and presents a gray mottled appearance between crossed nicols. Possibly this material is fibrous chalcedony cut normal to the fibers. Rarely there are grains of quartz filling the areas of the radiolarian tests. The particles which make up the matrix of the cherts usually have a much finer grain than those found in the radiolarian remains. In cherts in which the radiolaria are not well preserved, it is possible to locate their position between crossed nicols by this difference in the size of the grain.

The abundance of the radiolarian remains varies considerably. In some specimens they are quite sparsely distributed through the ferruginous matrix. In others, the clear spaces are so numerous that they almost touch, leaving little more than the interstitial spaces for the iron stained matrix (plate 30D). Plates 30A, B and C show the usual proportions of matrix and of radiolarian skeletons.

Shaly Cherts.—The red, shaly cherts are somewhat different in appearance. They contain a larger proportion of earthy material and iron oxide than the typical cherts. They have a dull luster and break with a rough fracture into irregular fragments. They are soft, as compared with the siliceous red cherts, and can be readily scratched with a knife. Often they are rather porous and absorb moisture readily. Examples of very soft shaly cherts are to be seen on Red Rock Island in the Bay of San Francisco, where they occur interbedded with unusually soft red shales.

Under the microscope these shaly cherts show a matrix so deeply stained with red iron oxide that it is practically opaque. The radiolaria are similar to those in the siliceous cherts save that they are much better preserved. In looking for material for a study of the radiolaria it was at first thought that the light colored cherts would be the most favorable on account of the greater transparency of the sections, but it was soon found that these highly siliceous cherts seldom show well preserved radiolaria. In thin sections of such rocks, the radiolaria are usually represented only by vaguely defined, rudely circular or elliptical areas a little clearer of inclusions than the rest of the section. Apparently, in cherts low in iron oxide and earthy material, when the amorphous silica began to crystallize there was little to preserve the outline of the original form, and there was a tendency for the silica of the matrix to merge with the silica of the radiolarian skeleton so that the sharpness of the original outline became lost. In the earthy variety there was not this tendency to fusion. The earthy material, besides its effect in preventing fusion of silica of the matrix with that of the skeleton, makes the radiolaria more readily visible because of the contrast between the clear areas and the dark base.

These shaly cherts differ from the siliceous red cherts in that it is possible to dissolve out a large part of their iron oxide with hydrochloric acid. A thin section of a typical siliceous red chert was boiled in 1:1 acid for several hours without producing any noticeable effect upon it. A thin section of a shaly red chert from Red Rock Island, rich in iron oxide, was treated with acid and most of the iron oxide dissolved. It was then apparent that the matrix was composed of a cryptocrystalline aggregate that showed a low birefringence and appeared to be chalcedony. The chert contained a few well preserved radiolaria, but after the acid treatment they became almost invisible.

One shaly chert, from Point Richmond, is peculiar in that it contains large amounts of a mineral that appears to be glauconite. This mineral ranges from a deep green to a pale yellowish green, and is non-pleochroic. It shows no definite structure or cleavage and occurs in masses of irregular form. The relief of the mineral is high and, on testing grains in suitable oils, it is found that the index of refraction is a little above 1.60. Between crossed nicols, it is seen to be a very fine grained aggregate. On rotating the stage, irregular wavy areas of darkness pass over the mineral, but the component grains cannot be made out with the highest powers. The birefringence ranges from almost zero to a little over .020; the variable values appear to be due to interference between overlapping scales or flakes of the mineral. In the shaly part of the rock some material is found that, from its optical properties, appears to be kaolinite. Here and there are seen some very fine irregular flakes of quartz.

There is no sharp distinction between the siliceous red cherts and the shaly red cherts. In fact, considering the red varieties alone, it would be possible, in a large number of specimens collected from various places, to arrange a gradational series from the most siliceous red chert down to the softest of the red shales. All varieties are found and some of the hand specimens, if seen alone, could with difficulty be classified as cherts or shales. While all intermediate varieties between two distinct types may be found, it is possible at each place to make clear distinctions between the shales and cherts. In the field one can always make the distinction on the basis of hardness. No matter how soft the chert, the shale partings are always softer so that there is a marked distinction between adjacent beds. Chert beds are never observed to pass into shale beds when traced along the strike. A further distinction is based on the presence of radiolaria. The harder layers of chert always contain numerous radiolaria. The softer shale partings never contain more than one or two in each thin section, and usually do not contain any.

The red cherts seldom show any fine lamination, such as will be described later in connection with some of the lighter colored varieties. The rhythmic bedding is much better developed in these red cherts and shales, but fine lamination in individual beds is almost unknown.

VEINING OF THE CHERTS

One of the characteristic features of the Franciscan cherts is the large number of veins which cut them. Generally they consist of white quartz, that contrasts strongly with the deep colors of the cherts. Besides quartz, chalcedony or manganese oxide may form veins in cherts, and iron and manganese oxides may coat the walls of open fissures. This characteristic veining is not confined to the red cherts, but may occur in any of the well bedded varieties.

Each bed of chert usually contains its own system of veins; the fissures seem to have been confined to the more brittle cherts and did not extend into the shales (plate 26B). Where the shales have been hardened by heat, some veins may run through both the shales and cherts. Even in these there is a strong tendency for veins to be limited to chert. The planes of these veins are, with few exceptions, approximately normal to the bedding of the cherts. They vary in size from those which can scarcely be seen with the microscope in thin sections, up to veins a quarter of an inch in width. Usually they are less than a sixteenth of an inch wide. As described later, wider veins may occur near igneous contacts, but these are more irregular in thickness and have an entirely different arrangement. In hand specimens it is generally impossible to see any evidence of displacement along these veins, but in thin section slight displacements are visible. One vein may offset another, or a radiolarian may be cut in two and the two parts displaced by a small amount. The quartz of the veins is granular and the grains are much coarser than the grains of the chalcedonic matrix of the rock. The same is true when the veins are filled with chalcedony.

LEACHING OF THE RED CHERTS

In many cases the quartz veins run through the cherts with no appearance of any alteration of the walls by circulating waters. In a few instances there is evidence of the leaching of the walls of the vein and the abstraction of iron oxide. In other cases, where there are no quartz veins, the rock is seen to be traversed by a network of irregular white or pale greenish streaks, extending transversely across the beds, and contrasting strongly with the deep red color of the unaffected chert (plate 31A). On examining these streaks they are found to mark a zone of leaching and discoloration along some fissure through the chert. In places the process has gone so far that a large proportion of the chert is greenish with little cores and residual patches of red chert within the network of fissures. In a few instances red shales have been seen interbedded with greenish cherts which show residual patches of red coloration, evidently indicating that the more easily fissured cherts had permitted freer circulation of waters than the shales.

In many places the upper and lower surfaces of the beds of red chert may show irregular networks of white streaks. These lines of decoloration are confined to the surface layer of the chert beds and appear to be due to the circulation of waters along the contacts between chert and shale.

Occasionally one may find rather large bodies of well bedded greenish or gray chert. These cherts show an occasional residual core of red chert on the interior of the beds. They appear to have once been ordinary red cherts, altered by leaching or reduction of the iron. Often they contain considerable pyrite in specks, crystal grains, and small masses and the decoloration may be due in part to the reduction of iron oxide by the solutions which deposited the pyrite. Apparently part of the iron has been removed—perhaps it has gone into the pyrite when this is present—since analyses show a lower content of iron oxide than do the red cherts. It is possible by heating small splinters of the green chert in an oxidizing flame to change the color to red, but it never becomes as intense as it is in the unaltered red chert.

In some instances, deep colored red cherts are found which contain crystals of pyrite. Occasionally such crystals, showing perfectly developed bright faces of the pyritohedron, occur in the midst of solid, red chert little changed by any action of solution. This pyrite may be syngenetic or it may be an example of metasomatic replacement without volume change.

RESISTANCE TO CHEMICAL WEATHERING

The cherts are very resistant to chemical decay. In streams draining areas of Franciscan rocks the larger proportion of the boulders at some distance from the source of supply are chert, and of these a large part are of the red varieties. This is in spite of the fact that cherts may occupy only a limited portion of the area drained by the stream. Along the coast in Marin County, where short streams drain Franciscan areas, the beach pebbles are largely composed of chert, and the sands also are found to be composed of fine grains of chert.

In spite of their high resistance to chemical action they are somewhat attacked. This is seen on examination of fragments of chert which have lain on the surface for some time. On these chert fragments the radiolarian remains stand up in slight relief, due to the greater purity of the silica filling these skeletons, which enables them to resist better than the impure matrix. Quartz veins also stand out in slight relief on the surface of blocks long exposed to the action of the weather.

GRAY AND GREEN CHERTS

While many well bedded green and gray cherts are the result of the decoloration of cherts originally red, there are some of these cherts which do not seem to be due to this sort of action. These occur interbedded with the red cherts and the color difference is sharply marked along the lines of bedding. Sometimes green streaks run parallel to the bedding of the red cherts. These facts indicate original differences at the time of deposition.

Another variety of light colored chert, which cannot be shown to be altered red chert, is a translucent rock with a vitreous luster and bright, clear, green color. This chert is very hard, frequently being hard enough to scratch quartz. It has a perfect conchoidal fracture. In thin sections it appears to be nearly colorless, with a slight clouding due to minute inclusions, and between crossed nicols it is seen to be made up of an extremely fine grained aggregate of cryptocrystalline silica. Another hard, vitreous variety like the green chert is black in color, resembling some of the flints from the Chalk. In thin section it also consists of colorless cryptocrystalline silica, with a very small number of minute black specks. Sections of both the black and the green flinty cherts show occasional spots of vague outline, that are clearer than the rest of the rock. The dimensions of these spots are about the same as those of the radiolaria in other cherts, and they appear to represent original radiolarian remains. That this is the correct interpretation seems certain from the fact that in some of these cherts that contain many inclusions the details of the outlines of radiolaria are clearly seen. Rarely a chert of this sort is found which is colorless in hand specimen and shows the faint cloudiness of chalcedonic silica.

LAMINATED BLACK AND WHITE CHERTS

This variety of bedded cherts shows well marked lamination, a character not common in Franciscan cherts. They are white to cream colored with fine bands of black chert running through them parallel to the bedding. They are interbedded with gray or dirty yellow shale. Good exposures of this variety are to be found in the vicinity of Redwood City and on the military road between Fort Baker and Fort Barry in Marin County.

Moistened surfaces of this chert show distinctly the small, clear, round spots representing radiolarian remains. In thin sections the radiolaria usually do not appear to advantage, on account of the lack of contrast between them and the matrix in which they lie. The black and white banding is due to differences in the purity of the silica in the different bands. The black bands are composed of silica which is purer and clearer than that in the white bands. They appear darker in reflected light because they are more translucent.

One specimen of this type of chert shows alternating bands of dark translucent and creamy white silica. There are places where veinlets of black chert run off from the black bands and cut across the white bands. The banding runs parallel to the bedding and apparently is original, yet there is no evidence that the vein cuts the dark portion of the chert. It seems to come from it and be a part of it. It is suggested that the black and white bands were laid down together, but that the white portions consolidated first, and during some slight movement became fractured so that the unconsolidated clearer silica was forced into the fissure.

MASSIVE WHITE CHERTS

Another variety, referred to before as massive white chert, occurs in large bodies in Marin County and in the San Miguel Hills in San Francisco. It also occurs elsewhere in lenses in the midst of other varieties of chert. This variety is characterized by the fact that only small amounts of shale appear in the partings.

Cherts of this variety differ in appearance from the black and white cherts before mentioned in that they are not laminated. They are usually pale, creamy white in color. The radiolaria are not readily apparent in hand specimens.

In thin sections the matrix is seen to be composed of nearly clear silica, clouded by extremely minute mineral grains. In this matrix, there are rounded or elliptical areas of clear silica which represent radiolaria with rather poorly preserved outlines. Between crossed nicols the matrix is seen to consist largely of cryptocrystalline silica in which there may be occasional areas of amorphous silica.

THE MATRIX OF THE CHERTS

This subject will be discussed more fully later, when the question of the origin of the cherts is considered, but it should be here emphasized that all these radiolarian cherts contain more silica than may be accounted for by the radiolaria which they now contain. The radiolarian skeletons are always embedded in a matrix of silica, which gives no evidence of organic derivation (plates 30A–E). As previously noted, the number of radiolaria present varies between wide limits.

CONCRETIONS IN CHERT

The occurrence of concretions in certain cherts in the Santa Ynez Mountains and in North Berkeley has been referred to (page 252).

In thin sections, these concretions are seen to be much like the cherts which enclose them, save that they contain less iron oxide than the matrix in which they are found. The material of the concretion consists of a ground mass of fine cryptocrystalline silica stained with streaks and grains of red iron oxide. Embedded in this ground mass are a number of radiolaria. One thin section across the boundary of a concretion showed a sharp line of contact between the concretion and the iron-rich chert in which it rested.

In a slide from one of these concretions considerable spherulitic chalcedony was found. Spherulitic chalcedony, as will be shown later, is often found in cherts which have been metamorphosed by igneous action. The three localities where these concretions are found are near intrusive igneous rocks and there is a possibility that the concretions may have been produced in some way as a result of metamorphism. However, they do not occur immediately at the contacts. They appear to be original features of the cherts; this is confirmed by the occurrence in them of radiolaria and by the general similarity of their material to the matrix in which they occur. The deflection of manganiferous bands around them may be taken to mean that the concretion was produced at a time when the chert was still plastic. A further indication of their original character is found in the fact that they are often surrounded by shale coatings. Under the influence of metamorphism the shale in the cherts usually disappears.

Shale Partings of the Radiolarian Cherts

In the region of San Francisco Bay and in all other parts of the Coast Ranges seen by the writer, the chert beds are separated by shale partings. In Oregon, in the Port Orford quadrangle,[14] the chert is occasionally interbedded with thin layers of volcanic ash, instead of the usual shale.

RED SHALES

The most common variety of shale is red in color and occurs with the red cherts. It shows no lamination or fissility and breaks into irregular pieces. As a rule, it is a little harder and more coherent than an ordinary clay shale, but some exceptional varieties are extremely soft and break up easily. The rock is remarkably fine grained and shows a somewhat irregular fracture similar to that of a broken cake of chocolate. The typical red shale closely resembles chocolate in manner of fracture and in texture. In most instances it is impossible,

[14] Diller, J. S., Port Orford Folio, U. S. Geol. Surv. Folio no. 89, p. 2, 1903.

with a hand-lens, to make out any of the constituent grains of these shales. In a few of them there are fine micaceous particles large enough to be distinguished with slight difficulty by the aid of an ordinary hand-lens.

When the red shales are examined with the microscope in thin section they are seen to consist of a mass of extremely fine mineral particles, with which are intermingled grains of red iron oxide, in such quantities as to make the slide almost opaque.

These shales disintegrate very rapidly when subjected to weathering action and, as a rule, they are exposed only in artificial cuts or in sea cliffs. They disintegrate in contact with water and break down rapidly into small irregular fragments with sharp corners and edges. After breaking to a size where most of the particles are between one-sixteenth and one-eighth inch in diameter, water seems to have no further effect on the shale in the way of rapid disintegration. Even boiling is then without noticeable effect.

By treating the red shales with dilute acid it is possible to dissolve out almost all of the iron oxide, leaving a residue having a pale greenish or cream colored tint; rarely a very pale pink color remains. On testing some of the residue after acid treatment in a qualitative way, it is found to contain large amounts of silica, and alumina, a little iron and managanese, together with small amounts of magnesium and calcium.

The more siliceous shales do not break down when the iron is dissolved out of them. The fragments of the shale retain their original size and shape. Their hardness and compact texture are about the same as before, so that it would appear that the iron is simply a pigment and has no cementing effect in the shale. Further treatment of these fragments with a solution of caustic potash causes them to break down into a slime.

On breaking up the residue left after the acid treatment of the shale and examining it under the microscope, it is found to be a crystalline aggregate of extremely fine grain. The mineral particles show a subparallel orientation on rotating the stage between crossed nicols. Though the aggregate never becomes totally dark, it shows a brightening and darkening as the stage is revolved. This behavior is shown by many ordinary shales, slates, and phyllites.

While most of the minerals cannot be distinguished with certainty on account of the extremely fine grain, there are occasional minute flakes of a mineral which, from its fracture, limpid appearance, birefringence, and index of refraction is determined as quartz. There are also occasional splinters of a dark, brownish, isotropic material having an index of refraction between 1.62 and 1.63 which appear to be rather basic volcanic glass. These are especially abundant in one red shale which came from beneath a flow of ellipsoidal basalt.

Interbedded with the soft shaly cherts previously described there are very soft, red shales. The best examples of these are to be found on Red Rock Island in association with beds of very soft shaly cherts. It was possible to remove all the iron oxide from these shales by treatment with acid. During the process the shale broke down, leaving a soft incoherent residue of pale cream color. On qualitative analysis this was found to consist largely of silica and alumina, with a trace of iron and manganese. It contained no calcium or magnesium. Apparently it consisted almost wholly of kaolin. Chemical analysis indicates that these soft red shales are much lower in silica than the ordinary varieties.

The red shales show evidence of leaching of their iron along channels of circulation, just as the cherts do. When the iron is removed the shale is either greenish or gray in color; the texture and general appearance are the same as before.

In some of the red shales peculiar green spots are found, due apparently to the local reduction of iron. These spots are circular or elliptical in cross section, and almost every one of them shows a tiny dot of yellow in the center, probably limonite.

GREEN AND GRAY SHALES

When the green and gray shales are examined in thin section they are seen to be much like the red shales from which the iron has been leached by dilute acids. They show a roughly oriented aggregate of the same sort of material which is left in the acid residue of the red shales. The green shales turn pink or faint red, like the green cherts, upon heating in the air.

CARBONACEOUS SHALES

At Tennessee Cove in Marin County and in Bagley Cañon at Mount Diablo, shale beds of another type are found. They are black shales containing considerable carbon and after ignition, they become grayish white. They are interbanded with white or gray cherts.

OCCURRENCE OF THICK BEDS OF SHALE

Most of the shales are seen in thin partings between beds of chert. However, there are occasional thicker beds of shale associated with the cherts. Some of these have already been mentioned, occurring at contacts between sandstones and cherts. In addition to these there are occasional zones in the midst of otherwise regularly and thinly bedded chert, which consist entirely of red shale. These may have thicknesses from a foot or so up to three, four or five feet, and occasionally even more. Such extra thick layers of shale may be fairly common. They only appear in artificial cuts, and it is probable that they are not long exposed there on account of their rapid disintegration.

On Mount Diablo there is one notable occurrence of this sort, in which the shale has a thickness of twenty feet. This shale is exactly like that which is ordinarily found as a parting between the beds of chert. In this thick bed there are a few thin ribs of red chert. The total amount of chert is small, aggregating about six inches out of the whole twenty feet.

Near the base of the Ingleside chert in the neighborhood of Twin Peaks there is a bed of red shale several feet in thickness. It is without bedding planes or banding of any sort, but is traversed by numbers of irregular cracks so that it breaks up into a large number of small irregular fragments. It contains numerous inclusions of some soft white material which looks like a greatly altered volcanic ash, although it is impossible to get any sort of a thin section of this material in which it might be examined microscopically.

Besides these small fragments there are rounded masses from one-half inch to an inch in diameter, which may be lapilli. These are roughly spherical in form and are coated on the outside with a layer of manganese oxide. The central cores of these bodies are sometimes unaltered. In such cases there is a dark brown to black core surrounded by soft white material apparently the same as that which composes the small white fragments found in the same shale. This white material is often discolored, and in such cases the lines of discoloration are concentric with the central core. A thin section of one of these cores shows laths of feldspar embedded in a glassy matrix which is sprinkled with minute particles of magnetite. The feldspar crystals are bent and splintered. They show a tendency to radiate from centers, four or five crystals being sometimes seen in an intersecting cluster.

In this shale there are a number of white horny fragments. In their form they somewhat resemble fish teeth, but their exact nature is not certain. Their outer surfaces possess a high luster like ivory, and they are unaffected by acids.

In the quarry in Piedmont, just across from the cemetery, a thickness of several feet of similar shale is found near the base of the chert. This contains the same toothlike fragments, and also contains certain rounded white flakes of uncertain nature which may possibly be fish scales. Thin sections of these shales show certain fragments with peculiar structures which represent sections of the forms just mentioned.

Analyses of Franciscan Cherts and Shales

The following tabulation gives the results of analyses of Franciscan cherts, together with the analyses of cherts from other localities:

I. Brownish red chert from Bagley Cañon, Mount Diablo. Melville, Bull. Geol. Soc. Am., vol. 2, p. 411, 1891.

II. Siliceous red chert from Red Rock Island.

III. Siliceous red chert from Point Richmond.

IV. Hard, dark chert from radiolarian rocks of the Lower Culm measures. Hinde and Fox, Quar. Jour. Geol. Soc., vol. 51, p. 629, 1895.

V. Analysis of a dark, nearly black, chert from southern Scotland. The Silurian Rocks of Britain. I, Scotland, Mem. Geol. Surv. United Kingdom, p. 641, 1899.

VI. A milk white hornstone from Central Borneo. Molengraaff, Explorations in Central Borneo, p. 194, Leyden, 1902.

VII. A *kieselschiefer* from the Hartz Mountains. Caddell, Proc. Roy. Phys. Soc. Edin., vol. 8, p. 217, 1884.

	I	II	III	IV	V	VI	VII
SiO_2	93.54	95.08	96.37	87.3	91.3	97.19	92.48
Al_2O_3	2.26	2.17	2.38	5.7	3.3	1.45	2.54
Fe_2O_3	.48	2.82	1.70	1.3	.7	1.12	.55
FeO	.79	......	......	1.4	1.4	......	.70
MnO	.23	......	......	......	......	......	......
CaO	.09	......	......	.3	trace	.05	1.36
MgO	.66	......	......	1.2	.8	trace	.32
K_2O	.51	......	......	.7	.6	1.15	.54
Na_2O	.37	......	......	......	.2		.54
Loss @ 110°C	.21			1.9	.9	.06	1.75
Loss on ignition	.72					.28	
	99.86	100.07	100.45	99.8	99.2	101.30	100.78

The extremely high silica and the important amounts of iron are the most notable features. No determination of titanium was attempted in analyses II and III. Qualitative examination of a number of typical specimens of red chert showed, however, that there was not enough titanium present to give a reaction on boiling with tin in hydrochloric acid after fusion with sodium carbonate.

The following are analyses of Franciscan shales interbedded with the cherts, together with an analysis of a soft gray shale parting from the cherts of the Lower Culm in England, and an analysis of average shale according to Clarke:

I. Analysis of a brownish red shale from the red cherts of Bagley Cañon, Mount Diablo. Melville, *op. cit.*
II. Partial analysis of red shale from Point Richmond.
III. Partial analysis of red shale from Red Rock Island.
IV. Partial analysis of green shale from Rock Ridge Quarry, Oakland.
V. Partial analysis of red shale collected at end of Twenty-fourth and Hoffman street-car line, San Francisco.
VI. Soft red shale from Red Rock Island, once mined as paint rock. Analysis by Irving Miller, given by Lawson in San Francisco Folio, *op. cit.*
VII. Analysis of soft gray shale parting from radiolarian rocks of Lower Culm. Hinde and Fox, Quar. Jour. Geol. Soc., vol. 51, p. 629, 1895.
VIII. Percentages of principal elements in Clarke's composite analysis of 78 ordinary shales: Data of Geochemistry, U. S. Geol. Surv. Bull. 616, p. 28, 1916.

	I	II	III	IV	V	VI	VII	VIII	
SiO_2	69.98	68.22	63.47	62.35	57.55	50.58	67.8	58.38	
TiO_2	....	....	....	....	....	.55	......	.65	
P_2O_5	.05	....	....	....	....	....	......	.17	
Al_2O_3	11.69	11.31	10.14	15.45	15.65	14.35	19.8	15.47	
Fe_2O_3	6.23	8.75	14.60	4.95	11.85	15.64	1.4	4.03	
FeO	1.08	....	....	.70	....	.65	.4	2.46	
MnO	.49	.13	.08	.55	1.20	.36	......	trace	
CaO	.38	.99	.74	2.05	1.65	1.77	......	3.12	
MgO	1.29	2.39	2.41	3.05	2.50	3.08	1.2	2.45	
Na_2O	3.72	....	....	....	....	.70	......	1.31	
K_2O	.73	....	....	....	....	3.84	4.8	3.25	
H_2O @ 110°C	1.03	1.39	1.44	1.75	2.40	3.30	.9	1.34	
H_2O on ignition	2.92	4.42	3.91	4.45	4.10	5.19	3.6	3.68	
Soluble	....	....	....	....	....	.38	......	......	
	99.59	97.60	96.79	95.30	96.90	100.39	99.9	2.64	CO_2
								.65	SO_3
								.05	BaO
								.81	C, organic
								100.46	

While there is considerable variation in these shales they approach, in many respects, the ordinary terrigenous shales. The high iron content is the most striking point of difference. Titanium was not determined in the samples represented by analyses II, III, and V. A qualitative examination of the material used for analysis IV gave no test for titanium on boiling with hydrochloric acid and tin.

METAMORPHISM OF THE CHERTS BY FRANCISCAN INTRUSIVES

The cherts have suffered more than the other members of the Franciscan group through the intrusion of igneous rocks. On account of their brittle nature and the numerous lines of weakness in the shale partings, the cherts have presented zones which were favorable to the intrusion of igneous rocks.

Changes in Color and Structure

Near the contacts with the intrusive bodies, the cherts often become massive through the disappearance of the shale partings. At first the parting planes may be seen, though most of the shale has disappeared, and the chert breaks easily along these planes. At a later stage, all trace of the bedding disappears; the rock becomes massive and will split in any direction with equal ease.

The colors also change. In many cases there is an increase in the brilliancy of the color. Bright shades of vermilion are often developed, while in other cases the cherts take on bright orange, yellow, or green colors. One hand specimen may show two or three different colors, each color being separated into patches which contrast strongly with one another. In other cases there is a bleaching of the colors of the cherts. Some inclusions of chert in basalt assume a dirty white or gray color, while others take on very pale shades of yellow or pink. A single block of chert may show both kinds of color change. One part of the block may be pale gray, green or brown, with streaks representing old parting planes; another may show bright reds or yellows, being massive and without streaks.

When examined with a hand lens, the bright vermilion contact phase of the chert shows a peculiar curdled appearance, as though the iron oxide had segregated into definite patches. In thin section this is seen to be the case. One of the vermilion rocks taken at Hunter's Point shows a matrix, composed largely of chalcedony in fairly large grains, in which are rounded masses of iron oxide considerably larger than the grains of iron oxide in the unaltered rock. All traces of radiolaria have disappeared in consequence of recrystallization of the rock. The yellow or orange contact phase is very similar in general appearance. In a section of one of these cherts the coloring matter is bunched together in little balls which, under high powers, are seen to be interlacing fibers of some yellow mineral. The matrix is chalcedonic silica, shown by the fibrous extinction of the grains.

Development of Quartzites

Sometimes rocks resembling quartzites result from the alteration of the cherts. In the field these rocks are massive and appear in prominent outcrops, showing little trace of the original bedding. They may be deep red, orange, yellow, brown, or sometimes black. They are vitreous rocks which, on fresh fractures, look almost homogeneous. Upon careful observation, however, faint outlines of individual crystals may be seen. On weathered surfaces these rocks show, in places, a peculiar glazed appearance as though they had been fused. The cause of this is unknown. In thin sections, the rock is seen to be made up of a mass of interlocking quartz grains, which are fairly transparent but contain a number of very minute, transparent inclusions, too small to be determined. Often the iron oxide is confined to the spaces between grains of quartz. In some sections the mineral which colors the rock is blue-black with the characteristic luster of magnetite. On testing the powder it is found to be magnetic. There are also some grains of a dark red mineral, probably hematite.

In other sections of quartzite the iron is present in the form of yellow oxide which in part is fibrous. It shows sharp, clear boundaries against the quartz, and does not appear to be due to alteration of other forms of iron oxide, but to have been produced at the time the rock recrystallized.

Quartz Veins

In the ordinary, unaltered chert the quartz veinlets run normal to the bedding. Near contacts with igneous rocks veinlets are seen which may run parallel to the bedding of the chert instead of across it. Such veins are irregular in thickness, often being lenticular, whereas the cross veins in ordinary chert are fairly uniform in thickness.

In the massive chert peculiar, curving, lenslike veinlets of quartz may be seen, arranged roughly in concentric groups. Plate 31B represents a pebble which shows some of these curving veinlets on its surface. At times the massive metamorphosed chert near the contacts of igneous rocks is cut by a great number of veinlets of quartz arranged in a complex network (plate 31c).

Spherulitic Cherts

Thin sections of cherts taken near igneous contacts may show a development of spherulites consisting of radial aggregates of fibrous chalcedony. These show a black polarization brush between crossed nicols (plate 30, F). The extinction is parallel to the fibers in all cases. Two varieties of chalcedony are present: one shows a negative elongation (*chalcedonite*), while the other, less commonly present, shows a positive elongation (*quartzine*). The spherulites may be very abundant, making up the larger part of the rock. Generally they are not large enough to be visible in hand specimen, but in certain instances they are as large as peas.

Under the name "Kinraidite," D. B. Sterrett[15] described a variety of this spherulitic chert in which the spherules were unusually well developed. This rock is found in Marin County and also at the Cliff House in San Francisco at the contact with, and as inclusions in, the intrusive basalt and diabase. In most cases the spherulites are red in color and are imbedded in a matrix of silica which is green, red, brown, or yellow. The spherulites range from microscopic dimensions up to an inch or more. They show a fibrous radial structure and are composed of chalcedony with a positive elongation.

Fusion and Assimilation of Cherts

In many exposures of the intrusive ellipsoidal basalt, as at Hunter's Point, in the sea cliffs in Marin County, and at Mount Diablo, blocks of chert may be found included in the basalt near its contact with chert masses. These blocks have been rendered massive, and otherwise altered by the heat of the intrusive in the manner outlined above. In certain instances there is also clear evidence of fluxing of the chert in the basic magma.

Blocks showing this action vary in size from twenty to thirty feet in diameter down to only a foot or so. Their central portions consist of highly colored vermilion or orange chert, unchanged save for their recrystallization under the action of the intrusive. Toward the outer

[15] Mineral Resources of the United States, pt. II, p. 870, 1910.

margins of these blocks the chert begins to take on a greenish color, which gradually becomes more pronounced as it is traced outward until it is impossible to tell where the chert ceases and the basalt begins. There is apparently a perfect gradation from one rock into the other. At Hunter's Point, near a contact of chert with basalt, certain of the inclusions seem to have progressed further than this. All trace of original chert is lost, save for the presence in the rock of rounded masses which resist erosion and appear to be more siliceous than the rest of the rock around them.

Condition of Cherts at Time of Intrusion

While the shale partings are often eliminated at igneous contacts, there are instances in which the cherts and shales have not been greatly changed by inclusion in the igneous rock. Occasionally the igneous rock contains numerous streaks of red material, which in their thicker portions, are found to be red shale exactly like that which forms the shale partings.

In places the pillow basalt is found to contain small blocks of chert and shale which have been only slightly altered and in which the shale partings have been preserved. Such small blocks prove that in these places the basalts must have intruded the cherts after the latter had consolidated. The intrusion of igneous rocks into unconsolidated muds and oozes would have caused a smearing out of the bedding and obliterated it in these small masses.

Mammillated Chert

Aleso Creek, which drains into the Santa Ynez River from the north, exposes a section of Franciscan gabbro, intrusive into radiolarian cherts. In this gabbro there are great numbers of inclusions of chert, many of which show mammilated surfaces very similar to the mammilations observable on the surface of the chalcedonic lining of cavities (plate 32). The blocks show no sign of shale parting, but are massive. Many are prevailingly gray or green in color, but some are pink or brownish red. The surfaces on which the mammilations occur are not planes, but are warped surfaces of rather irregular form.

The larger mammilations are elliptical in plan while the smaller ones are nearly circular, but where they are numerous and closely spaced the outlines of one mammilation interfere with those of another and the resulting forms are polygonal. The diameters of these mammilations range from one-half inch up to four inches. The usual diameter is from one inch to one and one-quarter inch. They are rather flat in profile. In examining blocks of chert which show these mammilated surfaces it is often found that, by proper application of the hammer, it is possible to develop still other mammilated surfaces beneath the outer one. The inner mammilations have no correspondence with those on the outer surfaces, having different radii and different centers.

A question arises as to the origin of these peculiar cherts. It might be urged, perhaps, that they are not radiolarian cherts at all, but are the result of hydrothermal deposition of silica in the gabbro. This hypothesis is unwarranted for the reason that the masses do not occur in veins nor do they have any connection with veins. They are isolated blocks often with rather angular outlines. They are unquestionably derived by alteration of the ordinary type of radiolarian chert, since they are reddish in color, have the texture of chert and are in all respects similar to many varieties of metamorphosed chert whose origin is definitely known to be due to thermal metamorphism at igneous contacts. Moreover, thin sections of some of them have revealed radiolaria.

The mammilations might be due to the recrystallization of the chert under the action of heat, resulting in the development of a spherulitic structure on a scale larger than is commonly found. However, thin sections of these cherts show a cryptocrystalline aggregate of silica with no fibrous chalcedony.

Another possibility is that the surfaces are the result of incipent fusion. Certain specimens of chert from Marin County show a rounding probably due to fusion. These mammilated cherts from Aleso Cañon do not appear to be of this type, since the rounding is not confined to the surface of the blocks. Additional surfaces may be developed beneath the outer one.

It would seem that the peculiar surfaces are the result of the spalling off of the chert governed by a system of irregular, curving fracture-cracks. Systems of curving cracks are often developed in chert masses under the action of heat, and something of the sort seems to have occurred here. This idea is supported by the finding of numerous lenslike quartz veinlets within the mass of the rock. These are not straight but curve more or less parallel to the mamillated surfaces.

Alteration of Chert to Glaucophane Schist

Another peculiar alteration of the chert at contacts of serpentine and basalt is a change to glaucophane schist. This has been described by Ransome[16] from contacts of chert with ellipsoidal basalt and serpentine on Angel Island. Here both chert and sandstone were altered to glaucophane schist at contacts of both the serpentine and the ellipsoidal basalt. Examples of similar action may be seen at a contact of ellipsoidal basalt with chert in the region of Red Rock Cañon, Santa Barbara County. Here little sheaves of glaucophane have been produced in the midst of rather massive white cherts.

The metamorphic rocks do not as a rule form a continuous border around an igneous mass, but occur in small separated bodies along the contact. Small isolated masses of glaucophane schist that occur in areas where no igneous rock is exposed are best explained by the idea that unexposed beneath the surface, there exists a body of igneous rock, or that before erosion, there was a body of igneous rock above the schist. In addition to the actually observed contacts, it is a very common thing to find, in creek-beds, large boulders of massive chert, altered by igneous action which show evidences of a change to glaucophane schist.

One boulder three feet in diameter, found in Perkins Cañon at Mount Diablo, is composed of radiolarian chert on one side while the other side is glaucophane schist. The chert portion is composed of red chert which has been somewhat altered; the shale has largely disappeared, but the partings are present, though intensely contorted. They are cemented, so that the rock splits about as easily across former parting planes, as parallel to them. The chert is traversed by some quartz veins.

In the portion altered to glaucophane schist, there is definite evidence of the former bedding of the chert. The glaucophane schist consists of alternating bands of hard and soft material. The softer bands of less siliceous schist appear to represent the original shale partings. The harder portions which are more siliceous represent the former chert layers, and owe their hardness to the excess silica which they contain.

The border zone between the chert and the glaucophane schist is rather narrow, but may be clearly distinguished everywhere. It is marked by a space within which the chert is cut by numerous stringers

[16] Ransome, F. L., The Geology of Angel Island, Univ. Calif. Publ., Bull. Dept. Geol., vol. 1, p. 193, 1894.

of glaucophane running between angular masses of chert. Also occasional veinlets of glaucophane are found in the red chert where no other evidence of the change can be detected. Apparently the shale partings were the most easily altered, since layers of soft glaucophane schist occasionally appear between bands of little altered red chert. The replacement of the chert by glaucophane schist and the preservation of the original bedded structure is so perfect that in a photograph of this block the glaucophane schist cannot be distinguished from the radiolarian chert.

In the Santa Ynez Mountains a specimen of red chert was found lying loose on the surface which showed a transition to glaucophane schist. In its unaltered portion it is ordinary red chert which is cut by several veinlets of a blue mineral. The unaltered red portion passes imperceptibly into a very fine grained blue rock which is considerably more porous in its texture than the red chert.

Still other varieties of these metamorphosed rocks are to be found in the form of large boulders of altered chert showing green, orange, or vermilion colors. Running through these rocks in veins and forming irregular masses within them there are considerable amounts of blue amphibole.

Certain cherts with an indigo blue color owe this color to the presence of a blue amphibole. These have been found in stream beds as pebbles. In their physical appearance in hand specimens they are like the ordinary cherts. They are very siliceous, show a conchoidal fracture, and differ from other cherts only in color. They do not, however, give evidence of radiolaria. In thin sections, they show a siliceous matrix, through which runs a considerable number of minute needles of blue amphibole.

A specimen of indigo chert, in the collection of the University of California, collected by Professor Lawson from North Berkeley, consists of hard blue chert, in bands, separated by bands of soft bluish material. The blue partings are found to consist of a mass of needles of blue amphibole while the cherty layers consist of an aggregate of quartz grains penetrated by numerous needles of blue amphibole.

The origin of the glaucophane schists is of some interest in connection with the present problem, as will appear later. The question cannot be answered with absolute certainty at the present time in the absence of numbers of careful analyses of altered and unaltered material. A large part of the soda in the blue amphibole may have been derived from the alkali in the shale partings in the original chert.

The iron necessary to form the glaucophane was of course already present.

The Franciscan sandstone has also locally been transformed to glaucophane schist along contacts with basalt, or with serpentine. The basalt itself may show development of glaucophane near the contact.[17]

The sandstones contain considerable amounts of plagioclase, and the soda in these feldspars may have been the source of the soda in the glaucophane molecule. It is possible, therefore, that in the contact metamorphism there was little introduction of material, but a recrystallization of original constituents in a peculiar way. This was the idea of J. P. Smith,[18] who concluded from his study of these metamorphic rocks that they had been formed solely by a process of recrystallization: "The results all show that there is no need of supposing that magnesian or alkaline or siliceous solutions have permeated the altered rocks, adding one substance and taking away another."

The notion of direct contribution from external sources is favored, however, by the very irregular distribution of the glaucophane schists around these contact zones. Also many of the contacts do not show any of this type of metamorphism, a fact hard to understand in case of pure thermal metamorphism. Also some rather small intrusive bodies have produced larger zones of contact action than some larger bodies. These peculiarities of distribution might be explained by the assumption that some peculiar mineralizer was present in the emanations from these basic rocks, under the influence of which the original constituents recombined in the unusual molecular combinations which are now found.

Louderback and Sharwood[19] have presented evidence to prove that in the alteration of radiolarian cherts to glaucophane schists, soda was introduced from external sources.

Distinctly favoring this idea is the study of certain rocks in San Benito County by Professor Louderback.[20] Here soda-rich minerals are often produced in large amounts in the contact zones of periodotite.

At this locality, a lenticular block of schist is included in a large mass of serpentine. In the included schist there are numerous veins

[17] Ransome, *ibid.*, p. 206, 1894.

[18] Paragenesis of the Minerals in the Glaucophane-bearing Rocks of California, Proc. Am. Philos. Soc., vol. 45, p. 183, 1906.

[19] Crocidolite-bearing Rocks of the California Coast Ranges, Bull. Geol. Soc. Am., vol. 18, p. 659, 1907.

[20] Louderback, G. D., Benitoite, its Paragenesis and Mode of Occurrence, Univ. Calif. Publ., Bull. Dept. Geol., vol. 5, p. 331, 1909.

of the hydrated sodium aluminum silicate, natrolite. This is associated with albite and other soda-rich minerals. In these veins the mineral benitoite, $BaTi(SiO_3)_3$, occurs. Neptunite [$(Na.K_2\ (Fe, Mn)\ (Si, Ti)_5\ O_{12})$] is also abundant. The natrolite veinlets and the associated minerals appear to be produced by the contact action of the peridolite magma. While the occurrence of natrolite and neptunite at this locality seems to be a unique occurrence, albite is a very common mineral in the Franciscan schists, often occurring in the form of veins.

In view of the foregoing facts, it would appear highly probable that, while a part of the alkali content of the glaucophane schists may have been originally present, there has also been a notable contribution of alkalies from some external source.

THE OCCURRENCE OF BEDDED CHERTS IN THE MONTEREY GROUP

There are other formations in the California Coast Ranges which contain banded cherts and shales. Of these the most important is the Monterey group of middle Miocene age, the cherts of which in some respects are similar to those of the Franciscan group. On account of this similarity, the Monterey cherts were studied in the hope that a comparison would throw some light upon the origin of the Franciscan cherts. The cherts of the Monterey group, as well as the bedded cherts of other horizons to be mentioned later, differ from the Franciscan cherts in that they contain no radiolarian remains.

Lithologic Types in the Monterey Group

The assemblage of strata in the Monterey group comprises several lithologic types: diatomaceous earth, diatomaceous shale, ordinary terrigenous shale, bituminous shale, "white shale," cherts of various sorts, limestones, sandstones, and tuffs. Various admixtures of diatomaceous earth with sand and volcanic ash are known. Associated with these, there are various extrusive and intrusive igneous rocks. The various members of this formation have been described in numerous publications.[21]

[21] Lawson, A. C., The Geology of Carmelo Bay, Univ. Calif. Publ., Bull. Dept. Geol., vol. 1, p. 1, 1893.
Arnold and Anderson, Geology and Oil Resources of the Santa Maria Oil District, U. S. Geol. Surv. Bull. 322, 1907.
Lawson and Palache, Geology of the Berkeley Hills, Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, p. 349, 1901.
Lawson, San Francisco Folio, *op. cit.*

DIATOMACEOUS EARTHS

The diatomaceous earth, popularly called "chalk rock," is the most characteristic of the rocks of the Monterey group. It is composed largely of the frustules of diatoms. The purer varieties are generally rather soft, sometimes powdery, and are white, cream or light gray in color. Generally the diatomaceous earth is massive and shows no well defined lamination, but occasionally it shows distinct thin bedding which rarely is of "paper thinness." Under the microscope the skeletons of diatoms are seen in a well preserved condition. In addition to the well preserved diatoms there is a considerable amount of material which seems to represent the finely divided debris of broken diatom frustules.

DIATOMACEOUS SHALES

The diatomaceous shales represent all gradations between ordinary shales and the pure diatomaceous earths. Under the microscope the shales are seen to consist of the skeletons of diatoms and irregular quartz grains scattered through a very fine grained matrix, the nature of which cannot always be determined by the microscope. Some of the finer materials of these shales may consist of the finely broken frustules of diatoms, but argillaceous matter is also present in variable amounts, as is indicated by chemical analysis (p. 290). They often contain notable amounts of lime and magnesia as carbonates. By increase in these different constituents, the diatomaceous shales pass into calcareous or argillaceous rocks.

The diatoms are not the only organic remains in these rocks. A few sponge spicules and radiolarian skeletons are also found. Locally the diatomaceous shales contain many radiolarian skeletons, in an excellent state of preservation. The less siliceous shales also contain numerous scales of fish, and occasionally the bones of fish are found. In a few instances bones of whales or other marine animals have been discovered.

Shells of foraminifera are characteristic of many of the rocks of the Monterey group and are found abundantly in many beds in a state of excellent preservation. Very often also they have been dissolved out, leaving characteristic moulds.

These diatomaceous shales have been regarded as the source of a large part of the petroleum of the California Coast Ranges; it is believed that the petroleum came from the organic matter of the diatoms whose remains are found in them.

The earths and shales contain considerable amounts of hydrocarbons and the term "bituminous shale" or "bituminous slate" is often applied to them. The bituminous shales vary in color from pale gray, through cream color, and various shades of chocolate brown and purplish to dead black. The color is due largely to the presence of variable amounts of bituminous matter. This can be seen in thin sections as irregular streaks of yellowish to brown material. Its presence may also be shown, even in the whitest varieties, by heating a fragment of the shale on a piece of platinum foil until redness is reached. The shale, on heating, first turns black; this color gradually burns away and the shale assumes a white or a pale gray color. If much iron is present it becomes yellowish or yellow brown. During the heating a characteristic odor is developed.

The black shales are often found to contain enough bituminous matter to burn alone when once ignited. In southern California such shales have, in places, become ignited by brush fires and burned for some time.[22] On fresh fractures, some of these show distinct streaks of oil. On breaking the black bituminous shales with a hammer a strong odor like that of kerosene may be noticed. Black shales of this type can be recognized at a distance in cliff sections from the fact that they weather with a pale blue color, produced by the presence of a thin white coating over the black shale. Some black shales contain numerous foraminiferal shells, appearing as white dots, usually scattered irregularly through the black matrix. At times they occur in definite bands, being absent from the shale in intervening spaces.

The bituminous shales often show a rather regular alternation with other shales or with sandstones. Black shales may alternate with brown shales or with ordinary terrigenous shales; pale gray shales may alternate with ordinary terrigenous shales, and so on. In such alternations the shale beds are sometimes only a few inches thick, but more commonly they are a foot or two thick and sometimes may be four or five or even ten feet thick. The typical, black, bituminous shale is usually a little harder than the ordinary, lighter colored, bituminous or diatomaceous shale.

In thin section these black, bituminous shales show a fine grained matrix deeply stained with brownish organic material. In sections of ordinary thickness this color is so deep that it is almost impossible to tell the nature of the matrix, without the use of some solvent.

Embedded in the matrix, there are numerous mineral grains and foraminiferal shells. The mineral grains may make up as much as

[22] Arnold and Anderson, *op. cit.*

twenty-five per cent of the volume of rock, and the foraminiferal shales may be nearly as abundant. The grains appear to consist largely of quartz and feldspar. They are angular, often sharply so, consisting of chips and splinters showing a maximum diameter of about a tenth of a millimeter and ranging down to grains almost too small to see under the microscope. The feldspars comprise both plagioclase and orthoclase. The foraminifera are often remarkably well preserved. The walls of the shell stand out clearly and all the minute details of the structure are well preserved. The material of the shell wall is aragonite, which is fibrous with extinction parallel to the fibers, these standing perpendicular to the wall of the shell. The minute perforations through the shell wall are preserved and may be seen clearly. The chambers may be filled with calcite and generally a single crystal fills a chamber. In a few instances the chambers of the shells are filled with opal, which may be dark brown in color, but usually is rather pale.

In addition to the complete and well preserved shells, there are many broken fragments of foraminifera scattered through the matrix. These have undergone only a mechanical separation, since the minute perforations through the shell walls are well preserved, and the aragonite of the shell has not been altered.

''WHITE SHALES''

Besides the diatomaceous shales and the diatomaceous earths, there are ''white shales'' of a peculiar type which reveal no trace of diatoms. These are light colored, usually white, gray, or cream colored. They break with an angular fracture with sharp definite edges. They are very light and rather soft, but in texture are firm enough to resist crushing in the hand and are often found in later stream gravels as pebbles. They are very porous, absorbing water readily, and will stick to the tongue if touched to it for a second. With a hand-lens they are seen to be rather compact, showing no sign of granular structure. They possess a luster and an appearance which, save for the absence of the small tubular passages, reminds one greatly of pumice. In these white shales there are numerous moulds of foraminifera, showing in many cases the delicate details of the external form of the shells. In some instances the lime carbonate of the shells is still present, not having been leached out.

Under the microscope these white shales are found to consist largely of opaline silica in which there are very small amounts of argillaceous matter together with a few minute, angular grains of quartz, and an occasional grain of feldspar. These mineral grains may make up as much as five per cent of the volume of the rock. When the lime carbonate of the foraminiferal shells is still present it is seen to be in the form of fibrous aragonite. The minute perforations of the shell appear clearly in such instances, and the chambers are usually filled with crystalline calcite. In most of these white opaline shales there are no other organic remains.

By treating the diatomaceous shales and the white opaline shales with caustic potash, amorphous silica goes into solution to an amount from fifty to seventy per cent. After dissolving the opaline or amorphous silica the residue consists of minute grains of quartz, feldspar and various other minerals, together with some argillaceous material. In addition to these substances there are often numerous fragments of volcanic glass. In some cases a large proportion of the rocks consist of this material so that gradations exist between the typical shales and acid tuffs.

MONTEREY CHERTS

In addition to the shales, siliceous rocks of a cherty nature are found in the Monterey generally at definite horizons. The cherts of the Monterey group may be divided into two types: the bedded cherts and the flinty cherts. The bedded cherts are like the cherts of the Franciscan in that they are rhythmically interbedded with shales. The flinty cherts are not so regularly bedded and generally occur locally, as lenses in other types of rocks, or as streaks in the ordinary bedded cherts.

Bedded Cherts.—The photographs (plates 33, and 34A) show the general appearance of the rhythmic alternations of chert and shale in the bedded type of the Monterey cherts. The relative proportions of chert and shale vary considerably in different parts of the same section. The bands of chert range in thickness from a quarter of an inch to three feet, but the usual thickness is between an inch and four inches and probably averages about two inches. The shale partings range from mere films to eight inches, but the usual thickness is between one-quarter inch and one inch, and probably averages about three-quarters of an inch. Occasionally thick beds of shale, up to five feet in thickness may interrupt an otherwise thin banded alternation of chert and shale, just as in the Franciscan cherts there are occasional interruptions by rather thick shale beds. Unlike the Franciscan, beds of a very peculiar sandstone a few feet thick may also interrupt the ordinary alternation of chert and shale. The cherts may dip at steep angles and may occasionally show intense plication and contortion, but such severe disturbances are not as common as in the Franciscan cherts. There is also less disturbance by minor faults.

As in Franciscan cherts, if one views a section of Monterey cherts from a distance, he gets the impression that they are in definite and persistent beds. If, however, the section be examined carefully at close range, certain remarkable irregularities will be found.

Since the beds are usually less disturbed, it is possible to see these minor irregularities of bedding to much better advantage than in the Franciscan cherts. The irregularities consist of a thickening and thinning of beds of shale and chert and in lenslike terminations of both chert and shale beds of exactly the same nature as those observed in the Franciscan cherts, and described above.

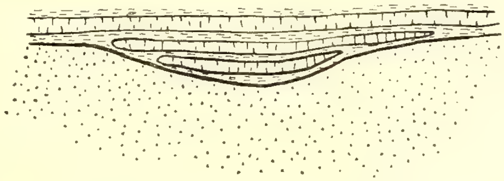

Fig. 10. Occurrence of minor lenses of chert in a depression of the surface between a sandstone and a chert formation in the Monterey group.

The lenslike development of shale beds is much more common in the Monterey cherts than in the Franciscan cherts. The lenslike character of the beds of chert is about equally developed in both formations. In the photographs (plates 33 and 34A), numerous examples of the wedging-out of beds of chert and shale may be seen, together with the resultant branching of neighboring beds of chert or shale, as well as examples of thickening and thinning.

When the contact between the cherts and sandstones is observable, it is seen that the shale partings in the cherts run parallel to the contact between the two rocks. There are, however, some local variations which might be represented diagrammatically. In the little irregularities of the contact plane, one often sees short lenses covered by overlying layers of chert in the manner indicated in figure 10.

There are numerous lithologic variations in the bedded cherts. They range from rather soft cherts, which can be easily scratched with a knife, to varieties which are quite hard, though none of them scratch quartz. In color, they may be white, cream color, pink, yellow, brown or black, depending upon the nature of the impurities present, and the amount of iron oxide which they contain. In texture they range from loose porous varieties which will adhere to the tongue, up to dense compact varieties which look like wood opal. The bedded cherts of the Monterey group break with rather jagged surfaces. They seldom show the smooth conchoidal fracture of the Franciscan cherts, probably due to some difference in the condition of the silica which composes them. They show a dull earthy luster and not the waxy luster characteristic of the Franciscan cherts, and of the flinty cherts of the Monterey.

One very characteristic feature of the bedded cherts of the Monterey is the minute lamination. Each bed of chert shows a great number of fine bands of different color, or different shades of the same color, parallel to the bedding of the chert. These bands are so thin that there may be twenty or thirty of them in a layer of chert an inch

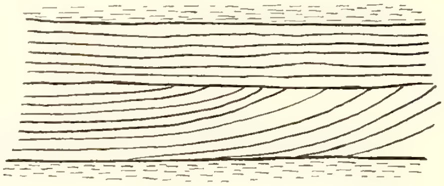

Fig. 11. Discordance of lamination within a single bed of chert.

in thickness. This lamination of the chert beds is almost universal, but some bedded white cherts fail to show it and occasionally a black bedded chert is not laminated.

In spite of the fact that this lamination is so well developed and is nearly parallel to the bedding, the cherts show very little tendency to cleave along the laminae. Occasionally there may be a slight tendency in this direction, but it is very exceptional, and as a general rule, the chert beds break up into fragments of irregular form along cracks which run transversely to the bedding planes.

As revealed in cross sections of the chert bed, the laminae are indicated by bands of different color. These often run nearly parallel with the bedding of the chert and are remarkably regular, though there are numerous exceptions to this statement, some of which are rather peculiar.

In certain specimens a sort of false bedding is shown by the laminae of the bed. This relation might be explained on the supposition that there had been a certain amount of scouring by the currents which deposited the material of the chert (fig. 11 and plate 33B).

In some of the beds, the laminae are seen to abut upon the bounding surface of the bed at a notable angle (fig. 12). This is also shown in plate 34A. This relation also might be explained as due to scouring of the currents which deposited the coarser sediments.

Occasionally a layer of chert will show a lenslike termination. In such instances the laminae of the chert may follow the walls of the

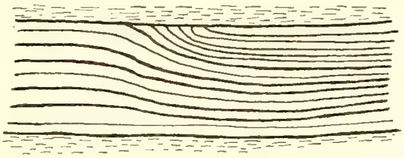

Fig. 12. Discordance between lamination and bounding surface.

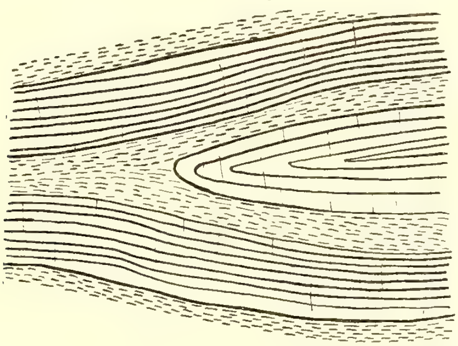

Fig. 13. Termination of a chert layer showing lamination in closed curves.

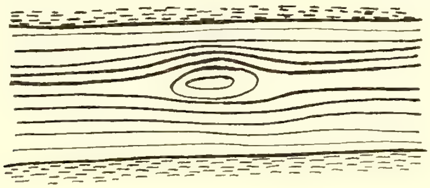

Fig. 14. Peculiar lamination in Monterey chert.

chert layer, and close upon themselves as indicated in the diagram (fig. 13). Obviously a relation of this kind cannot be explained by current scouring in the deposition of later material.

Occasionally, in the center of a thick bed of chert, the laminae will have the structure indicated in figure 14. The outer bands run through in a general way parallel to the surface of the chert bed, but the laminae in the interior close upon themselves. If the laminae were due to variations of thickness in original deposition, one would not expect them to have the relations shown in the figure.

Some beds of chert show relations about as indicated in figure 15. Photographs of this sort of banding were obtained, but the details were too faint to bring out in reproductions.

Sometimes some of the laminae are discontinuous and consist of a series of isolated lenses of different color, along the same general line. In some instances the lamination appears as irregular wavy bands, while the planes bounding the bed are straight and parallel to one another.

In thin section the bedded cherts are found to be composed largely of amorphous silica; only occasionally is there much cryptocrystalline chalcedonic silica. Embedded in this amorphous matrix there are numbers of mineral grains, together with some foraminiferal shells. Under the microscope the lamination of the cherts is seen to be due to slight differences in the material composing the bands. The

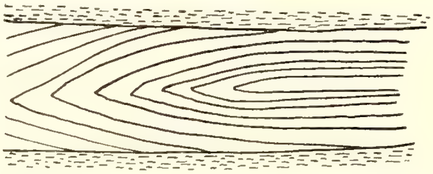

Fig. 15. Peculiar lamination in Monterey chert.

nature of these differences varies in different cherts. Some of the cherts are wholly composed of amorphous silica and the lamination is due to the fact that one part of the chert is stained with iron oxide while the adjoining portions are not so deeply stained. In some of the cherts, the lamination is due to variations in amounts of bituminous matter in the different parts. In some instances all the rock may be isotropic, but one part appears slightly more opaque than the adjacent parts, due perhaps to the presence of a small amount of argillaceous material. In such instances the darker bands seen in the hand specimen correspond to the more transparent material. Some of the lamination is due to alternating strips of amorphous and chalcedonic silica. The latter, in the hand specimens, appears as dark gray to black bands with a waxy luster contrasting with the lighter colored portions of opaline silica, which show a dull earthy luster. The amorphous silica appears somewhat incoherent and contains more impurities, while the chalcedonic silica is dense and fairly pure. Banding of this kind is liable to be irregular, with ragged outlines.

Aside from their banding, another feature of thin sections of these cherts is their peculiar streaked appearance. A lamina which in hand specimen appears of uniform color, may show in thin section a streaky appearance which resembles somewhat the flow lines in felsitic igneous rocks. Cherts which do not show well developed lamination, still show this streaky appearance.

Sometimes the moulds of foraminiferal shells have been filled by chalcedony, but in the greater number of the bedded cherts studied, the material of the shells has been leached out, leaving the empty mould of the shell; or else the original lime carbonate is still present, and the chambers are empty or filled with calcite. In those cases where the shell is replaced by silica, the silica shows a different degree of crystallization from that in the matrix of the rock. If the matrix is amorphous, there is notable difference because the silica filling the cavity is generally chalcedonic. If the matrix is chalcedonic there are differences in grain.

Aside from a few foraminifera there is a notable scarcity of organic remains in the chert. Sometimes structures remotely resembling diatoms are made out, but as a rule there is nothing which would be referred to as organic in its origin. No radiolaria were found in any of the sections of chert which were studied.

The shale partings which separate the layers of the bedded cherts of the Monterey group are usually ordinary terrigenous shales. Occasionally yellow or brown bituminous shales may separate the chert layers, but such instances are not so common. No instances are known where black bituminous shales come between cherty layers.

In the Telegraph Cañon Quarry, east of Berkeley, a bed of medium, coarse grained sandstone two inches thick is found lying between two chert layers in the place of the fine grained shale which ordinarily occurs. Above and below this layer the chert is separated by shale partings. In hand specimen, this sandstone is well cemented and of dark yellow to brown color. Under the microscope it is found to consist of angular fragments of quartz and feldspar cemented by iron oxide. The feldspar is largely plagioclase and is so little altered that in ordinary light the grains of feldspar look much like the quartz grains, being absolutely clear and limpid. No well rounded fragments of any sort are seen, all the grains having sharp corners.

This is the only case known to the writer where a thin sandstone parting occurs between two beds of chert. However, beds of a peculiar sandstone to be described later are often interbedded with cherts and shales. This interbedding may be rather regular so that beds of sandstone a few feet thick alternate with horizons of bedded chert and shale which are only a few feet thick.

In one instance a two foot bed of this sandstone was found bedded with cherts and shales and separated from the chert on either side by a shale parting. Within the mass of the sandstone there were several lenses of chert from six inches to two feet long, lithologically like the cherts above and below. These lenses were at different horizons in the sandstone bed. Some were in contact with the shale parting at the base of the sandstone, while others were entirely included within the sandstone.

Flinty Cherts.—The flinty cherts of the Monterey group differ from the bedded cherts in several ways. They are usually in thicker bodies, not so well bedded, and they do not show a rhythmic alternation with ordinary shales. They seldom exhibit the lamination shown by the bedded cherts and when they do show lamination it is not so evenly developed. They are generally black in color, though occasionally they are dark brown with a red or yellow cast. They usually show a fair conchoidal fracture, though the edges which may be thus produced are not as sharp as those which may be produced in ordinary chalcedony. They possess a vitreous or waxy luster, while the bedded cherts are usually rather dull or earthy.

The black color appears to be due to the presence of small amounts of bituminous matter. In thin section the silica is seen to be stained with dark brown material. On breaking a piece of this rock under the hammer it gives rise to a fetid odor strong enough to be perceptible for a distance of several feet away. On heating, these cherts gradually lose their color and become gray.

The black flinty cherts contain, scattered through their mass, large numbers of perfectly preserved foraminiferal shells. Under the microscope these are seen to retain their original structures and frequently consist of the original aragonite. In some cases the chambers are filled with calcite, and in others they are still open. Occasionally only the mould of the shell remains.

In thin section these cherts are found to consist largely of cryptocrystalline chalcedonic silica stained with organic matter. Between crossed nicols they present a mottled, granular appearance resembling greatly the appearance of thin sections of ordinary chalk flints. The larger grains in this aggregate may be seen, on rotating the stage, to possess a fibrous wavy extinction. No isotropic silica is distinguishable, though there may be considerable present between the minute grains which polarize the light. Its presence is shown on treatment with caustic potash. The presence of much chalcedonic silica is a point of difference from the bedded cherts, which contain isotropic silica.

The lamination observable in some varieties runs in general parallel to the bedding. It may not appear at all in hand specimens, although in thin section the laminae are revealed in the form of alternating bands containing different proportions of organic material. Some specimens show minute streaks of calcareous matter which effervesces with acid. In thin sections these bands are seen to be composed of granular masses of calcite or of strings of calcite granules embedded in the chalcedonic matrix of the rock, running parallel to the bedding.

In other varieties the black flinty chert shows a very pronounced alternation with layers of compact, white, earthy silica. The alternate layers range in thickness from one-eighth to one-quarter of an inch, the contrast in color giving this rock a very striking appearance (plate 34B).

Sometimes the banding is due to the alternation of black flinty chert with very thin stripes of white chalcedonic chert. In such cases the only difference between material of the stripes is the presence or absence of organic matter.

The lamination in these flinty cherts is often rather irregularly developed. Sometimes the laminae show a remarkably wavy or crumpled appearance. There may be a lenslike development of the different laminae. In other cases white bands run for a distance and die away to reappear again an inch or so further along. In such instances if one examines the intervening space carefully, he may see that, while the white color is not developed, the band is marked out by slightly different character of material, or by the presence of several exceedingly minute white lines. It would appear as though the bands were due to silica of different structure in which locally the white color had not been developed. In some specimens the white bands appear on weathered surfaces, but not on fresh fractures.

This type of chert, though not found rhythmically interbedded with terrigenous shales, is often interlaminated with white siliceous shales in which it may occur as lenslike beds, short lentils or nodules. Small irregular streaks of this black flinty chert are frequently found in the midst of the layers of the ordinary bedded cherts, as before stated. Sometimes thick masses of the gray or white earthy cherts, without shale partings, show a more or less regular alternation with bands of black flinty chert, so that the general appearance is similar to that seen where ordinary chert is interbedded with shale partings. In all cases where they are encountered, the flinty cherts show a remarkable tendency toward lenslike development. The lenses are often rather thick, two to three feet being not uncommon, and tend to approach a nodular character. In all cases the lenses or nodules lie parallel to the bedding of the surrounding rock whether it is chert or white shale.

Both types of chert contain much less silica soluble in caustic potash, than do the diatomaceous earths and bituminous shales. In cherts only three or four per cent of the silica is soluble in caustic potash. Their silica content ranges from eighty-five per cent to ninety-five per cent silica.

ANALYSES OF CHERTS AND SHALES

The following table gives analyses of cherts and shales of the Monterey formation:[23]

I. White porcelain shale, easily scratched with a knife and breaks with a conchoidal fracture. Fairbanks, Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, p. 13, 1896.
II. Analysis of a chalky shale from Carmelo Bay. Lawson and Posada, *ibid.*, vol. 1, p. 25, 1893.
III. Analysis of an ''opaque flint.''
IV. Analysis of a ''clear black flint.''
V. Soft white diatomaceous shale, Graciosa Ridge, Santa Barbara County.
VI. Soft white diatomaceous shale, Purisima Hills, Santa Barbara County.
VII. Soft white diatomaceous shale, San Julian Ranch, Santa Barbara County.
VIII. Soft white diatomaceous shale, two miles south of Casmalia, Santa Barbara County.
IX. Gray glassy porcelain shale from same hand specimen as no. 8.
X. Hard black clear flint near Zaca, Santa Barbara County.

	I	II	III	IV	V	VI	VI	VIII	IX	X
SiO_2	86.92	86.89	92.37	98.1	72.50	65.62	83.19	80.59	92.88	97.02
Al_2O_3	4.27	2.32	2.46		11.71					
Fe_2O_3		1.28			2.35					
CaO	1.60	.43	1.70		.32					
MgO	trace	trace			.83					
K_2O / Na_2O	2.48	1.26 / 2.32			1.88					
H_2O @ 100°C. / H_2O ignition	5.13	4.89	2.74		9.54	11.00				
	100.40	99.39	99.27		99.13	76.62				
Specific gravity	2.12	1.8–21	2.54	2.57						

[23] Analyses V, VI, VII, VIII, IX, and X are given by Arnold and Anderson, *in* U. S. Geol. Surv. Bull. 322, p. 45, 1907.

OTHER FORMATIONS OF THE MONTEREY GROUP

Besides the terrigenous shales, bituminous shales and diatomaceous earths, other rocks are found in the Monterey group in close association with the cherts.

Limestones.—Some dense gray limestones occur. On weathered surfaces this limestone may be yellowish from the presence of a coating of soft ocherous limonite. The beds are often lenticular and may contain the bones of marine animals. They contain in addition to the lime carbonate, carbonates of iron and magnesia, and phosphate of lime.

Sandstones.—There are two distinct types of sandstone associated with the Monterey cherts. One of these is of the ordinary type and requires no special description. The other type is rather unusual in its nature and often occurs interbedded with the cherts in beds a few feet thick.

Sandstones of this type are fine grained and are generally pale gray in color. The light coloration is due to the presence of an earthy, white substance which occupies the spaces between the grains. An occasional dark grain is seen. Often the sandstone is firm in texture, but in many places it is very porous and may be broken in the fingers.

This sandstone has been described by Professor Lawson,[24] as follows:

> The microscope shows that the body of the rock is composed of fragments of quartz, orthoclase and acidic plagioclase and siliceous rocks, the quartz greatly preponderating. All these are remarkably angular and are embedded in an amorphous cloudy matrix which resembles the insoluble residue of the chalky shales. The sharply angular fragments of quartz and feldspar are very uniform in size, ranging in diameter from about 0.12 millimeters to .5 millimeters. The dark particles are not uniform in composition, but many of them are volcanic glass. This remarkable rock, though here called a sandstone, has rather the character of a quartzose tuff than of a detrital rock, and its intercalation in the cherts and shales, which generally include little detrital material, supports this suggestion. The question of its origin is, however, left open for the present. No fossils have been found in these rocks.

In some respects this sandstone resembles that found as a parting between chert layers, described above. However, there are important differences and the sandstone parting may be a distinct type. The sandstone parting is brown in color and contains no volcanic glass.

Tuffs.—There are numerous intercalations of tuff in the Monterey group. One of these, found near San Luis Obispo, is 800 feet thick.

[24] San Francisco Folio, *op. cit.*, p. 10.

Similar beds are intercalated in the organic shale at many points. The diatomaceous shales frequently contain a large admixture of volcanic material. The tuffs are acidic, and usually rather soft and unconsolidated.

Other Formations in California Similar to the Monterey Group

Diatomaceous earth, bituminous shales, and cherts are known in other formations in the California Coast Ranges.

The Upper Cretaceous Moreno formation contains diatomaceous shales and is regarded by Anderson and Pack[25] as a source of petroleum.

The Oligocene Krayenhagen shale contains considerable amounts of diatomaceous shale and some chert.

Similar shales have been described from the upper Miocene Santa Margarita (San Pablo) formation in the Sunset-McKittrick field.[26]

Origin of the Monterey Cherts

With regard to the origin of the cherts in the Monterey group, there has been some difference of opinion among geologists.

Hypothesis of Secondary Silicification

One idea, which has been accepted by several geologists, is that the cherts are formed by the silicification of diatomaceous shales. This idea seems to have been first advanced by Fairbanks[27] in the San Luis Folio:

> Over large areas it has undergone silicification, which has so changed its appearance that, were it not for numerous transition phases, the origin of the silicified beds would often be difficult to recognize. The different degrees of change can be traced from the dark bituminous shale through the light porcelain-like varieties to the flinty forms. Some of the flints are opaline, while others have a waxy appearance and still others are jet black. The metamorphism has affected the rock so irregularly that often considerable variation can be seen in the same hand specimen.
>
> Analyses show that the unaltered shale generally contains 80 to 90 per cent of silica, and the flints as high as 98 per cent. In those areas of shale which have undergone the most metamorphism the bands are generally sharply folded and contorted and are filled with a network of veinlets of chalcedonic quartz.

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[25] U. S. Geol. Surv. Bull. 603, 1915.

[26] U. S. Geol. Surv. Bull. 406, p. 67, 1910.

[27] *Op. cit.*, p. 4.

The change which the shale has undergone is not so much the introduction of new silica as the transformation of that which it already contained. The non-polarizing amorphous silica of the unaltered shale has given place to the polarizing chalcedonic variety.

Fairbanks believed that this silicification occurred in large part before the deposition of the Upper Miocene San Pablo formation, since the base of the latter formation contains boulders of Monterey chert.

Arnold and Anderson,[28] in describing the Santa Maria Oil District, discuss the origin of the cherts in the following words:

The soft shale has been described in the preceding pages as ''unaltered,'' and in referring to the harder varieties different degrees of ''alteration'' have been mentioned, for the reason that the best explanation of the origin of the harder rocks appears to be that they are products of metamorphism of the soft variety. It is believed that the soft white and chocolate-colored organic shale represents the original state of the beds of the whole formation, and that a process of silicification and crystallization has caused the changes, this process having been aided possibly by structural disturbances and pressure. The beds of soft shale are usually found in attitudes only gently disturbed, whereas the harder shale is most commonly much folded and is invariably the component rock of folds where the forces have been especially intense. This fact may throw light on the problem of the alteration of the shale, and yet it may be simply the outcome of the removal of the softer portion of the formation in the regions of greatest uplift and disturbance. The chief agent in causing the change was probably infiltrating water carrying silica in solution. In some places the process may have been simply or largely infiltration in the extremely porous original shale and deposition of silica in the interspaces, thus giving rise to hardened and compacted irregular granular aggregates of the original amorphous silica and the new crystalline silica combined, the result being an increase in the total percentage of silica. In more extreme cases the original material was probably partly taken in solution and redeposited, being replaced almost entirely along bands or in spots, and the change being carried to a less extent along other layers and in other areas, or else the replacement was almost complete throughout. As the rock was rendered more compact in this process a shrinkage may have been the result, or the same volume may have been retained and the pores filled. That solution took place along with the deposition seems to be shown by the almost complete destruction of the forms of organisms.

It is possible that the differences in the shales may be original, the result of variation in the material deposited. Whole series of beds of different material might have been deposited, giving rise to harder, more siliceous rocks than the softer varieties, and the same material might have been locally deposited in thin beds or in lenses and nodules, or have been intermingled with the others to form the intermediate varieties. But it would be difficult to say what this material might have been, and the more or less completely crystalline character of the harder shales shows that metamorphism has taken place. The most plausible theory, therefore, is that the Monterey shale as originally laid down was fairly constant in character and that it has undergone alteration extensively, as well

[28] U. S. Geol. Surv. Bull. 322, p. 46, 1907.

as very locally, through the agency of siliceous waters, the older portions of the formation, and possibly the more disturbed portions, having been most generally subjected to the change. The limestone has in places been altered after a fashion somewhat similar to that of the siliceous shales, being changed to marble, probably as the result of solution and redeposition.

Again in 1910, Arnold and Johnson[29] discuss the origin of the cherts in the following words:

> The Monterey shale has been subjected to a varying degree of alteration, none of it pronounced enough, except in certain restricted localities, to greatly change the appearance of the formation. Silicification has taken place, however, especially in the lower and middle portion, but the process by which the silica was so intimately introduced into the shales is not fully understood. A suggestion is at hand in secs. 13 and 14, T. 30 S., R. 21 E., where an intense local silicification has taken place along fractures in a much folded and possibly faulted zone of the Monterey. The rock has been so altered as to closely resemble both in hardness and color the grayish-green phases of jasper and chert seen in the pre-Cretaceous Franciscan formation. It is conceivable that solutions percolating along similar, though perhaps smaller, fractures resulting from the folding and faulting to which the Monterey shale has been subjected have produced a less intense but none the less definite silicification in other parts of the series.

While the idea of the origin of the cherts by the introduction of silica into previously existing rocks has certain points in its favor, it seems impossible to reconcile this hypothesis with many other facts concerning these cherts.

The rhythmic bedding seen in much of the chert is opposed to the hypothesis. Whenever the bedded cherts occur, they are characteristically separated by argillaceous partings. The chert layers vary in thickness from one inch to six inches. The shale partings vary from one-eighth inch to two inches. On the other hand most of the diatomaceous earth is rather massive. Throughout considerable thicknesses, it consists largely of siliceous material, showing little admixture of shale. Where bedding is apparent in the diatomaceous earth, the beds are generally much thicker than the beds of chert and shale seen in the cherts. The bedding of the diatomaceous earth is usually due, not to clean cut, regular alternations of chert and shale, but to minor variations in the diatomaceous earth itself. It seems improbable for this reason, that such thin bedded material as the cherts could be derived from ordinary diatomaceous earth.

One might imagine the cherts to come from the introduction of silica into ordinary shale. They might be due to the introduction of

[29] Preliminary Report on McKittrick Sunset Oil Region, California, U. S. Geol. Surv. Bull. 406, p. 57, 1910.

silica, along lines of fracturing in an originally massive argillite, resulting in bands of chert in shale. In such a case, one would not expect the bands to possess the remarkable regularity seen in the bedded cherts, nor expect them to be parallel to the original bedding of the formation, as revealed in intercalated sandstones and limestones.

The other two possibilities that remain, under the silicification hypothesis, are:

1. Some substance, easily replaced by silica, was originally interbedded with ordinary shale, thin layers of this material alternating in a rhythmic way with thin layers of shale. The only possibility that seems reasonable here, is that this original material, in alternation with shale, was limestone. This possibility is barred at once by the finding of lime carbonate in shells of foraminifera embedded in the chert. It would be impossible for them to remain unchanged while a limestone matrix became silicified.

2. Thin beds of diatomaceous earth may have been laid down in regular alternation with thin beds of shale. Later these layers of diatomaceous earth may have been compacted into chert by the later introduction of silica that filled the pores; or the silica of the diatomaceous earth may have been aggregated into compact jaspery layers by the solution and redeposition of the skeletons of diatoms.

FACTS OPPOSING THE HYPOTHESIS THAT CHERTS ARE ALTERED DIATOMACEOUS SHALES

The evidence presented in the following paragraphs seems conclusive in indicating that the cherts are not due to an alteration of diatomaceous shales.

1. If the cherts are due to the introduction of silica into beds of diatomaceous earth in alternation with beds of shale, it is hard to understand why the intervening shale beds were not silicified also. Yet they present all the characters of ordinary unaltered shale, and show no sign of silicification.

2. The cherts may be found, in many cases, resting on, or interbedded with, the peculiar soft sandstones of the Monterey group. If there had been an introduction of silica in solution, these porous rocks should certainly have become completely silicified and altered to quartzite. On the contrary, they are usually soft—often so soft that they may be easily broken in the fingers—and are very porous. They are certainly as permeable to solution as the diatomaceous shales.

3. In one case, described above, very small lenses of chert are found within a stratum of sandstone, that, in its turn, is enclosed within bedded cherts. The sandstone is soft, and very porous. The lenses of chert are of the ordinary sort and exactly like the bedded cherts that enclose the sandstone bed on either side. If these lenses had been produced by the silicification of small lenticular masses of diatomaceous earth in the sandstone, the solutions must have permeated the sandstone and filled the pore spaces in it.

4. If one believes that these cherts were originally diatomaceous earths, then the remains of diatoms and radiolaria must have been obliterated, during the alteration, since the cherts do not now show them. Such an alteration is hard to understand, when one remembers that the delicate shells of foraminifera are often found in a well preserved state in these cherts. However, the solutions may have been able to dissolve silica but not to dissolve lime carbonate. It is also possible that if opaline silica were introduced into a diatomaceous earth, the filling of the pore spaces with material of about the same refractive index, would cause the organisms to become invisible.

5. A further fact, that is incomprehensible on the assumption of silicification, is the occurrence of white diatomaceous shale, chocolate bituminous shale, black flinty chert, black bituminous shale, white and gray bedded cherts and terrigenous shales, interbedded with one another, and all exposed in the same section. On the idea of original differences in deposition, such a section presents no special difficulties.

6. In many instances the cherts appear to be confined to definite horizons, while the siliceous shales are confined to other horizons. Arnold, for example, found that the lower part of the Monterey shale in the Santa Maria district was characterized by cherts, while in the upper part the organic shales were the predominant type. Lawson[30] found in the Concord quadrangle that there were three distinct horizons of siliceous shale in the Monterey group, all separated by sandstones. Of these the lower horizon is predominantly cherty, while the other two are characterized by siliceous shale and do not contain chert, except in small amounts. In view of this it seems difficult to accept the notion that the cherts occur in those parts of the formation which are most contorted. The upper horizons in the Concord area are about as much disturbed as the lower and yet they contain little chert, and the general relations do not bear out the idea of chert formation in regions of greater disturbance. In many places the

[30] San Francisco Folio, *op. cit.*

chert beds lie almost flat. In other places, though they are inclined, they do not show the contortion which would be expected if they had been greatly disturbed. The apparent relation in certain places between degree of disturbance and the existence of bedded cherts may be better explained on a mechanical basis. The bedded cherts tend to show the greatest contortion because they are most incompetent, the alternation of hard and soft beds rendering them much more susceptible to minor plication than the more massive diatomaceous shales, which, while they may be thin bedded, are still much more uniform in lithologic character.

7. If cherts are due to changes, induced by metamorphism severe enough to change soft diatomaceous earth to jaspery silica, we would expect the same action to change shales and limestones associated with the cherts, which is not the case.

8. Cherts show a peculiar branching of beds and a wedging out of shale partings, before referred to. These would not be expected in beds of organic ooze formed by skeletons of pelagic organisms, dropping to the ocean bottom. Such beds should be of wide extent.

Considering the black flinty cherts, that do not show such regular bedding, they also do not appear to be silicification products, because of certain peculiarities of the foraminiferal shells, that occur in considerable numbers in them. In numerous instances the original calcium carbonate of the shell still remains. In a few instances it has been replaced by silica, and in some instances it has been leached out, leaving the tiny mould in the midst of the chert. In those cases where the lime carbonate of the shell is still preserved, it is fibrous and is apparently in its original condition. In a few instances the chambers of these shells are filled with opal; in many instances they are filled with calcite; in most cases they are found unfilled.

One specimen collected by Professor Lawson from the Monterey at Carmel, shows many of these foraminiferal shells in an excellent state of preservation. The rock is black flinty chert, and in this siliceous matrix the foraminifera are embedded. On breaking the rock the fracture passes through these shells. The septa between the chambers are perfectly preserved. The chambers of the shells are empty. This specimen is cited particularly because of the numerous well preserved shells which it contains. Similar examples, though not so striking in appearance, are quite common.

In view of the preservation of the foraminiferal shells, it is impossible to believe that such a rock could be due to silicification or to crystallization of the silica of diatomaceous shale. One can imagine conditions under which solutions would dissolve and redeposit silica without affecting even delicate shells of lime carbonate. The evidence presented later under the heading of "Alteration of Chert" shows that solutions may carry silica without dissolving calcium carbonate. It is, however, impossible to believe that silica was carried in solution, in any form, and deposited in the chert in such a way as to leave the open chambers of the foraminiferal shells unfilled.

The facts set out above lead to the conclusion that the cherts of the Monterey are not due to metamorphism, or silicification of diatomaceous earth or bituminous shales. The other alternative is that they were originally formed in somewhat the same condition, and in the same relations, in which we now find them. The inclusion of empty foraminiferal shells in a matrix of silica seems only to be explained on the assumption that the shells were caught in a gelatinous mass of silica and were thus preserved.

Accepting this idea of original gelatinous silica it is possible to believe that this silica was produced by the solution of the skeletons of diatoms on the sea bottom. It is conceivable that under the influence of acids generated by decaying organic matter the siliceous tests were dissolved. That this did not happen is shown by two things:

1. The presence of unaltered foraminiferal shells proves that such acids, if present, were not very powerful solvents.

2. The diatomaceous earths, which certainly contained large amounts of organic matter, show no evidence of solution and are now earthy, rather poorly consolidated rocks.

The solvent effect of ocean water under pressure was evidently not important since it was not powerful enough to remove calcareous matter from the foraminiferal shells and could therefore hardly be be expected to cause silica to go into solution. It seems certain that the gelatinous silica of the cherts was derived from some other source than a diatom ooze.

The variations in lithologic types seen in the Monterey, are not due to different stages of alteration, but are due to original variation in the nature of the material which was accumulating. The final product depends upon the relative proportions of diatom frustules, clayey material, and gelatinous silica which made up the original deposit.

ALTERATION OF CHERT

The peculiar relations between black flinty chert and white shales seen in certain instances require some discussion. Fairbanks[31] makes the following statement:

> Some portions of the diatomaceous beds have undergone a transformation and hand specimens were obtained in which the flinty alteration product appeared sharply marked off from the unaltered portion by lines running directly across the bedding.

One occasionally sees masses of black flinty chert which show irregular patches of porous white shale within them, the boundaries between the two lithologic types being quite sharp and distinct.

One specimen in the possession of the writer brings out these relations very well; it is only one of many similar occurrences. It consists in its central portion, of typical flinty chert, black in color. Toward the borders, the chert becomes slightly discolored and is brownish instead of black. The boundaries between the black chert and the surrounding brownish chert are vague and irregular (plate 35c).

The outer portions of the mass, and a portion of the central part, consist of white shale. This material is firm and resists crushing to a considerable degree, though it is porous and rather easily scratched with a knife. The boundary between the brown chert and the white shale is irregular, there being numerous indentations and reëntrants in the boundary line; yet the actual line of separation between these two lithologic types is sharply defined. One passes immediately from chert to shale without a transition zone. There are, however, occasional small elliptical patches of brown chert within the white shale. The boundary between the white shale and the chert bears no relation to bedding, so the relation between the two materials was not produced in the original deposition of the rock.

Two possibilities present themselves in explanation of the observed relations: either the black chert is due to the introduction of silica into the shale; or the white shale is the result of the partial disintegration of the chert—the removal of a portion of its silica, leaving the remainder behind in a porous condition.

In thin section the white shale around the outer portion of the specimen is found to consist almost entirely of amorphous silica. Scattered through this material are numerous grains of polarizing minerals, quartz and feldspar being determinable. No diatoms or radiolarians appear, but the section shows numerous foraminiferal

31 San Luis Folio, *op. cit.*

shells. These show the perforations of the shell, the shell walls, and the septa, perfectly preserved in the original fibrous aragonite. The chambers in this particular specimen are not open but are filled with crystalline calcite, though other specimens of the same sort show the original shell walls with open chambers.

The chert in the center of the specimen is also full of foraminiferal shells. One or two lie partly in the chert, and partly in the shale, occurring on the border between the two types of material. Under the microscope the chert is found to consist of cryptocrystalline silica.

Since the facts before presented bar the possibility of the cherts being due to silicification of diatomaceous shales, one is forced to adopt the other possibility, and believe that the white shale here is the result of the partial disintegration of the chert.

The black chert appears to consist of two varieties of silica—one isotropic, the other anisotropic. The white shale contains only isotropic silica and it would appear that the chalcedonic silica had been removed by solutions, leaving the opaline silica behind in a porous network. This is the reverse of what might be expected, but it may well be that the hydrated form of silica is more stable under conditions of weathering than the chalcedonic variety. Another peculiar fact is that this change has taken place without the removal of the lime carbonate of the shells.

The extreme sharpness of the contact between the two types of material might be suggested as opposed to this idea of partial leaching; neither would it be expected on the idea of silicification, so that it cannot be raised as a serious objection. Moreover, as will be brought out presently, this abrupt boundary seems to be usual when compact silica of this sort is changed in the manner described.

The partial removal of silica from massive, compact, siliceous rocks, to form a porous material is a rather common occurrence.

Keyes,[32] for example, has described an analogous occurrence in certain cherts in Missouri. These cherts occur in small nodules and in nodular bands in limestone. They are very compact, translucent rocks when first removed from the limestone, breaking with a conchoidal fracture. They quickly slacken under the air to a fine, intensely white powder. Before being affected by atmospheric attack these cherts do not appear to be fossiliferous. After the disintegration has gone part way they are found to be filled with fossils, whose presence is revealed by the disintegration of the matrix.

[32] Keyes, C. R., A Remarkable Fauna at the Base of the Burlington Limestone in Northeastern Missouri, Am. Jour. Sci., vol. 144, p. 447, 1892.

Hovey[33] has also described similar alterations of chert. He states that in certain cherts of Missouri, the chemical difference between the fresh and the altered chert is very slight, but the physical difference is remarkable. He describes altered chert as extremely porous and breaking easily between the fingers. All gradations in the process of alteration are to be found. Some chert is perfectly fresh except for an outer shell of decomposition, while other specimens are altered throughout their whole mass. The altered chert is sometimes spoken of as "tripoli."

Russell[34] describes similar occurrences in certain cherts of Tennessee and Alabama. In the Silurian and Carboniferous limestones the flinty concretions are exceedingly hard and apparently highly durable when fresh. When exposed to the atmosphere, they crumble to a fine white powder, bearing no resemblance to the original rock. The change is abrupt, but the original homogeneity is shown by concentric lines and bands of various tints which run without interruption through both the solid and friable portions.

The flints from the chalk of England[35] show similar changes. Between crossed nicols, the flint shows a fine mottled appearance like that exhibited by certain types of chalcedonic silica. While a microscopic study of thin sections of flint shows little evidence of the presence of opal; still on treatment with caustic potash, opal may be dissolved out so that the flints appear to consist of a mixture of chalcedonic and opaline silica. When treated with a hot solution of caustic potash the opaline silica is removed, leaving the chalcedonic silica behind in a firm porous mass which retains the original form of the flint fragment.

If a flint from the chalk be treated with acid until all the adherent lime carbonate is removed, it will be found to be coated with a pure white rind of porous silica, apparently due to the weathering of the flint. In such specimens it will be noted that the line of junction between the porous white silica and the black flint is extremely sharp. It is also a fact that if a freshly broken black flint be exposed to the weather for a number of years, it gradually becomes covered with a white coat of porous silica.

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33 Hovey, E. O., A Study of the Cherts of Missouri, Am. Jour. Sci., vol. 148, p. 401, 1894.

34 Russell, I. C., U. S. Geol. Surv. Bull. 52, p. 21, 1889.

35 Sollas, W. J., The Origin and Formation of Flints, *in* The Age of the Earth, pp. 132–65, London, 1908.

Hill, W., Flint and Chert, Proc. Geol. Assoc., vol. 22, p. 61, 1911.

In order to compare the behavior of these flints with the Monterey flinty cherts the writer tried certain experiments upon both rocks. A specimen of flint was treated with acid until all lime carbonate was dissolved away. Portions of the white siliceous rind were examined under the microscope and found to consist of isotropic silica. On putting a piece of the flint with the adherent white crust into caustic potash solution for a short time the white rind went into solution very rapidly, leaving the black flint untouched.

On exposing a piece of black flint to the action of caustic potash for a time, it was found that the opal in the flint gradually went into solution and after a long time the alteration proceeded so deeply that the flint became covered with a white rind of porous silica. On powdering this rind and examining it under the microscope it was found to consist, not of isotropic silica, but of anisotropic silica. A specimen of black flinty chert from the Monterey was treated in the same way and similar effects were produced.

It would appear from the above observations that the flints, and the black, flinty, Monterey cherts consist of an intimate mixture of two types of silica. One type is amorphous and soluble in caustic potash. The other type is anisotropic and not soluble to any large extent in caustic alkalies. Under the action of surface water, in weathering, the anisotropic silica is removed from the flint or from the flinty chert, leaving the opaline silica behind. If the chert or flint be treated with caustic potash the reverse effect occurs, and opal goes into solution leaving the chalcedonic silica behind in a porous mass.

The flinty cherts of the Monterey group show numerous examples of this change. The exposed surfaces of black cherts are usually covered with a white coating, showing the change which they are undergoing. Fragments of black, flinty cherts become bleached so that the soil over such a chert horizon is filled with white angular fragments of bleached chert. Often the flinty cherts will show alteration to white amorphous material along fissures as indicated in plate 35A. In other cases blocks of chert show a coating of white shale resulting from their alteration. This alteration cuts across original banding in the matter shown in plate 35D, indicating that the association of white shale and black chert is due to secondary action. Sometimes a black chert shows white bands developed on a weathered surface, but on breaking it open, the white bands do not appear on the interior though the appearance is such as to suggest a banded structure (plate 35D).

It appears, then, that some of the white shales are really weathered cherts; but this does not imply that all the white shales are formed in this way. The writer has not had opportunity of investigating this particular question in the field and of reaching any conclusion with regard to the relative amounts of this sort of white shale. While he is convinced that this is the origin of much of the non-diatomaceous white shale, he is also aware that there are great thicknesses of diatomaceous earths which undoubtedly represent former diatomaceous oozes, accumulated on the sea bottom. Much of the white shale which does not now show organic remains may be due to the alteration of these diatomaceous earths; but this is not established. All the non-diatomaceous white shales may be due to the weathering of chert.

In one specimen of white shale in the collection of the University of California there are found streaks of black cherty material. These when examined closely may be seen to be due to the silicification of white shale along cracks. A specimen of this kind if seen alone might easily give rise to the opinion that the cherts were due to the introduction of silica along cracks. The evidence presented before shows that this cannot be the origin of the cherts. It is believed that instances of this sort are due to the local deposition of silica during the process of leaching silica from a mass of chert in the manner above suggested.

Comparison of the Bedded Cherts of the Monterey and Franciscan Groups

While the bedded cherts of the Monterey and the cherts of the Franciscan are similar in many ways, yet they also show a great many points of difference.

Their most striking common feature is probably their rhythmic bedding—the alternation of chert and shale, repeated hundreds of times. Due probably to the incompetence resulting from the thin bedding of such greatly dissimilar rocks the Monterey cherts are locally contorted like the Franciscan cherts.

The Monterey cherts are not cut by so many cross veins as are found in the Franciscan cherts; in fact veining is uncommon in them. In the Franciscan the veins are often filled with white quartz. In the Monterey cherts the vein filling is chalcedonic.

With regard to the rocks themselves, the most noticeable difference is probably in the color. The bedded Monterey cherts are usually of a dull color, yellow to gray, while the colors of the Franciscan cherts are varied and brilliant, because of the large amounts of iron and manganese oxides which they contain.

In thin sections of the Franciscan cherts isotropic material is not abundant, but it is quite common to find large amounts of isotropic silica in the Monterey cherts. Although the Franciscan cherts are largely recrystallized and contain little amorphous silica, the radiolarian remains are still quite prominent. In the Monterey cherts very few organic remains other than foraminifera are found.

The lamination seen in the Monterey cherts, which is so characteristic of them, is not so common in the Franciscan cherts. While lamination does exist in some of the Franciscan cherts it is less pronounced, and there is no sharp contrast, as a general thing, between the bands of different material. They grade into each other almost imperceptibly. In rare cases a rock may be found in the Franciscan cherts which shows as strong banding as is found in the Monterey cherts.

The Monterey cherts do not show the waxy luster and well developed conchoidal fracture shown by most of the Franciscan cherts, and as a general thing they contain a larger amount of earthy material. This statement meets exceptions in the case of the *flinty* cherts of the Monterey. The Monterey cherts are less dense than the Franciscan cherts.

The difference in the nature of the two groups of cherts is reflected in a comparison of the shales which are interbedded with them. In the Monterey group the shales appear to be ordinary terrigenous shales, while the shales of the Franciscan are unlike ordinary shales.

In the Franciscan, the shales and cherts are not intercalated with thin beds of sandstone. In the Monterey cherts there are numerous beds of a peculiar type of sandstone in close association with the bedded cherts.

OCCURRENCES OF RADIOLARIAN ROCKS

The following paragraphs will describe certain occurrences of radiolarian rocks in other parts of the world. While the larger and more important occurrences are summarized, no attempt is made at completeness.

Radiolarian remains are found in many types of sedimentary rocks. Hill[36] in a summary of the literature treating of their occur-

[36] Hill, W., Rocks containing Radiolaria, Proc. Geol. Assoc., vol. 23, p. 62, 1912.

rence has shown that they may occur in tuffs, marls, clays,[37] chalk,[38] limestones, and in coprolites. Cayeux[39] has also described radiolaria from fine grained glauconitic rocks of the sandstone type (gaize) of Jurassic and Cretaceous age. These consist of grains of quartz and glauconite with numerous skeletons of radiolaria and diatoms, together with sponge spicules, the whole cemented by opal, chalcedony, and argillaceous material.

In spite of the wide spread distribution of radiolaria there are only certain types of sediments in which they are numerous: (1) radiolarian earths; (2) very fine grained mudstones; (3) some diatomaceous earths; (4) bedded radiolarian cherts.

The Radiolarian Earths of Barbados

A typical example of a fossil radiolarian ooze is found in the radiolarian marls of Barbados and the adjacent islands.[40]

The island of Barbados contains three formations. The basal beds consist of sandstones, grits and shales known as the Scotland Beds. These beds are folded and unconformably above them is the Oceanic series of Miocene age, above which are raised coral rocks and reefs.

The members of the Oceanic series blend gradually into one another, but can be separated into four members.

1. At the base are calcareous deposits, consisting of white limestones, some of which are soft and chalky. These have a thickness of about forty feet. The basal member contains from sixty to eighty per cent of calcium carbonate, largely in the form of shells of foraminifera.

Toward the top of the first member the number of siliceous organisms begins to increase, until the second member of the series is reached.

2. The second member, which has a thickness of 130 feet, is composed of the remains of siliceous organisms, mostly radiolaria, with

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37 *See also* Shrubsole, W. H., Notes on the Radiolaria of the London Clay, Quar. Jour. Geol. Soc., vol. 45, pp. 121–124, 1889.

38 *See also* Holmes, W. M., On Radiolaria from the Upper Chalk, Quar. Jour. Geol. Soc., vol. 56, p. 694, 1900.

39 Cayeux, L., Contribution à l'étude micrographique des terrains sédimentaires, Lille, 1897.

40 Jukes-Brown and Harrison, The Geology of Barbados, Quar. Jour. Geol. Soc., vol. 47, p. 197, 1891; Quar. Jour. Geol. Soc., vol. 48, p. 170, 1892.

Gregory, J. W., Contributions to the Paleontology and Physical Geology of the West Indies, Quar. Jour. Geol. Soc., vol. 51, p. 255, 1895.

some diatom frustules and sponge spicules. The siliceous earths are very soft, low in specific gravity, and poorly consolidated. Generally they are white in color at the surface, but below the surface they are often yellow, drab or pink. The second member contains less than one per cent of calcareous material and may contain as much as seventy-seven per cent of organic silica. The rock is seen under the microscope to be a mass of siliceous remains, the finer portion of which consists of finely broken organisms with considerable argillaceous matter. In the purest siliceous earths the tests are closely packed in a matrix of siliceous fragments. In the more impure varieties the argillaceous matter may make up half the rock. The most siliceous of these rocks are permeated with silica in a colloidal state, probably derived from the siliceous organisms.

3. The third member which lies above the siliceous earths and grades into them, is a calcareous earth, forty-five feet thick, containing layers of pumiceous sand. Calcium carbonate, largely in foraminiferal shells, varies from forty to sixty per cent.

Both the upper and lower foraminiferal marls contain from one to twenty-five per cent of colloid silica, which appears to be diffused through the mass of the rock. Siliceous organisms rarely occur in these rocks, though the silica which they contain was probably once in the form of organic remains. In the transition beds, which contain both calcareous and siliceous remains, the radiolarian skeletons are poorly preserved.

In both the siliceous and calcareo-siliceous earths, there occur cherty nodules. These consist largely of siliceous skeletons, which are cemented by amorphous silica.

4. Above the upper calcareous beds there is a mass of very fine argillaceous earth, which has a thickness of twenty-five feet, and is of various colors, red, pink, yellow, white or mottled. It is regarded as being the equivalent of the Red Clay of modern abyssal ocean depths. It contains only a trace of calcium carbonate in an occasional foraminiferal shell and consists of fine argillaceous material with a few radiolarian skeletons. The argillite is exceedingly fine grained and has a peculiar greasy feel. The mineral fragments which it contains are angular, as are those of the present red clay. Feldspar is rather common in these fragments, while quartz is rare.

Harrison and Jukes-Brown[41] made a series of analyses of modern Red Clay for comparison with those of the variegated red and yellow

[41] Harrison and Jukes-Brown, Notes on the Chemical Composition of some Oceanic Deposits, Quar. Jour. Geol. Soc., vol. 51, p. 313, 1895.

earths of the upper member of the oceanic deposits of Barbados. There are certain points of difference—for example, the modern Red Clay contains less alumina and more iron than the Barbados earths—but such variations are to be expected in a material like the Red Clay and, as a result of their chemical work, Harrison and Jukes-Brown were convinced that this earth is the equivalent of the modern Red Clay.

It is believed that the oceanic deposits originated in deep water, because of the general character of the deposits, and the practical absence of larger organisms than radiolaria and foraminifera. The chemical work above cited points to a deep sea origin for the upper member and the siliceous earths are exactly what one would expect the modern radiolarian oozes to become. Also the Oceanic Series contains a species of echinoderm which has never been found at depths less than 1000 fathoms.

The succession of beds in Barbados is interpreted to mean that the region sank beneath the ocean, beyond the reach of terrigenous sediments, and continued to sink gradually until it reached depths comparable with those under which radiolarian oozes are now accumulating (2000–3000 fathoms). After a long period of abyssal conditions there was a reversal and a reëlevation of the region into depths at which calcareous oozes could accumulate, after which the region sank again and red clay was deposited.

The only objection ever made to this interpretation of the Barbados earths as abyssal deposits was made by Rust.[42] He states that the radiolaria found in the Barbados earth are of types which, according to the "Challenger" report, are dwellers in the deep sea, but that the large admixture of foraminifera and other shells make it doubtful whether these rocks are really abyssal.

In Trinidad,[43] there is a succession of oceanic deposits quite similar to those in Barbados. These oceanic deposits are called the Naparima marls and are believed to be Miocene. They rest unconformably with gentle dips upon an older series of red and blue clays and sandstones. In this series, as in Barbados, there is a continuous gradation from a basal member, consisting of buff to cream colored

42 Rust, Beiträge zur Kenntniss der fossilen Radiolarien aus Gesteinen der Trias und der palaeozoischen Schichten. Palaeontographica, XXXVIII, 121, 1891–92.

43 Harrison and Jukes-Brown, The Oceanic Deposits of Trinidad, Quar. Jour. Geol. Soc., vol. 55, p. 177, 1899.

Guppy, R. J. L., The Tertiary Microzoic Formations of Trinidad, West Indies, Quar. Jour. Geol. Soc., vol. 48, p. 519, 1892.

globigerina marls, into a set of passage beds which comprise white chalky calcareo-siliceous earths. From these passage beds, there is a continuous gradation upward into whiter and more siliceous beds of much lower density, which are composed largely of the skeletons of radiolaria. In Trinidad, the globigerina marls are 120–140 feet thick and the radiolarian earths are 40–50 feet thick.

The radiolarian marls here often show scales with pearly luster, which represent the fragments of the frustules of diatoms. Some of the marls contain as much as twenty per cent of these. The deposits of Trinidad contain more quartz and argillaceous matter than those of Barbados, apparently being laid down closer to land. The radiolarian earths also contain more calcium carbonate, some of them running as high as twenty per cent. The foraminifera of these marls, according to Guppy, are those which are found now in deposits in depths of 1000 fathoms.

Similar siliceous earths are found at other points throughout the same general region. Radiolarian earths are said to occur in the island of Hayti,[44] and deposits like the Barbados earths occur at Baracoa, in Cuba,[45] where they are reported to have the same relations as do the rocks of Barbados.

In Jamaica, no radiolarian earths are known, but a white limestone—the Montpelier White Limestone—is regarded as a deep sea deposit. It is free from terrigenous material and contains no molluscan remains or shallow water corals.

Radiolarian Mudstones

in Gondwana Series

As illustrations of radiolarian rocks of the second class, there might be mentioned certain shales in the Gondwana series of India.[46]

The Upper Gondwana series, near Madras, is divided into two groups. The lower group is called the Sripermatur group, and consists of two formations. The upper formation is composed of thin bedded, pale, buff colored or white shales, containing plant remains. It is ten feet thick. The lower formation is composed of sandstones, grits, and micaceous sandy shales which attain a thickness of fifteen feet. The upper shales contain plant remains and some marine fos-

[44] Quar. Jour. Geol. Soc., vol. 48, p. 219, 1892.

[45] Gregory, J. W., Quar. Jour. Geol. Soc., vol. 51, p. 293, 1895.

[46] Coomaraswamy, A. K., Occurrence of Radiolaria in the Gondwana Beds near Madras, Geol. Mag., vol. 39, p. 305, 1902.

sils—ammonites and pelecypods. These shales are porcelaneous with a smooth conchoidal fracture. Under the microscope, they are seen to contain numerous radiolaria, rather poorly preserved, together with tiny fragments of clastic quartz, and specks of carbon. These are all embedded in a fine siliceous paste, which remains dark between crossed nicols. The plant remains are fragmentary and were probably drifted some distance from the shore. Their presence has been accepted as proving the shallowness of the water in which the shales were deposited.

It is interesting to note the association of these radiolarian shales with coarse sandstones and conglomerates of the Gondwana series. Underlying these shales there are rather coarse sandstones. Immediately overlying the Sripermatur group are coarse, compact conglomerates with sandstones and grits, apparently conformable on the lower beds. The Gondwana series is believed to have been deposited, in large part, by fluviatile action. Locally, however, rocks of unquestioned marine origin are intercalated with the continental deposits.

RADIOLARIAN ROCKS OF AUSTRALIA

Certain radiolarian rocks of Australia which occur in association with radiolarian cherts belong to the second class. These occur in both the Silurian and Devonian systems of New South Wales.[47]

Radiolarian beds of lower Devonian are well developed near Tamworth. The whole thickness of the radiolarian series is here at least 9260 feet. It consists largely of jointed claystones which contain numerous radiolaria. In these claystones the radiolaria constitute about half the volume of the rock. In addition, cherty shales, black radiolarian cherts, radiolarian limestones, coralline limestones, and submarine tuffs, are interbedded with the claystones. No red radiolarian cherts occur at Tamworth.

The claystones which contain the radiolaria are dark brownish gray to olive brown when fresh, but weather to a yellowish color. They are usually quite soft and are very fine grained, all the particles being less than .05 millimeter in diameter, and most of them ranging from .025 millimeter to the size first mentioned. The claystones are

[47] David and Pittman, On the Paleozoic Radiolarian Rocks of New South Wales, Quar. Jour. Geol. Soc., vol. 55, p. 16, 1899.

Hinde, G. J., On the Radiolaria in the Devonian Rocks of New South Wales, *ibid.*, p. 38.

Benson, W. N., Spilite Lavas and Radiolarian Rocks in New South Wales, Geol. Mag., vol. 50, p. 17, 1913.

Süssmilch, C. A., An Introduction to the Geology of New South Wales, Sydney, 1914.

free from calcium carbonate and are very finely laminated, the laminae being about one millimeter thick. They occur in thin beds ranging from 2.5 centimeters to 15 centimeters in thickness, occassionally reaching a thickness of 30 centimeters.

The radiolarian claystones contain abundant plant remains. There are numerous impressions of *Lepidodendron australe,* some of which still contain carbon. In places these remains are very abundant, three to ten leaf impressions occurring per square foot of surface.

The radiolarian claystones show evidence of shallow water deposition. In two places near Tamworth, ripple marks were found in them.

Lenticular beds of a siliceous limestone occur at various horizons, irregularly interstratified with the other rocks. The thickness of these lenses ranges from a few inches to two feet. They contain numerous radiolaria.

Dense, black radiolarian cherts occur locally. In thin section, they are seen to be laminated, the lamination being due to alternate bands of lighter and darker material. The radiolaria appear as clear areas in a darker matrix consisting of silica containing particles of carbonaceous material. The radiolaria are generally filled with chalcedonic silica, but occasionally they are filled with granular quartz. They are very numerous, it being estimated that each cubic inch of the rock contains about 1,000,000 radiolarian skeletons.

The following analyses by David and Palmer indicate the chemical nature of various rocks of this series:

I. Black radiolarian chert.
II. Radiolarian cherty shale.
III. Radiolarian shale.

	I	II	III
SiO_2	91.06	80.50	67.87
Al_2O_3	3.79	9.57	15.25
Fe_2O_3	2.01	2.67	5.08
MnO	trace	trace	trace
CaO	.45	.60	1.71
MgO	.46	.76	1.46
K_2O	.84	1.68	2.21
Na_2O	.28	1.18	1.37
CO_2	--------	--------	absent
P_2O_5	trace	.11	.12
SO_3	.35	trace	-------
Organic matter	-------	.86	-------
Water @ 100°C	.32	.45	2.37
Combined water	.97	1.29	2.10
	100.53	99.67	99.54

The radiolaria are best preserved in the more opaque cherts, but are not so well preserved in the more siliceous cherts, or in the claystones. Microscopic examination reveals the fact that the radiolarian claystones contain about as many radiolaria as the black chert. Yet the silica content of the black chert is much higher, being about ninety-one per cent as against sixty-eight per cent in the claystones. The excess silica in the cherts is not believed to be of organic origin. David and Pitman suggest that it may have been leached from the tuffs and deposited in the chert horizons.

David and Pitman believe that these claystones were deposited in comparatively shallow water, because of the numerous plant remains. Hinde believes that this is not certain proof and points to the dredgings of Agassiz, which showed that plant remains might be carried out for considerable distances from land and deposited in deep water. Hinde is of the opinion that the claystones are the equivalents of the recent Red Clays. The presence of ripple marks, however, is certainly opposed to this interpretation.

The Woolomin series, of lower Devonian age, extends from Tamworth to Bingara and appears to underlie the Tamworth series. Its thickness is unknown. It covers an area of 1000 square miles. This series comprises radiolarian claystones, tuffs, and spilitic lavas, feldspathic cherts with radiolaria, and red jaspers. Red, thin bedded, radiolarian cherts form belts up to 100 feet thick in this series, though the average thickness of the belts is considerably less. The whole series has been intruded by serpentine.

The jaspers contain radiolaria. They are hard, flinty rocks of a bright red color, traversed by microscopic veins and stringers of quartz. Hinde states that these rocks resemble those of California and those from the Culm measures of Devon.

At Jenolan Caves, west of Sydney, radiolarian rocks of Silurian age appear. The series is described as consisting of red and green claystones and talcose slates at the base. These are well bedded and contain numerous radiolaria. Then comes 300 feet of rhyolite lava, then 300 feet of claystones, then 500 feet of limestone and then another 1000 feet of claystones and radiolarian cherts.

Radiolarian cherts of Silurian age outcrop at several places in the west part of New South Wales, where they are associated with rhyolites and are very similar to the rocks of the Jenolan District.

A radiolarian rock from Fanny Bay, Port Darwin, Australia, described by Hinde,[48] appears to correspond to the radiolarian earths

[48] Quar. Jour. Geol. Soc., vol. 49, p. 221, 1893.

of Barbados. It is dull white with a pale yellow to pink tint. In texture it is chalky with a very fine grain, being homogenous and giving no evidence of stratification.

In thin section, the ground mass appears to consist of amorphous silica in which are embedded the radiolarian remains, and also some grains of quartz and rutile. A chemical analysis gives the following results:

SiO_2	84.20
Al_2O_3	10.70
Loss on ignition	5.00
	99.90

In addition to the constituents named, the rock contained a trace of iron.

Diatomaceous Earths Containing Radiolaria

Some of the diatomaceous earths of the Monterey group contain important numbers of radiolarian skeletons.

A notable deposit of this type is found in Sicily. It is one of a group of Tertiary deposits of diatomaceous earth, found in the region of the Mediterranean Sea, in Sicily, Calabria, Greece and Africa. It is known as tripoli or tripolite from its occurrence in Tripoli in North Africa.[49]

Emil Stohr[50] has investigated the deposits in Sicily. There are numerous localities where tripoli occurs in the province of Girgenti, but at the locality of Grotte, it is particularly rich in radiolarian remains. The tripoli lies beneath the sulphur beds of Sicily. It is less than a meter thick, but is very persistent and easily recognized. The tripoli is exceedingly light, is laminated, is nearly white in color, soft and easily reduced to a powder. Occasionally the beds are so solid that they will ring with a blow of the hammer. Sometimes they are impregnated with sulphur, and always they are more or less impure by reason of the admixture of lime and clay. It contains numerous fish scales and foraminifera in addition to the remains of siliceous organisms. Stohr came to the conclusion that this was a deep sea deposit, because of the foraminifera which appeared to be deep sea forms.

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[49] Haeckel, E., Report of the Scientific Results of the Exploring Voyage of H. M. S. "Challenger." Zoology, vol. 18, pt. 1, Report on the Radiolaria.

[50] Stohr, E., Die Radiolarienfauna der Tripoli von Grotte Provinz Girgenti in Sicilium. Paleontographica XXVI, 71, 1879–80.

The Radiolarian Cherts

Although the various types of radiolarian rocks, previously mentioned, may reach local importance, the type which is most common among rocks containing radiolaria, is that exemplified by the Franciscan cherts. They might be referred to as bedded radiolarian cherts, for the reason that they occur in thin beds, generally separated by shale partings. It is a rather peculiar fact that when the radiolarian rocks are dense cherty rocks, they generally show this peculiar bedding. The more massive varieties of radiolarian rocks are almost always soft and poorly consolidated. Since the bedding is so characteristic the simple term ''radiolarian cherts'' may be used to designate them. Radiolarian rocks of this bedded type are called ''kieselschiefer'' by the Germans. They are apparently included under the term ''phthanites'' by the French and Belgian geologists.

In addition to the radiolarian cherts of the Franciscan group, radiolarian cherts are found in some of the older rocks of the Pacific Coast region.

KLAMATH MOUNTAINS

In the Klamath Mountains, there are red cherts associated with fossiliferous limestones of Devonian age.[51] These show the usual round, clear spots and appear to be radiolarian cherts, though no definite lattice structures are now discernible.

SIERRA NEVADA

Radiolarian cherts are found in some of the members of the bed rock complex of the Sierra Nevada. Specimens of red chert from the Sierra Nevada can not be distinguished from Franciscan cherts.

Professor Lawson has found radiolaria in cherts of the Calaveras near Colfax.

Waldemar Lindgren[52] described radiolarian rocks from the Federal Loan area near Nevada City. These rocks are a part of the Calaveras and are described by Lindgren as ''siliceous argillite.'' The rock has been considerably metamorphosed and while the descriptions indicate that it somewhat resembles the cherts of the Franciscan formation, it is almost entirely massive and shows no distinct bedding with argillaceous material.

In the Nevada City Special Folio,[53] Lindgren described bedded

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[51] Diller, J. S., Am. Jour. Sci., vol. 165, p. 345, 1903.

[52] The Gold Quartz Veins of Nevada City and Grass Valley Districts, 17th Ann. Rep. U. S. Geol. Surv., part II, p. 1, 1896.

[53] U. S. Geol. Surv., Folio no. 29, 1896.

cherts from the Calaveras in the area of the Grass Valley Special Map. He regarded them as replacements of limestone:

> The area along the western margin of the district consists of grayish, not very fissile clay slates, alternating with much white or light colored chert, breaking in small, sharp, angular fragments.
>
> This chert is probably derived from limestone by a process of silicification. There are no outcrops of limestone within the area, yet the peculiar bowl-shaped depression on the top of the ridge 2500 feet northwest from the North Star Mine, known as the ''Devil's Punchbowl,'' can be explained only as a collapsed cave formed by the leaching out of limestone mass.

Bedded cherts are reported five miles west of Coulterville.[54] They are also found on the southwest slope of Hunter Mountain, where they are associated with tuffs.

WASHINGTON

Bedded radiolarian cherts are known also in the Peshastin formation in the state of Washington.[55] The age of this formation is not certainly known, other than that it is pre-Tertiary. On account of the considerable amount of deformation and intrusion which has affected it, it is regarded as Paleozoic. Weaver states that it is somewhat similar to rocks of the Calaveras formation of the Sierra Nevada, and that it is also somewhat similar to the Cache Creek series in British Columbia. It is therefore provisionally referred to the Carboniferous.

The Peshastin formation is predominantly composed of black slates and fine grained, dark colored quartzites. It contains occasional bands of red and green radiolarian chert. It is cut by serpentine and other basic eruptives and also contains amphibolitic schists. In the Mount Stuart quadrangle, Smith describes some of these schists as glaucophane schists. In the Snoqualmie quadrangle there are blue schists, said to owe their color to the presence of graphite in green amphibole.

ALASKA[56]

In the region around Cook Inlet and Prince William Sound, in

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[54] Mother Lode District, U. S. Geol. Surv. Folio no. 63, p. 4, 1900.

[55] Smith, G. O., Mount Stuart Folio, U. S. Geol. Surv. Folio no. 106, 1904.
Smith and Calkins, Snoqualmie Folio, *ibid.*, Folio no. 139, 1906.
Weaver, C. E., Washington Geol. Surv. Bull. 6, 1911.

[56] Palache, C., Harriman Alaska Expedition, vol. 4, pp. 26, 27, 56, pl. 2.
Stanton and Martin, Mesozoic Section on Cook Inlet and Alaska Peninsula, Bull. Geol. Soc. Am., vol. 16, p. 391, 1905.
Grant and Higgins, Reconnaissance of the Geology and Mineral Resources of Prince William Sound, U. S. Geol. Surv. Bull. 443, 1910.
Martin and Katz, A Geologic Reconnaissance of the Iliamana Region, U. S. Geol. Surv. Bull. 485, 1912.
Martin, Johnson and Grant, Geology and Mineral Resources of Kenai Peninsula, Alaska, U. S. Geol. Surv. Bull. 587, 1915.

southern Alaska, there are numerous exposures of radiolarian chert. These cherts are of varied colors, black, gray and green, being the most common varieties. Brown and red varieties are also found. They are thin and rather evenly bedded rocks, consisting of hard siliceous layers from half an inch to two inches, and rarely over three inches in thickness. These are separated by thin partings of soft shaly material. They are intensely crumpled and contorted and are often displaced by small faults. Photographs of the cherts at Bear Bay and Halibut Cove shown in the references enumerated are exactly like photographs obtained from Franciscan radiolarian cherts.

In thin section the cherts are seen to be very fine grained and show no clastic material. Poorly preserved radiolaria are seen, in the thin sections, where they appear as clearer spots in the stained and clouded matrix of the rock. Occasionally, the remnants of broken spines or residuals of the lattice structure may be seen. The age of the cherts has been definitely determined at Kamishak Bay.[57] Here the cherts occur in rather massive beds interstratified with thinner beds of limestone, shale and sandstone. The shales and limestones, interbedded with the chert, contain fossils—mainly *Pseudomonitis subcircularis.* This species, which is very abundant in these rocks, is characteristic of the Upper Triassic. Associated with the bedded cherts is a limestone containing *Haliobia superba,* also a characteristic Upper Triassic form. At Bear Bay and Cold Bay on Cook Inlet[58] *Pseudomonitis subcircularis* is again found in limestones interbedded with cherts. In other places, where there are no fossils, the relations of the cherts to other fossiliferous rocks are such as to indicate that they are probably Upper Triassic. These relations and the peculiar lithology of the formation have been the basis for the correlation of various areas of cherts with the known Upper Triassic cherts of Kamishak Bay and other points on Cook Inlet. Beside the limestones, the cherts are associated with arkose sandstones and black shales and with small amounts of conglomerates. They are also associated with ellipsoidal basalts. These appear from the descriptions to be often in the form of lava flows with tuffs, though much of the basalt appears to be intrusive. The relation between the cherts and the ellipsoidal basalts is very close; in some places the areas of the two rocks are so intermingled that they cannot be separated accurately in the mapping. The basalts commonly show a very well developed pillow structure.

[57] U. S. Geol. Surv. Bull. 485, p. 48, 1912.

[58] Bull. Geol. Soc. Am., vol. 16, p. 394, 1905.

In addition to these basalts, the cherts are associated with diabase and gabbro, and in the southern Kenai Peninsula dunite occurs with the cherts. Besides the basic igneous rocks, the cherts are cut by dykes of dacite porphyry.

Palache makes the following statements concerning these rocks:

> With the exception of the dike rocks, this section bears an altogether extraordinary similarity in structure and lithologic character to the radiolarian cherts and associated igneous and clastic rocks of the Franciscan Series of the California Coast Range, especially well developed on the San Francisco Peninsula.

In addition to the rocks above described, there are slates, graywackes, cherts, and greenstones in this region which are considerably more deformed and broken and show more metamorphism than those referred to the Upper Triassic. These are associated in some places with glaucophane schists. The exact relations of this group are uncertain. They may be an older series or may be the metamorphosed equivalents of the Upper Triassic cherts.

CODDEN HILL BEDS

Bedded radiolarian cherts occur in the Culm of southwestern England in Devon, Cornwall and West Somerset. The radiolarian cherts of this area have been called the Codden Hill Beds.[59] The Culm measures consist of a basal series of dark argillaceous shales containing persistent beds of dark limestones. Above these come the radiolarian cherts with their interbedded shales, and overlying them is a series of sandstones, grits, and shales.

The cherts occur in beds that as a rule range in thickness between two and four inches. Some are only an inch thick, while others may be as much as nine inches thick. The color varies somewhat, ranging from white to light gray, bluish, dark gray, to black. They are crossed by many joint planes perpendicular to the bedding surfaces, which cause the rocks to break up into numerous small rhomboidal blocks. They are often cut by veins of white quartz.

Alternating with the beds of chert, are shaly beds, usually of a white or grayish color. They are much thinner than the cherts, in no case exceeding two inches, and are sometimes lacking altogether. The material of these soft shaly partings breaks up readily into thin flakes or laminae when placed in water, and the softer varieties break down into a very fine mud when so treated.

[59] Hinde and Fox, On a well marked Horizon of Radiolarian Rocks in the Lower Culm Measures of Devon, Cornwall and West Somerset, Quar. Jour. Geol. Surv., vol. 51, p. 609, 1895.

In thin section, the cherts are seen to contain radiolaria. Some of the *shale partings* contain so many radiolaria that they have a somewhat gritty texture and were on this account described by earlier workers as fine grits.

In a few instances beds of dark limestone containing radiolaria and sponge spicules alternate with the siliceous beds. As a general rule, however, the cherts contain no lime. Even those cherts which contain casts of calcareous organisms, are free from lime, all traces of it having been leached out.

Under the microscope, the cherts show a fine grained siliceous matrix in which the tests of the radiolaria are embedded. In some instances the siliceous ground mass is clear; in others it is dark and turbid from the presence of fine particles of carbonaceous material or ferrous minerals. Sometimes minute prisms of rutile and zircon are seen. Between crossed nicols the matrix shows the characteristic speckled appearance of cryptocrystalline silica, similar to that shown by flint.

The chert beds are laminated on a very fine scale. This structure is best seen in the light gray cherts, where it consists of alternating bands of lighter and darker material. In thin section the lamination is seen to be due to regular layers of dark amorphous material and finely granular mineral particles.

The radiolarian tests vary greatly in their abundance. In some beds they are thickly crowded together, while in others they are sparsely scattered through the siliceous matrix. The silica within the radiolarian tests is generally clear, and nearly transparent, being free from the rutile needles, and dark substances disseminated in the ground mass. It is either granular or, more commonly, it has a radiate fibrous structure. The preservation of the tests varies considerably. In some of the cherts the boundaries between the siliceous cast and the siliceous matrix of the rock are vague and the radiolaria may not be easily visible if the ground mass is clear. Between crossed nicols the radiolarian tests appear as circular areas of speckled or bright light on a nearly dark ground. In the shaly cherts the radiolaria are much better preserved.

In many of the cherts, sponge spicules are noticed in close association with the radiolaria, and some contain minute cubes of pyrite.

In most of the sections, detrital material appears to be absent. An exception to this is found in the presence of very minute flakes of mica. In some of the dark, hard platy varieties there is a certain admixture of minute chips of quartz, and flakes of mica which appear to be of detrital origin. These grains are from .03 millimeter to .065 millimeter in diameter.

The microscopic characters of these cherts are much like those of the radiolarian cherts of the Franciscan formation. One point of difference is to be noted. In the Codden Hill cherts there are minute casts of rhombohedral crystals. These are probably left after the solution of calcite or dolomite. In some instances these casts have later been filled with silica.

Beside the radiolaria, remains of brachiopods, corals, crinoids, and goniatites, have been found occasionally in these cherts, or as casts in beds of siliceous shale.

Hinde and Fox regard these deposits as similar to the present radiolarian oozes and believe that the Codden Hill beds were laid down in the deep water of an open sea.

GOWER

Dixon and Vaughan[60] have described Carboniferous radiolarian cherts from Gower. Here fifty feet of radiolarian cherts lie over soft argillaceous limestones and shales. There is no evidence of unconformity below the cherts, though there is an abrupt change in the nature of the rock. While the upper contact is not well exposed, the cherts appear to pass upward into shales and sandstones.

The radiolarian cherts are interbedded with thin layers of shale. The cherts and shales are well laminated. The shales are barren of fossils except for a few lamellibranchs and indeterminate plant remains.

Under the microscope the cherts are found to contain abundant radiolaria and a few sponge spicules. The lamination is due to difference in color and grain of the rock, and in the proportions of organic and inorganic matter. The laminae are lenticular, many being sharply so. The inorganic matter referred to is said to be *fine quartz silt.*

These cherts are regarded by Dixon as constituting a "lagoon phase," which is defined as a group of rocks whose characters show that they were deposited in a coastal area of wide extent but extremely shallow—a wide coastal shelf having a long extent parallel to the shore. Due to the extreme shallowness of the water it is cut

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60 The Carboniferous Succession in Gower, Quar. Jour. Geol. Soc., vol. 67, p. 477, 1911.

off from communication with the deeper portions of the sea, and no strong currents sweep over it. The rise and fall of the tide, if large, would be a source of strong currents, but it is assumed that along the margin of the lagoon, swamps and vegetation would exist which would cause such a retardation of the tidal flow that there could be no effective communication. It is necessary to postulate further that some sort of barrier cut off the coarse sediments derived from the land.

The lagoon phase further implies, as pointed out by Dixon, a continuous and very gentle subsidence at a rate sufficient to compensate for filling by sediments. In such an unusual area there might be peculiar types of sediments and faunas.

It is found that some of the calcareous mudstones associated with the formation of chert contain *Modiola* and other fossils, indicating shallow and brackish water. The peculiar lenslike bedding of cherts and shales (wedge-bedding) described before in connection with the Franciscan radiolarian cherts, is well developed in these beds in Gower. Dixon explains it, and also the fine lamination of the separate beds, as due to the gentle scouring of currents laden with the finest sediments.

Dixon notes the lack of calcareous fossils in the cherts. He believes that this was due to some peculiar condition of the sea at the time of the deposition of the cherts. Either a change in the lime content or a change in temperature are suggested as competent to account for the absence of calcareous organisms from the cherts themselves. In this type of lagoon the deposition of radiolarian skeletons gave rise to the radiolarian cherts; and it would appear from the discussion that the interbedding with shale is believed to be due to the action of currents which were transporting the material.

MULLION ISLAND

Fox and Teall[61] have described radiolarian cherts from Mullion Island, which lies off the Lizard Peninsula in southwestern Cornwall. The cherts are associated very intimately with an ellipsoidal basalt, which is the dominant rock of the island. The stratified rocks make up a small part of the island, and consist of radiolarian cherts, and some limestones in a narrow band, entirely surrounded by igneous rocks.

[61] On a Radiolarian Chert from Mullion Island, Quar. Jour. Geol. Soc., vol. 49, p. 211, 1893.

The cherts are interstratified with shale in thin bands varying from one-quarter of an inch to several inches in thickness. Thirty bands were counted in one thickness of three feet. In some places layers of chert pinch out, while other layers thicken into nodules. The chert bands are generally traversed by a network of white quartz veins.

The radiolarian remains are best seen on surfaces which have been somewhat weathered; on these they stand out as rounded protuberances. In many specimens it is possible to see the reticulated nature of the skeletons with a hand lens. Some thin sections show the radiolaria closely spaced and nearly in contact with one another; in others they are less numerous and more widely spaced.

The shales which separate the chert bands vary in color from brown or buff to nearly black. They have been searched for fossils, but only one microscopic form, not identifiable, has ever been found.

The pillow basalt which surrounds the chert shows relations that suggest intrusion. It would appear to be analogous to some of the intrusive basalts of the California Coast Ranges. Fox and Teall, however, believe that the igneous rock was a contemporaneous lava flow because of the fine grain of the rock and the pillow structure which it possesses. They suggest that it would be possible for lavas flowing over the sea floor to tear up layers of the bottom deposits and insert themselves between the layers.

Radiolarian cherts are also known on the neighboring mainland.[62] They are dark to black rocks cut by numerous veins of quartz and interbedded with clay slates.

SOUTHERN SCOTLAND

Bedded radiolarian cherts form a conspicuous portion of the Ordovician Rocks of southern Scotland.[63] They occur in both the Arenig and the Llandeilo, the lowest and the intermediate divisions of the Ordovician.

The basal portion of the Arenig division comprises ellipsoidal lavas, tuffs, and agglomerates of unknown thickness. Above these volcanic rocks there are a few feet of black graptolite shale, and above this are radiolarian cherts and interbedded mudstones. The Arenig

[62] Hinde, G. J., On Radiolaria in Chert from Chypons Farm, Mullion Parish (Cornwall), Quar. Jour. Geol. Soc., vol. 55, p. 214, 1899.

[63] Hinde, G. J., Notes on Radiolaria from the Lower Paleozoic Rocks (Llandeilo-Caradoc) of the South of Scotland, Ann. Mag. Nat. Hist., (6), vol. 6, p. 40, 1890.

Peach and Horne, The Silurian Rocks of Britain. I, Scotland, Mem. Geol. Surv. United Kingdom, 1899.

cherts are known to cover an area of at least 2000 square miles in this part of Scotland. Immediately overlying the Arenig cherts the Llandeilo division begins with radiolarian cherts and mudstones, which are conformable upon, and pass down into, the cherts of the Arenig division. The combined thickness of these cherts varies, in different parts of the region, between 70 and 200 feet. Overlying the lower Llandeilo cherts come graptolite shales and tuffs. Near the upper part of the Llandeilo division another horizon of radiolarian cherts is found, in certain parts of the region. This upper chert horizon is only a few feet thick, and consists of gray cherts with gray and orange colored mudstones, containing abundant volcanic ash. Above this there are occasional cherty ribs or bands, containing radiolaria, in alternation with black graptolite shales.

The color of the cherts varies considerably. Light and dark green, sometimes bright green, gray and dark gray, black, blue, red and chocolate colors are mentioned. The most common colors seem to be green and gray. They are hard, compact rocks with a hackly fracture. They are traversed in all directions by microscopic cracks and fissures. These are filled with quartz which is frequently stained by a dark substance, probably manganese.

In detail the bedding is somewhat irregular. Part of the cherts occur well banded in definite strata. Others consist of layers of elongated and flattened nodules, which occasionally coalesce, forming irregular lenslike beds which may persist for some distance. The surfaces of the banded cherts are often mammillated or botryoidal, and vary in thickness from a few inches to a foot or more, thus causing a ribbed appearance of the beds.

The cherts are associated with fine grained gray and red mudstones which form partings between the various chert layers. Occasionally the chert bands are interleaved with fine tuff instead of the usual argillaceous parting. The mudstones may pass laterally into chert by the addition of silica. These transition beds contain radiolaria.

The Arenig radiolarian cherts are closely associated with pillow diabase and diabase porphyrite and with tuffs of similar chemical composition. The volcanic activity represented by the rocks at the base of the Arenig continued during the period of deposition of the radiolarian cherts, and the cherts are interlaminated with contemporaneous bands of tuff and agglomerate.

This volcanic series passes upwards into red, green, and gray cherts which are interstratified with tuffs and breccias that clearly overlie the Middle Arenig band of black shales. Indeed the cliff sections leave no room for doubt that the radiolarian cherts were deposited contemporaneously with the volcanic eruptions, for not only are they intercalated with the breccias but the latter likewise contain fragments of organic chert with radiolaria, which must have solidified on the sea-floor before its disruption by the explosion.[64] ...

Here the intercalation of pyroclastic material, with radiolarian chert is admirably seen in several alternations of these rocks. As each band of tuff contains blocks of the chert, it is evident, that during pauses in the volcanic activity, the radiolarian ooze consolidated on the sea-floor as chert, and was disrupted by the successive explosions.[65] ...

Where the cherts are associated with the non-fragmental pillow lavas these are often found to contain included fragments of the cherts of lower horizons. In rare instances radiolarian chert has been observed completely filling the interspaces between the pillow-form masses.

The radiolarian cherts of this province are closely associated with graptolite slates, often resting on or being overlain by them. Occasionally thin layers of radiolarian cherts and their interlaminated mudstones alternate with layers of graptolite shales. In the Upper Llandeilo, black radiolarian cherts occur in bands, separated by graptolite shales instead of by the ordinary shale partings. In a few exceptional instances the cherts and associated mudstones are interbanded with graywackes, and the alternations may be rather rapid.

In thin section, the light colored cherts are seen to be composed of nearly clear cryptocrystalline silica somewhat clouded by very minute mineral particles. In this matrix there are clear areas with circular and elliptical outlines, representing the tests of radiolaria. There is a notable contrast in the silica filling the tests, and that which forms the matrix in which they rest. The silica of the matrix is much finer in crystallization than that which fills the radiolarian skeleton.

In the darker colored cherts, the matrix is stained by inclusions of iron oxide, manganese, and carbon, and in these rocks the lattice structures and spines of the radiolaria show distinctly as clearer areas in the turbid ground mass. In the unstained cherts no structure is observed in the remains of the radiolaria.

Besides the radiolaria the cherts contain a few sponge spicules with occasional remnants of uncertain origin. Occasionally the mudstones contain radiolaria, visible to the eye on fresh fractures.

Near the contact with granitic rocks the radiolarian cherts are metamorphosed. This metamorphism has occurred without change of

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64 Silurian Rocks of Britain. I, Scotland, p. 40.

65 *Ibid.*, p. 437.

chemical composition and consists in the development of coarsely crystalline quartzite from the cryptocrystalline silica of the chert. This recrystallization of silica is accompanied by the formation of minute scales of biotite, produced by the combination of the impurities of the matrix. The purer silica which fills the radiolarian tests contains no material for the formation of biotite and in consequence, the radiolarian remains may be much more conspicuous in slightly altered rocks than in the unaltered parts.

These radiolarian cherts are believed to represent accumulations of radiolarian ooze. It was thought by Hinde, and his idea was accepted by Dr. Peach, that they were of deep sea origin, deposited at depths greater than 2000 fathoms. Hinde[66] says:

> With the exception of the Radiolaria very few other organisms can be recognized in the sections of this chert rock. There are one or two spicules of Hexactinellid sponges, readily distinguishable from the detached Beloid spicules by their larger size and distinctive forms, and I have met with a few minute toothed plates and detached denticles, which bear a certain resemblance to the radulae of naked molluscs; there are further numerous almond-shaped hollow bodies about 1 millim. in length with imperforate siliceous walls, of whose nature I am quite ignorant. This Orodovician chert may therefore be fairly considered to be due to the accumulation of the tests of Radiolaria, and is thus a pure Radiolarian rock, equally as much as the Tertiary beds of Barbados and the Nicobar islands, which according to Haeckel, correspond to the recent Radiolarian ooze, ''and are certainly of deep sea origin, having probably been deposited at depths greater than 2000 fathoms.'' If this same conclusion is applicable to this fossil chert, it represents, as Prof. H. A. Nicholson has already pointed out, a true deep-sea deposit in the Palaeozoic period, the existence of which in the geological series has of late been disputed. The beds of fine-grained red and green mudstones associated with this chert likewise favor the same view of its origin in deep water.

Jukes-Brown[67] has taken exception to this idea of deep sea deposition. He regards these cherts as entirely different from the radiolarian earths of Barbados which contain chert nodules. He notes the interbedding of cherts with graptolite shales of terrigenous origin and points out that at Tannylaggie, west of Bladennoch, the radiolarian cherts are interbedded with graywackes and grits. These facts force him to the conclusion that the cherts are not radiolarian oozes, such as are now accumulating in the abyssal depths of the ocean. He cites several recorded occurrences which go to prove that radiolaria are preserved in deposits which are not abyssal but were formed in comparatively shallow water. He believes the graptolite shales are the

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[66] Ann. Mag. Nat. Hist., (6), vol. 6, p. 40, 1890.

[67] Jukes-Brown, A. J., The Building of the British Isles, pp. 12, 72, London, 1911.

equivalents of the blue muds and that the cherts were formed in water of only moderate depth, though probably at some distance from the shore.

IRELAND

The lower Llandeilo of eastern Ireland contains radiolarian cherts associated with tuffs and pillow lavas.

In the Arenig rocks of Ireland, in Tyrone County, ellipsoidal lavas are found associated with jaspers,[68] that do not appear to contain radiolaria.

> The special feature of interest in this Irish area is the remarkable development of volcanic materials which is there to be seen, spreading over a far wider area than in Scotland. The rocks include lavas associated with tuffs and agglomerates, likewise a varied series of intrusive masses. . . .
>
> One of the most conspicuous features in some of these lavas is the occurrence of the same sack-like or pillow-shaped structure which has been already referred to as so marked among the Arenig lavas of Scotland. . . .
>
> These greenish lavas are occasionally interleaved with gray flinty mud-stones, cherts, and red jaspers, which are more particularly developed immediately above. In lithological character, and in their relation to the diabases, these siliceous rocks bear the closest resemblance to those of Arenig age in Scotland. But no recognizable radiolaria have yet been detected in them.

URAL MOUNTAINS

Radiolarian cherts are known in the lower Devonian of the south Urals in the region around Orsk.[69]

These cherts occur in association with graywacke and are also associated with greenstone and serpentine. Sometimes they are intercalated with tuffs. In one section described by Rose (p. 191) the greenstone is described as being separated into ball-like masses.

The cherts contain abundant radiolaria and manganese ores occur in them.

Specimens of red radiolarian chert, in the collection of the University of California, brought from the Ural Mountains by Professor Lawson, are lithologically identical with the red chert of the Franciscan group. Professor Lawson[70] states that their appearance in the field is identical with that of the Franciscan cherts.

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[68] Geikie, A., Ancient Volcanoes of Great Britain, vol. 1, pp. 240, 244, London, 1897.

[69] Gustav Rose, Mineralogisch-geognostische Reise nach dem Ural dem Altai und dem Kaspischen Meere, Bd. 2, Berlin, 1842.

Murchison, R. I., The Geology of Russia in Europe and the Ural Mountains, London, 1845.

Rust, Beiträge zur Kenntniss der fossilen Radiolarian aus Gesteinen der Trias und der palaeozoischen Schichten. Palaeontographica, XXXVIII, 110, 1891–92.

Guide des excursions du VIIeme Cong. geol. inter., St. Petersburg, 1897.

[70] Oral communication.

THE ALPS

In the Upper Jurassic, at many places in the Austrian Alps, the Tyrol, Switzerland, Hungary, and Servia, there are radiolarian cherts.[71-72]

Rust distinguishes between jasper and hornstone. In the term, hornstone, he includes light to dark gray to black rocks composed of cryptocrystalline silica. The jaspers are rocks consisting of a mixture of fine white, or iron stained red, brown, and yellow clay, with silicic acid. While these rocks appear as definite types, there are transitions between them. Both types of rocks in these regions contain calcium carbonate. The hornstone contains lime carbonate as a fine powder and also as calcite rhombs. The jaspers contain lime carbonate in fine white crystalline bands. Often they contain radiolaria in such large numbers that the tests lie against each other, the interstitial spaces being filled with the clay-iron-silica mixture. In the hornstone the remains of radiolarians are only occasionally found, but they show sponge spicules in greater abundance than the jaspers.

Hahn[73] describes the cherts as consisting of layers of siliceous rock of an intense blood red color, or more rarely, of greenish color, which are interbedded with dense brown red, or greenish gray quartzose and argillaceous marls. The total thickness of these beds is from ten to twenty-five meters. Under the microscope the cherts are seen to be filled with radiolaria. Radiolaria are not so commonly preserved in the argillaceous layers, but the cherts contain many well preserved forms. These rocks are believed by Hahn to represent the present radiolarian oozes of the deep sea, such as now accumulate at depths between 3000 to 7000 meters.

In his description of the Davos Valley, in Switzerland, A. V. Jennings[74] refers to radiolarian cherts associated with red shales. They occur as lenticular bodies in shales believed to be Triassic in age, and are associated with serpentine and a variolitic diabase.

HARZ MOUNTAINS

Radiolarian cherts occur at many points in the Harz Mountains. They are of Lower Carboniferous age and correspond to the radio-

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[71] Rust, Beiträge zur Kenntniss der fossilen Radiolarian aus Gesteinen des Jura. Palaeontographica, XXXI, 269, 1885.

[72] Hahn, F. F., Geologie der Kammerken Sontagshorngruppe I, Jahrb. d. k. k. geol. Reichsanstalt, Bd. 60, Heft 2, S. 389–90, 311–420; Bd. 2, Heft 4, S. 637–712.

[73] Cited by Grabau *in* Principles of Stratigraphy, p. 459.

[74] Quar. Jour. Geol. Soc., vol. 55, p. 394, 1899.

larian cherts of England which occur at the same horizon. These cherts have been described by Caddell[75] in the following words:

> The kieselschiefer, or lydian stone of the Harz, is a compact, very hard, infusible, hornstone-like siliceous rock, with splintery fracture and dark color, and is impregnated with carbonaceous material and iron oxide. It occurs in beds made up of layers from 1 to 4 inches in thickness, and is traversed by numerous joints, and veined with quartz. . . .
>
> The Kieselschiefer beds are, in almost all the cases I have seen, intensely crumpled, and bent into sharply-defined folds, in a way which shows them to have been quite plastic at the time of their contortion.

Associated with these beds are ordinary shales and arkose sandstones. Adinoles occur in association with the cherts. These are an intimate mixture of quartz and albite, containing sometimes as much as ten per cent of soda. They resemble the hornstone very closely but are distinguishable by their greater fusibility.

OTHER OCCURRENCES IN CENTRAL EUROPE

In addition to the occurrences above listed there are other radiolarian cherts of Paleozoic age which will not be described in detail here.

Radiolarian Cherts of Saxony.[76]—These are intimately associated with clay slates, ''alum-slates,'' graywackes, quartzose sandstones, diabase flows and intrusive diabase. They are of Lower Silurian (Ordovician) age. The cherts and clay slates contain graptolites.

Rhine Valley.—Wilckens[77] has described radiolarian cherts from the Lower Carboniferous of the Rhine District.

Rust refers to several other occurrences of radiolarian cherts in central Europe. Cherts of Devonian age occur in Nassau and Hesse. Ordovician *kieselschiefer* occur at Rehau in Bayern and at Cabrieres in Languedoc. Carboniferous *kieselschiefer* occur near Braunau and Wildungen in Waldeck and in the Bukk Mountains in Hungary.

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[75] The Harz Mountains, their Geological Structure and History, Roy. Phys. Soc. Edin., vol. 8, p. 217, 1883–85.

[76] Rothpletz, Radiolarien, Diatomaceen und Sphärosomatiten in silurischen Kieselschiefer von Langenstriegis in Sachsen, Zeitschr. d. deut. geol. Ges., XXXII, 447, 1880.

Rust, *op. cit.*, Palaeontographica, XXXVIII, 107, 1891–92.

[77] Wilckens, O., Radiolarit im Kulm der Ottendorn-Elsper Doppel-Mulde, Zeitschr. d. deut. geol. Ges., Monatsblatt, 1908, p. 354.

Cited by Grabau *in* Principles of Stratigraphy, p. 459.

ITALY[78]

Radiolarian cherts occur in Liguria, Tuscany and on the Island of Elba. Pantelli states that the radiolarian jaspers of Tuscany are found in the Triassic, Cretaceous and Eocene. The jaspers on the Island of Elba are referred to the Eocene. Parona and Roverto describe jaspers which are believed to be Permian.

The Italian jaspers are intimately associated with serpentines, gabbros, diabases and variolites. They are also associated with glaucophane and other amphibolitic schists. Some of the igneous rocks are certainly extrusive and Lotti describes sections in which diabases are intercalated with jaspers in perfect conformity. There appears to be some dispute about the nature of the serpentine. Bonney[79] describes intrusive contacts of serpentines, but other workers seem to have regarded them as extrusive, and Pantelli[80] states confidently that he has proved the serpentines to be submarine lava flows.

The jaspers are ordinarily red, but various other colors occur. Green jaspers are next to red in order of abundance, while brown, yellow, violet, white and gray varieties are found. They are associated with siliceous argillites (*galestri*) that show all variations from hard compact varieties to varieties which are soft and easily broken down by the action of the weather. Siliceous limestones also occur with the jaspers. The jaspers contain deposits of manganese oxide.

They are well stratified in thin layers rarely exceeding five centimeters in thickness. The jasper layers are separated by argillaceous and (very rarely) by calcareous material. They are cut by numerous veins of quartz which, in general, stand nearly normal to the planes of stratification. They may reach a total thickness of several hundred meters.

In thin section, the jaspers show numerous radiolaria which appear as clear colorless areas within a matrix of iron stained silica. Rarely iron oxide appears within the radiolarian skeleton. The matrix consists of a mixture of amorphous and crystalline silica, colored by

[78] Pantelli, D., I diaspri della Toscana e i loro fossili, Atti del. R. Accad. dei Lincei, VIII, 35, 1880.

Lotti, B., Diaspri e ftaniti: Capitolo XIV. Descrizione geologica dell 'isola d'Elba. Memorie descrittive della carta geologica d'Italia, II. Rome, R. Ufficio Geologico, 1886.

Parona, C. F., Sugli schisti silicei a radiolarie di Cesana presso il Monginevra, Atti del. R. Accad. del. Sci. di Torino, XXVII, 305, 1892.

Parona and Roverto, Diaspri permiani a radiolarie die Montenotte, *ibid.*, XXXI, 167, 1895.

[79] Bonney, T. G., Notes on some Ligurian and Tuscan Serpentines, Geol. Mag., vol. 16, p. 362, 1879.

[80] Pantelli, *op. cit.*, pp. 37, 64, 65.

grains of iron oxide. Pantelli states that it is possible, in many cases, to dissolve the iron from this matrix, by the use of acid, leaving it nearly colorless. The radiolaria are better preserved in the red cherts than in the lighter colored varieties. According to Pantelli, the fossils appear to the best advantage in sections cut parallel or perpendicular to the planes of stratification. He states that he has looked for diatoms but never discovered them in these rocks.

The earlier Italian geologists regarded the jaspers as argillaceous rocks, silicified as a result of contact metamorphism around intrusive masses of serpentine and diabase. Savi, however, had noted the fact that jaspers often occurred at considerable distances from bodies of igneous rocks.

In 1879, De Stefani stated that the jaspers and siliceous argillites and also the manganese deposits associated with them were laid down as sediments in the deep sea. In 1879, Bonney,[81] in describing the serpentines of Tuscany and Liguria, referred to a banded, red, flinty rock, which he found on the border of a serpentine mass. In thin section this rock was found to be crowded with the remains of organisms. Bonney believed some of these to be minute gasteropods; some were believed to be sponge spicules; others were regarded as minute siliceous organisms. While he first recognized the presence of these organisms in the cherts, he does not seem to have been at all certain of their nature nor to have realized their importance. In the year 1880 there appeared the paper by Pantelli which gave an excellent description of the radiolarian jaspers and showed that they contained great numbers of radiolaria.

Pantelli regards the radiolarian jaspers as marine sediments because of the great number of radiolaria which they contain, and the association with manganese. He states that the jaspers, the siliceous argillites, and the associated red calcareous rocks were laid down far from land and in water over 1000 meters deep. He believes it impossible to regard the jaspers as due to contact metamorphism because of the great thickness and extent of some of the masses. He points out that certain areas of jasper are separated from the serpentines by a considerable distance, and that in some instances unaltered limestone occurs between.

Pantelli notes the common association of jaspers with basic igneous rocks and accounts for it on his hypothesis that the igneous rocks were submarine lavas. He believes that during the extrusion of these

[81] Bonney, *op. cit.*

lavas conditions were set up in the ocean water that prevented the existence of those organisms which devour the radiolaria. With their enemies thus removed the radiolaria were able to reach an enormous development.

Lotti objects to the interpretation of the jaspers as radiolarian oozes. He points out that many of them show no radiolaria in thin section. He believes that most of the difficulties would be removed if the jaspers were regarded as muds, silicified soon after their deposition on the sea floor, as an after-phase of the eruption of the igneous rocks. Such conditions would produce also an increase in the number of radiolaria.

More recently C. S. Du Riche Preller[82] has suggested that these rocks are silicified limestones:

> Associated rocks are the semi-crystalline schists known as *ftaniti* and *diaspri*, viz., silico-calcareous, reddish and green schists, harder than limestone indurated by taking up silica at the expense of lime, and containing radiolaria. Both, and notably the more highly indurated diaspri, form bands on the margins of ophiolitic rocks in proximity to calcareous masses. It is a noteworthy feature that metalliferous deposits are found only in euphodite and diabase, never in serpentine, though often near the contact of the latter; again, manganese occurs not in the ophiolitic rocks proper, but in the diaspri masses, though in the vicinity of the former.

BORNEO

Molengraaff[83] has described radiolarian cherts from Borneo which resemble those of California in many respects. The radiolarian cherts in this region form part of the Danau formation, which comprises clay slates, quartzites, sandstones, cherts, jaspers, some small lenses of limestone, hornstones, diabase tuffs, tuff breccias, diabase, diabase porphyrite, serpentines, gabbros and norites, together with some amphibolites and glaucophane schists. Some of the diabase occurs in the form of dykes and intrusive sheets, while part of it appears to have been extrusive. The serpentines and gabbros are intrusive into the sediments and the amphibolitic schists appear to be related to the contacts of these basic intrusives.

The Danau formation has been considerably folded and disturbed so that the cherts dip at steep angles and show contortion and shearing to a notable degree. The disturbance has been so great that it is not possible to be certain whether or not the chert occurs at more than

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[82] The Ophiolitic Groups of the Ligurian Apennines, Geol. Mag., Decade VI, vol. 3, p. 489, 1916.

[83] Molengraaff, G. A. F., Geological Explorations in Central Borneo. Amsterdam, 1902.

Ibid., On Oceanic Deep-Sea Deposits of Central Borneo, Kon. Akad. v. Wetenschappen te Amsterdam, Proc. Sci. Sec., vol. 12, p. 141, 1909.

one horizon. The formation is extensive and radiolarian chert was encountered at a great many points during the exploration. Molengraaff states that the Danau formation forms a belt at least sixty kilometers wide and 650 kilometers long and covers an area of about 40,000 square kilometers. The cherts in the Danau formation are estimated to be at least 100 meters thick. All over the area the radiolarian rocks remain constant in their nature and show everywhere the same macroscopic and microscopic characters.

The cherts are described as being of variable color—purple, blue, gray, red and white. Molengraaff distinguishes two types of rocks: (1) radiolarian hornstone; (2) argillaceous chert or siliceous clay-shale. Both types of rock, hornstone and shale, pass gradually into one another and all sorts of intermediate types occur.

The radiolarian hornstones are semitransparent, hard, brittle rocks with splintery fracture. They contain about ninety-seven per cent silica and show numerous radiolaria. The siliceous clay-shales are distinguished from the hornstones by their higher content of iron and clay and by their smaller content of silica. The number of radiolaria in them is variable, but is always smaller than in the hornstones.

The distinct stratification of the cherts of the Danau formation is caused by thicker strata of pure radiolarian hornstone alternating with thin layers which contain more clay and fewer radiolaria. While the usual parting between the chert bands is argillaceous, there are occasional partings that consist of limonite, which appears to represent the alteration of originally interbedded iron ore. Occasionally the cherts have been fractured and the resulting rock consists of fragments of white or red chert cemented by brown veins of limonite.

Microscopically the cherts are seen to consist of cryptocrystalline silica, and in this matrix the radiolaria are embedded. The radiolarian tests are full of quartz which is comparatively coarse in its crystallization.

Radiolaria occur to a limited extent in the tuffs which occur in close association with these cherts.

Dr. Hinde examined the material collected on this expedition and his report appears in an appendix to Molengraaff's book. He states that the radiolaria are very similar to those described by him from the California Coast Ranges. As far as the radiolaria are concerned, the cherts might be Lower Cretaceous, but he regards them as more probably Jurassic for the reason that they are overlain unconformably by rocks which are of Cretaceous age. The relations in Borneo are thus similar to those in California, since in both places the series containing the radiolarian cherts lies below recognized Cretaceous rocks.

Molengraaff regards these cherts and their associated shales as the equivalents of the radiolarian oozes and red clays of abyssal depths. Their freedom from terrigenous material, their association with manganese, and their great extent, cause him to believe that they were laid down in deep water far from any land. On account of the size of the basin of deposition, he regards it as highly improbable that the cherts could have been deposited near land through the cutting off of terrigenous material by a barrier of any sort. He regards the cherts as representing a long period of time, pointing out that their minimum thickness is 100 meters, and stating that only a few centimeters of material have collected on the ocean bottom since the end of Tertiary time.

MALAY PENINSULA

Radiolarian cherts also occur in the Malay Peninsula and archipelago.[84] These cherts vary in color from green or gray to bright red or yellow. Other varieties contain abundant carbon and are black. The carbon in some of the black cherts is so abundant that thin sections are nearly opaque. They are different in this respect from the cherts of Borneo. The shales interbedded with the cherts may also contain much carbon.

Scrivenor regards the cherts of the Malay Peninsula as shallow water deposits on account of their high carbon content. He admits the possibility that the cherts of Borneo, which cover large areas, might be abyssal deposits, but points out that they do not contain such large quantities of carbon as the cherts of the Malay Peninsula.

Scrivenor is inclined to accept the lagoon hypothesis of Dixon, and believes that the waters from which the cherts were deposited contained considerable amounts of dissolved silica. This increase in silica might be due to volcanic emanations, but he points out that, under conditions of tropical weathering, large amounts of silica get into solution in river waters. If such siliceous waters emptied into closed basins, the sea water would become highly charged with silica. The high concentration of silica would tend to hinder the growth of calcareous organisms and favor the growth of organisms which secreted siliceous skeletons.

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[84] Scrivenor, J. B., Radiolaria-bearing rocks of the East Indies, Geol. Mag., vol. 49, p. 241, 1912.

DUTCH EAST INDIAN ARCHIPELAGO

Radiolarian cherts are known from many of the islands of the Dutch East Indian Archipelago, occurring on the islands of Timor, Rote (Rotti), Savu, Ceram, Celebes, Buru and Mangoli.[85] In this region there are also serpentines and gabbros, diabases and diabase tuffs. Some of these are Paleozoic in age, but a large part may be Mesozoic.

On Rote and Savu, the radiolarian cherts are found in place. In the other islands they are found as detached blocks or as rolled pebbles in later deposits.

Most of the cherts are free from calcium carbonate, but some contain admixtures of calcareous material. Also there are radiolarian limestones associated with the cherts and in these limestones the radiolaria are largely replaced by calcite.

The limestones of Rote and Savu contain numerous *Halobia* and *Daonella*, and from their close association with the cherts, these rocks also are seen to be Upper Triassic. In Savu the limestones in one locality contain a Belemnite, *Asteroconites*, which is said to be characteristic of the Upper Alpine Triassic. The cherts on the other islands are believed to be Upper Triassic also, but there is a possibility that the cherts from Buru and Mangoli may be Jurassic or Lower Cretaceous.

THE PHILIPPINES

Radiolarian cherts occur in the Philippine Islands, there being numerous occurrences in Bulacan, Palawan, Mindoro and Mindanao, in association with rocks much like those associated with the cherts in California.[86]

The outcrops of chert are isolated and of limited extent and appear to represent lenslike bodies of chert; they are revealed by boulders and fissile slabs of chert from five millimeters to several centimeters thick, scattered over the surface of the ground.

The cherts are red, brown, and gray in color, frequently being laminated.

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[85] Hinde, G. J., Radiolaria from Triassic and other Rocks of the Dutch East Indian Archipelago VIII, Verbeek, Rapport sur les Moluques, pp. 709–51, Batavia, 1908.

[86] Fanning, P. R., Geologic Reconnaissance of Northwestern Pangasinan, Philippines Jour. Sci., vol. 7A, p. 268, 1912.

Smith, W. D., The Asbestos and Manganese Deposits of Ilcos North with Notes on the Geology of the Region, ibid., vol. 2A, p. 145, 1907.

Ibid., vol. 5A, p. 327, 1910.

In thin section this rock is seen to consist of a fine-grained, amorphous groundmass of chalcedonic silica, copiously stained with oxide of iron, with almost innumerable round and oval areas which are more or less clear. . . .

Between crossed nicols these areas are seen to be filled with a doubly refracting material which often exhibits undulatory extinction, and which is in a more or less granulated condition; by using a higher power, it is clearly evident that this granulated material, with every optical character of chalcedonic silica, constitutes both the ground mass and the clear areas.

Fanning reports that the andesite below the cherts of Pangasinan has been extensively silicified and believes that Lawson's theory of siliceous springs is applicable here, the underlying formation being silicified by waters which rose through it.

Associated with these cherts there are schists of various kinds, with serpentines. Also a peculiar "eruptive conglomerate" consisting of rounded masses of lava embedded in a soft matrix.

Smith regards the cherts of the Philippines as contemporaneous with the radiolarian cherts of Borneo, Java, and the Dutch East Indian Archipelago.[87]

The Novaculites of Arkansas, Oklahoma, and Texas[88]

These siliceous rocks are somewhat different from typical radiolarian cherts in that they are usually rather more massive and the regular alternation with shales is not so perfectly developed. Griswold thus describes the novaculite of Arkansas:

The Arkansas novaculite resembles chert not only in structure and composition but also in the manner of occurrence. Both occur as stratified rocks, but there are some general differences. The novaculites are much more homogenous than cherts. Chert beds are commonly associated in a nodular form with limestone strata; the novaculites on the other hand, occur in massive strata, usually presenting plane surfaces and having only thin layers of shale interbedded. Five or six hundred feet is the common thickness of the novaculite formation, which generally includes some flinty shales and soft shales or sandstones. The novaculites proper are the prominent members of the formation, however, and occur in massive beds from a few inches to twelve or fifteen feet in thickness. When thinner than about four inches the beds generally lose their novaculite character and are more like flinty shale. The massive beds are so closely associated that there often appears to be no parting between them, but stratification lines are indicated in quarries by thin seams of clay.

[87] Smith, W. D., Notes on Radiolarian Cherts in Oregon, Am. Jour. Sci., vol. 42, p. 299, 1916.

[88] Griswold, L. S., Whetstones and the Novaculites of Arkansas, Ann. Rep. Geol. Surv. Arkansas, vol. 3, 1890.

Derby and Branner, On the origin of certain siliceous rocks, Jour. Geol., vol. 6, p. 366, 1898.

The following analysis is given by Griswold as an average of several typical novaculites:

SiO_2	99.50%
Al_2O_3	0.20
Fe_2O_3	0.10
CaO	0.10
MgO	0.05
K_2O	0.10
Na_2O	0.15
Loss on ignition	0.10
Total	100.30

The specific gravity is 2.64. The hardness is that of quartz.

Under the microscope, according to Griswold, these rocks are found to consist principally of nearly pure quartz, arranged in a very fine grained mosaic. No fibrous structure is apparent, with the exception of a few spots of fibrous chalcedony which are seen in the more impure novaculites. No isotropic silica is found. The thin sections show an occasional cavity .05 millimeter in diameter. These possess rhombic outlines and are regarded as left by the solution of calcite crystals.

In addition to the typical novaculites, impure varieties are found. The novaculites are associated with sandstones and shales. Some of the shales are highly ferruginous and some contain notable amounts of manganese.

The thin bedded novaculites are often highly contorted. Plate 5 in Griswold's report represents well bedded, siliceous shales which show a wedging out of siliceous beds and also of the partings between them, resembling greatly the bedding seen in the Franciscan chert.

The origin of these rocks has been attributed to various agencies. Griswold believed that the novaculites represented accumulations of very fine grains of pure quartz, deposited on the sea floor at some distance from land, which later became consolidated by the permeation of silica.

Derby believed that the novaculites were replacements of calcareous sediments by silica. Rutley held a somewhat similar idea, regarding the novaculites as silicified dolomitic limestones.

Branner[89] suggested that the novaculites were metamorphosed cherts. He thought it possible that they might have been derived

[89] Ann. Rep. Geol. Surv. Arkansas, vol. 1, p. 49, 1888.

from rocks similar to the cherts and shales of the Monterey group of California.[90]

Griswold stated that the novaculites contained no organic remains, save at one locality where crinoid stems were found. Recently Charles Lawrence Baker, of the Bureau of Economic Geology of the State of Texas, has discovered radiolaria in these rocks. Through his courtesy the following description of the novaculites of Texas is presented:[91]

The Caballos novaculite of the Marathon basin of Trans-Pecos Texas apparently occupies the same stratigraphic position as the Arkansas novaculite of the Ouachita Mountain region of west-central Arkansas and east-central Oklahoma. In their respective regions both novaculites unconformably overlie strata of Fernvale-Richmond age; both are strongly folded with the associated sedimentary rocks in the structures of the Hercynian diastrophism, apparently contemporaneous in the two regions. E. O. Ulrich correlates the two novaculites and places them in the Oriskany, or upper part of the lower Devonian.

The lower forty feet of the Caballos novaculite is rather thin-bedded light brown chert with some layers of white novaculite. The upper fifty feet is massive-bedded, ripple-marked, and much-fractured white novaculite. No interbedded shale occurs as in the case of the Arkansas novaculite. Under the microscope the commercial varieties of both Arkansas and Caballos novaculite, suitable for use as fine abrasives, consist simply of a mosaic of interlocking, very fine and uniform grained, angular-contoured quartz particles. The non-commercial varieties, on the other hand, much more resemble the ordinary run of cherts. Under the microscope the latter variety exhibits irregular, somewhat rounded aggregations of coarser-grained quartz particles with wavy extinction in a ground mass of finer and more uniform grained irregular-contoured quartz particles arranged in a mosaic. The coarser aggregations or knots are sometimes seen to be the imperfectly preserved remains of radiolarians, each knot being the remains of one radiolarian. Only one specimen of the non-commercial variety of the Arkansas novaculite was collected by the writer. A slide made from this showed no radiolarians but precisely similar structure as the non-commercial varieties of the Caballos novaculites.

Both the Arkansas and the Caballos novaculites exhibit broad ripple-marking. There may be some question whether these are really ripple marks. Conceivably they might be produced by the Hercynian folding. The commercial varieties, which do not exhibit traces of radiolaria, may have been an original siliceous ooze in which the amorphous, soluble silica of the radiolarian skeletons had been changed to quartz before final consolidation, or selective metamorphism may have destroyed the radiolarian structures after consolidation, or there may never have been any radiolarians present in the commercial varieties. It is perhaps significant, as regards origin, that the radiolarian remains in the non-commercial varieties of the Caballos novaculites are always partially destroyed.

The Caballos novaculite is overlain, probably unconformably, by the Santiago chert, in some respects an even more remarkable formation than the novaculite. The Santiago chert is thin-bedded, banded, or ribboned, of dull shades of practically every color, but mostly green. Throughout its maximum-observed entire thickness of 450 feet there is *not even the thinnest layer of anything but chert.*

[90] Jour. Geol., vol. 6, p. 371, 1895.

[91] Personal communication, March, 1917.

Under the microscope the chert exhibits circular or nearly circular aggregations of coarser-grained quartz particles with wavy extinction in a fine and uniform-grained matrix of interlocking quartz granules. Each circular aggregation of coarser quartz particles is a well-preserved radiolarian skeleton. Radiolarian remains make up from five to fifty per cent of the total mass of the Santiago chert. This formation is regarded by Ulrich as most likely Kinderhook (lower Mississippian) in age.

Whatever may be the origin of the novaculites, the Santiago chert appears to be either a truly pelagic deposit or to have been deposited under conditions more or less unique and of which there is no known counterpart at the present day. Shallow marine waters receiving absolutely no terrigenous sediment and depositing no limestone are indeed conceivable but it is extremely likely that such shallow water deposits would contain remains of other forms of life in addition to radiolaria.

I may add that in all the slides examined by myself the only ones which contained the rhombohedral-shaped cavities which Griswold thought were once occupied by calcite crystals were of the more porous variety of the novaculite known as the Washita stone.

In the field, in the hand specimen and under the microscope I found nothing that I could consider as doing anything but support Branner's view that the novaculites are simply metamorphosed cherts. Lawson's view that the metamorphism of the Franciscan cherts is a change from the amorphous soluble to the crystalline insoluble variety of silica somewhat analogous to the process of devitrification of lavas may apply with equal force in the case of the novaculites and Santiago chert.

OCCURRENCES OF BEDDED CHERTS AND JASPERS WITHOUT RADIOLARIA

Besides the bedded cherts which contain radiolaria, occurrences of bedded cherts are known which are similar, in most respects, to the radiolarian cherts, except that the skeletons of radiolaria are absent.

Cherts and Jaspers of the Lake Superior District

Examples of bedded cherts and jaspers which do not contain radiolaria are to be met with in the various iron formations around Lake Superior. These iron formations are found at various horizons in the pre-Cambrian rocks of that region, and in spite of the fact that they occur at different horizons, and are in many instances separated from one another by great unconformities, they show a remarkable similarity in their lithologic characters. Van Hise and Leith[92] thus describe the iron formations, pointing out the distinction between an "iron ore" and an "iron formation":

[92] Geology of the Lake Superior Region, U. S. Geol. Surv. Monograph 52, pp. 461–462, 1911.

In simplest terms the iron-bearing formations of the Lake Superior region consist essentially of interbanded layers, in widely varying proportions, of iron oxide, silica, and combinations of the two, variously called jasper or jaspilite, where anhydrous and crystalline, and ferruginous chert, taconite, or ferruginous slate, where softer and more or less hydrous. These rocks become ore by local enrichment, largely by the leaching out of silica and to a less extent by the introduction of iron oxide. There are accordingly complete gradations between them and the iron ores. . . . Local phases of the iron-bearing formations are amphibolitic and magnetitic cherts and slates, cherty iron carbonates, ferrous silicate or greenalite rocks, pyritic quartz rocks, and detrital iron-bearing rocks derived from older iron-bearing formations. One of the most significant variations with reference to the origin of the ore is in the relative abundance of greenalite rocks and siderite.

In the iron-bearing formations the chert constitutes about seventy per cent of the total volume. The cherts and jaspers are also intimately associated with ordinary clastic rocks such as quartzites, graywackes and slates. Jaspers often occur rhythmically interbanded with slates.

The following description of the jaspery rocks of the iron formations is taken from the description of the Soudan formation. Similar rocks are described from all the other iron formations of the region:[93]

The ''jaspery'' phase of the Soudan formation consists of interlaminated bands of finely crystalline quartz, iron oxides, and various mixtures of the two. With these preponderating minerals are various subordinate constituents, among which amphibole is the most abundant, including actinolite, cummingtonite, and grünerite. Pyrite is also present in many places. The alternate bands of material of different color, combined with the complicated fracturing and brecciation of the formation, make it a striking rock which always attracts the attention of the traveler, even if he is not accustomed to closely noticing rocks. The bands of material of different color vary from a fraction of an inch to several inches across. The quartzose bands have various colors—nearly pure white, gray, red of various hues, including brilliant red, and black. The difference in the color is chiefly caused by the contained iron. Hematite, if in sufficiently fine particles, gives the brilliant red colors; magnetite and hematite in larger particles give the grays and blacks.

Between the bands dominantly quartzose are usually bands mainly composed of iron oxide. This iron oxide may be either hematite or magnetite or various intermixtures of the two. Occasionally also some limonite is present.

The chief varieties of the ''jasper'' are (1) the cherty variety, (2) the black-bedded variety, (3) the red banded variety, and (4) the white banded variety. With these are subordinate masses of (5) the carbonated variety and (6) the ore bodies.

1. The cherty variety is characterized by the presence of a predominating amount of gray chert, the iron oxide being subordinate. The rock is there a slightly ferruginous well-banded chert.

2. The black-banded form of the Soudan formation has dark-gray or black

[93] Monograph 52, pp. 124–125.

chert bands interlaminated with black iron oxide bands. The iron oxide is commonly in large part magnetite. Usually associated with this magnetite are some of the amphibole minerals already mentioned.

3. In the red-banded kind the quartzose layers are stained with innumerable minute flakes of hematite, which give the rock a red color, in many places a brilliant red. The iron oxide between the red bands is ordinarily hematite, usually specular hematite. With this hematite may be some magnetite. This red-banded variety is a well known jasper of the Lake Superior region to which Wadsworth has applied the name jaspillite.

4. In the white banded kind the quartzose bands contain comparatively little iron oxide. The iron-oxide bands between the layers of chert are generally hematite, but this hematite differs in many places from that of the jaspillite bands in that it is of the red or brown variety. With it also, in many places, there is a certain amount of limonite.

5. The banded carbonate variety, while subordinate in quantity, is important in reference to the genesis of the formation. It is a gray-banded rock, the light-colored layers of which consist largely of siderite. Between this sideritic rock and the ordinary forms there are all stages of gradation.

6. The positions of the iron-ore bodies will be fully discussed later. In the iron ores the silica is very subordinate, the place of the quartzose bands being taken by iron oxide. The iron ore is dominately hematite.

The iron formations of the Lake Superior District also contain considerable thicknesses of ferruginous slates. Some of these are massive. Other varieties are cherty and contain numerous separate bands of chert. Slate bands also occur as partings in some of the jaspery portions of the iron formations.

The greenalite rocks constitute the most unusual lithologic type in these formations. They are dull, dark green rocks of rather fine grain. They are generally well bedded with layers of slate or iron ore. They may be seen to grade into quartzite or slate in going up or down in the section. At times the greenalite rock may be seen to grade laterally into slate.

When the greenalite rock is examined closely, particularly when the surface is wet, it may be observed to contain numerous ellipsoidal granules of a green substance. These are slightly lighter green than the matrix in which they are embedded. They are so small and so much like the matrix in color that they are not likely to be noticed unless specially looked for. They are rarely larger than one millimeter in diameter, and usually are above 0.1 millimeter. These green granules are found to have a more or less definite composition, being a hydrous silicate of ferrous iron and magnesia.

The iron formations are remarkably well bedded. The beds are thin, rarely being over five or six inches thick and commonly being much thinner. Many of the jasper bands have oval terminations or end in an irregular manner. They are frequently seen to end, even in small exposures, and it would appear that a large part of the beds are only rather short lenses which do not persist for any great distance. Some specimens of chert show a fine lamination[94] within the separate beds.

Some of the earlier geologists believed that these iron ores and jaspers were eruptive rocks. Others, impressed with their banded nature, regarded them as sediments of some sort, believing that the silica of the jaspers was originally in clastic grains and later became metamorphosed to its present condition. The iron oxide was regarded by some as originally bog iron ore, by some as lake iron ore, while others thought that the bands of iron oxide might have originally been laid down as magnetite sands.

R. D. Irving[95] showed that the silica of the jaspers was often chalcedonic or amorphous, which varieties are known only as deposits from solutions. He pointed out that, for the most part, the jaspers showed no trace of fragmental origin.

He considered the hypothesis that the jaspers and iron ores were deposited from siliceous springs but rejected it principally because of the association of the iron formations with magnetitic and amphibolitic schists, which he regarded as having a common origin with the jaspers and iron ores:

> While we have, perhaps, in the deposition from some modern siliceous springs, a slight analogy to the interstratification of iron sesquioxide and silica, this analogy is, after all, but slight, and any theory of deposition from springs fails entirely to secure in its support any modern analogues for the various magnetitic and actinolitic schists whose production must be explained. Again there is nothing in the structure of these deposits to indicate spring deposition, and everything to indicate deposition in bodies of water. But of the formation of such deposits by chemical deposition in bodies of water we certainly have no modern instances.

From the occurrence of ferruginous carbonates in association with iron ores and jaspers, and the fact that the least altered rocks of the iron formation contain considerable amounts of such carbonates, he was led to the hypothesis that the iron formations were once thin bedded ferruginous and magnesian carbonate rocks associated with carbonaceous shales. These shales frequently contained some admixture of carbonate. This material was later silicified and, in the process of silicification, the iron was leached out in whole or in part. The iron remaining formed the coloring matter of the jaspers; that

[94] Clements, J. M., U. S. Geol. Surv. Monograph 45, p. 181, 1903.

[95] Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region, Am. Jour. Sci., vol. 132, p. 255, 1886.

which was leached out was redeposited in the form of bodies of iron ore. At places, he believed, the iron carbonate reacted with magnesium carbonate during the progress of silicification and there resulted the magnesian iron silicates that characterize the magnetitic and amphibolitic schists.

N. H. and H. V. Winchell,[96] in 1889, suggested that the Keewatin iron ores and jaspers might be chemical precipitates. They showed that these jaspers often contained considerable amounts of chalcedonic silica, a form which is produced only as a chemical precipitate. The banding of chalcedonic silica and hematite was regarded as indicating that the iron formations were deposited in water in regular strata. They showed that the Keewatin contained large amounts of volcanic material which they believed was largely erupted beneath the sea. They believed that the waters of the ocean, on coming in contact with molten material during these eruptions, dissolved out large amounts of magnesia, iron, potassium, and sodium, together with silica. The precipitation of the iron and silica from these waters resulted in the production of the iron formations. This hypothesis appears to be an early formulation of the one now adopted by Van Hise and Leith.

J. E. Spurr,[97] in 1894, presented a somewhat different theory of origin of the iron ores in the Mesabi Range. Spurr found certain specimens in the iron formations that consisted of a ground mass of finely crystalline silica in which was embedded rounded or subangular bodies of a green mineral. This mineral was a hydrous silicate of iron which he believed to be glauconite, though he was aware of the fact that the potash content was low. He believed that the original rock of the iron formations was an altered greensand, and thought that the alteration of the iron silicate gave rise to silica, iron oxides and iron carbonates. He regarded the banding of the iron formations as due to the deposition of the products of oxidation along zones of weakness in the original rock.

Van Hise and Leith[98] state that since the green granules contain no potash they cannot be regarded as glauconite. They suggest the name greenalite for the green granules of ferrous magnesian silicate.

Van Hise and Leith are convinced that the iron-bearing sediments were, for the most part, originally in the form of greenalite rock with

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[96] On a Possible Chemical Origin of the Iron Ores of the Keewatin in Minnesota, Am. Geol., vol. 4, p. 291, 1889.

[97] The Iron Ores of the Mesabi Range, Am. Geol., vol. 13, p. 335, 1894.

[98] Monograph 52, pp. 168–69.

subordinate amounts of cherty iron carbonate. This is based on the observation that some of the least altered parts of the formation, closely associated with slates, show much greenalite, and also that in studying a large number of thin sections it was possible to trace all gradations in the alteration of greenalite to iron ore. Many of the jaspers showed small residual patches of greenalite rock. The cherty iron carbonates have also been shown to pass over into iron ore. The ferruginous cherts are believed to result from the alteration of greenalite rock or cherty iron carbonate. Iron ores come from further alteration of ferruginous cherts.

Van Hise and Leith[99] also admit the possibility that the ferruginous cherts and interbanded iron ores may have originally been deposited as banded silica and ferric oxide or ferric hydrate.

As a result of the evidence which is fully presented and discussed in their monograph, Van Hise and Leith reached the conclusion that the iron formations were true marine sediments, though of an unusual and exceptional type. They also concluded that the iron oxide and silica were chemical precipitates from solution.

They point out the frequent close association in space and time (shown by interbedding) of the iron formations and the ellipsoidal basalts which were extruded in enormous volumes in the region of Lake Superior during various periods of pre-Cambrian time. They also point to the association of these peculiar extrusives with radiolarian cherts in many parts of the world.

They regard the ellipsoidal basalts as the "variant in the normal conditions of sedimentation necessary to produce the iron bearing formations," and believe that in these basalts they can recognize the source of the iron and silica.

They believe the material may have been carried in hot solutions, coming from the eruptive rocks during their crystallization, or leached by meteoric waters from the portions of the magma extruded subaerially, or, in small part, obtained by reactions between the iron rich basalt and the sea-water, when the basaltic magma was poured out on the sea floor.

They attempt to meet the objection that the Animikie Iron formations on the north shore of Lake Superior, which represent the maximum development of iron formation in the district, are not directly associated with volcanics of this type. They argue that the remarkably uniform character of these Animikie iron-bearing rocks, so distinct from pre-Cambrian iron formations, is due to distance from the

[99] *Op. cit.*, pp. 126, 243.

center of volcanic activity. They also point out that rocks referred to the Animikie on the east side of Hudson Bay show all the members of the ordinary iron formations of Lake Superior and are also intimately associated and interbedded with extrusions of ellipsoidal basalt. This indicates that this type of vulcanism was a feature of Animikie time.

The cherts and jaspers of Lake Superior may be contrasted with the cherts of the Franciscan formation by reason of their much higher iron content, their lack of radiolaria, and the presence of the peculiar greenalite granules. The absence of radiolaria might be regarded as due to the greater metamorphism of these older rocks. However, in some places the slates appear to have escaped unusual metamorphism, and in view of the great number of careful workers, and the large number of thin sections examined, it would seem that if the rocks had ever contained radiolaria in important amounts, some trace of them would have been discovered. It seems most reasonable to regard them as siliceous rocks not associated with radiolaria in any way.

In so far as the ferruginous cherts of Lake Superior are due to the alteration of greenalite rock and of cherty iron carbonate they appear of a distinct type from the Franciscan cherts. The red cherts of the Franciscan group show no evidence of alteration and appear to be the result of original sedimentation.

JASPERS OF SOUTH AFRICA

Jaspers, associated with iron ore, occur at several horizons, and at several localities in South Africa. These all resemble very greatly the occurrences in the Lake Superior District and need not therefore be described in detail.[100]

These iron formations are intimately associated with basic igneous rocks, both extrusive and intrusive. In many cases these show an ellipsoidal structure. No radiolaria have been reported from them, though they have not been studied in the same intensive manner as the Lake Superior rocks. Unlike the cherts and jaspers of Lake Superior, these rocks in South Africa are frequently associated with the blue soda amphibole, crocidolite, which in certain places occurs in abundance.

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100 Hatch and Corstorphine, The Geology of South Africa, London, 1909.
Rogers and Dutoit, The Geology of Cape Colony, London, 1909.
Stow, G. W., Geological Notes on Griqualand West, Quar. Jour. Geol. Soc., vol. 30, p. 581, 1874.

CONTRIBUTIONS OF EARLIER WORKERS IN CALIFORNIA TO THE QUESTION OF THE ORIGIN OF THE RADIOLARIAN CHERTS

The first description of the radiolarian cherts of the Franciscan group was written by Lieutenant Edward Belcher,[101] who visited the port of San Francisco during a voyage extending over the years from 1825 to 1839. In his notes, published over ten years afterwards, the following description appears:

> The appearance of the jasper, at its contact with the sandstone, is often very remarkable. The jasper appears not to have acted on or displaced the sandstone; its exterior for eighteen inches or two feet is usually rugged and mixed with carbonate of lime, quartz, and indurated clay; its interior, however, presents a very beautiful wavy disposition of the component laminae, a remarkable example of which occurs at Needle Rock. . . . It resembles an immense mass of sheets of paper, or bands of list, crumpled and contorted by lateral pressure. This contortion only occurs in the red jasper, the yellow being seldom (if at all) stratified, but generally separated by cracks into rhomboidal pieces.

In the year 1849, James D. Dana[102] published his description of the geology of the regions visited by him during the Wilkes Expedition. He describes the cherts occurring near Sausalito and San Francisco and states that they are subordinate members of the "talcose rock formation."

Dana divides the rocks of northern California and Oregon into groups, the oldest of which he refers to as the "Ancient Plutonic Series." He states that the various members of this division are intimately associated with one another and belong to a single series. This division includes granitic rocks occurring in northern California, which are said to grade into talcose rocks, while hornblende rocks and serpentine are the intermediate members in the transition. He believes that the talcose rocks in their turn pass into "prasoid rocks" and these into jaspers. In the "Shasty Mountains" (Klamath Mountains), Dana describes some very soft talcose rocks which he believes show transitions to a homogenous siliceous rock with a smooth conchoidal surface. He describes it as follows:

> This greenish rock would be called prase in hand specimens, and is often more or less translucent, with a smooth conchoidal fracture. It is very siliceous, consisting probably of silica and feldspar, with a trace of coloring

[101] Zoology of Captain Beechey's Voyage, London, 1839.

[102] Report of the United States Exploring Expedition during the years 1838–1842: X, Geology by J. D. Dana, Philadelphia, 1849

material, yet the feldspar is nowhere in crystals or grains, and in much of the rock must be sparingly present. We may distinguish it as *prasoid rock,* for it is abundant wherever the talcose formation occurs. . . .

A light greenish variety of this rock, near San Francisco, is associated with red and yellow jasper; some hills consist wholly of the latter material, while in others both the green and red rocks are associated, showing by their gradations the close relations between the jasper and the prase rock.

A variety resembling bloodstone is also met with, at times; it has a dark green color and jasper-like fracture, though no specimens were seen with the red spots of true bloodstone.

From the transitions here pointed out, it appears that the jasper and prase rocks are closely connected with the talcose series; and that the translucent prases and bloodstones here found are only varieties of its condition.

Later in the chapter he describes the cherts more fully:

The structure of the jaspery rock of San Francisco is worthy of description. The green, red and yellow varieties occur in the same vicinity. They form a series of layers, averaging two inches in thickness, and varying from half an inch to four inches. The layers are very distinct, and are partially separated by open seams, and on the front of bluffs or ledges the rock has consequently a riband-like appearance. The layers often coalesce and subdivide without regularity, though uniformly parallel. They are frequently twisted, and thus change, at short intervals, from a vertical position to a dip of twenty degrees. The colors, red and yellow, are often mingled, and sometimes appear as parallel bands. In some instances the surface is red, while the rock is yellow beneath: this has resulted from the burning of a tree on the spot; for by heat the yellow variety readily changes to red. A small specimen of the green variety had an agate-like structure, as if it had been formed from an aqueous solution.

The next reference to these rocks is found in a booklet by Philip T. Tyson,[103] published in 1851. He appears to have believed that they were metamorphosed sediments of some sort. The following appears in his descriptions of the region around Bodega:

The northwestern end of this small vale is abruptly terminated by steep acclivities, whose rocks mainly consist of several varieties of compact quartz such as chert, jasper, etc. There is every shade of white and gray to nearly black, as well as yellow, red, and brown, each color continuous in separate layers. It is evident that they were originally deposited in strata; and, besides having been changed in character by heat, were contorted and twisted in a remarkable manner anterior to, or during the period of their elevation.

John B. Trask, in 1853,[104] described the cherts at Presidio Point in the following words:

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[103] Geology and Industrial Resources of California, Baltimore, 1851.

[104] Geology of Sierra Nevada and Coast Ranges, California Sen. Exec. Doc. no. 9, p. 5, Sacramento, 1853.

On Presidio Point are to be found beds of a Jaspery rock having a riband-like appearance, and colors from a greenish hue through red-brown to red and yellow; this rock has been considered by Mr. Dana as a variety of the Prasoid rocks, . . . the gradation of prase into jaspery rocks exhibits a close relation of both.

W. P. Blake, writing to James D. Dana, in 1854, describes the occurrence of quicksilver ore at the New Almaden mine.[105] In his description he says:

I expected to find the ore in close relation with the deposit of tertiary age, and among bituminous shales, but in this I was disappointed. All the tertiary beds appear to have been washed away, and hard serpentine and trappean rocks constitute a large part of the ridge in which the ore is found. There are however large outcrops of sedimentary rocks, composed of alternating beds of argillaceous shales and layers of flint; they are highly tilted and much flexed. They are unlike any of the tertiary series that I have seen in the state and I am inclined to refer them to the lower Silurian age.

A footnote, at the base of the page on which the foregoing description occurs, is as follows:

Similar rocks (talcose and argillaceous shales and a Jasper rock) occur north of the harbor of San Francisco; they are more or less metamorphic and probably *not older* than stated by Mr. Blake. *J. D. D.*

Blake's first impression of these rocks was such as to make him believe that they were sediments and not metamorphic rocks. In 1856, probably influenced by Dana's opinion, he described them as as metamorphic equivalents of the Franciscan sandstone:[106]

The most distinct contortions and highly-inclined positions are, however, shown by a class of rocks which have not yet been mentioned. They are, to all appearance, a metamorphosed or changed portion of the sandstone formation. . . . Portions of the strata are very finely stratified, the layers being not over half an inch thick, and yet they are well defined and apparently very hard. . . . In these islets, and on Lime Point, there are beautiful flexures and folds of the strata, some of them of considerable extent, and others are local, showing many bends and short angles within the space of a square yard, resembling the compressed and crumpled leaves of a book in the number of thin layers, and their conformity through all the bends. . . .

The lithological characters of these strata are very interesting. They are hard, flint-like, and jaspery, and occur of various colors. The most common color is a dark reddish-brown, or a chocolate color, but this is often intermixed with yellow and green. Indeed, some of the fragments are beautifully spotted and banded with different colors, and form good specimens of ribbon-jasper or prase. Quartz in thin irregular veins, is a common accompaniment of the rock, and traverses it in all directions without any regularity in the trends of the fissures. It appears, in many cases, to form a complete coating around the frag-

[105] Am. Jour. Sci., vol. 17, p. 438, 1854.

[106] Pacific Railroad Rep., vol. 5, p. 155, 1856.

ments of the rock, so as to isolate them from the adjoining portions. The flat surface of one of the specimens, when viewed at a short distance, appears as if covered by a tangled mass of white cord.[107] It is probable that these flinty strata are similar to those seen by Professor Dana, and described in his report as *prasoid* rocks.

Although the direct transition from the unaltered sandstone and shale to these metamorphic strata has not been observed, there is little doubt that they are of the same formation, and that the jaspery condition is due to igneous agencies. The chemical composition of the sandstone and the shales is favorable to such a result. It is regretted that analyses of each, and of the metamorphosed portions cannot be presented.

In another place Blake[108] writes as follows:

At several places on the peninsula of San Francisco a peculiar, hard and flinty rock appears at the surface, and exhibits distinct stratification. It has a variety of colors, but a dark reddish brown is the most common. It is much traversed by irregular veins or seams of quartz, and has a banded or belted structure, so that it resembles varieties of jasper . . . all the characters of this rock, and its positions, indicate that it is an altered portion of the San Francisco sandstone formation.

J. S. Newberry[109] described the occurrence of jasper at a number of localities around the Bay of San Francisco, and suggested two possibilities in explanation of their origin:

. . . It frequently occurs in ridges, having the appearance of an erupted rock, protruded along lines of upheaval. It is red, yellow, or green in color, but oftenest blood-red, or some intermediated shade between that and pink, being usually somewhat mottled, clouded, or striped.

Veins of white quartz, generally small, traverse it in every direction, and, where it is weathered, it is often peculiarly cellular, ragged, and rough. Where stratified, the laminae which it exhibits are twisted and contorted in all possible directions, and whatever is the history of the material of which it is composed, whether it is thrown up from below, or, as is more probable, it is a metamorphosed form of the associated rocks, it is evident that it has been subjected to a high degree of heat. These jaspery rocks are, equally with the serpentines, a marked feature of the geology of the Coast Ranges, from the Gulf of California to the Columbia.

In 1865, Whitney published descriptions of the Coast Range formations in *The Geology of California.* In describing the radiolarian cherts of Mount Diablo, he says:

On the outside of this great central metamorphic mass, both on the north and south, but not entirely surrounding it, are heavy accumulations of jaspery rock,

107 See plate 31c.

108 Observations on Physical Geography and Geology of the Coast of California from Bodega Bay to San Diego, U. S. Coast and Geod. Surv. Rep. 1855, App. no. 65, 1856.

109 Pacific Railroad Rep. V, Geological Report, p. 12, 1856.

one of the most peculiar features of the mountain, and the material of which the culminating point itself is made up. On the north side of the North Peak, these beds are finely exposed, forming a lenticular mass about two miles long and half a mile wide. They have a nearly east and west strike and dip to the north. They are here, as elsewhere, of a red color, varying from a dull brick-red to a brilliant vermilion hue. The strata are usually thin, an inch being about their average thickness, and they are much folded together and twisted. These jaspery strata on the north side of the North Peak do not extend around so as to pass to the north of the Eagle Point Ridge, but may be traced in the ravines in which Bagley Creek heads, passing into the unaltered shales of undoubted Cretaceous age in which *Ammonites, Inoceramus,* and other fossils have been found, and which are largely developed to the north of the mountain as well as to the south. . . . No one making an examination of this part of the mountain could doubt that these jaspers are the result of the alteration of the Cretaceous shales.

. . . The red and green jaspery rocks, however, are the most characteristic forms, and having been here so unmistakably traced to their origin as Cretaceous shales, they have been of great service to us in recognizing this formation in other localities, where the facilities for tracing it out in all its connections, and of determining its age by fossils were less than they were found to be in this vicinity.

Whitney regarded his ideas as to the metamorphic nature of the various rocks of the Franciscan and their Cretaceous age, as proved by the finding of an *Inoceramus* in the rocks of Angel Island in the Bay of San Francisco.

When we consider certain facts regarding Whitney's work it is not surprising that he reached this conclusion regarding the origin of the cherts. Whitney, before coming to California, had worked in the Lake Superior region among Archean rocks. He had seen the ferruginous jaspers of that region classed as metamorphic rocks and it is but natural that when he encountered somewhat similar jaspers at Mount Diablo he should have regarded them as similar in origin to the occurrences in the region of Lake Superior. He was familiar, also, with the fact of the occurrence of similar "ribboned jaspers" in the Ural Mountains, and knew that they had been explained there as being highly silicified schists.[110]

At Mount Diablo, Whitney found jaspers and other rocks of Franciscan age resting *above Knoxville* shales as a result of displacement along an overthrust fault. Since he did not recognize the nature of this structure, it is only to be expected that, with his experience of similar rocks elsewhere, he should believe that the upper part of the mountain represented the exposure of a core of metamorphic rocks, and believe that the rocks around the base represented their unmetamorphosed equivalents.

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[110] Foster and Whitney, Report on Lake Superior, pt. II, U. S. Sen. Exec. Doc. no. 4, p. 3, 1851.

A further fact is that the Knoxville shales in the region are often black and thin bedded. In Bagley Cañon at Mount Diablo, Knoxville shales of this sort are exposed in the lower part of the cañon. Further up stream, in the Franciscan mass, above the plane of the thrust fault there is a large rib of chert several hundred feet long and seventy-five feet thick included in a mass of intrusive basalt. This chert is well exposed by the dissection of Bagley Cañon. It so happens that the chert horizon contains, as the cherts rarely do, some black, carbonaceous, thin bedded shales, much like those in the Knoxville. Altogether Whitney's conclusion was natural in view of the facts he found in Bagley Cañon, and his failure to recognize the nature of the structure there.

Whitney did his detailed work at Mount Diablo and used the results of his work there for the determination of Coast Range sequence. He never seems to have questioned his determinations at Mount Diablo, nor to have critically studied other sections. It is possible that careful study in other localities would have shown him his error.

In 1888, Geo. F. Becker[111] described these rocks in connection with his report on the quicksilver deposits of the Pacific Coast. He, also, regarded the Franciscan rocks as metamorphic equivalents of the Knoxville. He speaks of the cherts of the Franciscan group as "phthanites, or schistose rocks which have been subjected to a process of silicification, retaining their schistose structure." He says:

> . . . The shales of the Knoxville Group are sometimes unaltered, but more frequently silicified to chert-like masses of green, brown, red, or black colors, intersected by innumerable veins of silica. These highly altered shales, when very thin-bedded, break into parallelopipidic fragments, but where the beds reach a thickness of half an inch or more there is a decided tendency to conchoidal fracture. The green varieties are infusible before the blowpipe, while the brown specimens are more or less fusible. The only essential difference appears to be in the state of oxidation of the iron, which is partially soluble in the reddish rocks. The most convenient name for these rocks is phthanite, introduced by Haüy to designate quartzose, argillaceous rocks with a compactly schistose structure. This term has sometimes been employed in a more special sense to denote siliceous beds intercalated in limestone, but this limitation will not be adopted here.

As proof of their metamorphic origin he pointed to certain rather abrupt transitions which he thought he could establish:

> . . . The metamorphic character of the phthanites is manifest both from their structure and from transitions—which exist, for example, at Venado Peak, New

[111] Becker, G. F., Quicksilver Deposits of the Pacific Coast, U. S. Geol. Surv. Monograph 13, 1888.

Idria—into ordinary shales. Under the microscope, also, the most highly indurated specimens are found to contain fossils.

. . . In the mass of the phthanites included between the quartz veins remains of clastic structure are often visible, especially in reflected light. The most interesting constituents of foreign origin are round spots, which often retain evidences of organic character. Professor Joseph Leidy, at my request, has examined some of the thin sections containing such spots, which he regards as probably foraminiferous shells.

Becker seems also to have believed the Monterey cherts to be metamorphic also, since he speaks of them in the following words: "light cream-colored schists of Miocene age which occupy a narrow strip along the coast of California from the neighborhood of Santa Cruz southward."

Up to this time none of the geologists working in this region had noticed the presence of the radiolaria in the cherts. This is not remarkable, however, since no thin sections were made until Becker's work.

H. W. Turner,[112] writing in 1891, accepts Whitney's evidence of transition and metamorphism, as shown at Bagley Cañon, Mount Diablo. In an appendix to Turner's paper, Melville gives analyses of various rocks from Mount Diablo. He states that the "common red shale" passes into "silicified shale or phthanite." He writes:

The great mass of these deposits in Mount Diablo is exceedingly folded and distorted, yet shows the alternating layers of the two components, a phenomenon quite usual in this class of rocks in the Coast Ranges. This rock is very friable, and the phthanite can be readily separated from the shale.

In 1892 and 1893, H. W. Fairbanks[113] in two successive papers, showed the probability of the presence of an unconformity between the Franciscan rocks and the Knoxville. He pointed out that *Aucellae* were quite common in the Knoxville and that, although some of the Franciscan sandstones and shales were little metamorphosed, *Aucellae* were never found even in these slightly altered rocks. He showed that there were sharp contacts above which unaltered Knoxville shales rested on considerably disturbed and altered rocks of the older series. He pointed out, also, that at Mount Diablo an "amygdaloidal intrusive" cut the older series but was never found in the Knoxville. While these considerations tended to overthrow the old idea

[112] The Geology of Mount Diablo, California, Bull. Geol. Soc. Am., vol. 2, p. 383, 1891.

[113] The Pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Ranges, Am. Geol., vol. 9. p. 153, 1892.

Notes on Farther study of the Pre-Cretaceous Rocks of the California Coast Ranges, *ibid.*, vol. 11, p. 69, 1893.

that the cherts were metamorphosed Knoxville shales, Fairbanks, at this time, believed that the cherts were metamorphic rocks.

In 1894, F. L. Ransome[114] described the geology of Angel Island and during his study of this area the true nature of the organic remains was discovered. While Becker had recognized the presence of the remains of organisms in the cherts, he had failed to distinguish their true nature. Ransome's ideas regarding the origin of the cherts may be seen from the following quotation:

> . . . Having found the remnants of siliceous organisms in the less siliceous portions of the cherts, they were subsequently recognized in the more silicified facies as little spherical bodies of clear cryptocrystalline silica, possessing more or less definite boundaries. From the wavy extinctions observed upon turning the stage between crossed nicols, it is supposed that the silica is in the form of chalcedony. It is possible, if not probable, that, although the radiolaria are best preserved in the more earthy and less siliceous portions of the rock, they were originally much more abundant in the jaspery varieties, but have there become obscured by the solution and recrystallization of the abundant silica furnished by their remains.
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> Whatever may be the source of the silica forming the cherts and jaspers in other portions of the Coast Ranges, on Angel Island it appears unnecessary to call upon any hypothesis of a general secondary silicification to explain their origin. It is a more simple, and, in the light of the foregoing facts, a more probable supposition that they were *originally* siliceous deposits, the silica being derived largely from organic remains and varying in amount in different portions of the series, both vertically and horizontally, with the former abundance or scarcity of the siliceous organisms. When these were few, the non-siliceous components of the deposit would predominate and furnish a dark matrix for the preservation of the radiolaria. When, on the other hand, the latter were very abundant, the deposit would be largely opaline silica, in a condition susceptible to solution, and the organic structure would become obliterated.

Ransome suggested that these rocks be thereafter spoken of as "radiolarian cherts":

> Although, in many localities the name "bedded jaspers" may be applied to these rocks with perfect propriety, yet the investigation of their representatives upon Angel Island, appears to indicate that "radiolarian chert" is, on the whole, a better designation for them, inasmuch as it casts some light upon their origin, and suggests their relationship with similar cherts in Europe.
>
> The lessons to be drawn from these facts are that the jasper in its essential character is not a metamorphic rock, and that it was formed of siliceous sediments resulting in great measure from organic life, as has been demonstrated to be the case with similar rocks in other parts of the world.

In an appendix to Ransome's paper, J. G. Hinde described the radiolaria in specimens of the chert from Angel Island and in specimens collected by Professor Lawson from Buri-Buri Ridge on the

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114 Geology of Angel Island, *op. cit.*, vol. 1, pp. 199–200, 1894.

San Francisco Peninsula. He pointed out the fact that no other microscopic organisms could be recognized in the cherts, but stated that it was quite possible that diatoms had been originally intermingled with radiolaria. He believed that the more delicate diatoms, if originally present, might have been obliterated, while the coarser structures of radiolaria were only partly obliterated.

Later, a paper by H. W. Fairbanks[115] appeared, in which he described the cherts of the Franciscan formation. With regard to the origin of these rocks, he followed Ransome in believing that they were the equivalents of radiolarian ooze, and that practically all their silica was originally in the tests of radiolaria. He believed that a considerable part of the radiolarian tests had been obliterated in the changes to which the rocks had been subjected. After describing the microscopic character of the cherts, he concludes:

> The lessons to be drawn from these facts are that the jasper in its essential character is not a metamorphic rock, and that it was formed of siliceous sediments resulting in great measure from organic life, as has been demonstrated to be the case with similar rocks in other parts of the world.

His description of the general geological relations of the cherts, is in part as follows:

> The entire freedom of the jaspers from any fragmental material deposited in the ordinary way near a shore would indicate their formation in deep or at least quiet waters. The very rare occurrence, however, of limestone in this series and the abundance of sandstone would seem to indicate the absence of deep-sea conditions during the deposition of the greater portion.
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> No one has yet worked out the stratigraphic position of the jasper beds in the series, and ascertained if they are distributed through it or confined to a single horizon. The wide occurrence of the jasper beds may not, perhaps, result so much from any great extent vertically as from the extremely crushed and broken condition of the series as a whole. As a result of this condition, strata of the same or nearly the same horizon might be exposed in many places. So far as the writer is aware, jaspery beds are absent from the recognized Cretaceous, but in the Miocene there again appear flinty beds of probably the same origin, but wholly free from the secondary silicification so characteristic of the earlier ones.

In 1895, Professor A. C. Lawson's[116] report on The Geology of the San Francisco Peninsula was published. At this time there was presented the first complete and satisfactory description of these cherts and their associated shales.

Professor Lawson here recognized the fact that the silica of these cherts was not entirely due to the radiolarian skeletons present in

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[115] A Review of our Knowledge of the Geology of the California Coast Range, Bull. Geol. Soc. Am., vol. 6, p. 82, 1895.

[116] 15th Ann. Rep. U. S. Geol. Surv. 1893–94, pp. 401–76, 1895.

them and this, together with the field distribution of the areas of chert, led to somewhat different ideas concerning the mode of origin of these rocks. The following quotation will indicate the conclusions arrived at:

. . . As regards the organic origin of the silica of which the chert is composed, it seems to the writer that there are features both in the slides and in the field occurrence of the formation which do not harmonize with this supposition. In the slides having the radiolarian remains, the latter generally occur as casts of forms embedded in a matrix of silica which shows no evidence whatever of organic origin. The cavities of the Radiolaria have been filled with chalcedonic silica, and are in definite contrast with the non-chalcedonic matrix. The discrete character of the fossils is significant of their mode of accumulation. The silica seems to have been an amorphous chemical precipitate forming in the bottom of the ocean in which the Radiolaria thrived. The dead Radiolaria dropped into this precipitate, became embedded in it, and were so preserved. The state of preservation is variable, but this is ascribable to the molecular changes that have been in progress in the rock since its solidification, or to the solvent action of the same agencies which held in solution and precipitated the silica.

It thus seems to the writer that the bulk of the silica cannot be proved to be the extremely altered débris of Radiolaria. The direct petrographical suggestion is that they are chemical precipitates. If now we accept this hypothesis, it becomes apparent that there are three possible sources for the silica so precipitated, viz.: (1) Siliceous springs in the bottom of the ocean, similar to those well known in volcanic regions; (2) radiolarian and other siliceous remains, which may have become entirely dissolved in sea water; and (3) volcanic ejectmenta, which may have become similarly dissolved. The last is the least probable, because we are not actually familiar with such a reaction as the solution of volcanic glass by sea water. Our ignorance is, however, no proof that such solution may not take place under special conditions. Setting this third possibility aside, let us consider to which of the other two the field evidence points.

If the silica were derived from the solution of organic remains by sea water, or indeed, directly from organic débris, we should expect to find the cherts having a vast extent of fairly uniform thickness. On the other hand, if the silica were derived from siliceous springs we might have the formation developed in lens-like masses of varying thickness at different centers. The field evidence agrees in an unmistakable way with the second of our supposed conditions. The radiolarian cherts occur throughout the field, and indeed, throughout the Coast Ranges in a sporadic way. Although some of the occurrences are many hundred feet thick, they appear to thin out rapidly and do not form sheets comparable in extent to the San Francisco sandstone. Most of the individual occurrences, moreover, are of very limited extent, occupying only a few acres, or only a fraction of an acre, and it seems impossible to conceive that they had any other than a very local origin. Great numbers of these small patches of chert occur in the sandstone which are so small that they can not be represented in the mapping without gross exaggeration. The hypothesis of the derivation of the silica from siliceous springs and its precipitation in the bed of the ocean in local accumulations, in which radiolarian remains became embedded as they dropped to the bottom, seems, therefore, the most adequate to explain the facts, and there is nothing averse to it so far as the writer is aware. The abundance of the Radiolaria may be due to the favorable conditions involved in the excessive amount of silica locally present in the sea, or simply to the favorable conditions for preservation afforded by this kind of rock. If the springs were strong, the currents engendered might in some places have been sufficient to deflect sediment-laden countercurrents, and this may serve to explain the general absence of clastic materials in the chert.

It is entirely probable that radiolarian remains will be found in rocks which represent sediments deposited in the same sea as that in which the cherts were locally developed.

The alternation of beds of chert with partings of shale may perhaps be ascribable to a rhythmical or intermittent action of the springs. But in any theoretical consideration of the cherts, the stratification is their most obscure feature. . . .

ORIGIN OF THE RADIOLARIAN CHERTS OF THE FRANCISCAN GROUP

Statement of Thesis

As a result of a consideration of the various lines of evidence, discussed in the succeeding pages, the following conclusions have been reached:

The radiolarian cherts and their associated shale partings do not represent abyssal radiolarian ooze and Red Clay, but were deposited in shallow water or in water of moderate depth.

Four possible sources of the silica of the cherts are considered:

1. Radiolarian skeletons or siliceous parts of other organisms.
2. Silica contributed to the ocean by river waters and flocculated by the salts of the ocean.
3. Silica in emanations from igneous rocks.
4. Silica from submarine siliceous springs.

The petrographic study of the cherts together with certain peculiar features of their bedding indicates that they are not pure radiolarian oozes, nor are they siliceous oozes composed in part of radiolaria, and in part of the remains of other siliceous organisms. A portion of their silica is chemically precipitated and the radiolaria are simply incidental fossils, entombed in the precipitated silica.

It appears that the silica contributed to the ocean by the rivers *may* be precipitated entirely through the intervention of organisms. If it *is* chemically precipitated, it probably comes down in the form of magnesium silicate and not as silicic acid.

The last two hypotheses as to the source of the silica are regarded as interdependent, on account of the usual association of siliceous springs with vulcanism. It is concluded that the silica of the cherts arises from submarine siliceous springs associated with igneous activity of a peculiar type, which occurred during Franciscan time. Part of the silica may be a direct contribution from the cooling magmas. A part of it may be derived from preëxisting rocks or previously deposited sediments, by the solution of silica in heated subocean water, set into circulation by the intrusion of molten magmas into the water-saturated materials below the ocean floor.

The only serious objection which has ever been raised against this hypothesis of siliceous springs is one which was advanced by Rothpletz. He regarded the rhythmic bedding of the cherts with shaly material as due to alternations of deposition, and regarded it as improbable that there should be such alternation in the supply of siliceous springs.

Several possibilities are considered in an attempt to explain the rhythmic alternation of radiolarian cherts with shales. Of these the most important are:

1. Regular alternations of climatic conditions, due to seasonal variations or to climatic cycles.

2. Rhythm in deposition of silica due to periodic supersaturation and resulting precipitation.

3. Colloidal segregation with a regular separation of silica from shaly material.

The hypothesis of climatic variation encounters various objections. The most important are:

a. The distribution of fine terrigenous material does not depend upon the rivers, but upon the ocean currents which distribute the fine sediment along the continental margin.

b. The hypothesis of climatic variation will not explain the wedge-bedding, and lenslike character of both the cherts and shales.

The hypothesis of rhythmic precipitation of silica cannot account for the common lenslike character of the shale partings, though it is not inconsistent with the lenslike character of chert beds.

In the absence of another hypothesis, one is forced to the assumption of colloidal segregation of silica from intermixed shaly material. This hypothesis will explain the lenslike nature of both the cherts and shales. The objection that such a segregation would not produce the regular banding is removed if one considers the results of certain experiments on diffusion reactions in colloids. In these experiments a very regular separation of precipitated material is produced. The Liesegang rings show all the minor features of the banding of cherts and shales—wedging out of bands, etc. Certain experiments by Bradford produced bands of nodules and lenses.

An objection might be raised, however, that all the above diffusion reactions represent reactions occurring in a colloidal medium by the interaction of two dissolved salts. These bands are formed at the time of precipitation of the material. They involve no segregation of already precipitated material, such as the hypothesis above set out would require.

The writer has shown that if a solution of ammonium carbonate be allowed to diffuse into a suspension of clay, finely divided quartz, or other solid material, in a solution of sodium silicate, that a rhythmic segregation of silicic acid from the solid material will be brought about. These experiments prove that under certain conditions gelatinous silicic acid possesses the power to expel mechanical impurities from itself, and show that this segregation may occur in a rhythmic way.

The acceptance of the hypothesis of colloidal segregation as a means of explaining the rhythmic bedding, removes the objection to the idea that the silica of the cherts is, in large part, derived from siliceous springs.

Interpretation of Cherts as Volcanic or Metamorphic Rocks

Some of the earlier workers in Europe thought that the radiolarian cherts were volcanic rocks. Many others regarded them as due to metamorphism or silicification of ordinary shales. These ideas were abandoned about 1880, when radiolaria were discovered by Rothpletz[117] in the *kieselschiefer* of Saxony, and by Pantelli,[118] in the jaspers of Tuscany.

In California, certain workers, notably Dana, Blake, Whitney and Becker, regarded the cherts as due to the silicification of Cretaceous shales. This interpretation was generally accepted by geologists in California until Ransome and Lawson showed that they contained numerous radiolaria and were identical with radiolarian cherts in England and on the continent of Europe.

Interpretation of the Cherts as Fossil Radiolarian Oozes

There are many investigators who have regarded these rocks as the equivalents of the radiolarian oozes. Among those who hold that idea are two distinctly separated classes.

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[117] *Op. cit.*

[118] *Op. cit.*

Certain writers, as for example, Molengraaff, Hinde and Hahn, are impressed by the fact that radiolarian oozes are not known to be accumulating in depths of water less than 2000 fathoms at the present time, and that they occur in the deepest portions of the ocean. They believe that the radiolarian cherts are the equivalent of radiolarian oozes, which accumulated in the abyssal depths of the ocean, and believe that they were later uplifted to form part of the present continents.

Other writers hold that the radiolarian cherts are fossil radiolarian oozes, but were not deposited at extreme depths. Among these are probably to be included Ransome and Fairbanks, who did not insist upon the deposition of these rocks in excessive depths of water. Similar views are held by many other writers with regard to chert occurrences elsewhere. Dixon and Vaughan adopt an extreme view and regard these cherts as deposits formed in very shallow waters. Their views have been set out in preceding pages.

HYPOTHESIS OF ABYSSAL ORIGIN

We may first consider the view that the radiolarian cherts represent abyssal radiolarian oozes. Our knowledge of the present day, deep sea deposits favors this explanation. The only deposits forming at the present day, which contain abundant radiolarian skeletons are the radiolarian oozes. They are unknown in depths of water less than 2000 fathoms, and usually occur at much greater depths. They are known only in the tropics since only in the tropics are the radiolaria numerous enough in the surface waters to give rise to notable deposits on the sea bottom. If it be granted that the cherts are former radiolarian oozes, the distribution of present day deposits of this type would indicate that they were formed under tropical conditions in great depths of water.

Calcium Carbonate.—In favor of the idea of a deep sea origin for the Franciscan cherts, is the fact that they contain no lime carbonate. This is true for many of the occurrences of radiolarian cherts in other parts of the world. It is not, however, a general property of all the occurrences. Many cherts which appear to be identical with the Franciscan cherts contain lime carbonate, and must, therefore, have accumulated at depths such that all lime carbonate was not dissolved from the bottom deposits. The cherts of the Culm measures in England contain calcareous fossils. In the Alps calcareous layers occur in the radiolarian cherts. Limestones are rather closely associated with the cherts of Alaska and the East Indies. It appears then from the evidence of the lime content that radiolarian cherts may be deposited outside of the extremely deep portions of the ocean.

Manganese Oxide.—Professor G. A. F. Molengraaff,[119] who regards the radiolarian cherts as abyssal radiolarian oozes, and the shale partings as the equivalents of the red clay, points to the presence of managanese in these cherts as additional evidence in favor of his view. He believes that the mode of occurrence of manganese in the Borneo cherts is identical with that in which manganese occurs in the present, deep sea oozes. He finds it in the radiolarian cherts of Borneo in three distinct forms. It occurs in minute scattered grains throughout the chert, in nodules in the cherts and associated shales, and in beds, interlayered with shale in a manner similar to that in which the chert occurs. From his descriptions, the nodules do not appear to be abundant. Molengraaff points out that under ordinary conditions, manganese oxide accumulates with extreme slowness, and only in the very slowly accumulating, deep sea oozes does it become abundant enough to make up an appreciable part of the formation. He believes that the manganese aggregates itself into nodules in the deep sea oozes through the processes of solution and precipitation, and also by the movement of minute grains of manganese oxide through the colloidal clay to the centers of accumulation. He believes that there is an aggregation of silica in much the same way, but that the aggregation of silica takes place at a later stage than that of the manganese.

The presence of manganese in a sediment does not appear to be a proof of its abyssal origin. Manganese oxide is found in other than abyssal deposits though, according to Agassiz,[120] the nodules are only met with in the deeper sea waters. One example, which is sometimes referred to, is described by J. Y. Buchanan,[121] who writes of the finding of a large number of manganese nodules in the Firth of Clyde in a depth of only 104 fathoms. Later these nodules were found in abundance in other parts of the Firth of Clyde at a depth of ten fathoms. This fact, however, should not be pressed too strongly as contradictory evidence for the reason that these nodules are stated

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[119] On the Occurrence of Nodules of Manganese in Mesozoic Deep-sea Deposits from Borneo, Timor, and Rotti; their Significance and Mode of Formation, R. Acad. Sci., Amsterdam, vol. 24, p. 415, 1915.

[120] Three Cruises of the ''Blake,'' vol. 1, p. 141, Cambridge University Press, 1888.

[121] Proc. Roy. Inst. of Great Britain, vol. 17, p. 363, 1903.
Nature, vol. 18, p. 628, 1878.

by Murray[122] to be the results of chemical wastes thrown into the River Clyde.

As far as grains of manganese oxide are concerned, they occur in all terrigenous muds, as shown by analyses. Away from the deposits of manganese ore, the Franciscan cherts and shales contain only small amounts of manganese oxide, in spite of the fact that it is always present in them. The content of manganese oxide in the Red Clay, 1.21 per cent, is much higher than the content of manganese in the ordinary chert or shale of the Franciscan. The percentages of manganese oxide in radiolarian oozes are also higher than those of the Franciscan rocks.

Moreover, as far as the Franciscan cherts and shales are concerned, nothing has ever been found in them which resembles in the slightest degree the potato-shaped nodules of manganese so often brought up from abyssal depths by deep sea dredgings.

Another fact has recently been brought to light by Mr. G. C. Gester.* He has found evidence, in certain manganese deposits in the Franciscan cherts, that the original mineral was not manganese oxide, but manganese carbonate. Near the surface, the carbonate is changed into the oxide. The carbonate of manganese appears to have been originally deposited in lenses parallel to the bedding of the cherts. This discovery is opposed to the interpretation of the cherts as abyssal radiolarian oozes, for the reason that the manganese in the deep sea appears to be always in the form of manganese oxide and not in the form of the carbonate.

Red Color.—Certain facts indicate that the original color of a large part of the Franciscan cherts and shales were red—or at least that the iron was deposited in the ferric state. The only alteration of color which has been seen in the cherts, aside from changes due to intrusive action, is a change from red to green, due to leaching of waters circulating along fissures. The red color in the cherts bears no relation to the surface, and it does not seem possible that a general oxidation of the formation could have occurred. The conclusion that the color of the cherts and shales was originally red agrees well with the idea that they represent the radiolarian oozes and the red clay. The extreme fineness of grain of the red shales is also in accordance with the idea that they may represent abyssal red clay.

Chemical Composition of Shale.—If one compares the silica con-

122 "Challenger" Report.

* Personal communication, April, 1917.

tent of the Franciscan shales with the silica content of various analyzed specimens of red clay a notable difference becomes apparent. Red clay, on the average, contains between fifty and fifty-five per cent of silica. The analyses of various Franciscan shales, previously given, show that they usually contain over sixty per cent of silica. Only exceptional varieties are low in silica. The alumina in the red clay is also higher than in the Franciscan shales.

Terrigenous Minerals.—The presence of grains of quartz and rare flakes of mica in the red shales is opposed to the idea that they are the equivalents of the red clay, since these minerals are almost never found in the red clay.

Absence from Shales of Certain Things Characteristic of Red Clay.—Due to the slowness of accumulation of the red clay, it contains considerable numbers of shark's teeth, ear-bones of whales, meteoric particles, and manganese nodules. These are not found in every dredging, to be sure, but they are very common. In the considerable amounts of red shale that have been examined by the writer at many places, nothing corresponding to any of these has been encountered. The ear-bones of whales should of course be missing in a Mesozoic deposit, but no other explanation of the absence of shark's teeth, meteoric particles, and manganese nodules, seems forthcoming save that the red shale partings do not represent the red clay.

Rate of Accumulation.—Another point to be borne in mind is the extreme slowness of accumulation of the red clay, the rate being such that the teeth of sharks, extinct since Tertiary time, have not yet been buried. The statement has been made by one authority,[123] that a thickness of 500 feet would probably contain the whole accumulation of red clay in all geological time.

Assume that the average bed of chert is two inches thick, and that the shale partings will average one-quarter inch. This gives a thickness of shale equal to one-ninth of the thickness of the chert formations. The two principal formations of radiolarian chert on the San Francisco Peninsula have a thickness of 1430 feet, and on the above estimate, 160 feet of this would be red shale. Such a thickness of red clay could hardly be expected to accumulate during a portion of one geological period.

Rhythmic Bedding.—If the cherts represent radiolarian oozes and the shale partings represent beds of red clay, it is impossible to account for their rhythmic alternation. It is very improbable that in the open

[123] Lane, A. C., Science, n. s., vol. 37, p. 673, 1913.

ocean there should be any variation in sedimentation which would produce such a regular banding. No evidence has ever been discovered during the examination of many specimens of red clay and radiolarian ooze, brought up in sounding tubes, of any such rhythmic alternation of these two deposits.

Possibility that Red Shales may be Red Muds.—If the red clay be eliminated as a possibility, the only other red formation known in the deep sea, likely to be associated with radiolarian ooze, is the red mud of terrigenous origin. This is deposited off the shores of tropical lands, where conditions of oxidation predominate over those of reduction and where the amount of organic matter in the mud on the sea bottom is insufficient to reduce to sulphide form the iron oxide, brought down by the rivers. It is conceivable that in an ocean deep, close enough to shore, there might be alternations of terrigenous mud with radiolarian ooze. It is a remarkable fact that the greatest oceanic depths are comparatively near land masses. The deeps off the west coast of South America, the Aleutian Islands, the Kurile Islands and Japan, the Philippines, the Ladrone Islands, the Pelew Islands, between the Solomon Islands and New Pomerania, and to the north of New Zealand,[124] are examples in point. Agassiz[125] states that along the whole Atlantic Coast from the Bahamas to St. Thomas, the line between the continental curve and the 2000 fathom line is nowhere greater than fifteen miles distant from the shore.

In view of these facts, there is nothing contradictory in the idea of radiolarian oozes intermixed with red muds of terrigenous origin. Off the west coast of Central America, at the present time, radiolarian oozes occur in many places within 100 miles of the shore line. Here they are deposited just outside an area of blue mud, which differs from red mud only in that the state of oxidation of the iron is different. Analyses of the red muds agree more closely with the analyses of the Franciscan shale partings than do analyses of red clay, though here again the silica of red muds is lower and alumina is higher than the content of the same elements in the Franciscan shale partings.

Doctrine of Permanence of Ocean Basins.—The idea that radiolarian cherts may be deep sea deposits has an important bearing on the geological doctrine of the permanence of ocean basins. This doctrine is based, in part, upon the idea expressed by Murray and others, that nothing is known in the continents which can be regarded as the equivalent of the abyssal deposits. In so far as it is based on this

124 Murray and Hjort, The Depths of the Ocean, p. 137, London, 1912.

125 *Op. cit.*, vol. 1, p. 143.

idea, the doctrine of permanence of ocean basins cannot be used as an argument against the abyssal origin of the radiolarian cherts. In so far as it is based on independent considerations, such as conceptions of isostatic balance, it may make us cautious about accepting the idea of the abyssal origin of radiolarian cherts. As Chamberlin[126] has shown, most of the deposits which are suspected to have an abyssal origin are in such geographical locations that their interpretation as abyssal deposits need not come into conflict with any hypothesis of permanency of ocean basins. Most of the occurrences of such rocks are near the margins of continents, and one may think of them as situated on blocks of the earth's crust intermediate between well defined oceanic blocks and well defined continental masses. It would then be possible to regard them as carried down at one time by the relative subsidence of the ocean block, and again at a later time, raised with the continental mass. We might then believe, that while the cherts were abyssal, they were still laid down near land and partly within the zone of terrigenous deposition. The occurrences of the radiolarian rocks in England, Scotland, Barbados, Solomon Islands, New Zealand, Australia, Borneo and the Malay Peninsula and Archipelago, California Coast Ranges and Alaska, satisfy this requirement. The occurrence of identical cherts in the Urals, in the Alps, in the Sierra Nevada of California, and in the Peshastin formation in the state of Washington, causes the conception of permanence of ocean basins and the interpretation of radiolarian cherts as abyssal deposits, to come into decided conflict. Even in the absence of much evidence of a positive nature against the idea of abyssal deposition, one would feel hesitant about ascribing to the cherts a deep sea origin.

Significance of Carbon.—The presence of carbon, in certain shales interbedded with the Franciscan cherts, has been alluded to. The radiolarian cherts of the Malay Peninsula also contain considerable carbon and carbon is reported in many other occurrences. The presence of carbon has been cited by Scrivenor as evidence of shallow water deposition. It does not seem to the writer that this criterion is valid. On the suggestion made above—deposition in deep water not far from shore—conditions would be favorable for the inclusion of considerable carbon in the deposits. Agassiz[127] dredged up leaves, bamboo, sugar cane, and similar material from the ocean bottom in water 1000 fathoms deep, at a distance of ten miles from certain

[126] Chamberlin, T. C., Diastrophism and the Formative Processes. V, The Testimony of the Deep-Sea Deposits, Jour. Geol., vol. 22, p. 131, 1914.

[127] *Op. cit.*, vol. 1, p. 291.

islands in the Caribbean Sea. In other dredgings made off the west coast of Central America, and in the Gulf of Lower California, it was found that there was considerable vegetable matter in the muds accumulated in deep water.[128] Some of the specimens dredged by the "Challenger" from very deep water in the Celebes Sea, contained numerous fragments of wood. The presence of carbon is then simply a matter of distance from shore and distribution of ocean currents, and cannot be used as a criterion of the depth of water in which the sediments containing it were deposited.

Association of Cherts with Sandstones.—The Franciscan sandstone is a medium, coarse grained sandstone which appears to be, in large part, of continental origin.[129] None of it was laid down very far below sea level. In the neighborhood of San Francisco, there are two formations of radiolarian chert which divide the sandstone into three formations. If we regard the cherts as abyssal radiolarian oozes, like those of the present day, we must believe that the region sank from sea level to a depth of from 12,000 to 15,000 feet, and that this tremendous displacement occurred twice within Franciscan time, with two reversals of movement.

Nature of Sandstone-Chert Contacts.—Another fact which is opposed to the idea that the radiolarian cherts were laid down in the deep sea, far from shore, is the nature of the contacts of chert and sandstone. Even if we can accept the idea of two great displacements of the region during Franciscan time, we cannot think that such great depressions occurred suddenly. They must have gone on gradually, if at all, during a long period of time. During a time of gradual submergence, the nature of the sediments should change, passing from sandstone to shale and then from typical terrigenous material to material richer in lime carbonate until limestones accumulated, and at last sufficient depth was reached for the accumulation of siliceous oozes. Instead of such a change in sedimentation we find nothing approaching it. There is a transition at some contacts but it takes place within a very few feet or a few inches. No deposits of lime carbonate are known at any of the contacts between chert and sandstone. The nature of these contacts is absolutely opposed to the idea of the abyssal accumulation of the cherts.

Occurrence of Cherts in Lenses.—On the hypothesis that the cherts represent radiolarian oozes of abyssal origin, it is impossible

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[128] Bull. Mus. Comp. Zool., vol. 14, p. 291, 1888.

[129] Davis, E. F., The Franciscan Sandstone, Univ. Calif. Publ., Bull. Dept. Geol., vol. 11, pp. 1–44, 1918.

to account for the presence of lenses of chert within a sandstone which could not have been deposited far below sea level.

Possibilities which might reconcile the hypothesis of abyssal origin with the known facts.—In the case of the Franciscan cherts it might be possible to explain the alternation of the two main horizons of chert with coarse sandstone without involving extreme movements of the earth's crust. One might imagine a land mass somewhere to the east of the present Great Valley of California. Another mountain range with granitic rocks exposed to erosion is postulated on the site of the present Coast Ranges, or standing a little to the west of them. From the western mountain mass, it is conceivable that there might be a rapid depression toward the present site of the Great Valley, so that a narrow body of water of considerable depth existed there. From the Coast Range mountains, coarse sediments would be carried down into the deep water near the west side of the present valley. Then, during fluctuations of the level of the Coast Range province, which appears to have always been geologically unstable, there might have been times when the Coast Range was submerged. During these times no terrigenous sediment would reach the basin of accumulation save fine materials carried out from the land mass to the east. It might be possible in such a depression to get alternations of red shale with radiolarian ooze, during times of Coast Range submergence. At a later time the uplift of the region would cause a renewal of coarse sedimentation and the radiolarian oozes would be covered by sandstone.

Another possibility is that there was a large river carrying material and dropping it into an ocean deep not far from land. This river might have built up a delta in the shallower water near shore. Rivers change on their deltas, and occasionally these changes are very great, as for example the changes of the Hoang Ho River in China.[130] During the time of diversion of the river, there would result an accumulation of non-terrigenous sediment in the deeper parts of the basin. In this way it would be possible to get notable alternations in the character of the sediment without any great changes in the level of the land or in the relations of land and sea.

Opposed to both these explanations of the alternation of sandstone with cherts, is the evidence which goes to prove that the typical Franciscan sandstone is a continental deposit. If this is correct it would require that the region undergo an absolute change of level of at least

[130] Tarr and Martin, College Physiography, p. 160, New York, 1914.

12,000 feet before radiolarian oozes would accumulate on the continental deposits. As already pointed out, the twofold repetition of this movement with a twofold reversal during one geological period seems improbable. Also the nature of the contacts of chert and sandstone are not what might be expected on this hypothesis.

If the Franciscan sandstone were marine it might be possible to clear up the anomaly of the association of coarse sandstones with cherts by postulating some such condition as those suggested.

The occurrence of chert in lenses, however, could not be explained in this way.

Interbedding of Cherts with Coarse Mechanical Sediments.—Evidence that radiolarian cherts may be deposited in rather shallow water is found in the Ordivician cherts of Scotland, where there is a very close association of cherts with coarse arkose sandstones. In some instances sandstones are actually interbedded with thin beds of chert. In passing it may be remarked that a similar argument applies to the Monterey cherts, since their interbanding with sandstones is often very marked.

Ripple Marks.—That radiolarian rocks may accumulate in shallow water is also shown by the occurrence of radiolarian mudstones and associated radiolarian cherts in Australia. There the mudstones in certain localities show ripple marks. The radiolarian novaculites of Texas also show markings which have been interpreted as ripple marks.

Conclusion.—When all the facts regarding the Franciscan cherts and identical rocks elsewhere are considered, the only possible conclusion appears to be that the cherts did not accumulate as abyssal sediments.

HYPOTHESIS OF LAGOON DEPOSITION

Dixon and Vaughan in describing the radiolarian cherts of Gower advance the hypothesis of lagoon deposition, certain details of which are set out above.

The Lagoon Phase.—Dixon and Vaughan believe that the presence of the remains of pelagic organisms is not proof of a deep sea origin. They postulate some sort of barrier between the basin of deposition and the source of sediment. In the region thus screened from land contributions pelagic sediments are formed. They find it necessary to postulate a barrier between the open ocean and the lagoon in order to prevent the scouring of the deposit by strong tidal currents and its exposure to air during times of low tide. They believe this was effected by a barrier of vegetation on the outer rim of the lagoon.

Beside the difficulty of maintaining such a peculiar arrangement of land and sea, it is difficult to see why vegetation does not ultimately possess the whole area of shallow water. Fresh water coming into the basin, also, should render it brackish in the absence of free communication with the sea, and thus prevent the growth of radiolaria. Of course, the presence of a land barrier might deflect all the streams save the very small ones whose contribution would be compensated by evaporation. In the special case of the Franciscan the arid conditions suggested by the character of the sandstone would obviate the latter objection.[131]

Absence of Calcareous Organisms.—The absence of calcareous organisms is hard to understand on any theory of deposition of radiolarian oozes in shallow water. In all places in the present ocean where the water is clear and free from mechanical sediment, there are great numbers of lime secreting organisms. They make up the bottom deposits in such clear water, save where the depths are so great that the shells are dissolved. In all other cases, the calcareous organisms are so abundant that they mask the accumulation of the siliceous organisms.

We have, then, a strange contradiction: the radiolarian cherts of the Franciscan and also the radiolarian cherts in many other localities, by reason of their association with rather coarse mechanical sediments, appear certainly to have been deposited in shallow water; yet such conditions of shallow water, with freedom from mechanical sedimentation, are the ideal conditions for the accumulation of deposits of carbonate of lime.

Variation in Ocean Waters.—Dixon and Vaughan are aware of this difficulty in their hypothesis and attempt to explain it by suggesting temperature differences and chemical differences in the water of the sea during the deposition of the cherts.

It hardly seems possible that the temperature and chemical composition of the sea could alternate with the rapidity necessary on this hypothesis to explain the accumulation of a few feet of radiolarian ooze. In the beds above and below the cherts of Gower there are considerable numbers of ordinary calcareous fossils.

Enclosed Basins. Tropical Weathering.—Scrivenor presents an

[131] Davis, *op. cit.*

hypothesis of local variation in the composition of the water of an enclosed basin. Under conditions of tropical weathering, large amounts of silica are brought down to the sea by rivers. He believes that the waters of closed basins in the tropics might become highly charged with silica and thus favor the growth of radiolaria but not of calcareous organisms. They might become so changed as to prevent the growth of calcareous organisms altogether. As Clarke has pointed out, the waters of tropical rivers are high in silica in proportion to the other salts which they contain. Waters coming from granitic areas are high in silica and low in lime and magnesia. By the combination of a granitic area and tropical weathering one might expect large contributions of silica to the waters of the ocean, and if there were enclosed basins, notable chemical changes might be brought about. However, it seems certain, from the character of the sandstone, that Franciscan time was not characterized by humid tropical weathering.

Solution of Calcareous Remains in Shallow Water.—It is known that in deposits of calcium carbonate the remains of siliceous organisms tend to go into solution, probably because of the alkaline reaction of the water above such an ooze. This suggests the possibility that where siliceous remains are abundant there might be some cause at work, tending to dissolve calcareous organisms and prevent their accumulation with those of siliceous organisms, even though the water was not deep. However, no reaction can be imagined, which would do this. It seems extremely unlikely also because of the occurrence, in the cherts and diatomaceous shales of the Monterey, of great numbers of foraminiferal shells.

Change in Habits of Life.—Another possibility is that the habits of life of the calcareous organisms were different at the time of deposition of the chert. Jukes-Brown[132] says:

> It is also clear that it must be unsafe to draw conclusions as to the conditions under which any Paleozoic deposit was formed by assuming that the organisms whose fossil remains it contains had the same habits of life as their modern representatives.

Hill,[133] also, has discussed this question of the association of radiolarian rocks with rather coarse sediments, or with terrigenous muds, and the difficulty of accounting for the absence of calcareous organisms. He states that it was only in Tertiary time that deposits of cal-

[132] Jukes-Brown, A. J., Building of the British Isles, p. 12, London, 1911.

[133] Rocks containing Radiolaria, Proc. Geol. Assoc., vol. 23, p. 90, 1912.

careous ooze, like the foraminiferal oozes of today, were produced, and suggests that in earlier times the foraminifera were not as abundant in the open ocean as they are today. While at present it would be impossible to get a pure radiolarian ooze in shallow water, even at a distance from land, Hill believes that in pre-Tertiary time foraminifera were not adapted to life in the open ocean, while radiolaria could thrive there.

If this idea should find acceptance it would be possible to understand how the older deposits could contain fossil radiolarian oozes laid down in comparatively shallow water. However, the chalk of England is of Cretaceous age. It would seem also that the immense thicknesses of Paleozoic limestones owed their existence to some organic deposition, probably being largely foraminiferal. Also there is little in the hypothesis to interfere with the development of calcareous oozes in lagoons near shore, and it is hard to see why they would not form in association with radiolarian oozes in such places.

Possible Change in Rate of Solution of Calcareous Shells.—It might also be possible that present day conditions of solution of calcareous deposits were not duplicated in Franciscan time. As Chamberlin[134] has pointed out, the present temperatures, salinities, and gas content of the ocean water are largely due to the recent glacial period. The present conditions are in large part the result of absorption of gases and the circulation caused by the sinking of colder water at the poles. Possibly some change in general conditions of circulation in past time would permit the disintegration of calcareous remains at shallower depths than is now possible.

Significance of Franciscan Foraminiferal Limestone.—We have, however, a very effective check on all these ideas in the presence of a foraminiferal limestone laid down in Franciscan time. The Franciscan foraminiferal limestone shows the same relations to the sandstone as the radiolarian cherts. Its presence indicates that ideas of different habits of foraminifera, or of markedly different conditions of temperature, or chemical composition of the ocean as a whole are not applicable to the case of the Franciscan cherts. By analogy, such ideas are probably inapplicable to similar radiolarian cherts elsewhere. It then becomes exceedingly difficult to see how a true radiolarian ooze could be formed under the moderately shallow water which prevailed in the Franciscan basin of deposition. In shallow water, with freedom from mechanical sedimentation, it seems that the accumula-

134 Jour. Geol., vol. 24, p. 363, 1916.

tion of radiolarian ooze would be masked by the accumulation of calcareous organisms. It is not possible at the present time to get a radiolarian ooze at moderate or shallow depths, and it appears that it was not possible in Franciscan time.

RADIOLARIAN CHERTS NOT RADIOLARIAN OOZES

While the fineness of grain, the color, and the characteristic fossils of these rocks are in accord with their interpretation as radiolarian oozes, there are certain facts which are strongly opposed to this idea.

Presence of Excess Silica in Matrix.—The principal objection to the interpretation of the cherts as radiolarian oozes is based on the study of thin sections. The cherts contain much more silica than can be accounted for by the radiolarian skeletons which are now present in them.

A similar fact with regard to the cherts in New South Wales has already been mentioned. It was noted there that the radiolarian claystones contained as many radiolaria as the flinty cherts which were associated with them. Yet the silica content of the cherts was considerably higher than that of the claystones.

In the microscopic descriptions of many radiolarian cherts from other parts of the world, frequent reference is made to the presence of a siliceous matrix in which the radiolaria are embedded.

If the original material consisted entirely of the skeletons of radiolaria, it would not, without extensive alteration, have produced such a rock as chert. Even if the skeletons were so numerous that they were closely packed together they could not give enough silica to produce chert. The skeletons are not solid but consist of a delicate, open lattice work surrounding a central chamber. Such an ooze would give a porous, slightly consolidated rock like the radiolarian earths of Barbados, or similar in texture to the diatomaceous earths of the Monterey group in California. It is certain that a radiolarian ooze would not give rise to a chert until there had been a considerable amount of reworking of the silicic acid in the original skeletons. This alteration might have taken place in various ways. It may have occurred: (1) In the ooze on the sea bottom before consolidation; (*a*) by the solvent action of sea water; (*b*) by the solvent action of organic acids produced in the decomposition of organic matter; (2) after the radiolarian ooze had been consolidated into a rock like the Barbados radiolarian earth.

Possible Changes in Ooze.—The solvent effect of sea water under pressure was suggested by Professor Lawson as a possible mode of change. In the deep sea the pressure may so increase the solvent power of water as to dissolve radiolarian skeletons and reprecipitate the silica in the gelatinous form. This idea meets with the objection that the Franciscan cherts by their intimate association with the Franciscan sandstone, must have been deposited in shallow water. Similar objections would meet the application of this idea to other occurrences of radiolarian chert.

One might imagine, also, that a change occurs in the siliceous oozes on the sea bottom, analogous to that observed in certain foraminiferal oozes. In the dredging and sampling of bottom deposits it is found that the upper layers of foraminiferal oozes are made up of unbroken shells of foraminifera, but in the deeper layers there remain only the coarser and more resistant fossils in a fine paste composed of broken and disintegrated shells. In this way there finally results a rock which is all organic, but in which there are preserved only a few fossil forms.

However, it does not seem permissible to argue from analogy with limestone. In the limestone the fossils preserved are those of the coarser and heavier shells, which are able to resist solution. In the radiolarian oozes there are not such differences in the organisms. They are all much alike and there is no apparent reason why one skeleton should be preserved in preference to another. Yet the chert contains excellently preserved skeletons embedded in a matrix which shows no sign of organic derivation.

Another idea is due to Julien,[135] who believes that organic matter, in its decomposition, gives rise to complex organic compounds which possess the property of dissolving the skeletons of siliceous organisms. These substances combine with the silica, in the process of decomposition, forming compounds of silica with organic acids. On oxidation, silica is liberated from these compounds in the gelatinous condition. This hypothesis is opposed by the red color of the cherts and shales, which indicates oxiding conditions during their deposition, and the absence of any large quantity of decaying organic matter.

The fact that the white diatomaceous earths of the Monterey group are almost unconsolidated and show no evidence of solution would indicate that such action of organic material was not very powerful.

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135 Julien, A. A., On the Geological Action of the Humus Acids, Proc. Am. Assoc. Adv. Sci., vol. 28, p. 311, 1879.

These diatomaceous earths must certainly have been associated with much organic matter, at the time of their deposition. We cannot escape this conclusion by regarding the white diatomaceous earths as accumulations on the ocean bottom under oxidizing conditions and believing that when the bottom was stagnant the action of organic acids gave rise to the solution of silica, producing cherts. This is shown by the existence of foraminiferal shells in the Monterey *cherts.* In the presence of acids produced by decaying organic matter these shells should have been broken down.

Evidence against Ideas of Change on Sea Floor.—There is no evidence of such changes in present radiolarian oozes. Murray states that the delicate structures of some radiolaria are apparently reduced by some solvent action of the sea water, but it does not appear to produce modifications of any importance in the nature of the radiolarian oozes.

We have another excellent check on both the foregoing ideas that silica in radiolarian oozes may be dissolved on the sea bottom with the resulting formation of cherty rocks. The radiolarian earths of Barbados appear, from their lithologic nature and their stratigraphic relations to other formations of peculiar types, to represent true radiolarian oozes. This interpretation of their origin is generally accepted. Yet in these earths, there is no evidence, aside from the presence of an occasional cherty nodule, of the formation of any cherty silica like that which makes up the radiolarian cherts. It would appear, therefore, that there was no solution of silica on the sea bottom either under the action of pressure, decaying organic matter or similar causes, which was competent to alter radiolarian oozes into radiolarian cherts.

Possibility of the Alteration of a Radiolarian Earth to a Chert.—A radiolarian earth like that of Barbados may have been produced by the partial consolidation of a radiolarian ooze. After its formation, such a rock may have been subjected to pressure and to the slow circulation of water through its numerous openings. During a long period of time silica would be dissolved continuously, in accordance with the Riecke principle, from the points of contact of the skeletons, and deposited in the open spaces. Ultimately, through this process the whole rock would become a solid mass. During this change it would undergo a considerable degree of crystallization and a shrinkage in volume. Ideas such as this and those previously suggested appear to have been held by Fairbanks, who thought that the whole of the silica of these cherts was derived from radiolarian skeletons, and regarded them as the equivalents of radiolarian oozes. He says:[136]

> I have found every gradation in the specimens from those in which the radiolaria are distinctly marked, as Professor Lawson says, to those in which they are only faintly distinguishable from the matrix, or apparently absent. In my opinion this state of things gives good ground for the view that, owing to possible transformations through the action of sea water, and the secondary changes which are known to have taken place, there is no valid reason for denying the organic origin even when no organic remains are distinguishable.

Evidence opposed to the Idea that Matrix was derived from Radiolaria.—One who holds that the cherts are radiolarian oozes, altered on the sea floor, or changed after a partial consolidation, must regard the radiolaria that are now present in these rocks as survivors of a once very much larger number which made up the radiolarian ooze. He must believe that the greater proportion of the silica has been reworked by the actions above set out, until it is now found in the matrix.

There are cherts, which seen in thin section, might be taken as supporting the above contentions, provided such cherts existed alone. In them, one can see large numbers of radiolarian skeletons, among which there appear to be all transitions between radiolaria in a fair state of preservation, down to irregular areas of clear silica which are apparently fusing with the matrix of the rock.

There are, however, numerous other sections in which the radiolaria are not so abundant, but in which they are in an excellent state of preservation, and the apparent gradation to imperfect and much altered forms is not observable (plate 30A, B, C, and E). If one regards the matrix as due to reworking of the silica originally contained in the skeletons of the radiolaria, he is at a loss to account for the good preservation of the very few surviving forms, since they do not appear to be of any more resistant types than some which, in other rocks, are partially obliterated.

Moreover, some of the beds in a given outcrop will show numerous radiolaria, apparently being crowded with them. Other beds in the same section show only a few radiolaria in a matrix of red silica. Such differences can hardly be ascribed to anything other than to variations in original deposition. At one time there may have been more radiolaria in the surface waters than at another, or else there may have been a variation in the silica contributed from some inorganic

[136] Jour. Geol., vol. 5, p. 66, 1897.

source. It is hardly possible that beds so much alike and within a few feet of one another should have undergone such radical differences in crystallization of the original silica, either in an ooze on the sea floor, or in the later alteration of the rocks.

Evidence is also found in the fact that different portions of the same bed, or different portions of the same hand specimen, or even of the same thin section, show different numbers of radiolaria. One specimen, of red siliceous chert, in the possession of the writer brings out this fact in a striking way. The specimen shows three zones running parallel to the bedding. The upper zone is characterized by a large number of radiolarian skeletons, which is also true of the lower zone. Through the center of the specimen there runs another zone, that, though in other respects exactly like the upper and lower zones, contains only a very few radiolaria. Such differences cannot be due to difference in the degree of crystallization and reworking which has affected the rock. Similar specimens are common, and they indicate that the proportion of radiolaria to the total amount of silica accumulating, varied from time to time during the deposition.

A similar, banded distribution of radiolaria was noted in a thin section of a *kieselschiefer* from Lautenthal in the Harz Mountains. In this thin section there are two bands. One band contains numerous radiolaria, showing a few of the details of the outlines and the spines. These are represented by areas of clear silica, which between crossed nicols are seen to be made up of spherules of radiating fibers of chalcedony, or of cryptocrystalline silica. These organisms are embedded in a matrix of dark silica which appears in large part to be non-polarizing, with here and there a spot of light. The other band shows no radiolaria. It consists of silica clouded in a streaky manner by masses of pigment. This band is almost wholly composed of non-polarizing silica. Between crossed nicols, with the gypsum plate, no reaction can be observed, as the stage is turned, save in a few isolated patches which appear to have undergone crystallization.

Possibility that Matrix may be Derived from other Organisms.—If we abandon the idea that all the silica in the cherts was originally in the form of radiolarian skeletons, we may have yet another possibility. We may regard the cherts as originally a mixed ooze, containing other organisms than radiolaria. It may be possible, for example, that some part of the silica was originally in the form of diatoms. It is well known that some radiolarian oozes in the neighborhood of the Philippines contain such a large proportion of diatoms that they were at first called diatomaceous oozes. Diatoms possess a finer and much more delicate structure than do the radiolaria. In solution or metamorphism these more delicate structures would tend to alter first so that it is possible that they might entirely disappear from a rock in which the radiolarians were still fairly well preserved. It might be possible to regard the cherts as radiolarian oozes and explain all the peculiarities of the preservation of radiolarian skeletons and their relation to the siliceous matrix of the rock by this means.

This seems to have been first put forward as a suggestion by Hinde,[137] who wrote:

> No other microscopic organisms besides radiolaria can be seen in the Angel Island or in the Buri-buri beds. It is quite possible that diatoms may have been intermingled with radiolaria in these deposits, but the fossilization, which has been sufficient to obliterate most of the radiolarian structure, would completely destroy all traces of the smaller and more delicate diatoms.

Crandall[138] later made a more definite statement regarding this possibility:

> There is another possible origin for the large beds of jaspers in the Franciscan series and this is suggested by similar beds in later deposits. The siliceous Miocene shales resemble very closely the jasper beds under discussion except that they do not show so much folding and distortion. These Miocene shales are diatomaceous, deep sea deposits, altered since the time of their deposition. It is reasonable to assume that the older jasper beds may have been formed similarly to those of the Miocene age whose origin is known.
>
> The fact that remains of diatoms do not show in slides of the jaspers does not prove that they were not there originally. These jaspers are mostly amorphous silica and must have passed through a stage of solution and re-disposition from their original form so that all traces of diatoms might easily be lost.
>
> This hypothesis is worthy of consideration because of the large deposits of siliceous shale that we have in California; and it is more reasonable to consider the older jaspers formed after the same method of later shales, than to assume a different set of conditions and different organisms to have existed without any definite proof. The presence of radiolaria does not affect this either way, because small amounts of any organism might be present with the diatoms and have their skeletons preserved.

An objection to this last hypothesis, though it certainly is not a very serious one, is found in the fact that in none of the slides of Franciscan chert has anything resembling a diatom been found. It might be expected that occasionally some diatom would escape complete obliteration.

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137 Univ. of Calif. Publ., Bull. Dept. Geol., vol. 1, p. 238, 1894.

138 The Geology of the San Francisco Peninsula, Proc. Am. Philos. Soc., vol. 46, p. 46, 1907.

Another objection to the idea is based on the nature of the Barbados earths. Here diatoms are found in considerable amounts in the radiolarian earths, and they appear not to have been greatly changed. This, however, may be explained as due to the Tertiary age of these beds and the fact that they have not been subjected to as many changes as have the older rocks.

Another objection to all hypotheses of this type is found in the cherts of the Monterey. These show, as pointed out in detail previously, no evidence of having been derived from diatomaceous earths, and they appear to have been formed by the precipitation of gelatinous silica. The Monterey cherts are independent in origin from the diatomaceous earths which are associated with them.

Other Sources of Silica of Matrix.—Still other possibilities have been suggested for the source of the excess silica. It may be possible that the silica was derived from sponge spicules or volcanic glass present with the radiolaria. No evidence can be presented in favor of the idea that any of these were the source of the excess silica. The sponge spicules would not be very easily altered and would be as likely to be preserved as the radiolaria. It does not seem probable that volcanic glass could be so completely altered that it would not somewhere leave evidence of its presence in the cherts. Small amounts of it, which have been little altered, are found in some of the red shales.

Possible Differences in Radiolaria.—So far in the discussion, it has been assumed that radiolaria were all alike in their power of resistance to alteration. Some radiolaria possess skeletons consisting of pure silica; others possess skeletons composed of chitinous material; and still others possess skeletons partly of chitinous material and partly of silica. It may be that the skeletons which are in part chitinous are easily decomposed by bacterial action, leaving the silica which they contain in a very finely divided condition. This finely divided silica, organic in its source, might form a paste in which siliceous skeletons were embedded. On consolidation this would give a matrix showing no organic structure. This explanation of the matrix would clear up many of the difficulties and still permit us to regard the cherts as entirely of organic origin. It is opposed, however, by certain facts regarding the bedding, which will be pointed out later.

Hypothesis of Later Silicification.—Another possibility is that the cherts are really radiolarian oozes which have been changed into cherts by the introduction of silica at some later time. Absolutely no evidence in favor of this view was observed anywhere. By analogy with the Monterey cherts this explanation is not admissible; many of the arguments which oppose the hypothesis of later silicification of those cherts hold good for the Franciscan cherts. The hypothesis is opposed entirely to certain facts regarding the bedding of the cherts.

Rhythmic Bedding not known in Present Siliceous Oozes.—One fact which opposes the idea that the cherts are radiolarian oozes or mixed oozes is the regular rhythmic bedding. There is nothing known from the records of investigations of marine deposits which corresponds to the peculiar rhythmic bedding of the Monterey and Franciscan cherts. There are a few instances of alternation of diverse types of deep sea sediments, but the radiolarian oozes and diatomaceous oozes never show any regular alternation with shaly material in the manner now to be found in the radiolarian cherts. It seems certain that if radiolarian oozes ever showed such a regular alternation it would have been detected in the core samples taken from bottom deposits.

The minor irregularities of bedding, such as the occurrence of bands of nodules, and short irregular lenses, of the sort previously described and shown in photographs, are incomprehensible on the idea that the cherts are radiolarian oozes. Such deposits of skeletons of pelagic organisms should be in wide spread sheets covering wide areas of the ocean floor.

There is, however, the possibility of segregation of some sort in the radiolarian ooze on the sea bottom, so that, before the consolidation of the material, the radiolarian skeletons were separated in large part from the shaly constituents of the ooze. This segregation might conceivably be in a regular manner and result in the rhythmic bedding now seen. While this is a bare possibility, facts are known which render it very improbable. The lower portions of the cores brought up in sounding tubes from the radiolarian oozes, occasionally show a slight amount of lamination, but nothing comparable with the regular alternation of chert and shale is seen. Moreover, the core samples show that the deposit, a few inches below the surface has already progressed far toward a consolidated condition. This fact renders it impossible to believe in such a segregation in *radiolarian oozes* as has been suggested.

The Barbados earth also gives information on this question. Here we have a deposit which represents a radiolarian ooze, and is the only undisputed occurrence of such material. The Barbados earth shows a certain slight lamination, but does not show any trace of rhythmic alternations of chert and shale. Evidently radiolarian oozes and rocks formed from them do not show a bedding like the radiolarian cherts.

Occurrence of Chert in Lenslike Bodies.—The occurrence of isolated bodies of chert, in the midst of the sandstone, is extremely difficult to reconcile with an idea that the cherts are radiolarian oozes. If they are, no reason appears for the swarming of radiolaria in such localized areas, save that of a local and limited supply of silica. The only possibility which occurs here is to be found in some hypothesis of siliceous springs.

Conclusion.—In view of the various lines of evidence presented and the peculiarities of the radiolarian cherts, it seems certain that the cherts are not the equivalents of radiolarian oozes or of mixed oozes of diatoms with radiolaria. One is forced to the conclusion that a considerable part of the silica of the cherts has some other source than the skeletons of radiolaria, probably being organic, while *the radiolaria are simply incidental fossils,* caught in a deposit of silica which was gelatinous at the time of their inclusion.

Evidence that a Portion of the Silica of the Radiolarian Cherts was Chemically Precipitated

It does not seem probable that the radiolarian cherts represent pure radiolarian or mixed organic oozes containing radiolaria. The occurrence of chert in lenses and nodules is more in agreement with their interpretation as chemical precipitates of some sort.

The general appearance of fresh, unaltered chert is in accord with the idea that a considerable part of the silica was once in the gelatinous condition. The smooth, conchoidal fracture, waxy luster and lack of grain are characteristic of substances which are believed to be colloidal in origin.

The fact that the cherts consist largely of chalcedony is also in favor of the idea that they were originally in the condition of gelatinous silica. Lindgren[139] says:

> The work of Hein, Leitmeyer and others leads to the conclusion that chalcedony is in all cases composed of quartz fibers and that it always results from the crystallization of gelatinous silica either "in statu nascendi" or at a later time, and that gelatinous silica may in becoming crystalline either turn into granular quartz or into fibrous quartz, *i.e.,* chalcedony.

139 Lindgren, W., Processes of Mineralizations and Enrichment in the Tintic Mining District, Econ. Geol., vol. 10, p. 233, 1915.

Possibly caution is necessary in the application of this particular criterion to the Franciscan cherts, since it is found that in certain cherts at igneous contacts there has been a crystallization of fibrous chalcedony, giving rise to spherulitic cherts. It seems probable, however, that in these cases the silica was in the amorphous condition at the time of intrusion of the igneous rocks.

That a large part of the silica of the cherts was originally in the gelatinous form is shown by the gradation in crystallization of the matrix. This was first pointed out by Professor Lawson. The Franciscan cherts show all gradations between rocks whose matrix is now composed of amorphous silica and those whose matrix is now all chalcedonic silica. These represent various stages in the crystallization of originally amorphous silica.

Hypotheses of Chemical Precipitation

Certain hypotheses have been, or might be, advanced which regard the silica of the cherts as a chemical precipitate, and look upon the radiolarian skeletons as merely incidental to the accumulation of this inorganic silica.

HYPOTHESIS THAT THE SILICA OF THE CHERTS IS DERIVED FROM RIVER WATERS AND PRECIPITATED BY CHEMICAL PROCESSES

It may be possible that the silica which comprises the cherts is derived from river water coming down into the basin of deposition, precipitating its silica upon mixing with the saline waters of the ocean. The hypothesis is somewhat similar to one suggested by R. A. Daly[140] for the jaspers of the Lake Superior District:

> Leibig states that the same alkaline carbonate lessens the solubility of colloidal silica in water. It is also a familiar fact that this carbonate precipitates most of the silica from solutions of water glasses, silicate of sodium, silicate of potassium, etc., substances which are present in river waters. The suggestion lies near that we may have here a partial explanation of the puzzling cherts and jaspers so specially associated with the Lake Superior ores. In this view they are due to the throwing down of silica from river-waters relatively rich in dissolved silica or silicates.

Lack of Silica in Ocean Water.—The hypothesis of precipitation of silica by ocean water is based upon two facts, the presence of silica

[140] The Limeless Ocean of Pre-Cambrian Time, Am. Jour. Sci., vol. 173, p. 93, 1907.

in river waters, and its almost complete absence in ocean water. All rivers contain dissolved silica. The absolute amount carried by them depends upon the climate and general nature of the rocks exposed in their hydrographic basin, so that it is variable for different rivers. Important amounts of silica are thus carried to the ocean by rivers, but the waters of the ocean contain only very minute amounts of silica. As shown by Murray and Irvine,[141] the amounts are so small that it is improbable that siliceous organisms are able to obtain their silica from the dissolved silica of the ocean.

Murray and Irvine showed that in *filtered* sea water the quantity of silica in solution was extremely small, ranging from one part in 220,000 to one part in 460,000. E. Raben obtained results which were lower than these. He found that the ocean contained somewhat varying amounts of dissolved silica which ranged from 0.2 milligrams to .4 milligrams per liter. Ordinary sea water seldom contains more than one or two parts of dissolved silicic acid per million. It is apparent that the silica which is brought down to the ocean by rivers must be eliminated in some way, since it does not accumulate in the ocean. It may be precipitated by the intervention of organisms, or by some chemical process. The statement is often made that this silica is precipitated through the intervention of siliceous organisms, but there is evidence that the inorganic methods are important.

Source of Silica of Siliceous Organisms.—Murray and Irvine show that, with the extremely minute quantities of silica present in sea-water, it is improbable that siliceous organisms would be able to pass through their bodies enough sea water to supply them with the amount of silica necessary to build their skeletons. They suggest that these organisms derive their silica by some process of decomposition of clay. While the greater part of the suspended colloidal clay of rivers is precipitated upon coming into the ocean, by the flocculating power of the dissolved salts, there is a considerable amount of clay in suspension even at great distances from the land and in waters of high salinity. Sea water may contain as much as 2000 tons of clay per cubic mile. Sea water contains about 17,000 tons of soluble silica per cubic mile, an amount considerably greater than the suspended clay, but the clay occurs in discrete particles, and it is possible in this way for an organism to obtain, at one time, a comparatively large supply of silica. It would be impossible for an organism to pass enough water through its body to get the same amount of silica.

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141 Murray and Irvine, On Silica and the Siliceous Remains of Organisms in Modern Seas, Proc. Roy. Soc. Edin., vol. 18, p. 229, 1891.

These writers show conclusively that diatoms obtain their silica from clay. Experiments indicate that diatoms are able to live in water free from dissolved silica, which contains suspended clay. When diatoms are placed in water absolutely free from suspended clay particles but containing dissolved silica, they do not appear to be in a healthy condition, but as soon as clay in suspension is introduced, the same diatoms become quite vigorous. It would appear probable that radiolaria also obtain their silica from clay particles. Murray and Irvine suggest that sponges derive their silica from the clay in the sea bottom in which they are growing.

The experimental work of Murray and Irvine would then indicate that organisms do not play an important part in the precipitation of the silica of ocean water.

The general distribution of organisms in the ocean points to the same thing. In the open oceans there is an abundance of these siliceous organisms, yet here there is very little silica. If organisms precipitated the silica brought down by rivers there should be a swarming of these organisms near the points where the large rivers come into the ocean, instead of in the open ocean where there is so little silica.

Coagulation of Colloidal Silica.—It is a well known fact that electrolytes tend to cause the coagulation of colloids and their consequent precipitation from solution. It is therefore possible that when the river waters containing colloidal silica or colloidal alkaline silicates come into the sea water, which is rich in strong electrolytes, that there should be a precipitation of the silicic acid. This would be an important source of silica, provided some mechanism existed capable of concentrating it into definite areas of sedimentation.

Quantitative Importance of Silica of Rivers.—Quantitatively, the amount of silica, which might be thus precipitated, is important. Clarke, in the *Data of Geochemistry,* gives the results of calculations on amounts of material brought to the ocean by rivers. He finds that 319,170,000 metric tons of silicic acid are brought down into the ocean each year by all the rivers of the world. This amount of silica is completely precipitated, since there is no accumulation of silica in the ocean.

Considering the amount of calcium which is precipitated annually, the results of the calculations vary somewhat with the period which is assumed for the age of the ocean. If an age of 100,000,000 years be taken, then the amount of calcium which is precipitated annually would be 552,142,000 metric tons; if the age of the ocean be 50,000,000 years, then the amount which is precipitated annually is 546,614,000 metric tons. Taking the larger figure as correct and assuming that all the calcium is precipitated in the form of calcium carbonate, then 552,142,000 metric tons of calcium would yield in round numbers 1,362,000,000 metric tons of calcium carbonate. This means that if all the silica could be precipitated in the form of chert and all the calcium in the form of limestones, that cherts would be about one-quarter as abundant as limestones. While a portion of the silica may come down in the form of potassium silicate in glauconite, this would not affect the above ratio very seriously. Clarke[142] has calculated that about 65,045,000 metric tons of glauconite would be required to precipitate the potassium which goes out of solution in the ocean in one year.

Separation of Silica from Coarse Mechanical Sediment.—It is possible that silica might be precipitated in the form of silicic acid by coagulation, as above assumed, and then concentrated in places far from the shore. It is well known that water from rivers, on entering the ocean, tends to float on top of the denser salt water and to spread out over the surface of the sea in a fanlike form, extending to considerable distances before mingling with the salt water below.[143] Molengraaff[144] states that a river in Borneo forces its waters out to distances of fifty to sixty kilometers from the land. Out to this distance the waters are discolored by the mud of the river water, which mixes very slowly with the sea water.

If silicic acid were precipitated in the gelatinous condition, in the manner suggested, its flocculent nature would cause it to sink very slowly, and it might be carried out beyond all except the very finest mechanical sediments.

On this hypothesis it would appear necessary that the depth of accumulation should be sufficiently great so that calcareous remains would be dissolved.

Objection that no Sediments of this Type are known.—As presented, this hypothesis involves no unusual factors and if it is true the various processes should be at work at the present time. Somewhere we should expect to find sediments which should be the present day equivalents of the radiolarian cherts. The hypothesis then en-

142 Clarke, Proc. Am. Philos. Soc., vol. 51, p. 226, 1912.

143 Clarke, Smithson. Misc. Coll., vol. 60, p. 24, 1912–13.

144 Explorations in Central Borneo, Leyden, 1902.

counters the objection that we know of no red mud which shows such a high proportion of siliceous organisms as this would require. This objection has little force, since the presence of radiolaria in a red mud would be very largely a matter of a special combination of circumstances. Since only a few occurrences of red mud are known at the present time it might well be that none of them was exactly like that required by the theory.

A very serious objection to this hypothesis is to be found in that absolutely no evidence of accumulations of gelatinous silica has ever been found in oceanic investigations.

Objection Based on Idea that Silica is Precipitated Organically.—The idea of chemical precipitation of silica contributed by rivers is based, in part, on the work of Murray and Irvine. They concluded that siliceous organisms did not utilize the dissolved silica of the ocean.

Certain biologists appear to differ with them. For example, Johnstone[145] claims that it is not necessary that the organisms shall pass all the water through their bodies in order to utilize the dissolved material. He states that the lower organisms can probably absorb material over their entire surface. By this means they could extract silica from very dilute solutions.

Johnstone refers to the work of Raben, who made very careful determinations of the silica in Kiel Bay at different periods of the year. Raben showed that twice a year the amount of dissolved silica reached a maximum. Immediately after each of these maxima there was a maximum in the number of diatoms in the bay. This might be taken to indicate that the diatoms were dependent upon the dissolved silica.

Chemical Objections to the Hypothesis.—Even if one disregards the work of Raben and assumes that the silica from river waters is all eliminated by inorganic precipitation, serious objections may still be raised against the hypothesis above outlined.

On examining it further, it is seen that there are other possibilities for the precipitation of silica beside the flocculation by electrolytes. In fact, it appears from experiments that the flocculating power of even such a strong electrolyte as sodium chloride is rather low. Strong solutions of sodium chloride will fail to precipitate completely the silicic acid in dilute solutions of sodium silicate.

Beside the experimental evidence of the inefficiency of sodium

[145] Johnstone, James, Conditions of Life in the Sea, Cambridge University Press, 1908.

chloride as a flocculating agent, there is another method of proving the objection. If one examines the analyses of waters of desert lakes, he will find that many of these lakes contain large quantities of salts in solution, and that their salinities may be several times as great as that of sea water. In spite of these high salinities, it will be found that they frequently contain appreciable quantities of silica, amounting to many times that contained in sea water. It would appear from this fact that the coagulating power of strong electrolytes was insufficient to precipitate silica from ordinary ocean water.

Moreover, silica may be precipitated in combination with some base in the form of an insoluble silicate. Sea water contains notable amounts of magnesia and a smaller proportion of calcium. Magnesium silicate is extremely insoluble and one would expect that on coming into the ocean, the silica of the rivers would be precipitated in the form of magnesium silicate. Calcium may possibly aid in the precipitation of silica, but its silicate is relatively much more soluble and since its proportion is smaller, its effect is undoubtedly unimportant. Murray and Irvine[146] found that if one part of silicic acid was added to 100,000 parts of sea water the silica would be precipitated within 144 hours and that the precipitate was principally magnesium silicate with some silicic acid and traces of calcium silicate.

Also, on considering the analyses of enclosed lakes, it is found that as a general rule when the magnesia is high, silica is absent or present in only small amounts. Exceptions are found in those instances where the salinity is so low that the absolute quantities of magnesia and silica are very small.

While the question is rather complex, involving the physical chemistry of solutions of several salts, and is further complicated by the colloidal nature of the silicic acid, still the general survey of the available evidence indicates quite clearly that, in the presence of large concentrations of magnesia, such as exist in the ocean water, silicic acid comes down in the form of magnesium silicate.

The possibility of precipitation in other ways is suggested by the experiments of Murray and Irvine. They showed that in sea water, magnesium silicate was soluble at the rate of ten parts per million, while it is known that the actual content of silicic acid is only about one or two parts per million. Murray and Hjort[147] suggest that silicic acid might enter into combination with alumina:

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[146] Proc. Roy. Soc. Edin., vol. 18, p. 229, 1891.

[147] *Op. cit.*, pp. 183, 184.

Silica, as being a colloid, has not a definite solubility; its existence as a hydrosol is limited only by the coagulating action of the electrolyte solutes of sea-water or by its precipitation in combination with a base. As to the former effect, we have no data except that sodium chloride is comparatively feeble as a coagulant. It is remarkable that no silica seems ever to reach the bottom as a chemical precipitate of calcium or magnesium silicate, although magnesium silicate, is known to be soluble to only one part in 100,000 of water. This perhaps indicates that the silica in solution in the sea is always below saturation point, so that a local concentration large enough to determine precipitation never occurs. Or again, excess silica perhaps combines with what little alumina there is in sea water and is deposited as clay; if that were the case the limit of dissolved silica would be set by the solubility of this substance, which may well be less than that of magnesium silicate.

Occurrence of Chert in Lenslike Bodies.—The hypothesis as above presented possesses the further disadvantage that it fails to provide any explanation for the local occurrence of chert in lenses. Under it, one would expect the deposition of silica to take place over rather large areas.

A modification of Scrivenor's idea, set out above, might perhaps meet the objection. We might think of conditions of humid tropical weathering of granitic rocks, with rather shallow enclosed basins along the margins of the land. In the water of these basins, the continued accession of waters rich in silica and poor in lime and magnesia would finally produce important modifications. The magnesia would ultimately be used up in combination with silica, and waters would be produced which would be rich in alkaline chlorides. From these waters one would get precipitates of silicic acid together with the deposition of tests of radiolaria—provided radiolaria could exist in waters of this peculiar composition. The skeletons of the radiolaria would be perhaps the only fossils, since calcareous organisms might not thrive in such water.

In objection to this, it may be pointed out that the Franciscan sandstone indicates that the conditions in Franciscan time were not those of humid tropical weathering.

HYPOTHESIS THAT THE SILICA OF THE CHERTS IS DERIVED FROM SUBMARINE SILICEOUS SPRINGS

The idea that the silica of the cherts comes from siliceous springs is one which was held by certain of the earlier geologists in Europe. It was held up to the time when radiolaria were found in certain of these cherts. Since that time most European geologists appear to have regarded the silica of the cherts as entirely of organic origin.

Professor Lawson, in his study of the Franciscan cherts, came to the conclusion that there was more silica in them than could be attributed to the radiolaria. He invoked the aid of siliceous springs to account for the excess silica. The details of his statement have been previously given.

This hypothesis possesses the advantage that it readily accounts for the occurrence of chert in lenses, a fact which presents difficulties on most other hypotheses.

Fanning believes he has confirmation of this hypothesis in the occurrence of radiolarian chert in the Philippines. Here the cherts occur in small isolated masses and, where the andesite below the cherts is exposed, it is found to be extensively silicified, Fanning believes this was caused by siliceous springs which came up through it.

One objection, which is sometimes made to the application of this hypothesis, is the fact that the conduits or channels through which these springs reached the surface are not found. It might be expected that occasionally one would be encountered, since there are many lenses of chert. By analogy with known siliceous springs we should expect the rocks around such a conduit to be silicified. While it may not be possible to say definitely that we find the conduits of siliceous springs, there are certain occurrences which are at least suggestive. Occasionally the Franciscan sandstone shows irregular fissures which are bordered by narrow rims of intensely silicified rock resembling a green chert. No large or extensive occurrences of this sort have been found, but it is reasonable to suppose that these fissures represented channels of circulating siliceous waters.

One very serious objection to the hypothesis of siliceous springs was raised by Rothpletz[148] in discussing the *kieselschiefer* of Saxony, and this objection appears to have been instrumental in discrediting the hypothesis. Rothpletz regarded the rhythmic bedding of the *kieselschiefer* as due to regular alternations in deposition. If the silica comes from springs, he could see no reason why there should be such regular alternations in the supply.

HYPOTHESIS THAT THE SILICA OF THE CHERTS IS OF MAGMATIC ORIGIN AND CHEMICALLY PRECIPITATED

The jaspers of the Lake Superior District contain no radiolaria, but are otherwise very much like the radiolarian cherts. Van Hise and Leith, as set out above, believe that these jaspers and the associated iron ores are due to solutions derived from the ellipsoidal basalts which were extruded in large quantities in this region during pre-Cambrian time.

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[148] *Op. cit.*

HYPOTHESIS THAT THE SILICA OF THE CHERTS IS OF MAGMATIC ORIGIN PRECIPITATED BY RADIOLARIA

Another idea regarding the origin of the radiolarian cherts was proposed by Dewey and Flett[149] in connection with a discussion of pillow lavas. They show that the pillow lavas belong to the group of *spilites.* This is a group of basic igneous rocks of varying types, but always characterized by soda-rich feldspars. In the British Isles, spilitic lavas have been erupted repeatedly and on a large scale. Associated with them, are rocks which are believed to represent the intrusive members of the spilitic group.

The spilitic rocks are as a rule very completely decomposed throughout their whole mass. The thoroughly decomposed character of the rocks and of most of the feldspars which they contain, makes the occurrence of fresh albite in them a peculiar feature. It is believed that the formation of albite and the decomposition of the rock is an after-phase of vulcanism.

Tending to show this supposition correct, is a peculiar feature of the contact zones, produced in these rocks where they have been intruded by granite. The lavas are of Lower Carboniferous age and the granite was intruded during the Upper Carboniferous. Yet at the time of the intrusion of the granite the spilitic rocks were greatly decomposed, and the vesicles were filled by secondary minerals. This is shown by the character of the minerals developed in these vesicles during the contact metamorphism. Also, the new basic feldspars, developed in these rocks as a result of the metamorphism by the granite, have not been greatly altered since Carboniferous time. It would then appear that the thorough-going alteration in Carboniferous time was produced by some agent more powerful than ordinary weathering.

The albite diabases, which occur in association with the spilitic lavas, and which represent an intrusive member of the spilitic group, have produced a considerable amount of alteration of shale to adinole. Adinoles when most perfectly developed consist of nearly pure albite. No shales are so rich in alkalies as these adinoles, so that there is no escape from the conclusion that soda has been added to the shale at the contact of the albite diabases.

The formation of adinoles by the albite diabases and the albitization of the extrusive spilites make it appear certain that during the

149 On some British Pillow Lavas and the Rocks associated with them, Geol. Mag., vol. 48, p. 202, 1911.

later stages of the crystallization of these rocks, vapors or solutions were given off which contained considerable amounts of soda.

Dewey and Flett point to the frequent occurrence of radiolarian cherts with pillow lavas. They call attention to the fact that thin beds of radiolarian cherts are interbanded with some of the lava flows. Also, in certain localities,[150] radiolarian cherts occur in masses among the pillows, filling the spaces between them.[151] Assuming the submarine extrusion of such basaltic lavas, they suggest that when the igneous rocks of this group cooled they exhaled vapors or solutions rich in sodium silicate. In the sea water thus enriched in silica, radiolaria would multiply and give rise to deposits of radiolarian skeletons.

In this hypothesis the organic precipitation of silica is stressed, while in the hypothesis of Van Hise and Leith the emphasis is placed on the inorganic precipitation. The evidence presented above indicates that the silica of the Franciscan cherts is in part organic and in part inorganic.

ORIGIN OF THE RHYTHMIC BEDDING OF THE RADIOLARIAN CHERTS

One of the most characteristic features of the radiolarian cherts of the Franciscan group, as well as of the cherts of the Monterey group, is the rhythmic alternation of cherts and shales. Since this peculiar feature is undoubtedly connected in some way with their origin, a discussion of the origin of radiolarian chert must include a consideration of the possible causes of the alternation of such different lithologic types.

Variation in Ocean Currents

The first explanation which comes to mind, perhaps, is that the alternation of chert and shale was due to some variation in ocean currents. It is not possible to discuss this question fully because of insufficient knowledge regarding the causes of variation in such currents, or of the manner in which they change. It seems extremely improbable, however, that such currents could change rapidly enough or in such a regular alternation as to produce the bedding.

[150] E.g., Scotland.

[151] Jaspers which were probably once radiolarian cherts occur in Anglesey. They are often found here filling spaces between pillows in pillow basalt. Greenley, Quar. Jour. Geol. Soc., vol. 58, p. 425, 1902.

Variation Due to Regular Seasonal Changes

It might be possible to explain the rhythmic bedding as due to a regular alternation of river currents with seasonal variations.

OTHER EXAMPLES OF RHYTHMIC ALTERNATION

Explanations of this type have been advanced to explain similar rhythms in stratification in other instances. A case in point is the laminated glacial clay. This clay occurs in thin beds, which alternate with layers of lime carbonate, or there may be alternations of clays of different colors, e.g., red with gray, or alternations of clay with sandstone. The thickness of the beds is very uniform and is rather small, ranging from one-half inch to one and one-half inches. These banded clays have been described from the Pleistocene glacial deposits at several points in the northern United States[152] and in Canada.[153] Similar laminated clays in Sweden have been described by Gerard de Geer.[154] Recently Sayles[155] has described laminated argillites in association with a supposed Permo-Carboniferous tillite in Massachusetts.

The generally accepted explanation is that these alternations in deposition were produced by seasonal variations, the clay layer being laid down in the summer, for example, and the carbonate layer in the winter.

Allen[156] has described some ribbon shales in the lower part of the Chancellor formation of Upper Cambrian age in the Field Map Area. The formation consists of a rather uniform calcareous and dolmitic shale rich in iron. The shale weathers in many characteristic shades, and while on fresh surfaces no great differences are seen, on weathered surfaces the shale is characteristically banded or striped. This striping appears to be due to slight differences in the chemical composition of the different layers, developed by weathering. The layers vary in width from a fraction of an inch to one and one-half inches. Sections several hundred feet thick may show this striping throughout. This

[152] Berkey, C. P., Laminated Interglacial Clays of Grantsburg, Wisconsin, Jour. Geol., vol. 13, p. 35, 1905.

[153] M. E. Wilson, Kewegama Lake Map Area, Quebec, Can. Geol. Surv. Memoir 39, p. 104, and plates 25 and 26, 1913.
24th Ann. Rep. Ontario Bureau of Mines, pt. III, pp. 5–6, 1915.

[154] On Late Quaternary Time and Climate, Geol. Foren Förhandl. vol. 30, p. 459, 1908.

[155] Sayles, R. W., Bull. Geol. Soc. Am., vol. 27, p. 110, 1916.

[156] Allen, J. A., Geology of the Field Map Area, British Columbia and Alberta, Can. Geol. Surv. Memoir 55, 1914.

particular case is explained as being due to slight differences in the deposited material, as a result of the regular variation of summer and winter.

APPLICATION OF HYPOTHESIS TO RADIOLARIAN CHERTS

If we attempt to apply this hypothesis to the radiolarian cherts there are two special cases which might be discussed: (1) hypothesis that cherts are radiolarian oozes; (2) hypothesis that cherts are chemical precipitates.

Hypothesis that Cherts are Radiolarian Oozes.—We might think first of an area of the ocean bottom, at some distance from land, on which the skeletons of radiolaria are accumulating. Think of the climate on land as of such a nature that it shows a marked variation in its seasons, as for example, an alternation of a dry summer with a rainy winter. During the dry season the rivers flowing from the land would be contracted and would carry their load of sediment out to a certain distance from the shore. Beyond this limit radiolarian oozes would accumulate. During the rainy season the streams would be swollen and much sediment would be carried out to a greater distance than in summer. Under such conditions a transition zone would be formed between the terrigenous sediments on the landward side, and the pelagic sediments on the ocean side, within which the seasons would be marked by a characteristic alternation of sediments.

On the assumption that the change was annual, the radiolarian oozes would accumulate at the rate of one to three inches per year. No definite figures are available on this point, and since radiolaria may obtain their silica from the decomposition of clay particles we have no absolute check on the amount of silica coming down by organic precipitation. It seems, however, highly improbable that siliceous oozes could accumulate at this high rate.

Hypothesis of Chemical Precipitation.—Adopting for the discussion, the idea of a chemical precipitation of silica from river water, we might suppose that all the silica comes down in the form of silicic acid. This silicic acid might be assumed to be flocculent, so that it would travel out beyond the finest mechanical sediments before deposition. On such an assumption there would be a zone in which mechanical sediment of very fine grain was being deposited. Further out there would be a zone of chemically deposited silica. As long as conditions of river supply remained constant, the boundary between these zones would remain fixed. If annual floods occurred silica would be carried out further at one season than at another and the fine silt would be carried out beyond its usual place and deposited above the accumulation of silica of the preceding season. As the seasons changed a regular alternation of sediments would be produced.

There is an effective check on the notion of annual variation, in the thickness of material which must accumulate in order to explain the bedding on this hypothesis.

The Franciscan terrane has an average width of fifty miles in the California Coast Ranges. Chert does not cover the whole area, so we might assume that the width of a belt of chert was twenty-five miles, measured transversely to the shore line. Assume that all the silica of the cherts was originally brought down in the form of dissolved silica by river waters. Each linear mile of this deposit of silica—twenty-five miles in width—will then correspond to an area 25 x 5280 x 5280 = 696,960,000 square feet. This area must be covered, in one year, to such a depth that when the rocks are consolidated there shall be beds as thick as the average Franciscan chert. Assuming two inches as the average thickness of chert beds, then each layer of resulting chert must contain a volume of chert equal to $696{,}960{,}000 \div 6 =$ 116,160,000 cubic feet. The final density is about 2.5. Each cubic foot of chert weighs 2.5×62.3 pounds $= 156$ pounds. The total weight of silica in one layer of the dimensions specified is equal to $\frac{116{,}160{,}000 \times 156}{2000} = 9{,}600{,}480$ tons of silica. Clarke, in the *Data of Geochemistry,* estimates that 319,170,000 metric tons of silica are carried each year into the ocean by all the rivers of the world. 319,170,000 metric tons is in round numbers equal to 352,000,000 tons. According to this calculation the whole of the silica of the rivers of the world in one year would produce a layer of chert twenty-five miles wide, two inches thick, and having a length a little less than thirty-nine miles.

$$\left(\frac{352{,}000{,}000}{9{,}060{,}480} \doteq 39.\right)$$

The linear extent of the Franciscan terrane is several hundred miles; the amount of river-borne silica coming into the basin could at most be only a small fraction of the total amount contributed to the ocean by all rivers. It is obviously impossible to believe that seasonal alternations could give the rhythmic bedding, on the hypothesis of chemical precipitation. Even the most liberal estimates of conditions would indicate that a great many years would be necessary for the formation of one bed of chert.

Rhythmic Bedding Due to Cyclic Changes of Climate

The hypothesis of seasonal alternations appears quantitatively inadequate to explain the rhythmic bedding. It may be possible that climatic variations extending over periods of many years might produce the bedding.

STATEMENT OF HYPOTHESIS

We might imagine as before, regions on the ocean bottom where either radiolarian oozes were accumulating or where there was an accumulation of precipitated silica. When the climate reaches the most humid stage, mechanical sediment will reach a point where, under ordinary conditions, silica is deposited. On this hypothesis shale would be deposited only once in many years, during an unusually wet season. An extra dry year would produce no change in the part of the basin where silica was being deposited. It is possible that the entire thickness of a shale parting might be laid down during one wet year, since terrigenous material would be more abundant than silica.

EVIDENCE IN FAVOR OF IDEA OF EXISTENCE OF CLIMATIC CYCLES

There is a certain amount of evidence which indicates the existence of cyclic changes of climate. Many writers have pointed out such evidence.[157] They have studied rainfall records, variations in glaciers, and similar phenomena and have arrived at various periods of climatic oscillation. For example, an eleven-year period and a thirty-five-year period have been advocated, and it has been shown that there is a rather regular alternation in sun-spot frequency corresponding to these periods.

Ellsworth Huntington,[158] from a study of ruins in various arid regions of the world, has become convinced that the climate has changed enough to render regions once habitable, now uninhabitable. He has found evidence which leads him to believe that these changes have taken place in a pulsatory manner. While his ideas with regard to major periodic changes of climate have been disputed, on occasion, the idea of shorter period climatic cycles finds support in the

[157] Ward, R. DeC., Changes of Climate, Pop. Sci. Mon., vol. 69, p. 458, 1906.

[158] Geog. Jour., September and October, 1912.

The Climatic Factor in Arid America, Carnegie Publication no. 192, Washington, 1914.

work of A. E. Douglas,[159] who describes striking variations in the rate of growth of trees. It appears that the thickness of rings of growth varies according to the climatic conditions. Measurements of many tree stumps have been made and the results of these measurements compared with rainfall records over a period of forty years. The result showed a very close agreement between rate of growth and amount of precipitation. The measurements of old trees showed that for many years back the climate has changed in a pulsatory manner.

ORIGIN OF MINUTE LAMINATIONS OF CHERTS

In both the Franciscan and Monterey groups, the beds of chert are found to be laminated. As noted, this is quite common in the Monterey cherts, and less frequent in the Franciscan. The suggestion has been made that these laminations mark yearly alternations of condition, while the major bedding planes may be due to cyclic changes or due to some other cause than climatic variations. In the study of Franciscan cherts, no evidence was obtained on this point, but in the case of the Monterey cherts it is quite clear that this lamination is not due to seasonal variations. This is shown by the fact that many of the lines of lamination close upon themselves in elliptical curves, suggesting concretionary action of some sort.

OBJECTIONS TO BOTH HYPOTHESES OF CLIMATIC VARIATION

In both the preceding hypotheses for explaining the rhythmic bedding by climatic changes, a rather simple method of transportation of sediment has been assumed. It has been assumed that the currents from rivers, entering the ocean, came into still water and that the final resting place of the sediment was determined by the strength of the river currents and the distance to which they were able to maintain themselves through the more quiet water of the ocean. In this way alternations in the volume of rivers would be competent to produce alternations in the nature of the sediments at certain special areas in the basin of deposition.

It would appear from the distribution of terrigenous muds that the conditions were much more complex than this. If a map showing the distribution of areas of terrigenous sediments be examined, it will be found that the fine terrigenous muds form rather uniform bands along the continental margins. They show no unusual seaward exten-

159 Weather Cycles in the Growth of Big Trees, Mon. Weather Rev., pp. 225–237, June, 1909.

sion opposite the mouths of large rivers, nor are they unusually narrow at those parts of the shore line where there are no streams. The conclusion is forced upon us, that they are transported by ocean currents and distributed by them all along the coast. For this reason alternation of high river stages with stages of low water would have little effect in determining the ultimate position of deposition of the finer sediments, or in producing rhythmic bedding in any terrigenous muds. The final disposition of material depends upon ocean currents, which are in all probability independent of climatic cycles.

The hypotheses of climatic variation are also opposed by the occurrence of both cherts and shales in lenticular beds, or in nodules. Such features could not be produced in fine sediments carried by the action of gentle currents.

Two other hypotheses have been suggested by Lawson and Palache.[160]

Rhythm in Growth of Radiolaria

If the cherts could be accepted as being radiolarian oozes it is possible to explain the alternation as due to a periodic variation in the growth of the radiolaria. It is known that diatoms show a periodic variation in development. The work of Raben, before referred to, showed two maxima per year in the number of diatoms in Kiel Bay. These variations, however, were very short in period, and it seems unlikely that they could result in the observed alternations. Such an assumption would lead to an improbable conclusion regarding the rate of accumulation.

A further objection has been referred to before. Core samples of radiolarian oozes show no evidence of such bedding. Neither is such an alternation shown in the Barbados earth.

Rhythm in Siliceous Springs

If the idea of siliceous springs as a source of the silica were proved, it is conceivable that there might be a rhythmic variation in the supply of silica from these springs, so that one would get periods of silica precipitations alternating with periods of ordinary sedimentation. Here again, though the idea seems improbable, there is not much evidence either to prove or disprove it. However, it is said that the siliceous waters in Steamboat Springs, Nevada, show a variation in flow, dependent on rainfall.

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[160] The Berkeley Hills, Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, p. 445, 1901.

Hypotheses which Postulate the Cause of the Rhythmic Bedding in the Nature of Gelatinous Silica

The Monterey and Franciscan cherts both show regular alternations of chert and shale and yet there are many differences between them. In spite of the differences in the characteristic fossils, and the marked differences in the nature of the shaly partings, the chert beds in both formations are about the same thickness and show almost identical peculiarities of bedding. This is strongly suggestive of the idea that the rhythmic alternation is due to some property of gelatinous silica, since this seems to have been about the only common factor in the two formations.

A further fact is that this similarity in thickness of the chert beds in the Franciscan and in the Monterey does not appear to depend upon the amount of shale. In general the beds of chert are of about the same thickness where the shale partings are thick, as where they are thin.

RHYTHMIC ALTERNATION DUE TO SUPERSATURATION AND RHYTHMIC PRECIPITATION OF SILICA

It may be possible to explain the rhythmic bedding of chert and shale by means of a rhythmic precipitation of silica. One might regard the silica as due to siliceous springs, as emanations from igneous rocks, or as contributed by rivers coming into a basin of deposition.

Silicic acid tends to form supersaturated solutions, and silica might continuously increase in concentration in the water of the basin of deposition, until it reached a state of supersaturation when precipitation would occur. When precipitation began, it would continue until the concentration of silica reached that necessary for saturation. After the precipitation took place the accumulation of silica in solution would begin again and the concentration would gradually increase during a certain period of time when another precipitation would occur. If during this process, fine shaly material was slowly and continuously coming into the basin of deposition, the final result would be alternations of shale with chert. If the conditions of supersaturation and precipitation were uniform, there would be deposits of chert of uniform thickness.

On this hypothesis, we could account for the abundance of radiolaria in the chert and their small number in the shale. At the time of precipitation of the silica the water would be cleared of most of the radiolaria through their being entangled in the gelatinous silica. However, since it seems necessary to assume that a number of years are required to accumulate enough silica for a bed of chert, it may be necessary to invoke another factor. It may be possible that the radiolaria would thrive to an unusual degree in water which contained a high concentration of silica. It might then be expected that their number would be very great at a time just before the precipitation of the chert layer.

In any case of gradual addition of silica to an ocean basin by the slow contribution of rivers we would expect that, during the long time necessary to accumulate enough silica for a single bed of chert, the ocean currents would gradually mix the water and render its composition very uniform. Obviously it would be a very difficult matter to supersaturate the ocean, so that this explanation does not seem very probable if one regards the silica as coming in from river waters.

If the hypothesis of siliceous springs or the hypothesis of solutions emanating from igneous rocks be accepted, the idea of supersaturation and rhythmic precipitation has more to recommend it. The more rapid addition of silica to a limited volume of the sea water would give much better opportunities for supersaturation of smaller volumes and the precipitation of silica from them. Even here it would appear that this idea of rhythmic precipitation would fail to explain the rather uniform thickness of the chert layers. Due to such causes as variations in currents, one would expect variations in the volume of water which would become supersaturated at one time, and a consequent variation of the thickness of the deposited chert.

POSSIBILITY THAT THE RHYTHMIC BEDDING MAY BE DUE TO SEGREGATION IN A COLLOIDAL OOZE

Another possibility which requires consideration, is that finely divided gelatinous silica and shaly material were deposited together in a colloidal mixture and that, at a later stage, there was a tendency for segregation in the ooze and the gelatinous silica then aggregated itself into the definite layers or beds which are now found.

An idea, somewhat similar to this, has been advanced by Lang,[161] in an attempt to explain the peculiarities of certain limestones. He studied the Liassic rocks of the Charnmouth Cliffs in England, where a series of blue-gray marls are traversed by indurated bands and

[161] Lang, W. D., The Geology of the Charnmouth Cliffs, Beach and Fore-Shore, Proc. Geol. Assoc., vol. 25, p. 293, 1914.

nodules of impure limestone. He concluded, as a result of his investigations, that a calcareous ooze had originally been deposited, and that at a later stage the lime carbonate had aggregated itself into nodules and bands.

At first view, this idea might appear to be improbable, when applied to the radiolarian cherts, on account of the fact that the contacts of chert and shale are quite sharp and distinct, and a perfect plane of cleavage exists between chert and shale. It might be supposed that such results could not be due to segregation. However, concretions very often show abrupt endings and sharp boundaries against the surrounding material and there is no reason why such sharp distinctions should not be found in segregated shale and silica.

Also there are certain minor features of the bedding which render the notion of segregation very probable. These peculiar minor features of the bedding of the cherts and shales in both the Franciscan and Monterey cherts have been described in detail in preceding pages and may be summarized:

1. Lenticular and nodular character of the beds of chert. These might be explained also by rhythmic chemical precipitation of the silica of the cherts and the irregular settling of gelatinous silica. They cannot be explained by the shearing out of chert layers, either before or after solidification, since the shale partings on either side show absolutely no evidence of mechanical disturbance.

2. Lenticular character of the shale partings. This can be explained by the assumption that the *shales are chemical precipitates.* The shales of the Franciscan cherts are, in appearance, very unlike ordinary shales and it is conceivable, though unlikely, that they might have been produced in some way by chemical action. However, the shales of the Monterey cherts are shales of the ordinary type. They could not be distinguished in any way from ordinary terrigenous shale. Since the shale of the Monterey chert is clearly a mechanical sediment, the notion of chemical precipitation cannot be used as a means of explaining the lenticular character of the shale partings.

These two features of the bedding of cherts have been noticed before. Dana speaks of the coalescence and subdivision of beds of jasper, in his description of Franciscan cherts. Fox and Teall[162] noticed these features in the cherts of Mullion Island and considered the possibility of "concretionary action," but abandoned it because of the presence of radiolaria in the cherts. They explained these features as

[162] Quar. Jour. Geol. Soc., vol. 49, p. 213, 1893.

the result of movements in unconsolidated sediments. This explanation will not hold for these peculiarities exhibited by the Franciscan and Monterey cherts, since in these rocks lenticular shale beds occur where there is no evidence of shearing or displacement.

Dixon and Vaughan[163] mention "wedge bedding," but they regarded it as produced by the contemporaneous erosion of beds of silt and siliceous ooze, due to scouring of rather strong currents in shallow water. The ideas of Dixon and Vaughan, regarding the lagoon hypothesis, seem untenable, for various reasons pointed out on a previous page. Even if the hypothesis be accepted, it is impossible to explain this peculiar bedding by the scouring of currents. Current scouring should not always confine itself to one horizon. It would certainly result in cutting across several beds and result in sections of the general nature indicated in the diagram (fig. 16). Nothing of

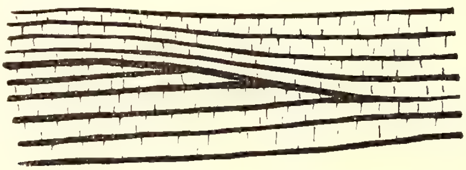

Fig. 16. Result of current scouring in bedded silt and ooze.

this sort has been observed in either of the formations of bedded chert in California. The beds simply terminate at certain points without evidence of contemporaneous erosion of any kind.

Every stratum of mechanically deposited sediment is lens shaped. If the shale partings in the cherts are mechanical sediments, and the alternation is due to variations in currents, it would be expected that the shales would occasionally show a lenslike termination. However, the shales are very fine grained and must have been carried by gentle currents, so that the area of such lenses would be large. As a result we would expect the terminations to be rather rare, and found only in an occasional section. In the Telegraph Cañon section of the Monterey cherts, east of Berkeley, there are at least a hundred terminations of this kind observable in a single small quarry. In the plates showing details of the bedding of the Monterey it will be noted that there are numerous terminations of shale partings, even in the few square feet covered by the photographs. Similar features are very

163 The Carboniferous Succession in Gower, Quar. Jour. Geol. Soc., vol. 67, p. 477, 1911.

common in other sections of Monterey cherts and they are also frequent in the Franciscan cherts. They are altogether too numerous to be explainable as due to the gradual feathering out of layers of sediment. Another fact which is opposed to this interpretation is the abrupt termination of some of the shale beds. Shale beds, deposited by gentle currents, should taper down gradually. Many of the terminations shown in the photographs are very abrupt.

It seems certain that the idea of mechanical production of these lens shaped terminations is unfounded. It may be possible to explain the lenticular character of the cherts by supposing them to be chemical precipitates, but the explanation will not hold for the shales. The only other possibility is to believe that the shaly material and siliceous material were deposited together and later underwent a segregation.

In volume 55 of the *Quarterly Journal of the Geological Society of London,* David and Pitman present a section showing details of interbedding of radiolarian cherts and submarine tuffs. These show nodules, stubby lenses, and branching sheets of radiolarian cherts with similar features in the interstratified tuffs. The relations are almost identical with those observed in Franciscan cherts and shales. In the New South Wales occurrence, the details of the boundaries are extremely irregular due to minute indentations. In the Franciscan the boundaries of lenses and nodules are smoothly rounded.

Other remarkable features of the bedding are what might be expected on the idea of segregation in colloidal mixtures. These are:

1. Pinching and swelling of beds of chert and shale, not due to thickening and thinning produced by folding.

2. Rounded knobs in chert without any lithologic difference between the knob and the rest of the bed.

3. Manner in which the irregularities on one bed are compensated by corresponding variations in surrounding beds.

4. Convergence of lamination shown in many cherts of the Monterey group.

All of these last mentioned facts would be difficult to explain on other hypotheses, but they fit in very well with the idea that the rhythmic alternation is due to some sort of colloidal segregation.

It appears therefore that no hypothesis yet presented will explain all the facts observed with regard to the rhythmic bedding, save the one of colloidal segregation. This hypothesis is in agreement with all the observations on the features of this rhythmic bedding.

An objection, which might be made, is that the regular bedding would not be expected on the notion of segregation. The objection is robbed of its force when certain similarities between this bedding and the bandings produced by diffusion reactions in colloids are considered.

Liesegang showed that if a glass plate were coated with gelatine, impregnated with potassium bichromate, and a drop of silver nitrate solution were placed on the plate, that a series of concentric rings of silver chromate would be formed around the drop. The rings of the precipitate were closely spaced in the neighborhood of the drop of silver nitrate, but became successively further and further apart as the distance from the center increased.

In some excellent figures, recently published by Stansfield,[164] it may be seen that while these Liesegang rings are fairly regular, they are by no means perfectly so. They show a frequent wedging out of the bands and many other small irregularities.

Morse and Pierce[165] modified the experiment somewhat, and allowed solutions to diffuse down into test tubes, filled with gelatine which had been impregnated with various reagents. They found that as the diffusion proceeded, horizontal bands were formed in a direction transverse to the test tube. They formed bands of this kind, consisting of other substances than silver chromate, even forming strata marked out by numerous bubbles of carbon dioxide. In this experiment the bands were more closely spaced near the top, from whence the diffusion was proceeding. Stansfield has shown that, under certain conditions, it is possible to get the bands equally spaced instead of arranged at progressively increasing distances.

Bradford[166] has called attention to the peculiarities of certain of these stratifications. He experimented with test tubes containing agar gel in which small amounts of either potassium sulphide or of manganese sulphate had been dissolved. In any case the tube was treated with a solution of the other reagent.

The resulting stratification of the manganese sulphide is different from any stratification of this sort which has hitherto been produced. The difference consists in that many of the zones are separated into a number of concretions, which in some cases are joined by rods to those of succeeding zones. He points out that these structures

164 Stansfield, J., Retarded Diffusion and Rhythmic Precipitation, Am. Jour. Sci., vol. 43, p. 1, 1916.

165 Morse, H. W., and Pierce, G. W., Diffusion and Supersaturation in Gelatine, Proc. Am. Acad. Sci., vol. 38, p. 625, 1902–03.

166 Bradford, S. C., The Liesegang Phenomenon and Concretionary Structures in Rocks, Nature, vol. 97, p. 80, 1916.

appear very similar to certain structures in concretionary limestone and advances a theory to explain these limestones as a result of diffusion phenomena.

In all the diffusion reactions, above described, it will be noticed that the banding is due to the diffusion of a solution of one reagent into a colloidal medium impregnated with a solution of the other reagent. Liesegang showed that such reactions might occur, even in non-colloid media.

Cole[167] has recently used a somewhat similar hypothesis to explain the banding of flints in the chalk. Liesegang had suggested that the banding of flints in limestones was due to some sort of diffusion reaction. Cole suggests that waters containing dissolved silica (derived perhaps from the solution of siliceous tests, and spicules, originally in the chalk) might diffuse down through the chalk during the early stages of its uplift. During its downward diffusion such silica might be precipitated in bands and nodules in the midst of the chalk. Later, still other silica might precipitate with these bands as nuclei. This combination of factors would account for the regularity of the banding and also explain the replacement phenomena which are sometimes observed in chalk flints.

This hypothesis involves a slightly different idea from that involved in the experiments before mentioned. In this hypothesis only one solution is involved—the solution of silicic acid. No mention is made of the precipitant. Possibly the solid lime carbonate precipitates the silica from its solution in a rhythmic way.

In all the above experiments the banding was produced *at the time of formation of the precipitate.* There was no movement of already precipitated material. The hypothesis which was above set out in explanation of the peculiarities of bedding of the chert involves a segregation of material already in the solid state, and the objection might be raised that there was no similarity between the two sorts of phenomena.

In certain experiments performed by the writer this latter effect was produced. It was found possible to produce a *rhythmic segregation.*

In these experiments finely divided clay, which would remain in suspension in quiet water for an hour, was used. A suspension of this clay was mixed with a moderately strong solution of sodium sili-

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[167] Cole, G. A. J., The Rhythmic Deposition of Flint, Geol. Mag., Decade VI, vol. 4, pp. 64–68, 1917.

cate. Above the mixture thus produced a solution of ammonium carbonate was poured, taking care to avoid mixing of the ammonium carbonate solution with the suspension of clay. As the ammonium carbonate diffused down it produced a flocculation of silicic acid, and in the formation of the gelatinous silica a banding resulted, consisting of alternate layers of fine clay, and clear silica jelly (plate 36). Evidently as the silica assumed the gelatinous state it was able to force the clay aside.

The bands varied somewhat in width in different experiments. They were approximately equally spaced, and while fairly regular, they showed all the minor structures which have been described as seen in the bedding of chert. They showed lenslike terminations of both clay bands and silica bands; they showed an irregular thickening and thinning. Some nodules were produced.

This separation of gelatinous silica into bands occurred not only with clay but with other substances. The experiment was modified somewhat by using some of the red shale partings between chert beds in the Franciscan, powdered to pass a 100-mesh screen. This powder was suspended in a solution of sodium silicate. The coarser particles settled to the bottom, and the supernatant liquid, containing much fine suspended shale, was siphoned off, leaving the mass at the bottom, consisting of incoherent shale particles permeated with a solution of sodium silicate. Over this, a solution of ammonium carbonate was carefully poured and diffusion allowed to go on as before. There resulted a series of bands of clear silica jelly and red shale, which duplicated many of the features of the chert and shale beds.

In another experiment, pure white crystalline quartz was powdered to pass a sixty-mesh screen. This was put into a solution of sodium silicate and after the coarser particles had settled to the bottom the supernatant liquid was withdrawn, leaving a mass of fine quartz grains permeated by a solution of sodium silicate. After pouring ammonium carbonate over this mass and allowing it to stand for some time it was found that a sharp banding had resulted, giving clean cut, lenslike bands of quartz sand interbedded with layers of silica jelly.

In all these instances the number of bands which would form seemed to be limited. After a few bands were produced in the upper part of the silica suspension, the gelatinous silica formed around the particles of clay, shale or quartz without further segregation, as shown in the photographs (plate 36).

The segregation occurred independently of whether the impurity in the silica was a colloid or a crystalline substance. The experiments show conclusively that silicic acid possesses the ability to free itself from mechanical impurities and that it can do so in a rhythmic manner.

While the evidence presented indicates that the bedding of the cherts and shales is due to some sort of segregation in a colloid mass of mixed silica and shaly material, and the experiments cited are proof that such rhythmic segregation can occur, it is not possible at the present writing to state the exact manner in which the banding is brought about.

We might think of an ooze consisting of two substances, one of which tended to dissolve and reprecipitate about definite centers. Due to this process of recrystallization there might result a segregation into definite bands, as in the concretionary limestones mentioned above. This type of process is not applicable to the cherts, since the silica there is in the amorphous condition.

The ultimate physical structure of the colloidal gels is believed to be that of a honeycombed framework through which liquids may diffuse. There is a slight analogy here with crystal structure. Crystals in their formation are often able to exclude from their substance certain foreign materials. It is barely possible that colloids in forming gels may tend in a similar way to exclude foreign material.

It is possible that a solution of silicic acid might diffuse through a fine mud on the sea floor and that the silicic acid should be precipitated throughout the mud in regular layers, thus producing the rhythmic bedding.

Perhaps a fine mud was permeated with a solution of silicic acid or some silicate, and by the diffusion of some other substance into it, as in the above experiments, a regular rhythmic banding was brought about.

We might think, also, of an ooze which consisted of a mixture of fine shaly material with minutely divided particles of gelatinous silica. In such a substance, given sufficient time, there might be a tendency for the minute particles of gelatinous silica to aggregate themselves into larger masses, and during their assemblage it might be possible that shaly material would be excluded in the form of definite bands. Experiments were tried with a view of testing this idea. Finely divided gelatinous silica was mixed with fine clay and the mixture allowed to stand for several months. In that time, however, no evidence of tendency to segregate was observed.

It is possible also that there may have been a fine mixture of the type just postulated and that some substance diffused into this mixture (possibly ammonium carbonate from decaying organic material) which possessed the property of changing the surface tension of one of the colloids in the mixture. Due to this change in surface tension the colloid may have tended to aggregate rather than to remain in the dispersed condition. In such a segregation there may have been a purification of silica in a rhythmic manner.

The last cases postulated are not like the conditions produced in the experiments performed by the writer. There the silica was in solution at the time of diffusion of the ammonium carbonate and during the diffusion there resulted the flocculation of silica jelly in such a way as to expel the clay in regular bands—a different state of affairs from one where the silica is already in the gelatinous condition.

To summarize the above: no other hypothesis explains the peculiarities of bedding of the cherts and shales. The hypothesis of colloidal segregation will explain these peculiarities. All the features of bedding may be duplicated in the bandings resulting from diffusion reactions in colloids. Experiments show that a rhythmic segregation of silica from mechanical impurities can occur. While the exact method by which the segregation was brought about cannot be specified, at the present time, it seems clear that the banding of the cherts and shales did result from some sort of rhythmic segregation of colloidal silica.

CONCLUSIONS

In the foregoing pages, various hypotheses regarding the source of the silica of the cherts are discussed. It is shown that there are serious objections to any hypothesis which regards all the silica of the cherts as due to radiolaria or other siliceous organisms, and the probability of an additional inorganic source of silica is shown. The hypothesis that silicic acid would be precipitated from the dilute solutions carried in river waters is shown to be an impossible explanation of the source of the additional silica.

Only two other sources of silica then remain, in the absence of other possibilities. These are the emanations from igneous rocks and the supply of silica from siliceous springs.

The hypothesis of siliceous springs explains the local occurrence of the chert in lenses. There appears no reason why submarine siliceous springs should not exist. Where known on the land, such springs are associated with vulcanism, and it is probable that submarine siliceous springs would be related in some way to igneous activity beneath the sea floor.

Submarine springs are known, though, from the nature of the case, one would expect records of them to be scarce.

Russell[168] describes a number of sublacustral springs in Mono Lake and refers to sublacustral springs elsewhere. In Mono Lake, the upward flow of water discharged from some of the springs causes a low moundlike elevation of the surface of the lake. The flow of discharged water is sufficient to deflect a boat.

There is a large submarine spring off the coast of Florida, about nine miles south of St. Augustine and about two miles from shore. The orifice is about sixty feet across and the water emerges with enough force to cause a distinct convexity of the surface in calm weather. It is difficult to row a small boat across it on account of the outward movement of the water.[169] This spring is shown on the U. S. Coast and Geodetic Survey Chart—St. Augustine Inlet to Halifax River, Florida. The general depth of water is fifty-five feet, but in the spring a sounding of 126 feet was obtained.

At Tarpon Springs, Florida, a spring emerges beneath the waters of a small shallow bay, a few feet below mean tide level. A sounding of 125 feet was obtained in this spring.

According to E. Lester Jones, superintendent of the U. S. Coast and Geodetic Survey, these springs were merely noted incidentally, and it is probable that a systematic investigation would reveal many others.[170]

All during the Franciscan period there appear to have been irruptions of pillow lavas. This is shown by the finding of boulders of basic igneous rock of Franciscan type and boulders of glaucophane schist in conglomerates in the Franciscan sandstone. In California, glaucophane schists are known only in the Franciscan and appear to be always the result of contact action of basic igneous rocks.

In working in areas of Franciscan rocks one is so impressed by the frequency of intrusive contacts of the pillow basalt, that he is likely to regard all these rocks as intrusive masses which came into the

168 U. S. Geol. Surv. 8th Ann. Rept., pt. I, p. 287, 1886–87.

169 Watson and Sanford, U. S. Geol. Surv., Water Supply Paper 319, p. 208, 1913.

170 Personal communication.

Franciscan at the close of the period. Further it is not always easy to decide whether or not a certain mass of basic igneous rock is intrusive or extrusive. The commonly used criterion of pillow structure is useless. It has often been assumed that the presence of a pillow structure was proof of a submarine extrusive origin. As has been shown by Lawson and Ransome, the presence of pillow structure has no such significance. On Angel Island, Ransome found an unmistakable intrusion of ellipsoidal fourchite, cutting sandstones and cherts. Professor Lawson has described similar sections at Hunter's Point and in Marin County. There are numerous other places in the Coast Ranges where pillow lavas show intrusive contacts. The grain of the pillow lavas, also, is no criterion of their mode of eruption. While certain pillow lavas may be rather coarse grained, most of them show an exceedingly compact texture, and this is characteristic of some intrusive masses of considerable size. One has to resort to other means to determine the nature of such rocks.

Professor Lawson has described intercalated flows of basic lavas in the lower sandstone formation of the Franciscan group. At Point Bonita, Ransome found evidence that there were both intrusive and extrusive varieties of pillow lava. The writer has seen several cases of basic lavas, some of which showed ellipsoidal structure, intercalated with the radiolarian cherts in such a way as to leave no question of their extrusive nature. At the Miller Ranch, near Sargent, there is an area of several square miles of fragmental igneous rock of Franciscan age, which is lithologically identical with the type of lava that elsewhere shows the ellipsoidal structure. It is poorly sorted and shows no evidence of stratification, so that it may possibly represent a tuff erupted beneath the sea.

In view of the evidence it is clear that all during Franciscan time there were eruptions of basic igneous rock of a peculiar type. During these progressive eruptions, the earlier formed rocks, such as sandstones and cherts, would be intruded and metamorphosed by masses of igneous rocks passing through them on their way to the surface. Both intrusive and extrusive facies were produced.

In California, the intrusive masses of these igneous rocks show contact zones which are characterized by the addition of soda to the altered rocks. In other regions igneous rocks of the same type as the igneous rocks of the Franciscan, have produced contact zones characterized by the addition of soda. Probably, though not certainly, this soda was in the form of sodium silicate.

Two possible sources of solutions of alkaline silicates may be suggested. It is possible that the alkaline silicates are direct contributions from the cooling magma, escaping from extrusive masses, and also rising through fissures in the crust, from larger intrusive masses below, as these gradually cooled. It is possible, also, that the alkaline silicates are not direct contributions from the magmas, though produced as a result of their intrusion. If a body of molten magma were injected into the rocks beneath the sea floor, it would set up an active circulation. The water, thus set into circulation, would be sea water, containing abundant alkali salts. It is conceivable that such waters, being heated by the intrusion, and acting on the rocks beneath the ocean floor, the unconsolidated sediments, or the igneous material itself, would take large amounts of silica into solution in the form of alkaline silicates.

Regardless of which hypothesis may explain the true source of the soda-rich solutions associated with the basic rocks of the Franciscan, it seems certain that if large bodies of this type of magma invaded the region beneath the sea floor, the intrusion would give rise to great numbers of submarine springs, the waters of which would be rich in sodium silicate.

It would appear, therefore, that the hypothesis, which attributes the cherts to the solutions coming from the ellipsoidal basalts, and the hypothesis of submarine siliceous springs were mutually interdependent.

On this combination of hypotheses it would not be necessary that there be extrusive lava in immediate association with the cherts. If there were magma reservoirs beneath the surface, slowly cooling, these would give rise to siliceous springs. The existence of igneous rocks erupted at various times during the Franciscan period is a proof of the existence of subterranean reservoirs of molten magma.

The question of the mode of precipitation of silica from such siliceous springs might present some difficulty. It has been shown that dilute solutions of silicic acid or sodium silicate would precipitate little silica on mixing with ocean water, but that the silica would come down in combination with magnesium or aluminum. In the case of siliceous springs, however, the solutions would probably be more concentrated and the precipitation of a large proportion of their silicic acid might then occur through the flocculation by electrolytes present in the ocean water. It is possible, also, that the magnesium in a volume of sea water around such a source of supply might be greatly reduced by the precipitation of magnesium silicate and that after this had occurred pure silicic acid would come down.

This idea of the origin of the cherts accounts for the world-wide association of radiolarian cherts with this particular type of igneous rock, and also for the frequent association with glaucophane schists. The constant association of these rocks implies some genetic relation between them.

There are exceptions to the above statement, but they are very rare. For example, the novaculites of Arkansas, Texas and Oklahoma do not appear to be associated with igneous rocks of this sort. Also certain occurrences of ellipsoidal basalts show no association with cherts.

Another mode of accounting for the frequent association of the two types of rocks is a modification of Harker's idea that tectonic conditions affect the type of igneous activity. It is conceivable that the radiolarian cherts may represent radiolarian oozes and that in the abyssal depths where such oozes accumulate the tectonic conditions might be favorable for the eruption of igneous rocks of this peculiar type. Steinmann[171] has applied this idea to certain occurrences in the Alps. He believes that under the great depths of the ocean, there are bodies of gabbro-peridotite magmas, and thinks that when the abyssal sediments are raised above the surface of the sea, these basic magmas are injected into the sediments. However, the idea is not very convincing, since it encounters the fact that the cherts are not abyssal sediments.

Another fact which is in harmony with this idea of the origin of the radiolarian cherts is that in none of the oceanic investigations has anything at all like the radiolarian cherts been discovered. It has been shown that they are not like radiolarian oozes nor like any type of rock which might be derived from these oozes. In spite of the absence of these present-day equivalents, radiolarian cherts while certainly not abundant, are yet found in many places in the world. If formed under conditions of ordinary sedimentation, either mechanical, organic, or chemical, one would expect somewhere to encounter their equivalents in process of formation. The fact that such has not been found points to the conclusion that the formation of these cherts

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[171] Steinmann, G., Geologische Beobachtungen in den Alpen. II, Die Schardt'sche Ueberfaltungstheorie und die geologische Bedeutung der Tiefseeabsätze und der ophiolitischen Massengesteine.

Abstract by O. Wilckens *in* Neues Jahrbuch f. Mineralogie, Geologie und Paläontologie, Jahrgang II, 92, 1906.

required some unusual condition not now present in the basins of deposition. As pointed out by Van Hise and Leith, the ellipsoidal basalts seem to be the abnormal factor in their occurrence.

The question of the origin of the characteristic rhythmic bedding has been discussed. Of all the ideas suggested, two only appear of any promise. These are the idea of rhythmic precipitation due to periodic supersaturation and the idea of colloidal segregation. As pointed out, the idea of rhythmic precipitation is incapable of explaining all the facts, and it is necessary to appeal to the idea of segregation to explain the bedding of the cherts. Certain experiments are cited which indicate the possibility of such segregation.

At the time of precipitation of the cherts, there must have been numerous radiolaria thriving in the siliceous waters and their skeletons were accumulated in the ooze forming on the sea bottom. No calcareous organisms are found, indicating that the conditions were not favorable for their development. The radiolarian skeletons seem to have undergone a segregation also and to have behaved like the other colloidal silica. This might be expected on the idea of segregation, since the silica of the skeletons is in the colloid form and might be expected to behave in somewhat the same manner as the gelatinous silica. It must be admitted that so far it has not been possible to bring this about in an experiment.

The exact nature and mode of origin of the shale partings in the Franciscan cherts is left in doubt. It is in appearance not an ordinary clay shale. Its properties and its chemical composition are those which might be expected if a red mud became consolidated into a rock. On this interpretation it should be regarded as a terrigenous sediment accumulating in the basin in which silica was being precipitated. There is also the possibility that it might be in part, or wholly, a chemical precipitate resulting from the separation of certain substances brought out in the siliceous springs. It might also be a combination of mechanical, terrigenous sediment with chemical sediment of the type suggested. The shale partings of the Monterey cherts appear unquestionably to be mechanical sediments, and we might, by analogy with them, regard the Franciscan shales as mechanical sediments of unusually fine grain. However, in the Lake Superior District, cherts occur interbedded with iron oxide, and this iron oxide has been interpreted as a chemical precipitate. In the absence of further evidence, therefore, no absolute statement can be made, other than there is nothing about the Franciscan shales which opposes their interpretation as terrigenous muds.

The Monterey cherts resemble the Franciscan cherts in many ways, as previously pointed out. The latter have here been interpreted as due to siliceous springs associated with the intrusion and extrusion of certain igneous rocks of a peculiar type. The question arises as to whether the Monterey cherts have an origin similar to that postulated for the Franciscan cherts.

The Monterey cherts appear to have been laid down in the form of gelatinous silica. Evidence has been presented to show that they were not derived from diatomaceous earths. No sources of silica appear possible for the Monterey cherts which were not discussed in connection with the Franciscan cherts.

During Monterey time there was considerable igneous activity, both extrusive and intrusive. There are many important beds of tuff associated with the Monterey group, and some of the rocks referred to as sandstones contain so much volcanic glass that it is possible that they may represent tuffs, instead of ordinary clastics. Further than this, many igneous rocks are known in the Monterey group which are rich in soda minerals. These show the peculiar alteration of feldspar and its replacement by such soda-rich minerals as analcite and natrolite, both of which were cited by Dewey and Flett in support of their idea that the spilitic rocks gave rise to emanations of sodium silicate solutions. Rocks of this type, in association with the Monterey, have been found by Fairbanks,[172] who described an analcite diabase from southern California.

Haehl and Arnold[173] described basic rocks of somewhat similar nature from the Santa Cruz Mountains in San Mateo County.

It seems probable, therefore, that the Monterey cherts had an origin similar to that postulated for the Franciscan cherts.

172 The Geology of Point Sal, Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, pp. 1–92, 1896.

173 The Miocene Diabase of the Santa Cruz Mountains in San Mateo County, California, Proc. Am. Philos. Soc., vol. 43, p. 16, 1904.

EXPLANATION OF PLATE 25

Fig. A. Franciscan cherts in Golden Gate Park, San Francisco, showing thin bedding and contortion of the cherts.

Fig. B. Franciscan cherts exposed in quarry by cemetery, Piedmont. Shows rhythmic alternation of cherts and shales, the pinching and swelling of the chert beds, and wedging out of cherts and shales.

Fig. A

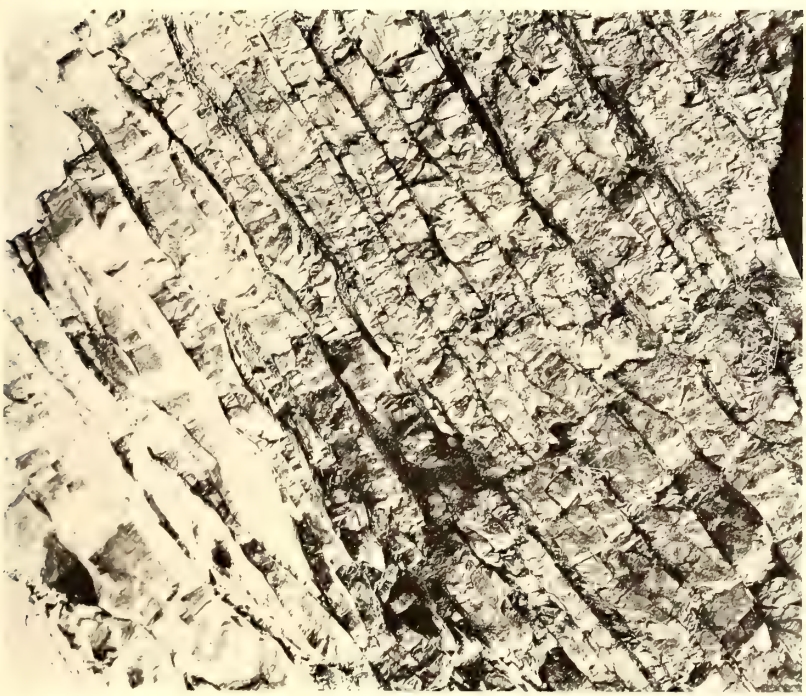

Fig. B

EXPLANATION OF PLATE 26

Fig. A. Franciscan chert on Twin Peaks Boulevard. Showing rhythmic alternation of red cherts and shales.

Fig. B. Franciscan chert in Perkins Cañon, Mount Diablo. Shows the veining of the cherts.

Fig. A

Fig. B

EXPLANATION OF PLATE 27

Fig. A. Franciscan chert near Tennessee Cove, Marin County. Shows mounding of chert, pinching and swelling of chert beds, and the wedging out of shale partings.

Fig. B. Franciscan chert, Twin Peaks, San Francisco. Shows pinching and swelling of beds and wedging out of shale partings.

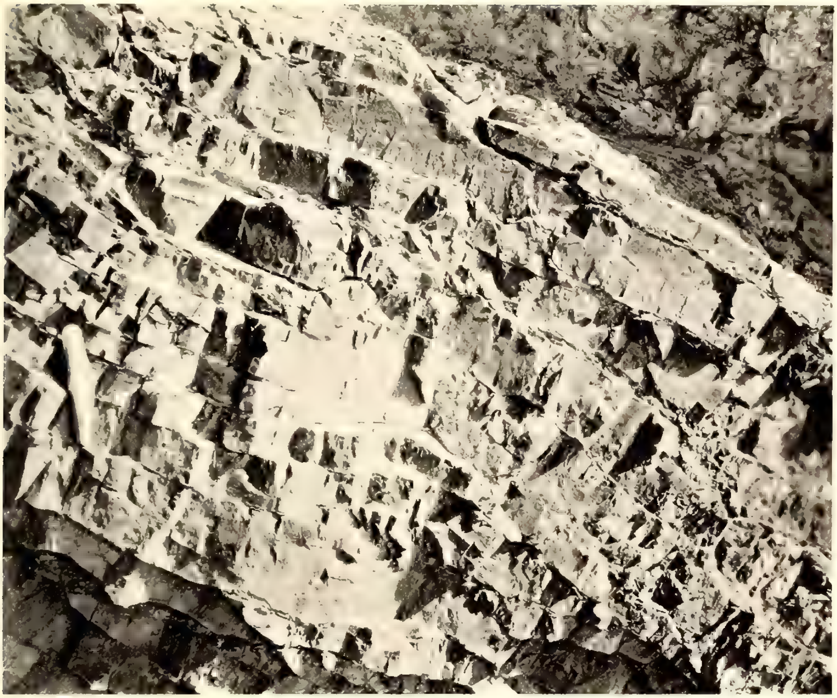

Fig. A

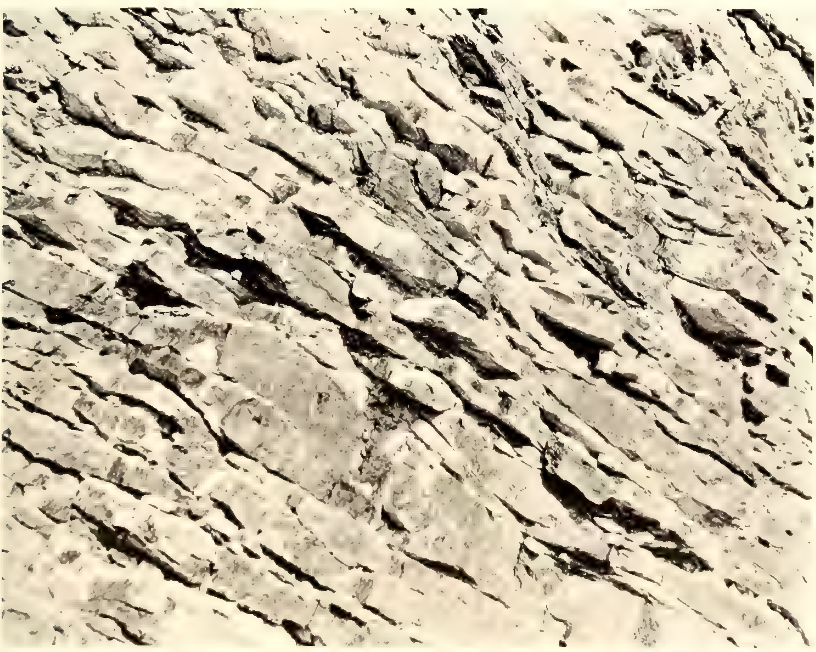

Fig. B

EXPLANATION OF PLATE 28

Fig. A. Franciscan chert, Tennessee Cove, Marin County. Shows pinching and swelling of chert, lenslike beds of chert, and the wedging out of shale partings.

Fig. B. Franciscan chert, Twin Peaks, San Francisco. Shows the occurrence of the typical red radiolarian chert in short lenses and nodules.

Fig. A

Fig. B

EXPLANATION OF PLATE 29

Fig. A. Concretions in red radiolarian chert, from the Franciscan group in the Santa Ynez Mountains.

Fig. B. Concretions in red radiolarian chert, from the Franciscan Group in the Santa Ynez Mountains.

Fig. C. Concretionary red chert, from the Franciscan area in North Berkeley.

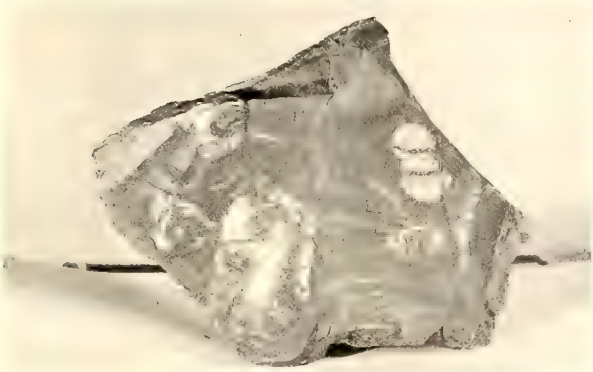

Fig. A

Fig. B

Fig. C

EXPLANATION OF PLATE 30

Thin sections of radiolarian chert

Fig. A. Mount Diablo. (Mag. 25×.)

Fig. B. North Berkeley. (Mag. 25×.)

Fig. C. Mount Diablo. (Mag. 15×.)

Fig. D. Mount Diablo. (Mag. 10×.)

Fig. E. North Berkeley. (Mag. 12×.)

Fig. F. Spherulitic chert. (Mag. 12×.)

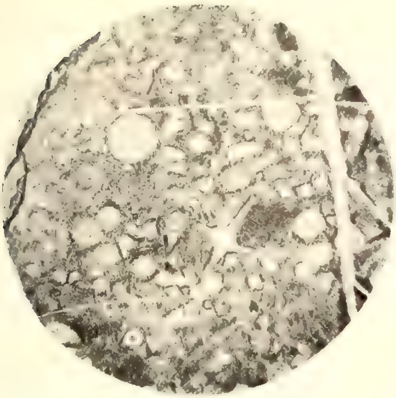

Fig. A

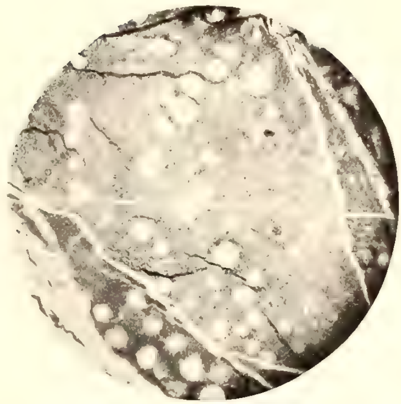

Fig. B

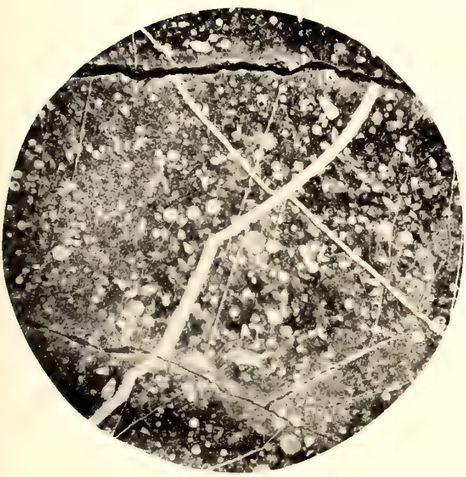

Fig. C

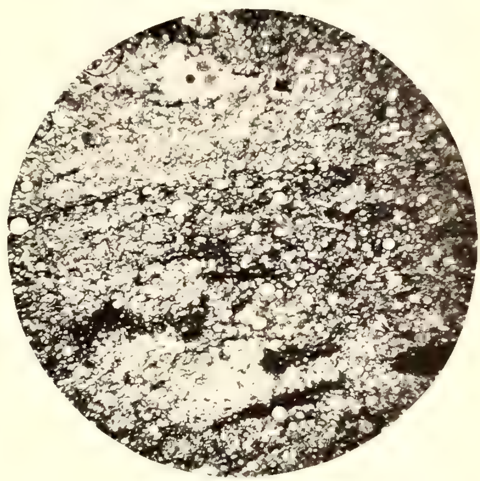

Fig. D

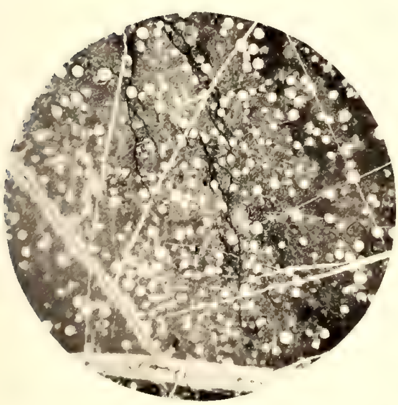

Fig. E

Fig. F

EXPLANATION OF PLATE 31

Fig. A. Specimen of red radiolarian chert showing leaching along fissures.

Fig. B. Pebble of red chert, showing the type of curving quartz veinlets which are developed at the contact with igneous rocks.

Fig. C. Chert rendered massive by contact action with development of network of quartz veins.

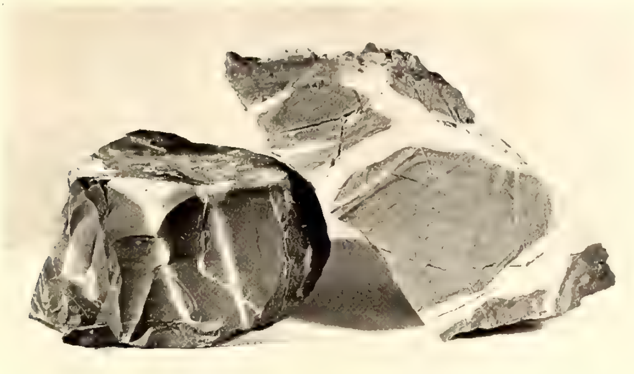

Fig. A

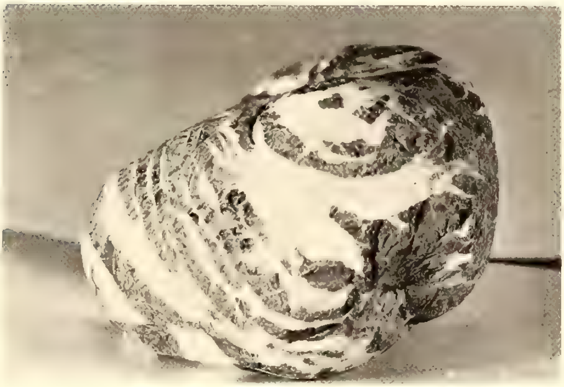

Fig. B

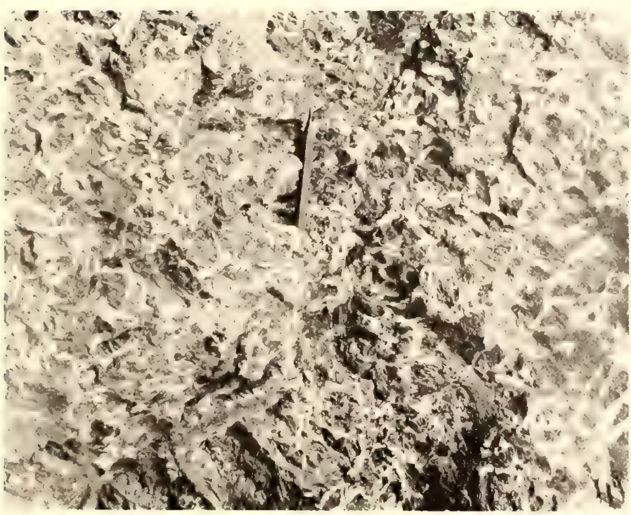

Fig. C

EXPLANATION OF PLATE 32

Fig. A. Mammillated surface developed on chert inclusion in gabbro. Aleso Cañon, Santa Ynez Mountains. (Two-thirds natural size.)

Fig. B. Mammillated surface developed on chert inclusion in gabbro. Aleso Cañon, Santa Ynez Mountains. (Two-thirds natural size.)

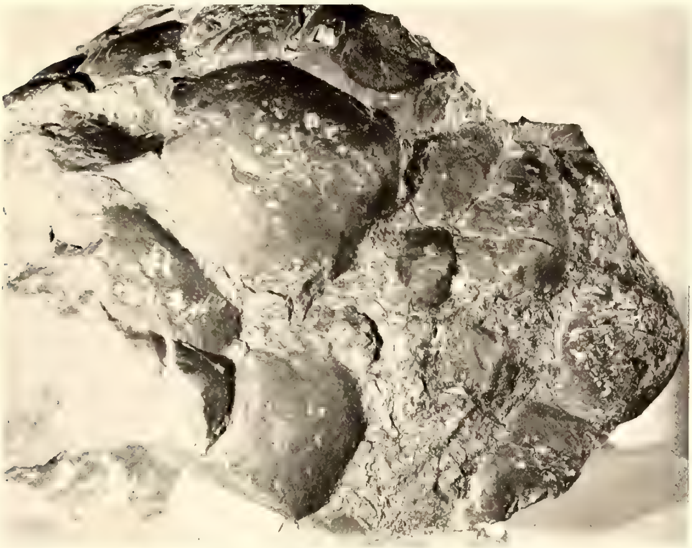

Fig. A

Fig. B

EXPLANATION OF PLATE 33

Fig. A. Monterey chert, Telegraph Cañon, east of Berkeley. Shows wedging out of chert and shale beds. The ruler is one foot long.

Fig. B. Monterey chert, Telegraph Cañon, east of Berkeley. Shows the wedging out of shale and chert beds, and minor irregularities of bedding.

Fig. A

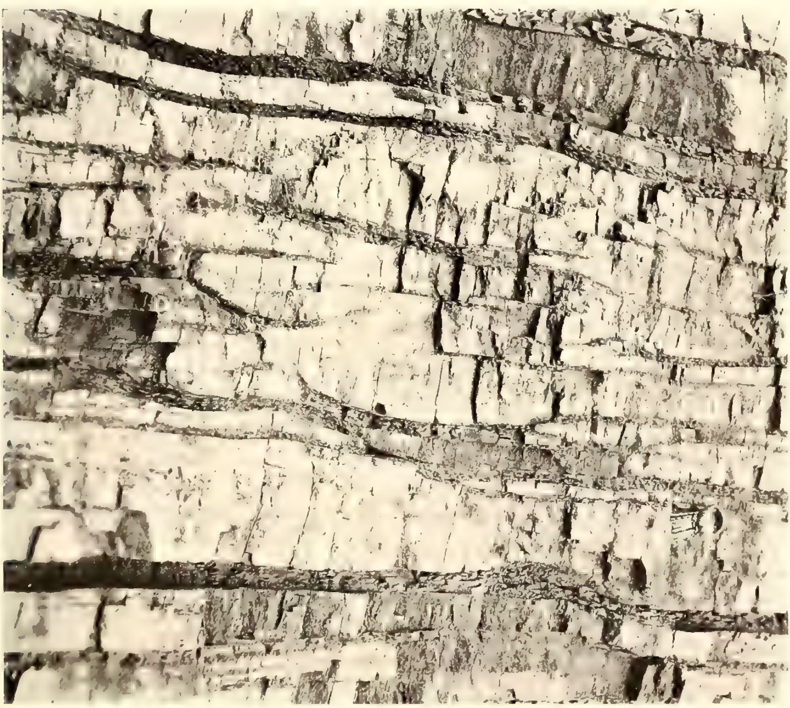

Fig. B

EXPLANATION OF PLATE 34

Fig. A. Monterey chert, Telegraph Cañon, east of Berkeley. Shows wedging out of small chert beds. Shows the manner in which laminations of chert abut upon the bounding surfaces of the beds.

Fig. B. Banded chert from Monterey, showing alternations of black flinty chert with white shale. (Two-thirds natural size.)

Fig. A

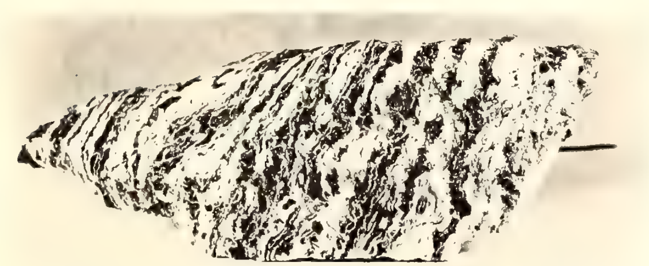

Fig. B

EXPLANATION OF PLATE 35

Fig. A. Monterey chert, showing weathering of chert to white shale. Note the alteration to white shale along fissures.

Fig. B. Monterey chert, showing unconformity in the lamination of the chert.

Fig. C. Monterey chert, showing weathering of black flinty chert to white shale. The base of the specimen is approximately parallel to the plane of bedding. Notice the manner in which the alteration transgresses the bedding.

Fig. D. Weathering of black flinty chert to white shale. Notice the transgression of bedding by the alteration. Notice also the development of white bands on the weathered surface.

Fig. A

Fig. B

Fig. C

Fig. D

EXPLANATION OF PLATE 36

The results of three experiments on the segregation of clay from gelatinous silica under the influence of diffusing ammonium carbonate solutions. (Two-thirds natural size.)

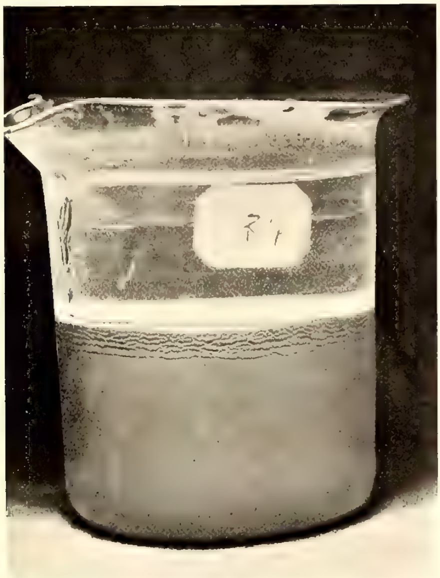

Fig. A

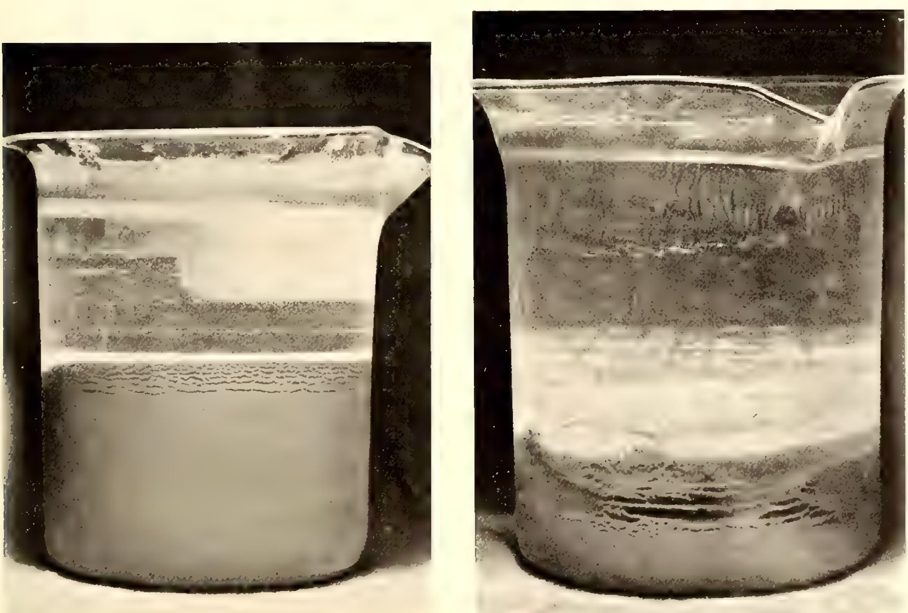

Fig. C

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A CESTRACIONT SPINE FROM THE MIDDLE TRIASSIC OF NEVADA

BY
PIRIE DAVIDSON

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A CESTRACIONT SPINE FROM THE MIDDLE TRIASSIC OF NEVADA

BY
PIRIE DAVIDSON

Among the vertebrate materials collected in the Middle Triassic beds exposed in the West Humboldt Range of Nevada there is a single fairly preserved spine of a cestraciont. Isolated spines resembling this specimen have been found in the Devonian, Sub-Carboniferous and Coal Measures of this country. One specimen, *Cosmacanthus elegans,* from the Lower Triassic of Idaho has been described by Evans.[1] Cestraciont teeth have been described from the Middle and Upper Triassic of California and Nevada by Miss Wemple[2] and by Bryant.[3] The teeth described by Miss Wemple represent the same locality as the specimen described here, which is a new species.

COSMACANTHUS HUMBOLDTENSIS, n. sp.

Type specimen no. 9162, Univ. Calif. Coll. Vert. Palae. From the upper part of the Middle Triassic, Straight Cañon, West Humboldt Range, Nevada.

The spine (figs. 1 and 2) is of medium size, tapering quite abruptly with a slight curve backward. The greatest length is 59.5 mm. and its greatest width 12 mm. It is bilaterally symmetrical and is made up of a long plain inserted portion which has a deep furrow posteriorly, and a short exserted portion which is partly covered by small closely set sculptured tubercles. Most of the projecting part is closed posteriorly and the furrow extends into it as the medullary cavity.

[1] Evans, H. M., A new cestraciont spine from the Lower Triassic of Idaho, Univ. Calif. Publ. Bull. Dept. Geol., vol. 3, pp. 397–402, 1 pl., 1904.

[2] Wemple, E. M., New cestraciont teeth from the West American Triassic, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 71–73, 1 pl., 1906.

[3] Bryant, H. C., Teeth of a cestraciont shark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, pp. 27–30, 1914.

The line separating the smooth base from the ornamented distal portion runs obliquely upward from anterior to posterior at an angle of about 45°. The lateral faces are slightly rounded. The inserted portion tapers to a quite sharp point in which the groove is wide open, shallow and has sharp edges. There is but slight indication of the arrangement of the tubercles in rows.

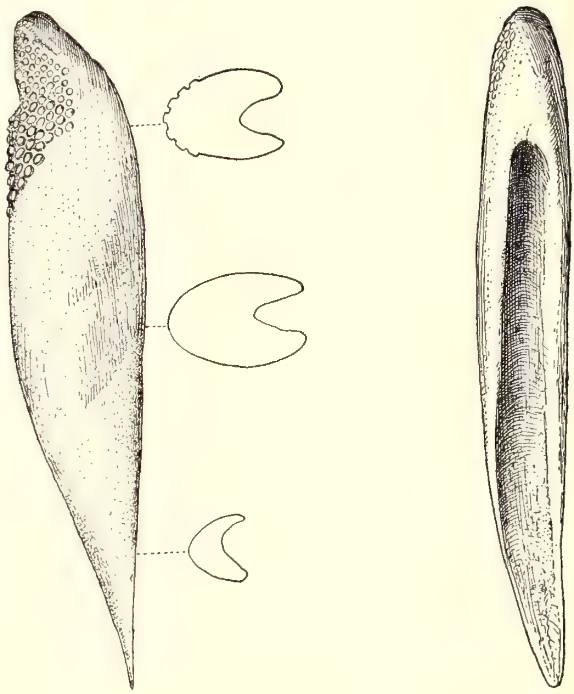

Fig. 1. *Cosmacanthus humboldtensis,* n. sp. Lateral surface of spine. Type specimen no. 9162. × 1½.

Fig. 2. *Cosmacanthus humboldtensis,* n. sp. Posterior surface of spine. Type specimen no. 9162. × 1½.

This spine resembles many other Ichthyodorulites in having bilateral symmetry, a smooth inserted portion and the exserted portion partly ornamented by sculptured tubercles.

From the description of *Cosmacanthus* Agassiz by Woodward[4] it probably belongs to that genus.

It differs in many respects from *Cosmacanthus elegans* Evans from the Lower Triassic of Idaho. Although the upper end is broken off,

[4] Woodward, A. S., Catalogue of the fossil fishes in the British Museum, pt. 2, p. 111, 1891.

its length was probably less than half as great. The greatest width of the Idaho specimen is 23 mm. and that of the Middle Triassic spine 12 mm. The shape of the spine, proportion of ornamented and unornamented surface, arrangement of tubercles and type of their sculpturing are very different. *Cosmacanthus elegans* has a strongly marked anterior enamel keel which is absent in the Nevada specimen.

This spine resembles *Asteracanthus ornamentissimus* Agassiz[5] in the absence of an anterior keel. In size, however, as well as in general form, distribution and detail of ornamentation, the two spines are unlike.

In general appearance it resembles *Geisacanthus bullatus* St. John and Worthen[6] from the Chester limestone, Chester, Illinois. This, however has a strong enamel keel and the part represented as ornamented is greater in extent. The shape of the inserted portion differs from that of the Nevada spine. The sculpturing of the tubercles is similar, although their size and arrangement are not the same.

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[5] Agassiz, L., Recherches sur les poissons fossiles, III Atlas, tab. 7, figs. 11, 13, 14, 15, 1843.

[6] St. John, O., and Worthen, A. H., Descriptions of fossil fishes, Palaeontology of Illinois, Geol. Surv. Illinois, vol. 6, pt. 2, pp. 446–447, pl. 17, figs. 3, 4, 1875.

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BY
JOHN C. MERRIAM

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INTRODUCTION

Early in the spring of 1911, John R. Suman, then a student of the University of California, brought to the writer a small collection of fossil bones and teeth obtained on the Mohave Desert by H. S. Mourning of Los Angeles. This collection was presented to the University by Mr. Mourning and Mr. Suman, and constituted the basis for the first study of the Mohave faunas. In a brief article[1] published soon after receiving this collection, the writer called attention to the importance of this discovery, as it offered the possibility of correlating the deposits of the Mohave region with those of the extensive mammal-bearing formations of the Great Plains area, and might ultimately assist in determining the time relations of formations in the Pacific Coast province to deposits of the Great Basin and Great Plains areas. The collection was considered to represent approximately an upper Miocene stage, and to point toward close faunal relation of the Mohave region with the Great Plains area in the period during which this fauna flourished.

In the spring and early summer of 1911, C. L. Baker, then fellow in palaeontology at the University, visited the locality reported by Mr. Mourning and secured a considerable collection of mammalian remains. Mr. Baker was joined later by Wallace Gordon and by Mr. Suman, who assisted with the work. In connection with the

[1] Merriam, J. C., A Collection of Mammalian Remains from Tertiary Beds on the Mohave Desert, Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, pp. 163–169, pl. 29, 1911.

palaeontologic study it was necessary to make a geological reconnaissance of the formations concerned. The results of this investigation have already been published by Mr. Baker.[2]

In December, 1911, a second expedition under the charge of Mr. Baker visited exposures of Tertiary beds near El Paso Peak on the northwestern border of the Mohave Desert, and made further collections, which added considerably to the list of forms obtained by the preceding expedition. On the December, 1911, expedition, the party with Mr. Baker consisted of J. Guintyllo, S. H. Gester, and G. E. Stone. The geologic section of the region near El Paso Peak has been described by Mr. Baker[3] with the results of his work on the correlation of events in the physical history of the region.

In January, 1913, H. S. Mourning and J. P. Buwalda visited the exposures of Tertiary mammal-bearing beds in the area north of Barstow, and obtained an excellent collection of the fauna at localities previously visited by Mr. Mourning. This collection was supplemented by specimens purchased from Mr. Mourning, and by some very useful material which Mr. Mourning kindly presented to the University.

In December, 1913, and January, 1914, J. P. Buwalda assisted by E. R. Brainard, E. M. Butterworth, and C. Stock, made a further examination of the Tertiary beds in the region of the El Paso Range in the northwestern part of the Mohave region, and obtained a collection of mammalian remains which adds much to our knowledge of the fauna of this section.

In March, 1915, the Pliocene beds west of the town of Mohave and at the type locality of the Ricardo beds west of the El Paso Range were visited by J. P. Buwalda and the writer. On this excursion a number of important specimens were secured from the lower portion of the Ricardo section at the type locality.

In the summer of 1915, a party working under direction of J. P. Buwalda worked over exposures of the Ricardo in the El Paso Range and secured a very valuable representation of the mammalian fauna of these beds. In addition to Dr. Buwalda this party included C. L. Moody, Edward Thatcher, and J. M. Douglas.

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2 Baker, C. L., Notes on the Later Cenozoic History of the Mohave Desert Region in Southeastern California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, pp. 333–383, pls. 34–43, 1911.

3 Baker, C. L., Physiography and structure of the Western El Paso Range and the Southern Sierra Nevada, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 117–142, pls. 8–10, 1912.

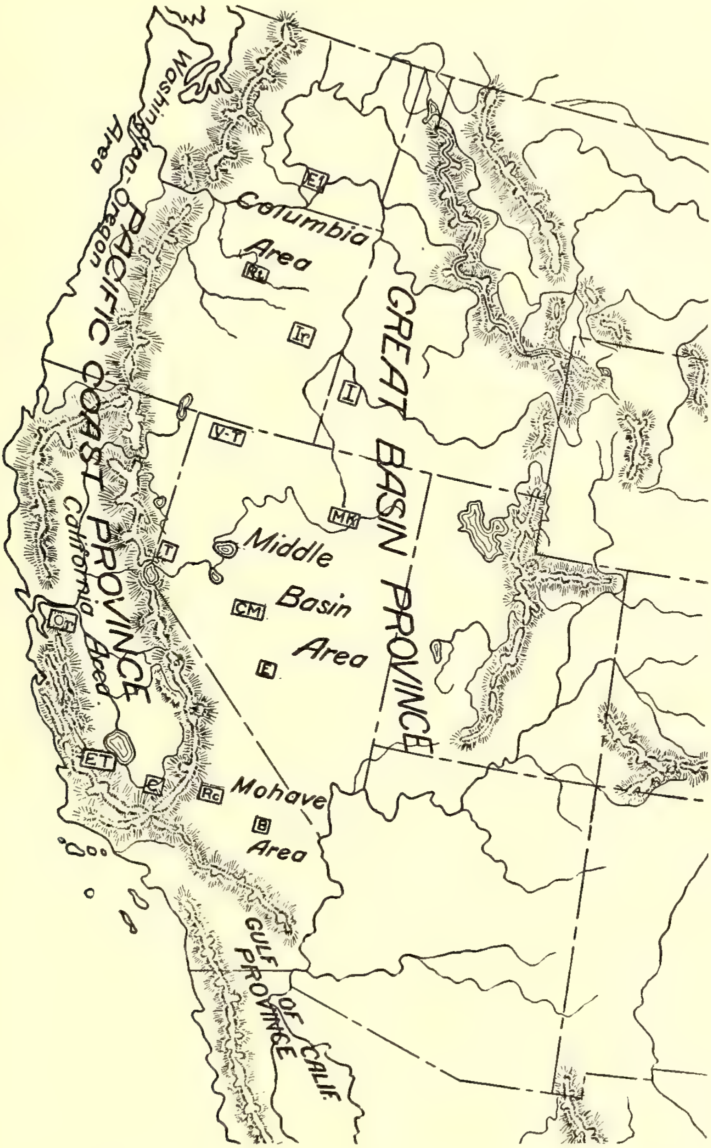

Fig. 1. Outline map illustrating occurrences of Miocene and Pliocene mammal faunas in Tertiary provinces of the United States west of the Wasatch Range. B, Barstow beds; Rc, Ricardo beds; C, Chanac formation; ET, Etchegoin-Tulare beds and Merychippus zone; Or, Orinda beds; E, Esmeralda beds; CM, Cedar Mountain beds; T, Truckee beds; MK, McKnight Miocene; V–T, Virgin Valley and Thousand Creek beds; I, Idaho beds; Ir, Ironside Pliocene; Rt, Rattlesnake Pliocene and Mascall Miocene; El, Ellensburg formation.

GEOGRAPHIC SITUATION AND EXISTING PHYSICAL CONDITIONS IN THE MOHAVE AREA

The Mohave area is a province or subdivision of the Great Basin region, of which it forms the southwest corner. The Great Basin is separated from the Coast or Pacific region on the northwest side of the Mohave area by the abruptly rising Sierra and Tehachapi ranges. On the southwest side of the Mohave, the San Bernardino, San Gabriel, and other ranges extending between the San Gabriel and the Tehachapi, form a clearly marked boundary.

To the north the Mohave area extends into valleys between the parallel ranges situated to the east of Owens Lake. To the northeast it grades almost insensibly into the Middle Basin or Nevada area of the Great Basin. A natural boundary seems to be fixed by a range running nearly parallel with the California-Nevada line southeast of the Amargosa Range. To the east the Mohave area may be limited by more or less irregular groups of mountain ranges lying between the San Bernardino Range and the Opal Mountains and Dead Mountains west of the Colorado River at the southern end of Nevada. Considering this area in a broad sense, rather than as limited strictly to the Mohave Desert, the Mohave area seems naturally to reach east and southeast to the western border of the plateau, lying to the east of the Colorado River.

The Mohave area is in general one of extreme aridity at the present time. The rainfall is about five inches in the western portion of the desert near the town of Mohave, and may be one or two inches less in the region farther to the east, near Barstow. Living streams are rare, and travel in all of this region has necessarily been limited by scarcity of localities at which potable water can be obtained. In recent years the development of artesian water has made agricultural operations possible in regions which previously had been uninhabitable.

EXISTING LIFE OF THE MOHAVE AREA

The vegetation of the Mohave area is at the present time limited to desert types, and the contrast with the flora on the opposite side of the mountains bordering the desert to the west is marked. Plants of arboreal types comprise only a very few junipers and the tree yuccas. The creosote bush is commonly present and is the dominant plant of this area.

The Recent mammalian fauna of the desert includes thirty-five species, of which twenty-one are rodents. The Ungulata include only the pronghorn antelope (*Antilocopra americana*) and the desert bighorn (*Ovis nelsoni*). The Carnivora include the desert coyote (*Canis ochropus estor*), the Mohave Desert kit fox (*Vulpes macrotis arsipus*), the California raccoon (*Procyon lotor psora*), a spotted skunk, a striped skunk, the northwestern cougar (*Felis oregonensis*), and the desert wildcat (*Lynx eremicus eremicus*). The rodent fauna comprises thirteen genera which are included in the representative list given below, kindly furnished for this study by Dr. Joseph Grinnell.

Recent Mammals Known from the Mohave Desert

Myotis californicus pallidus Stephens	Little pallid bat
Pipistrellus hesperus hesperus (H. Allen)	Western bat
Eptesicus fuscus (Beauvois)	Large brown bat
Antrozous pallidus (LeConte)	Desert pallid bat
Nyctinomus mexicanus Saussure	Mexican free-tailed bat
Canis ochropus estor C. H. Merriam	Desert coyote
Vulpes macrotis arsipus Elliot	Mohave Desert kit fox
Procyon lotor psora Gray	California raccoon
Spilogale phenax C. H. Merriam	California spotted skunk
Mephitis occidentalis holzneri Mearns	Southern California striped skunk
Felis oregonensis Rafinesque	Northwestern cougar
Lynx eremicus eremicus Mearns	Desert wildcat
Onychomys torridus pulcher (Coves)	Desert grasshopper mouse
Reithrodontomys megalotis deserti Allen	Desert harvest mouse
Peromyscus maniculatus sonoriensis (LeConte)	Sonora white-footed mouse
Peromyscus crinitus stephensi Mearns	Stephens Cañon mouse
Neotoma intermedia desertorum C. H. Merriam	Desert wood rat
Neotoma fuscipes mohavensis Elliot	Mohave wood rat
Microtis californicus mohavensis Kellogg	Mohave River meadow mouse
Thomomys perpallidus perpes Merriam	Lone pine pocket gopher
Perognathus panamintinus bangsi Mearns	Bangs pocket mouse
Perognathus formosus C. H. Merriam	Long-tailed pocket mouse
Perognathus penicillatus stephensi C. H. Merriam	Stephens pocket mouse

Perognathus fallax pallidus Mearns	Pallid short-eared pocket mouse
Perodipus microps C. H. Merriam	Small-faced kangaroo rat
Perodipus panamintinus C. H. Merriam	Panamint kangaroo rat
Dipodomys deserti Stephens	Big desert kangaroo rat
Dipodomys merriami simiolus Rhoads	Allied kangaroo rat
Citellus beecheyi fisheri (C. H. Merriam)	Fisher ground squirrel
Citellus mohavensis (C. H. Merriam)	Mohave ground squirrel
Ammospermophilus leucurus leucurus (C. H. Merriam)	Antelope ground squirrel
Lepus californicus deserticola Mearns	Colorado Desert jackrabbit
Sylvilagus auduboni arizonae (Allen)	Arizona cottontail
Antilocapra americana (Ord)	Pronghorn antelope
Ovis nelsoni C. H. Merriam	Desert bighorn

Of the Recent fauna only a few genera are known from the Tertiary of the Mohave area. A number of the existing forms, such as the bighorn, are probably immigrants from the Old World, which arrived considerably later than the deposition of the youngest Tertiary beds of the Mohave. Unfortunately we have as yet been able to obtain only a very meager representation of the rodent fauna of the Tertiary beds of this region. When this fauna is better known a number of genera now living will undoubtedly be recognized in the Mohave Tertiary.

OCCURRENCE AND NOMENCLATURE OF THE MAMMAL BEDS

Geologic sections of the Tertiary beds in the Mohave region are most satisfactorily exposed in an extensive series of deposits in the Barstow syncline north of the town of Barstow, and in excellent exposures around Ricardo Post Office in Red Rock Cañon, between the eastern foot of the Sierras and the El Paso Range. These deposits, with other exposures spread widely over this area, have been referred by C. L. Baker,[4] and earlier in part by O. H. Hershey,[5] to the Rosamond series on the assumption that they represent one great period of accumulation.

While the name Rosamond may be used tentatively for the middle and late Tertiary sediments of the Mohave area it has not been demonstrated that the several formations represented are as closely related in their depositional history as they appeared in the first investigations. It seems necessary to discuss the beds in the Barstow syncline

[4] Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, pp. 333–383, 1911.

[5] Amer. Geol., vol. 29, pp. 365–370, 1902.

and those at Ricardo as distinct divisions, since the evidence of the faunas indicates that the deposits were laid down in rather widely separated epochs. The known fauna of the Barstow syncline occurs near the top of the section, and it is very doubtful whether beds containing a fauna like that of the much more advanced stage of Ricardo is present in the Barstow section. The fauna at Ricardo occurs through the greater part of the Red Rock Cañon section. Though it is possible that the lower Ricardo beds contain a faunal assemblage similar to that of the Barstow region, evidence indicating the presence of a typical Barstow fauna has not been obtained. The Rosamond series of Hershey may include beds containing the older fauna of Barstow, but it is doubtful whether it comprises sediments of the stage represented at Ricardo.

In an earlier publication the writer[6] referred to the fauna of the Barstow syncline as the Mohave fauna, this name being considered mainly as a geographic designation. Later, in order to avoid confusion with other Tertiary faunas occurring in the Mohave area, the name Barstow[7] has been used for this faunal assemblage, and Barstow formation[8] for the beds containing the Upper Miocene or Barstow fauna. This formation comprises the uppermost of five divisions in the Barstow syncline, described by Baker[9] as the Fossiliferous Tuff member, and any other beds which may be recognized as representing the horizontal or vertical extension of the same depositional unit. The limits of the Barstow formation may be found to correspond with those of the Fossiliferous Tuff member, or they may include a greater range of sediments above and below. It is possible that the Barstow fauna occurs in all of the strata of the Barstow syncline. It is also easily possible that the lowest strata of that section will be discovered to contain a faunal assemblage much older than the particular Upper Miocene assemblage known in the Fossiliferous Tuff. The Resistant Breccia Member immediately below the Fossiliferous Tuff in Baker's Barstow syncline section seems to contain a representation of the Barstow fauna, and may ultimately be included in the Barstow formation. Should the Resistant Breccia be recognized as a distinct formation the name Barstow group may be used for the sequence of formations.

[6] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 168, 1911.

[7] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, p. 285, 1915; vol. 9, pp. 7, 49, 1915; vol. 9, p. 171, 1916.

[8] Merriam, J. C., Pop. Sci. Mon., p. 252, March, 1915.

[9] *Op. cit.*, vol. 6, pp. 345–346, 1911.

The Barstow formation will be recognized as a division of the Rosamond Series if the Barstow syncline corresponds to the type section of the Rosamond at Rosamond station, as has been assumed by Hershey and by Baker. As yet it seems difficult to make certain of correlation between the Barstow syncline and the type Rosamond section, as palaeontologic evidence is lacking at Rosamond. If the Barstow formation is considered as a member of the Rosamond, it is presumably a late member of the series.

The section of deposits at Red Rock Cañon was first described by G. K. Gilbert,[10] who gave the essential features of the stratigraphic succession and referred to the exposures as the Red Rock Cañon beds. More than twenty years later, in 1896, H. W. Fairbanks[11] gave a further description of the section at Red Rock Cañon furnishing estimates of thickness, degree of deformation, and extent of distribution of the beds. Following the usage of Gilbert, Fairbanks referred to the section as the Red Rock Cañon beds.

In a paper reviewing the Eocene of North America in 1900, J. H. Smith[12] used the heading "Mohave Formation" for a paragraph which, with the exception of a little more than one line, consisted of a quotation from Fairbank's description of the sediments in the region of El Paso Range and Black Mountain. Smith's reference was directed especially toward a portion of the section near Black Mountain from which Fairbanks reported leaves determined by F. H. Knowlton as Eocene. Recent investigation of the area in which the leaves were found has not made clear the stratigraphic relations of the plant horizon, and it is possible that the lowest beds at Black Mountain from which the reported Eocene leaves were obtained may actually represent an Eocene horizon.

In discussing the Cenozoic history of the Mohave Desert in 1911 C. L. Baker[13] referred the Red Rock Cañon section to the Rosamond Series. In his paper[14] on the Physiography and Structure of the Western El Paso Range Baker continued use of the term Rosamond Series for the Red Rock Cañon section.

Following the discovery that the fauna from the beds in Red Rock Cañon is sharply distinct from that in the Barstow section, the writer

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[10] Geographical and Geological Explorations West of the 100th Meridian, pp. 142–143, 1875.

[11] Amer. Geol., vol. 17, pp. 68–69, 1896.

[12] Jour. Geol., vol. 8, pp. 455–456, 1900.

[13] Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 354, 1911.

[14] Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 117–142, 1912.

has described numerous mammalian forms from the Red Rock Cañon section as representing the Ricardo fauna,[15] Ricardo beds, or Ricardo Pliocene. In a recent article[16] the name Ricardo formation was used for the stratigraphic unit containing the fauna of the beds at Ricardo Post Office.

In some respects there may be justification for use of the name Red Rock Cañon beds, formation, or group for the stratigraphic sequence containing the fauna at Ricardo, as this was the first designation used for the section. The name was however not used for nomenclature purposes either by Gilbert or by Fairbanks, and has the disadvantage of extreme length, including as it does three words. The term Mohave formation occurring in Smith's article is again evidently not applied for naming purposes, as it is merely a heading for a division of the paper, with other names a considerable proportion of which are not actually formations. The application of the name is not clear, as it may be presumed to refer to Eocene beds, and an Eocene formation distinct from the Ricardo group is possibly present in the Black Mountain region. Use of the name Mohave, if it were now adequately defined, would certainly lead to confusion of the fauna at Red Rock Cañon with the Barstow fauna known from the large exposures in the middle of the Mohave Desert. It has therefore seemed necessary to continue use of the name Ricardo for the fauna occurring in the Red Rock Cañon section. In the geologic sense the name Ricardo group may be used for the sequence of strata exposed at Ricardo Post Office with its upward and downward extension within the depositional unit. It is not improbable that several formations may ultimately be mapped within the limits of the Ricardo group. The stratigraphic relation of the Ricardo to the Barstow is not determined, as the two are not known to be in contact. Should the two faunas be found to overlap, the stratigraphic units would perhaps be combined, but distinctness of the faunas makes this improbable.

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15 Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, p. 285, 1913; vol. 7, p. 436, 1913; vol. 8, p. 276, 1914; vol. 8, p. 285, 1915; vol. 9, p. 5, 1915; vol. 9, p. 54, 1915; vol. 9, pp. 170–171, 1916.

16 Merriam, J. C., Pop. Sci. Mon., vol. 86, p. 253, March, 1915.

GEOLOGIC RELATIONS OF THE TERTIARY FORMATIONS

The Tertiary sediments of the Mohave area rest upon a basement including granites and schists of pre-Tertiary age, and extrusive igneous rocks presumably at least as old as Lower Miocene. A flow of basic andesite or of acid basalt overlies the granitic rocks and underlies the basal Tertiary sediments of the Barstow syncline. A rhyolite described by Lindgren from the Calico Mountains is stated by Baker to underlie beds considered to represent the Rosamond Series.

Excepting marine deposits of Eocene age, the oldest Tertiary rocks in the Mohave area of which the age is certainly known are included in the Barstow formation representing the upper Miocene. The Barstow fauna is found in the uppermost or Fossiliferous Tuff member of the five divisions referred by C. L. Baker to the Rosamond Series in the section north of Barstow. The Resistant Breccia member immediately below the Fossiliferous Tuff member of Baker's section also contains mammalian remains presumably of the same faunal stage as those of the member immediately above. The only known fossil remains occurring below the Resistant Breccia member in the Barstow syncline section consist of a single imperfectly preserved fresh-water gastropod found in the third member from the upper end of the section. This specimen does not furnish definite evidence of age of the beds in which it occurs.

Leaves stated by F. H. Knowlton to resemble Eocene species were collected by H. W. Fairbanks[17] near the base of the Ricardo section at Black Mountain near El Paso Range on the western border of the Mohave area. There is some doubt as to the age of these specimens, as also regarding their occurrence, and recent examination of the old coal workings from which the plants were obtained has not furnished sufficient information to permit a judgment as to the age of the plant-bearing beds.

Dr. Fairbanks reported the occurrence of a seam of coal fourteen inches thick, enclosed between clay strata, and apparently occupying a position below the tuffs to the southeast of Black Mountain. Impressions of leaves in the clay above the coal were examined by Dr. Knowlton who reported that they represent three small fragments of plants belonging in two species, *Sapindus affinis* Newb. and *Anemia subcretacea* (Sap.) Ett. and Bard. This material was considered as

[17] Amer. Geol., vol. 17, pp. 63–74, 1893.

hardly sufficient to warrant speaking with positiveness concerning the age of the beds, but the species were considered as certainly Tertiary and seemed to belong to the Eocene. Both species were stated to have quite a wide geographic distribution and with several unimportant exceptions to be confined to the Eocene.

At the writer's request the old coal workings on Black Mountain were recently examined by J. P. Buwalda who reports upon them as follows:

> The location of the old coal workings is about two miles to the southeast of Black Mountain, and in the saddle between that mountain and the main El Paso Range. The coal mines were worked at least 12 or 15 years ago. There is only one shaft available and that can no longer be entered. The coal seen in this locality is at the base of the sedimentary series. The Ricardo here lies on a metamorphosed complex quite certainly of pre-Cretaceous age. It is not possible to say certainly that the leaf formation is a member of the Ricardo formation. It might be a freshwater formation deposited upon the metamorphosed complex of the El Paso Range in early Tertiary time, and the Ricardo beds may be of later date deposited unconformably upon it. The stratigraphic relations around the coal mine are not clear.
>
> The dump from the coal mine has been burned over so that no solid material is left. A few impressions of two or three plants resembling rushes were found but no determinable specimens were obtained.

Near the extreme western border of the Mohave Desert area the Eocene is represented by marine deposits of the Martinez or Lower Eocene stage.[18a] This section has an estimated thickness of at least 5000 feet. How far the marine Eocene deposits extended over the Mohave area originally is not known. It is possible that land or fresh-water beds were accumulating in this area contemporaneously with the marine Eocene, or the sea may have covered a considerable portion of the area. No marine deposits of later age than Eocene are known in the Mohave area.[18b]

Barstow Syncline Section.—The section in the Barstow syncline consists in a large part of volcanic materials with beds of clay and shale at some horizons. The deposits are evidently partly of terrestrial and partly of lacustrine origin. At rare horizons, remains of fresh water mollusca including *Planorbis* and *Anodonta*(?) are abundant. In other beds scattered and weathered bones, representing a large tortoise and numerous mammals belonging to the open plains type probably indicate accumulation on dry land. Baker held that

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[18a] Dickerson, R. E., Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, p. 293, 1914.

[18b] Since this paper was written Wallace Gordon has discovered marine beds of middle Tertiary age on the western border of the Mohave area near Quail Lake, 35 to 40 miles west of Lancaster on the main line of the Southern Pacific Railroad.

the Rosamond as described by him was accumulated mainly "under the same conditions of desert aggradation as operate in the region at the present day." As is suggested in the following discussion (p. 450) the writer considers that during deposition of the Barstow beds the climate may have been considerably more humid than at the present time.

The Barstow syncline section was divided by Baker into the following five members:

1. Fossiliferous tuff member (uppermost division).
2. Resistant breccia member.
3. Fine ashy and shaly tuff member.
4. Tuff-breccia member.
5. Basal breccia member (lowest division).

The five divisions in the Barstow syncline were considered by Baker to represent to some extent local conditions, the number of members being possibly increased or diminished at other localities in

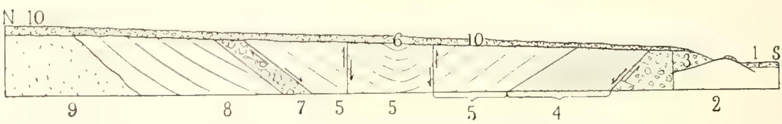


Fig. 2. North and south section through the middle of the minor axis of the Barstow syncline. Length of section is approximately three miles. (1) Basin alluvium. (2) Basic andesite or acid basalt. (3) Basal breccia member. (4) Fine ashy and shaly tuff member. (5) Resistant breccia member. (6) Uppermost beds of fossiliferous tuff member. (7) Coarse granodiorite breccia, separated from (8) by an unconformity. (8) Tuff-breccia member. (9) Granodiorite. (10) Unconformable mantle of alluvial debris, dipping toward basin. (After Baker.)

this area. It is perhaps desirable to give a distinct formation name to each of the five divisions, but a more intimate knowledge of the geology of this region must be obtained before the divisions are all recognized as representing more than local phases of the series. A more complicated history for the beds of this section than that now known may yet be demonstrated.

The lowest or Basal Breccia member in the south limb of the Barstow Syncline rests upon the eroded surface of both granodiorite and a basic andesite or acid basalt. The Basal Breccia contains fragments of the rocks below it. The fragments are mostly angular or subangular. The rocks of this member evidently represent a type recently designated as fanglomerate by A. C. Lawson.[19] This division is at least several hundred feet in thickness.

[19] Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 325–334, 1913.

The Tuff-Breccia member, or second division from the base, differs from the lowest member in being composed of finer fragments containing less granitic material and in having a much larger proportion of volcanic ash in the matrix. It is considerably over a thousand feet in thickness in the north limb of the Barstow syncline. The upper limit of this member was considered by Baker to be defined by an unconformity of unknown extent. This division is made up of variegated beds ranging from cream-color through red, purple, brown, and green.

The Fine Ashy and Shaly Tuff member, numbered three above the base, has a thickness of approximately 500 feet. It consists of fine materials comprising ash toward the base, and dark, compact mudstone toward the top. A single fossil, a *Planorbis,* was found in this division.

The Resistant Breccia member, number four, may be designated as a fanglomerate. It is in general coarser than the Tuff-Breccia. It differs from the basal member in having a larger percentage of volcanic ash. It weathers into badland forms, and contributes some of the characteristic scenic features of the region. This division is approximately 1000 feet in thickness. The beds range in color from gray to brown and red, but are not as brilliantly colored as in the Tuff-Breccia member. A considerable collection of mammalian remains was obtained in this division. These specimens seem to represent the fauna known from the typical horizon of the Barstow in the fifth division immediately above.

Of the Fossiliferous Tuff member, the typical Barstow, forming the uppermost portion of the section, evidently only a portion is now available for study, the remainder having been removed by erosion. There is a gradual gradation from the coarser beds of the Resistant Breccia member into the fine, overlying beds of the Fossiliferous Tuff. The uppermost division is made up mainly of bluish-gray to yellowish-brown, slightly indurated strata, composed largely of fine arkose with a considerable percentage of volcanic ash. The principal deposits of mammalian remains representing the Barstow fauna occur in this member of the Barstow syncline section.

Ricardo or Red Rock Cañon Section.—In the extensive exposures of sediments constituting the type section of the Ricardo group at Red Rock Cañon between the El Paso Range and the Sierra Nevada, the mammalian fauna is distinctly different from that of the Barstow syncline, and of a later phase. This section includes more than three thousand feet of deposits which are largely tuffaceous. The section as given by Baker is as follows:

	Feet
Brownish to red tuff-breccia	-----
Ashy, tuffaceous beds, quite coarse and poorly assorted up to	75
Fine, well cemented breccia	40
Arkose and lava-breccia interbedded with tuff	-----
Vesicular basalt	-----
Tuff-breccia, fine, gray, poorly stratified	50
Vesicular basalt	50
Tuff-breccia, light gray, rather fine, poorly stratified	300
Gray beds interspersed with layers of dark red	150–250
Pink-spotted tuff-breccia forming one massive bed	100
Dark, red breccia with thinner interstratified gray layers	250 +

Dr. J. P. Buwalda, who has made a careful study of the type section of Ricardo, giving especial attention to the highest and lowest portions, has kindly furnished the following description and measurements:

Estimated Section of the Strata Exposed Along Red Rock Cañon near Ricardo

	Feet
Extending from the upper of the basalt flows to the top of the exposed section. Beds of yellowish arkosic material, consisting of coarse angular particles of quartz and feldspar and containing a large admixture of angular fragments of granitic rock; muddy sandstones gray, light bluish gray or brown in color and which because of lack of classification of their materials are indistinctly bedded; occasional layers of ash, pumiceous material, and brown calcareous material. The general lack of classification and of distinct bedding in the materials and their angular character indicate that they are quite certainly waste-slope and playa lake deposits	1350?
Columnar basalt, vesicular at upper surface	25?
Grayish blue arkosic strata, with some clay layers	40?
Of the section beneath the lavas the lower portion consists principally of bluish arkosic material, the middle portion of tuffaceous strata including several hundred feet of massive pumiceous tuffs of pink and brown hues, and the upper portion, immediately beneath the lava, consists principally of bluish arkosic beds with some clayey material	1400?

Mammalian remains are found through the whole of the Ricardo section. At a number of horizons, both above and below the lavas, specimens have been found relatively abundant. It is possible that further collecting along the strike of the beds will disclose other localities in which material will be found well represented at horizons from which as yet little has been obtained.

PALAEONTOLOGIC MATERIALS AVAILABLE

Remains of Tertiary vertebrates are known from a wide area in the Mohave region. They are not abundant in many places, but at a few localities fragmentary specimens are found scattered over the ground in considerable numbers. Connected parts of skeletons are rare. At a number of points where bones were found in place in the Tertiary sediments they were disconnected, and it is evident that the mode of deposition of the beds, and of the accumulation of remains, were such that skeletal parts were generally widely scattered and broken or weathered before final burial.

The preservation of teeth and bones available is commonly good; that is, the bones have not rotted nor broken down to a great extent since burial.

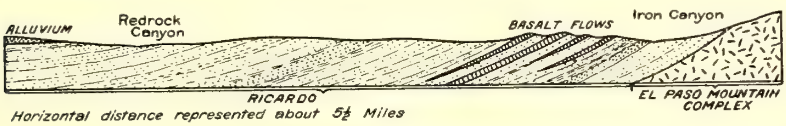


Fig. 3. Somewhat generalized north and south section through the Ricardo beds, extending from the basement complex of El Paso Mountain to the alluvium of the Mohave Desert. Section prepared by J. P. Buwalda.

The collections obtained represent several thousand specimens, mostly teeth and portions of limb bones. In a few cases good skull material was secured.

In the Barstow beds vertebrate remains are found almost exclusively in the uppermost zone of the Barstow syncline as described by Baker. This division of the section was designated by Baker[20] as the Fossiliferous Tuff member. In this portion of the section there are occasional layers several inches in thickness containing an unusually large representation of mammalian bones. One horizon of this nature furnishing many remains of *Merychippus,* was known in the field as the Merychippus bed or zone. Bones were found in the Resistant Tuff member or fourth horizon, but were not discovered, so far as the writer is aware, in the first, second, and third of the five members, counting upward from the base of the section.

In the Ricardo beds mammalian remains were found through the greater part of the section. Good specimens are not abundant at any horizon, but at a few localities fragments are common. At nearly all horizons careful collecting will uncover a small representation of the fauna.

[20] Baker, C. L., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 345, 1911.

BARSTOW FAUNA

Mollusca
- Anodonta?
- Planorbis mohavensis Hannibal
- Limnaea, sp.

Testudinata
- Testudo mohavense, n. sp.

Aves
- Buteo, sp.

Carnivora
- Canid (Canis?), sp. small
- Tephrocyon, near temerarius (Leidy)
- Aelurodon, near wheelerianus Cope
- Aelurodon, Dinocyon, or Amphicyon, sp.
- Machaerodont, sp. *a*
- Machaerodont, sp. *b*
- Machaerodont, sp. *c*
- Felid?, indet.
- Pseudaelurus, sp.

Rodentia
- Lepus?, sp.

Proboscidea
- Tetrabelodon?, sp.

Equidae
- Hypohippus, near affinis (Leidy)
- Parahippus? mourningi Merriam
- Merychippus (Protohippus) intermontanus Merriam
- Merychippus calamarius stylodontus, n. var.
- Merychippus sumani Merriam
- Protohippus? or Pliohippus?, sp.

Suidae
- Prosthennops?, sp.

Oreodontidae
- Merycochoerus? buwaldi, n. sp.

Camelidae
- Procamelus, sp. *a*
- Procamelus, sp. *b*
- Pliauchenia, sp.
- Alticamelus?, sp.

Cervidae
- Dromomeryx or Cervus?, sp.

Bovidae
- Merycodus necatus? Leidy
- Merycodus? coronatus Merriam

Relation of the Barstow Fauna to its Environment

The fauna of the Barstow beds is as a whole that of an open country affording fairly abundant grass and herbage, and evidently better watered than the Mohave Desert at the present day. The abundance of remains of grazing horses of the *Merychippus* type, the presence of mastodons, oreodonts, abundant merycodonts, a considerable variety of camels, and a peccary all indicate that nutritious vegetation must have been more abundant than at present. The *Merychippus* forms would probably not have been present in such numbers unless grasses were well represented.

The climate of the Mohave area during the time of deposition of these mammal-bearing beds was not improbably semi-arid, like portions of the Great Valley of California at the present day. The relatively small representation of peccaries and oreodonts and of the *Hypohippus* group, and the presence of large tortoises is possibly to be correlated with open semi-arid character of the country.

That small bodies of water were present at times in this area is shown by the discovery of an abundance of fresh water molluscan remains at certain horizons.

Stage of Evolution and Relationships of the Barstow Fauna

RELATION TO TERTIARY FAUNAS OF THE GREAT BASIN REGION

The fauna of the Barstow beds represents a stage in the evolution of Tertiary mammalian faunas not previously distinctly recognized in the Great Basin Province. It seems clearly later than the Middle Miocene stage of the Mascall and Virgin Valley; and is markedly older than Rattlesnake, Thousand Creek, and Ricardo, representing the next known stage following the Middle Miocene in the Great Basin. The fauna of the Barstow has few if any species in common with that of the Ricardo, and is of a distinctly older type. Its nearest relationships are with the faunal assemblage of the Cedar Mountain region of southwestern Nevada, from which it possibly differs somewhat in stage.

Compared with the Middle Miocene faunas of the Mascall and Virgin Valley the Carnivora of the Barstow fauna show a more progressive stage. Large aelurodons are common, though *Tephrocyon,* a characteristic genus of the Great Basin Middle Miocene, is also well represented. *Aelurodon* is only doubtfully represented in the Middle Miocene. Among the ungulates *Hypohippus* is represented by a larger species than that of the Virgin Valley. The abundantly represented *Merychippus* is of a larger type, with longer-crowned cheek-teeth than that of the Mascall and Virgin Valley, and grades into forms which are difficult to exclude from *Protohippus.* Though such advanced forms as *Pliohippus* and *Hipparion* are reported from the Mascall no remains of either of these genera are certainly known from that formation. Some of the species previously listed from the Mascall have been obtained in the Rattlesnake by University of California parties. In the Virgin Valley beds, with a fauna similar to that of the Mascall, there is no suggestion of the presence of Equidae more advanced than *Merychippus.*

The *Dromomeryx* of the Barstow seems somewhat more advanced and less common than that of the Mascall and Virgin Valley. *Merycodus,* which is abundantly represented in the Barstow, is less common and less advanced in the Virgin Valley, and is unknown as yet in the Mascall. The relatively primitive *Blastomeryx* is well known in the Virgin Valley, but not found in the Barstow. *Blastomeryx* has not been reported from the Mascall up to this time.

Rhinoceroses are unknown in the Barstow, but this peculiarity of the fauna may be due to local conditions rather than to stage of development of the fauna.

Comparison of the Barstow fauna with that of the Rattlesnake and Thousand Creek is necessarily limited to a few groups, owing to the small representation of comparable types in the later faunas. The horses of the Rattlesnake and Thousand Creek comprise only advanced types included in the genera *Pliohippus* and *Neohipparion*, in contrast to the abundant *Merychippus* fauna of the Barstow. The camels of the Thousand Creek and Rattlesnake are in general larger forms than those of the Barstow. The advanced types of antelopes of the Thousand Creek fauna, represented by *Ilingoceros* and *Sphenophalos*, are much more progressive than *Merycodus* of the Barstow. They are possibly derivatives from the *Merycodus* group, which is not known in beds of the Thousand Creek stage.

The almost total specific distinctness of the Barstow and Ricardo faunas, taken with the wide difference of genera in groups with somewhat similar relations to their environment, makes it impossible to conceive of the two faunas as having existed contemporaneously in regions of quite similar topography only a few miles apart during the time required to deposit the many hundreds of feet of strata in which they occur. Comparison of the Barstow and Ricardo faunas shows that in nearly every comparable group in which there is a noticeable difference the Ricardo forms are more advanced. In the Canidae the typical Barstow *Tephrocyon* disappears in the Ricardo. The aelurodons of the Barstow are, where comparable, less specialized than those of the Ricardo. The protohippine *Merychippus* forms with a possible rare *Protohippus* or *Pliohippus* of the Barstow give place to specialized *Hipparion* and *Pliohippus*, with no forms as primitive as *Merychippus*. The camels of the Ricardo include larger forms than those of Barstow. *Dromomeryx* of the Barstow is not known from the type section of the Ricardo, and the Ricardo *Merycodus* appears somewhat more specialized than that of the Barstow.

The difference between the Barstow and Ricardo faunas can scarcely represent a time interval amounting to less than one-third of a geological period as faunal changes are ordinarily interpreted.

The exact relation of the Barstow fauna to that of the Cedar Mountain beds[21] is not entirely clear. The Cedar Mountain carnivores include a *Tephrocyon* apparently identical with *T. kelloggi* of the Virgin Valley, while the *T. temerarius* type of the Barstow fauna is absent. One large Aelurodon-like form of the Cedar Mountain does

[21] Merriam, J. C., Tertiary vertebrate fauna from the Cedar Mountain Region of Western Nevada, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 161–198, 1916.

not seem to be identical with any of the Barstow species. The Hypohippus-like forms of the Cedar Mountain beds are near the stage of advance in size seen in the species known from the Barstow. Protohippine horses are unfortunately very imperfectly known from the Cedar Mountain beds. One form is near the stage of the Barstow *Merychippus;* another seems relatively advanced, and may be more progressive than any but the most advanced type known from the Barstow. It is possible that more than one faunal horizon is represented in the Cedar Mountain region, and that the two protohippine horses came from different zones.

Merycodus is represented in the Cedar Mountain region most commonly by a type corresponding to *M. furcatus,* though *M. necatus* of the Barstow fauna is also present.

Rhinoceroses are represented in the Cedar Mountain beds, but are not thus far known from the Barstow.

On the whole the faunal assemblage of the Barstow balances near the stage of evolution of the Cedar Mountain beds. The dissimilarity may be due to the presence in the Cedar Mountain region of some horizons older and some younger than those from which the Barstow fauna has been obtained. A portion of the difference may be due to geographic variation. As the horizontal separation is not large and the environments were presumably not greatly different, the geographic factor may not be sufficient to account for the dissimilarity.

In general the Barstow and Cedar Mountain faunas are as near to each other as either is to any other known faunal assemblage in the Great Basin Tertiary series.

RELATION TO TERTIARY FAUNAS OF AMERICA OUTSIDE THE GREAT BASIN REGION

The nearest relationships of the Barstow fauna outside the Great Basin are with the Santa Fé beds of New Mexico. Several types which are among the most important forms of the Santa Fé beds are similar to species in the Barstow fauna. These include *Aelurodon wheelerianus, Merychippus calamarius, Procamelus* near *gracilis,* and *Merycodus necatus.*

As a considerable distance separates the Barstow geographically from the Santa Fé some difference in fauna is to be expected. It is also possible that the Santa Fé beds represent more than one horizon, or may include beds ranging into stages older or younger than the Barstow.

Several peculiarities of the Barstow fauna in comparison with other assemblages of nearly the same age inside and outside the Great Basin are not readily explained. With a considerable collection from the Barstow region, as yet no remains representing rhinoceroses have been seen, while they are known from the nearly allied Cedar Mountain and Santa Fé faunas. As this group was present in America until Pliocene time its absence from the Barstow region may be due to some peculiarity of the environment. It should be noted that rhinoceroses are also unknown in the Ricardo fauna.

Another peculiarity is the absence from the Barstow of *Merycodus furcatus* well represented in the Santa Fé beds. In the Cedar Mountain region both types of *Merycodus* are present, as are also rhinoceroses. The absence of these forms from the Barstow was possibly a peculiarity of this geographic area in Upper Miocene time.

Considering its relation to the recognized Middle Miocene of the Mascall and Virgin Valley, to the Pliocene of the Rattlesnake and Thousand Creek, and to the Upper Miocene of the Santa Fé, the position of the Barstow fauna evidently falls within the Upper Miocene. The position of the Barstow stage with reference to other Miocene faunas of the Great Basin and adjacent regions is approximately as follows:

Period	Great Basin Province	Great Plains and Rocky Mt. Province	Asia	Europe
Upper Pliocene		Blanco		Lignites of Casino
Lower Pliocene	Thousand Creek Rattlesnake Ricardo	Snake Creek	Hipparion fauna of China and Siwaliks in part	Hipparion fauna of Pikermi
Upper Miocene	Barstow Cedar Mountain	Santa Fé		La Grive-Saint Alban
Middle Miocene	Mascall and Virgin Valley	Pawnee Creek		Sansan Sables de l'Orleanais

The Snake Creek fauna[22a] of western Nebraska shows some interesting resemblances to that of the Barstow. In the Equidae, which

[22a] Matthew, W. D., and Cook, H. J., A Pliocene Fauna from Western Nebraska, Bull. Amer. Mus. Nat. Hist., vol. 26, pp. 361–414, 1909.

apparently furnish the best basis for comparison, the presence of numerous representatives of *Neohipparion, Protohippus,* and *Pliohippus* gives an assemblage much more advanced than that of the Barstow, in which only one form is referred to a genus more advanced than *Merychippus.* On the other hand the predominance in the Equidae of the Snake Creek fauna of forms of *Merychippus* near those making up the great bulk of the horses of the Barstow area suggests that the times of deposition of some portion of the Snake Creek and of the Barstow were not separated by a wide epoch.

In the Carnivora the Snake Creek possesses an advanced element in certain *Aelurodon* species, which may not be much more progressive than some seen in the Barstow. With this element at Snake Creek are *Tephrocyon* species, near if not identical with those of the Barstow.

In the artiodactyls, *Dromomeryx* is represented in the two areas; *Merycodus* is represented by closely related forms in Snake Creek and Barstow; the relatively primitive *Blastomeryx* is known at Snake Creek, but not as yet in the Barstow; certain camels at Snake Creek are presumably somewhat more progressive; and the appearance of *Neotragocerus* is probably an advanced character of the Snake Creek assemblage.

A part of the Snake Creek fauna is certainly more advanced than the Barstow, but connecting elements seem to indicate a shorter lapse of time between the Barstow and a portion of the Snake Creek than between the Barstow and Ricardo, as this part of the Snake Creek fauna though more widely removed geographically than the Ricardo is nearer to the Barstow in composition.[22b]

Description of Fauna

TESTUDINATA

Testudinate remains are not uncommon in the Barstow beds, but usually consist only of small fragments. Two specimens represent the greater part of the carapace and plastron, and a third shows important parts of both carapace and pastron. So far as known all of the material obtained represents land tortoises allied to the Recent genus *Testudo.* This group is represented in the Mohave area at the present time by the desert tortoise *Gopherus agassizii.* Two of the Miocene specimens greatly exceed the living form in size.

[22b] See recent discussion of this question by W. D. Matthew, Contributions to the Snake Creek fauna, with notes upon the Pleistocene of Western Nebraska, American Museum Expedition of 1916, Bull. Amer. Mus. Nat. Hist., vol. 38, pp. 183–229, pls. 4–10, 1918.

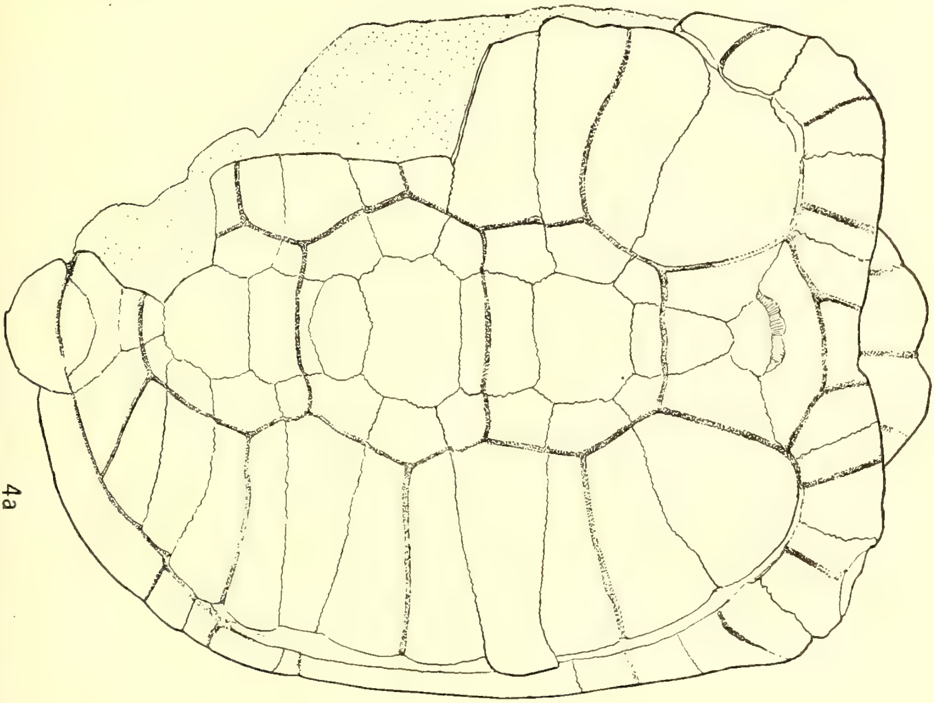
TESTUDO MOHAVENSE, n. sp.

Type specimen no. 21575, carapace nearly complete, plastron complete (figs. 4*a*, 4*b*); from the Barstow beds, Barstow syncline, Mohave Desert. Two individuals, nos. 21573 and 21574, much larger than the type specimen, but resembling it in general structure, are tentatively referred to this species.

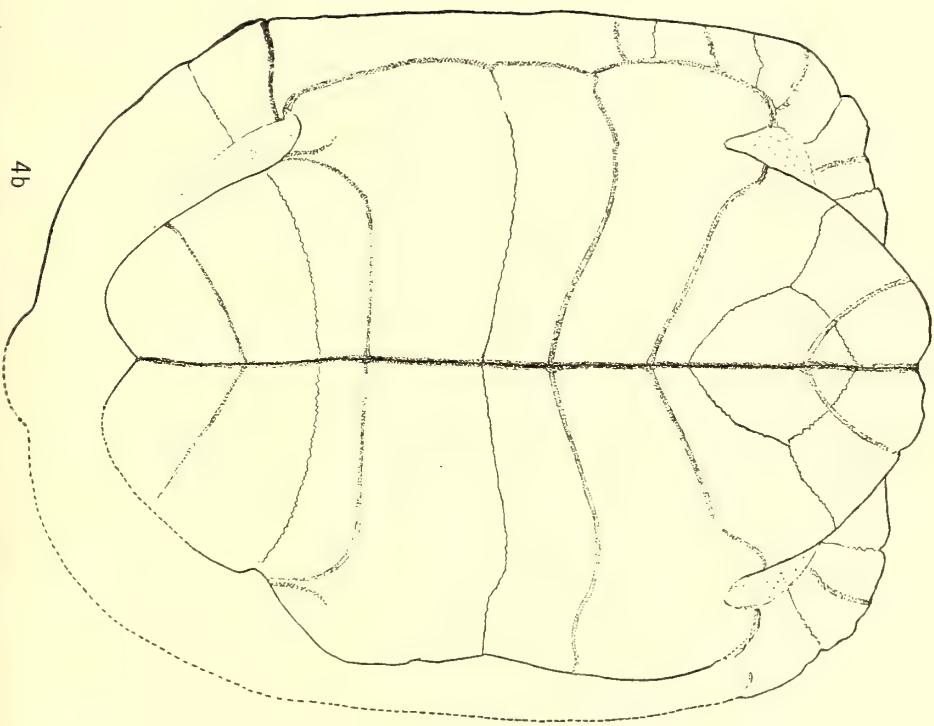
The characters of this species approximate those of a group of Miocene species referred to the genus *Testudo* though the assemblage of characters does not correspond to that in any of the known forms. In some respects, as in the nature of the epiplastral lip, it resembles the West American Oligocene genus *Stylemys*, but shows clearly a more advanced stage, which is comparable to that of *Testudo*.

The carapace of the type specimen is 232 mm. long with a width of 196 mm. The plastron of the type is 222 mm. long. The more nearly complete of the two large specimens referred to this species is 317 mm. wide and the plastron is approximately 375 mm. long. The carapace of the type (fig. 4*a*) is truncated or concave anteriorly. It is seen to be moderately arched in the type specimen, but distortion of the shell has made exact estimation of the form difficult. In the larger specimens the vault of the carapace is strongly arched. The plastron (fig. 4*b*) is strongly notched posteriorly. The epiplastral lip is strongly developed superiorly, but is not clearly set off from the contour of the posterior portion of the anterior lobe of the plastron. The separation of the epiplastral lip is not more distinct than in *Stylemys* and not less marked than in certain Miocene species of *Testudo*, as in *Testudo pansa*. The anterior lobe of the plastron projects slightly beyond the anterior end of the carapace. The bridge between the plastron and carapace extends from the anterior portion of the second costal to the anterior end of the sixth costal. The form and arrangement of the neural and costal plates are in general as in the *Testudo* group. Neurals two and four are octagonal, three is tetragonal, five is hexagonal. Neurals three and five are both relatively small. Neurals six and seven are both hexagonal and of nearly the same size, number seven being slightly longer anteroposteriorly. Neural eight is relatively very small and tetragonal. The anterior suprapygial is bifurcated, the posterior wings enclosing the cuneiform second suprapygial, and coming into contact with the lateral borders of the pygial.

The costals from the second to the seventh show much variation between the width of the lateral and median ends. The variation in



4a



4b

Figs. 4*a* and 4*b*. *Testudo mohavense*, n. sp. Type specimen, no. 21575, carapace and plastron, × ½. Fig. 4*a*, carapace from above; fig. 4*b*, plastron from below. Barstow Miocene, Mohave Desert, Californa.

width between the ends represents the stage of specialization seen in *Testudo* and is more advanced than in the Oligocene *Stylemys*.

Peculiarities in the form of the median series of plates appear in the small, anteroposteriorly-short, hexagonal neural five; in the relatively large size of numbers six and seven; in the small, narrow, tetragonal number eight; and in the contact of the bifid anterior suprapygial with the pygial. The modification in relative size of the fifth and sixth neurals is probably in part responsible for the position of the sulcus between the second and fourth vertebral scutes on the sixth neural instead of on the fifth where it is ordinarily located.

The distal ends of costals three and five are much narrowed and their proximal ends are in articulation with three neurals. Costals two and four are each in contact with one neural. Costal seven is not in contact with neural eight as costal eight wedges in between it and the narrow anterior end of neural eight.

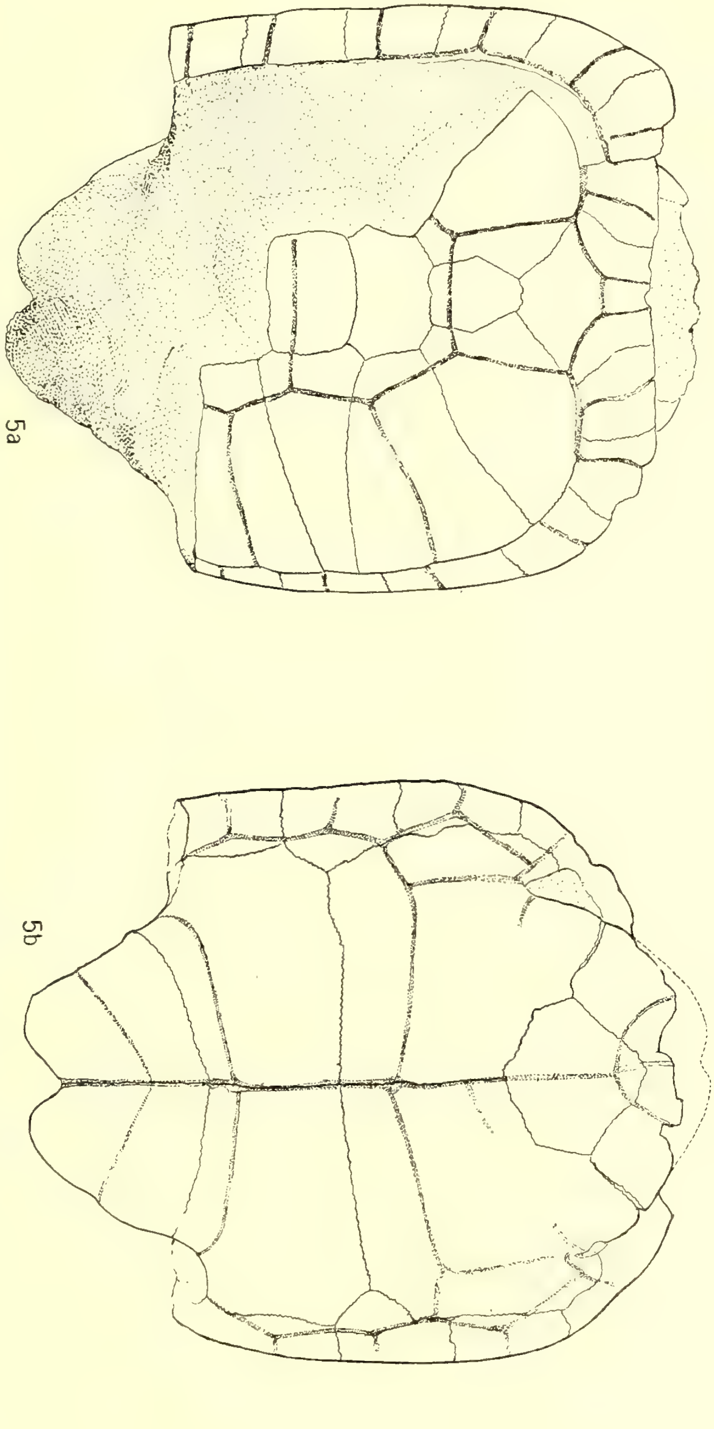
The characters of the neurals and costals may be due in part to individual peculiarities, but are probably to a considerable degree diagnostic of the group. They are suggested in part in other American Tertiary forms, but do not appear in this combination in any other species.

The large specimen, no. 21574 (fig. 5*a*), differs somewhat from the type specimen in form of the anterior neurals, but the differences seem to be within the limits of individual variation. In no. 21574 neural one is wider than in the type specimen, and tends to be hexagonal. The second neural is also wider in the large specimen. Neural three is relatively large compared with the second, but is tetragonal, while number two is octagonal. The third costal in the large specimen is much narower distally than in the type.

The peripherals on the free anterior and posterior borders of the type specimen have acute margins. On the anterior border they may be slightly flared. The middle of peripheral three is slightly behind the suture between costals one and two.

The pygial plate is considerably wider on the inner than it is on the peripheral margin. Its inner border comes in contact with the distal posterior ends of the bifid first suprapygial.

In the large specimen, no. 21574, the characters of the peripherals are essentially similar to those of the type. In specimen 21574 the peripherals forming the bridge are nearly vertical in position, with a moderate lateral angle. The bridge peripherals of the type may be similar to those of no. 21574, but are less satisfactorily preserved.



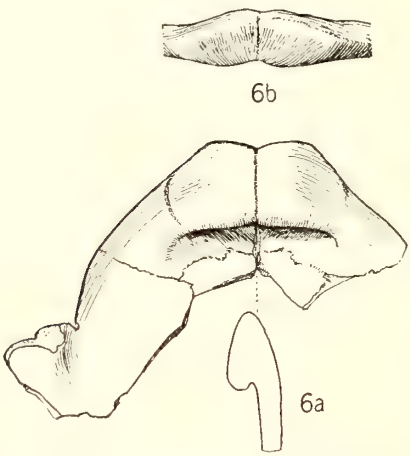
5a

5b

Figs. 5*a* and 5*b*. *Testudo mohavense?*, n. sp. Carapace and plastron, no. 21574, × ¼. Fig. 5*a*, carapace from above; fig. 5*b*, plastron from below. Barstow Miocene, Mohave Desert, California.

The peripherals are united with the costals by a union apparently consisting in each case of a process from the peripheral meeting the end of the costal. The end of the costal evidently passes the outer side of the process of the peripheral and fits into a pit on the peripheral.

The plastron projects considerably beyond the anterior end of the carapace in the type specimen and in the large individual no. 21574. The anterior and posterior ends are both distinctly notched.



Figs. 6*a* and 6*b*. *Testudo mohavense?*, n. sp. Anterior portion of plastron, no. 21573, × ¼. Fig. 6*a*, dorsal view of plastron with section along median line; fig. 6*b*, anterior view of lip of plastron. Barstow Miocene, Mohave Desert, California.

The entoplastron is rhomboidal to hexagonal with an angle developed on each posterior border. The hypoplastral-xiphiplastral suture is some distance behind the inguinal notch.

The epiplastral lip is not clearly defined on the anterior border of the plastron, but the lip is strongly developed superiorly. The considerably thickened upper portion of the lip projects backward on the type specimen to a point immediately over or slightly posterior to the anterior end of the entoplastron as it appears on the inferior side of the plastron. On a portion of a large specimen, no. 21573 (fig. 6*a*) the same relations are observed, but the epiplastral bones overlap the entoplastron superiorly, so that the suture on the upper side is farther from the anterior border. In the type specimen the anterior end of the inferior surface of the epiplastral region is nearly flat. In no. 21573 the anterior end is sharply curved upward (fig. 6*b*).

The sulci between dermal scutes of the type specimen are sharply impressed but do not have raised borders. The nuchal scute is considerably wider in the type specimen than in no. 21574. In the type, the sulcus between vertebral scutes three and four crosses the sixth instead of the fifth neural as in most species.

On the plastron the humero-pectoral sulcus is well behind the posterior end of the entoplastron. The pectoral scutes have an anteroposterior diameter of 27 mm. on the median side as compared with a width of 49 mm. for the abdominal scutes. This is an unusual width for pectoral scutes in *Testudo,* or even in the more primitive *Stylemys.*

The Barstow Miocene tortoises seem clearly more advanced than the Oligocene *Stylemys* in specialization of the neurals and costals, and to some extent in the development or stage of advance of the epiplastral lip.

The Barstow form seems in the nature of the epiplastral lip, in form of the entoplastron, in width of the pectoral scutes, and in the variations in width of the costals to be less specialized than some of the forms of *Testudo.* The stage of advance is approximately that of Miocene forms like *Testudo pansa* of the Pawnee Creek Middle Miocene or *T. impensa* of the Madison River Upper Miocene.

The Barstow form seems distinct from all of the described species. In view of the fact that *Testudo undata* and *T. klettiana,* described by Cope from the Miocene of New Mexico, are from beds presumably near in age to the Barstow beds the possibility of identity of the species must be considered. *T. klettiana* is described as having a quadrate pygial entirely unlike that of the Barstow species, while *T. undata* is a very large form. With the information available it is not possible to refer the Barstow specimens to either of Cope's species from New Mexico.

Measurements

	No. 21575	No. 21574
Carapace, length along median line	232 mm.	......
Carapace, greatest width	*a*196	317
Plastron, greatest length	222	*a*375

	No. 21575		No. 21574	
	Length	Width	Length	Width
Nuchal bone	33 mm.	72	72	90
Neural bone 1	28	18.2	48	39
Neural bone 2	24.5	33	40	68
Neural bone 3	19.5	32.2	*a*43	64.5
Neural bone 4	23.6	40.2		
Neural bone 5	16	25.8		
Neural bone 6	17.1	31.5		
Neural bone 7	25	31.2		
Neural bone 8	19	*a*14.4		
Anterior suprapygial bone	19	35		
Posterior suprapygial bone	15.5	25.5		
Nuchal scute	*a*10.2	29.8	26.5	18.2
Vertebral scute 1	42.5	*a*59	83	82.5
Vertebral scute 2	45	62.5	81	*a*110
Vertebral scute 3	50	72		
Vertebral scute 4	46.2	57		
Vertebral scute 5	45	....		
Pygial bone, length	24.5			
Pygial bone, width inner	36.5			
Pygial bone, width outer	*a*23			

a, approximate.

MEASUREMENTS—(*Continued*)

	No. 21575		No. 21574	
	Width proximal	Width distal	Width proximal	Width distal
Costal bone 1	------	------	----	----
Costal bone 2	14.2 mm.	45.8	32	9.3
Costal bone 3	32.6	16	56	15
Costal bone 4	14.2	45.5	31	79.5
Costal bone 5	30	11.2		
Costal bone 6	16	37		
Costal bone 7	13.2	-----		

	Anteroposterior diameter on median line	
	No. 21575	No. 21574
Epiplastrals	19.5	----
Entoplastron	44	73
Hyoplastrals	53.2	93
Hypoplastrals	44.8	70
Xiphiplastrals	48.7	82
Gular scute	35.6	----
Humeral scute	37.7	74
Pectoral scute	27	46.5
Abdominal scute	48.6	81.5
Femoral scute	35	46.5
Anal scute	28	50

a, approximate.

AVES

Very fragmentary remains of birds from the Barstow beds are determined by Dr. L. H. Miller as follows:

Tarsometatarsus of buteonid hawk, as nearly as determinable. Size larger than *Buteo borealis*, locality 2056; tibiotarsus, unmistakably *Buteo*, but size between *B. borealis* and *B. swainsoni*, locality 2061; femur, too fragmentary for determination, may belong with preceding, locality 2061.

CARNIVORA

CANID (CANIS?), sp. small

A fragment of a mandible, no. 19463, represents a small canid form evidently quite distinct from the *Aelurodon* and *Tephrocyon* species to which reference is made below. The mandible (fig. 9, p. 464) is small and slender, representing a form about as large as a fox. The dentition is not preserved.

TEPHROCYON, near TEMERARIUS (Leidy)

The typical material of this species consisted of a piece of a lower jaw containing the carnassial tooth, and a portion of an upper jaw with two teeth both badly preserved. This material was obtained by Dr. Hayden from the Niobrara sands. The horizon is presumably Upper Miocene. The lower jaw and M_1 figured by Leidy[23] show form and dimensions closely similar to those of a specimen obtained by Peterson[24] from beds at Whistle Creek, Nebraska, possibly belonging to late Miocene or Pliocene deposits.

A portion of a lower jaw, no. 19402, with P_3 to M_2 inclusive, from the Barstow beds of the Mohave region, California, very closely resembles the type of Leidy's *Canis temerarius* from the Nebraska formation and also resembles the specimen from Whistle Creek, Nebraska, referred to this species by Peterson.[25] M_1 of the Mohave specimen very nearly approaches in form and dimensions the original figured specimen of *Canis temerarius* Leidy, and the Mohave species is almost identical in form and dimensions with the corresponding parts of the specimen described by Peterson.

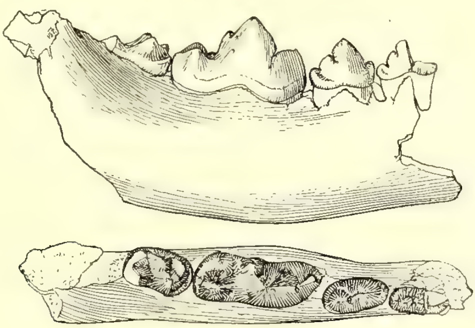


Fig. 7. *Tephrocyon*, near *temerarius* (Leidy). A portion of the mandible with dentition shown in superior and lateral views. No. 19402, natural size. Barstow Miocene, Mohave Desert, California.

The specimen from the Barstow beds (fig. 7) represents a species of *Tephrocyon* differing slightly from those thus far known in the Great Basin region. The relationship of this form to the genus *Tephrocyon* is shown in the large size of the metaconid and of the crushing heel of M_1, and in the presence of a well developed paraconid with a large antero-external shelf on the cingulum of M_2.

The Barstow form is very close to the typical *T. temerarius* but may be separated by subspecific or specific characters when better known. In the Mohave form M_1 seems a little heavier than in Leidy's type.

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[23] Leidy, J., Jour. Acad. Nat. Sci. Phila., ser. 2, vol. 7, pl. 1, fig. 12, 1869.

[24] Peterson, O. A., Mem. Carneg. Mus., vol. 4, p. 268, 1910.

[25] See comparison in Notes on the Canid Genus Tephrocyon, J. C. Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 366–367, 1913.

The Mohave form is distinguished from *Tephrocyon rurestris* and *T. hippophagus* by the smaller, more slender teeth. From *T. kelloggi* it differs in the relatively larger M_1, smaller M_2, and smaller metaconid in M_1. M_1 in the Barstow specimen measures 17 mm. in anteroposterior diameter as compared with 9 mm. in anteroposterior diameter in M_2. In *T. kelloggi* the anteroposterior diameter of M_1 is 15 mm.; of M_2, 10.5 mm. There is a small hypoconulid on the heel of M_1 in the Barstow specimen, while in the type of *T. kelloggi* this tubercle is not suggested. The heel of M_2 seems somewhat shorter than in *T. kelloggi.*

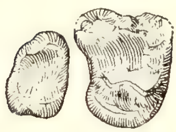

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Fig. 8. *Tephrocyon*, near *rurestris* (Condon). M^1 and M^2, no. 21512, occlusal view, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 9. Canid, sp. small. Fragment of mandible, no. 19463, lateral and dorsal views, × ½. Barstow Miocene, Mohave Desert, California.

P_4 and P_3 both possess a posterior cusp and a posterior basal tubercle. P_4 shows a small anterior basal tubercle. The anterior side of P_3 is not preserved.

Several specimens of mandibles slightly larger than no. 19402 represent a *Tephrocyon* species from the Barstow beds very near *T. temerarius.* It is possible that they belong to another species, but age and sex are presumably competent to account for the differences.

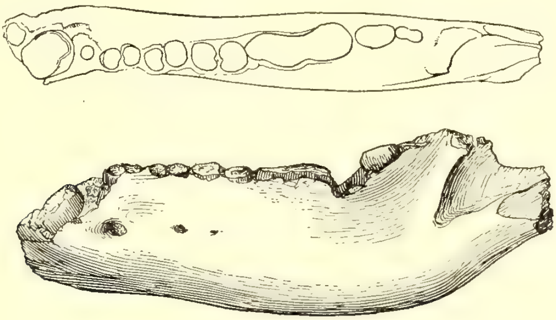
A portion of an upper jaw, no. 21512, with M^1 and M^2 imperfectly preserved (fig. 8) shows a form of molar teeth near that in *T. rurestris,* the type species of *Tephrocyon.* A portion of an upper jaw, no. 21513, with fragments of the premolars also suggests the characters of *Tephrocyon.*

AELURODON, near WHEELERIANUS Cope

Several mandibles in the collection from the Barstow represent large, heavy-jawed canids of the *Aelurodon* type (figs. 10 and 11). Unfortunately no one of the several specimens shows the dentition well enough to permit a fully satisfactory comparison with the described material. In general the characters of these specimens are, however, quite close to those of *A. wheelerianus* described by Cope from the Upper Miocene of the Santa Fé region.

In forms of the type seen in no. 19398 (fig. 10) the mandible is very thick and massive; the heavy teeth are closely spaced, with a tendency to be set transverse to the long axis of the jaw, there is almost no diastema, the roots of the premolars are very thick, and M_2

is relatively small. Especially noticeable is the very massive character of the ramus, which has nearly twice the bulk of that in a timber wolf with a cheek-tooth series of approximately the same anteroposterior diameter.



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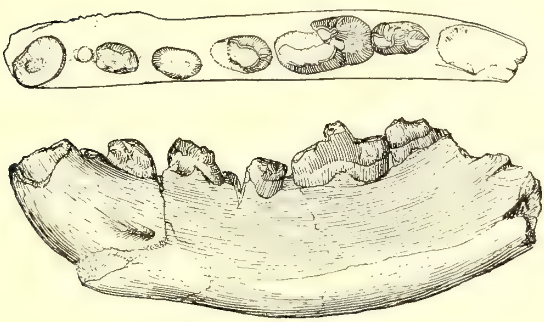

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Fig. 10. *Aelurodon,* near *wheelerianus* Cope. Mandible, no. 19398, lateral and superior views, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 11. *Aelurodon,* near *wheelerianus* Cope. Mandible, no. 21231, lateral and superior views, × ½. Barstow Miocene, Mohave Desert, California.

MEASUREMENTS

	A. wheelerianus type	No. 19455 Barstow	Canis pambasileus
Length, anterior side P_1 to posterior side M_3	95 mm.	88.5	92.7
M_1, anteroposterior diameter	28	28.4	28
M_2, anteroposterior diameter	12	10.3	12.2
Depth of jaw below M_2	35	*a*35.5	30
Greatest thickness of jaw below M_2	17	18	11.7

a, approximate.

The larger part of a mandible with imperfect dentition, no. 21231 (fig. 11), shows a form in which the mandible is thick inferiorly, but thinner above than in the common *Aelurodon* of the Barstow fauna. M_2 is considerably larger than in the common form. This species resembles the typical *Aelurodon wheelerianus* in many ways, and the distinctive characters of the specimen may be due merely to individual variation, or they may indicate a species distinct from that represented by no. 19398.

Measurements of no. 21231

Length, anterior side of inferior canine to posterior side M_1	98 mm.
Length of lower premolar series	*a*52
Inferior canine, anteroposterior diameter at base	*a*24.7
P_3, anteroposterior diameter	*a*13
M_1, anteroposterior diameter	25.8
M_1, transverse diameter	11.9
M_2, anteroposterior diameter	*a*13
M_2, transverse diameter	8.3

a, approximate.

AELURODON, DINOCYON, or AMPHICYON, sp.

A portion of a very large, much-weathered lower jaw, no. 21224, with the base of the canine represents a form much larger than *Aelurodon wheelerianus.* It may represent an *Aelurodon,* an *Amphicyon,* or a *Dinocyon* species. The space for incisors is small. The alveolus for P_1 is very small.

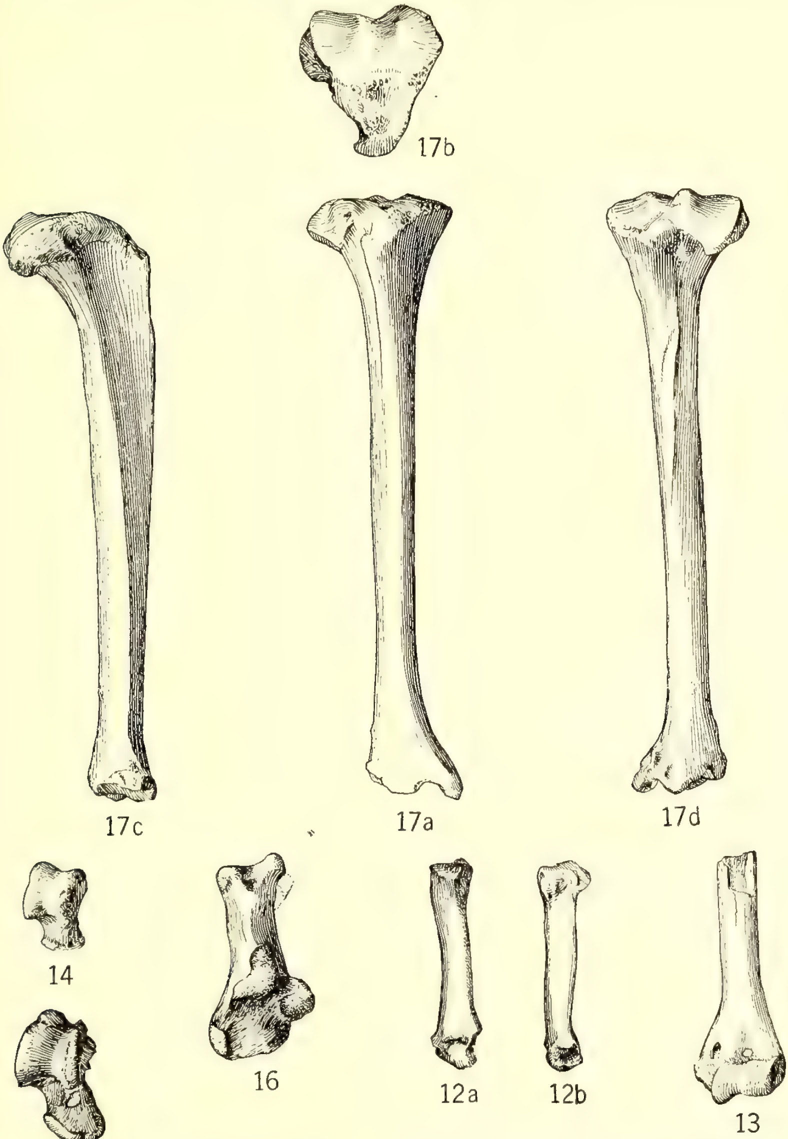
CANID SKELETAL ELEMENTS, indet.

A number of scattered skeletal elements representing forms of the canid type have been obtained in the Barstow. Noteworthy among the canid skeletal remains are a number of phalangeal elements which are considerably heavier than those of the typical wolves. A second and fifth metapodial of the anterior extremities (figs. 12*a*, 12*b*) represent this type. The short-headed, heavy-jawed tephrocyons and aelurodons of the Barstow fauna were presumably heavy-limbed, and it may be that the specimens before us represent one of these forms.

A humerus (no. 19468, fig. 13) from the Barstow shows in general the characters of this element in the canids, but is distinguished by the presence of an entepicondylar foramen.

A small, long-necked astragalus (no. 19469, fig. 14) resembles an astragalus from the Middle Miocene of Virgin Valley, and is possible with the Virgin Valley form to be referred to *Tephrocyon.*

A complete tibia and the distal end of a femur of the same animal represent a canid form presumably about as large as a coyote. The



Figs. 12*a* and 12*b*. Canid. indet. Second metacarpal?, no. 19469, × ½. Fig. 12*a*, anterior view; fig. 12*b*, median view. Barstow Miocene, Mohave Desert, California.

Fig. 13. Canid, indet. Humerus, no. 19468, anterior view, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 14. Canid, indet. Astragalus, no. 19469, tibial view, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 15. Canid, indet. Astragalus, no. 23119, tibial view, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 16. Canid, indet. Calcaneum, no. 23120, × ½. Barstow Miocene, Mohave Desert, California.

Figs. 17*a* to 17*d*. Canid, indet. Tibia, no. 19470, × ½. Fig. 17*a*, anterior view; fig. 17*b*, view of proximal end; fig. 17*c*, lateral view; fig. 17*d*, posterior view. Barstow Miocene, Mohave Desert, California.

distal portion of the femur is much heavier than in the coyote, but the shaft is more slender than in a greyhound specimen before the writer. The tubercle situated on the outer border of the popliteal surface is relatively about as prominent as in the coyote, but is relatively larger than in the greyhound.

The tibia (fig. 17*a*) has approximately the length of that in the coyote, but is much heavier, the increased bulk being particularly noticeable in the proximal half. The proximal end (fig. 17*b*) is much wider across the condyle than in the coyote; the heavy cnemial crest does not end distinctly above the middle of the shaft, but extends downward as a well marked ridge into the lower third of the shaft where it gradually fades. This character of the crest gives to the lateral view (fig. 17*c*) of the tibia quite a different outline from a similar view of the tibia of the coyote or of the greyhound. In the postero-superior region of the tibia the interosseous ridge is sharply marked, but the internal border is gently rounded instead of sharply angular as in the coyote and greyhound. The popliteal line arises on the inner or medial side of the popliteal notch instead of on the outer side as in the greyhound and coyote. The posterior side of the shaft is relatively narrow and less distinctly flattened than the coyote and greyhound.

MACHAERODONT, sp. A

The distal ends of several humeri belong to felid forms about as large as the Recent puma, and may represent one of the machaerodont forms described below. It is not possible to determine with certainty the genus to which they belong. On one specimen, no. 19465, there is a deep fossa on the anterior side (fig. 18) laterad of the entepicondylar foramen. The depression is evidently formed to accommodate the coronoid process of the ulna, and suggests frequent extreme pronation of this extremity.

MACHAERODONT, sp. B

A second type of humerus represented by no. 21223 (fig. 19) belongs to a much larger cat, probably a machaerodont.

MACHAERODONT, sp. C

A third type is represented by a portion of a gigantic ulna and femur, no. 21352 (figs. 20 and 21). This material evidently indicates a machaerodont form at least as large as the Pleistocene *Smilodon* of Rancho La Brea.

MACHAERODONT, indet.

A number of other loose limb elements are evidently to be referred to some of the types distinguished above. Several felid metapodials represent a machaerodont cat about as large as a puma. Among them is a metapodial five of the anterior limb, no. 19466 (figs. 22*a*, 22*b*), a moderately heavy element. The type of a foot represented by this phalanx seems heavier than in *Dinictis*, and a little less massive than in *Smilodon*. No. 21515 (fig. 23) possibly belongs to the same species. No. 19399 (figs. 24*a*, 24*b*) represents a smaller form of heavy metapodial possibly representing *Aelurodon*.

It is evident from the limb material present that at least three types of large cats were present in the Barstow fauna.

FELID?, indet.

The posterior end of a mandible, no. 21571 (figs. 26*a* and 26*b*), is from a form approximating the size of the Recent African lion, and would seem to have feline rather than machaerodine characters if it represents the cats. The angle is separated by a considerable distance from the condyle. It protrudes well behind the condyle, and is situated almost immediately below the base of the coronoid process. These characters generally distinguish the feline type from the more specialized machaerodine forms, in which the angle is nearer the condyle, does not project markedly behind the condyle, and is situated beneath the outer end of the condyle some distance laterad of the base of the coronoid process.

PSEUDAELURUS, sp.

A portion of a lower jaw without teeth (no. 21516, fig. 27) from the Barstow beds represents a cat of the *Pseudaelurus* type not differing greatly from *P. intrepidus* of the Upper Miocene Nebraska beds. The Barstow specimen approaches the type specimen of *P. intrepidus* in dimensions and in proportions of teeth and jaw, but seems slightly heavier. The California form possibly represents a distinct species, but this is not clearly demonstrated by the available material.

Measurements

	No. 21516	P. intrepidus Type
Height of mandible below anterior end of P_4	25.8 mm.	23.3
Greatest thickness of mandible below anterior end of P_4	12.5	12.3
Approximate length, posterior border P_4 to posterior border inferior canine	39.5	40.3

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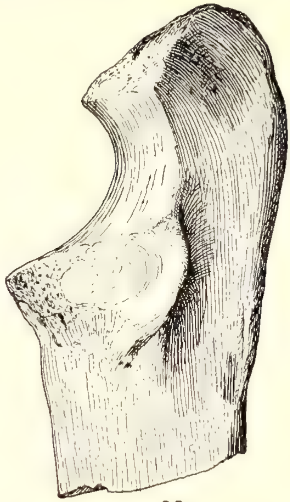

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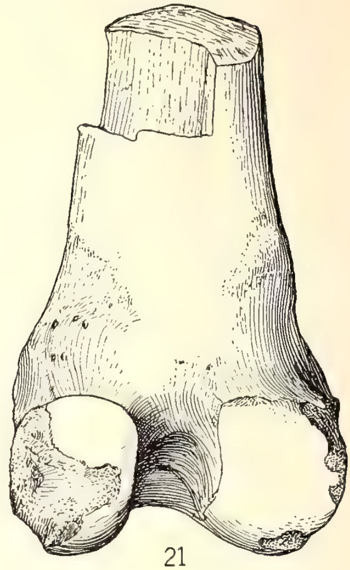

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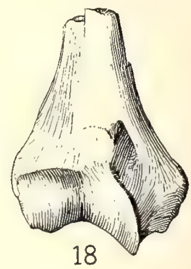

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23

22a

22b

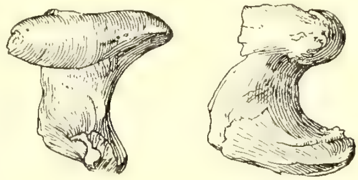
24a

24b

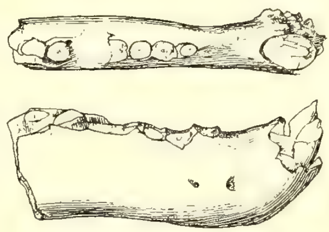
Figs. 18 to 25 represent felid forms from Barstow Miocene, Mohave Desert, California, × ½.

Fig. 18, Machaerodont, sp. A, Distal portion of humerus, no. 19465; fig. 19, Machaerodont, sp. B, fragment of distal end of humerus, no. 21223, anterior view; fig. 20, Machaerodont, sp. C, ulna, no. 21352; fig. 21, Machaerodont, sp. C, femur, no. 21352, posterior view; figs. 22*a* and 22*b*, Machaerodont, indet., metacarpal 5, no. 19466, fig. 22*a*, anterior view, fig. 22*b*, median view; fig. 23, Machaerodont?, indet., metacarpal 1, no. 21515, anterior view; figs. 24*a* and 24*b*, *Aelurodon?*, or Felid?, indet., metacarpal 5, no. 19399, fig. 24*a*, anterior view, fig. 24*b*, median view; fig. 25, Felid, possibly feline, indet., radius, no. 23121, anterior view.

Of the Old World forms *Pseudaelurus quadridentatus* from the Miocene of Sansan is apparently as near to the Barstow form as any of the described species. The forms from Pikermi recently referred to a new genus, *Paramacherodus*, by Pilgrim are distinguished by the more prominent anteroinferior angle of the mandible. This is also true of the *Paramacherodus* specimens from the Middle Siwaliks of India. *Sivaelurus* of the lower Siwaliks shows less prominence of the anteroinferior angle, as in the California *Pseudaelurus*, but one might suspect that the third inferior premolar is relatively smaller and that the form of the jaw is not identical in the two types. Lydekker's specimen of *Aelurogale sivalensis* described from the Siwaliks of the Punjab[26] shows rather more resemblance to the Barstow form, but Lydekker's specimen is referred by Pilgrim to the genus *Paramachaerodus*.



26a 26b



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Figs. 26*a* and 26*b*. Felid?, indet. Posterior end of mandible, no. 21571, × ½. Fig. 26*a*, posterior view; fig. 26*b*, inner view. Barstow Miocene, Mohave Desert, California.

Fig. 27. *Pseudaelurus*, sp. Mandible, lateral and dorsal views, no. 21516, × ½. Barstow Miocene, Mohave Desert, California.

RODENTIA

LEPUS?, sp.

A few fragmentary remains, no. 21232, from locality 2056, represent a rabbit-like form from the Barstow beds. An astragalus from locality 1396 is similar to that of *Lepus*.

PROBOSCIDEA

TETRABELODON?, sp.

Numerous fragmentary remains of proboscideans have been found in the Barstow fauna, but in general they indicate nothing more than the presence of a large Tetrabelodon-like form with somewhat

[26] Lydekker, R., Mem. Geol. Surv. India, ser. 10, vol. 2, pl. 44, figs. 7 and 7*a*, 1884.

advanced cheek-teeth on which the enamel may have a thickness of 8 mm. or more. On one specimen there is a trace of enamel on the tusk.

EQUIDAE

Remains of forms representing the Equidae are the most abundant fossils in the exposures of the Barstow syncline. Especially at one horizon, known as the Merychippus bed, in the upper portion of the section referred to by Baker[27] as the Fossiliferous Tuff member, scattered bone fragments and teeth are common. At least five species are known, two anchitheriine and three protohippine forms. The brachyodont forms comprise a large species of *Hypohippus,* possibly of the subgenus *Drymohippus,*[28] recently described from the Tertiary beds near Mina in southwestern Nevada, and a smaller form near *Parahippus.*[29] The protohippine forms include advanced species of *Merychippus* and a form presumably near *Protohippus.*

The brachyodont horses are very rare. A single jaw fragment of *Hypohippus* is known, and the number of skeletal elements referred to this group is relatively very small. Of the Parahippus-like form only two specimens are known, one representing the upper, the other the lower dentition. The collections of horse specimens from the Barstow syncline consist mainly of *Merychippus,* with a small percentage of more advanced forms evidently close to *Protohippus.*

HYPOHIPPUS, near AFFINIS (Leidy)

This genus is represented in the collections from the Barstow syncline by a fragment of a lower jaw with M_1 and M_2 from locality 2060, a fragment of an upper molar from locality 2058, and a few limb bones from localities 1398 and 2056.

The molars (fig. 28) in the lower jaw fragment, no. 21215, represent a very large species comparable in size to *Hypohippus affinis* of the Upper Miocene in the Great Plains region, or approximately comparable with *H. nevadensis* of the Stewart Valley beds in southwestern Nevada. Unfortunately the lower teeth of *H. nevadensis* of the Stewart Valley beds in southwestern Nevada are not certainly known. The dimensions correspond very closely with teeth from the Upper Miocene of Big Spring Cañon, South Dakota, described by Matthew

27 Baker, C. L., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 346, 1911.
28 Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, p. 420, 1913.
29 *Ibid.,* p. 427, 1913.

and Gidley.[30] This species seems very near *H. affinis*, but is possibly to be referred to *H. nevadensis* from an adjacent area. Were it not that the milk dentition of both *H. affinis* and *H. nevadensis* are known, it would be difficult to find means of separating the Nevada species from *H. affinis*.

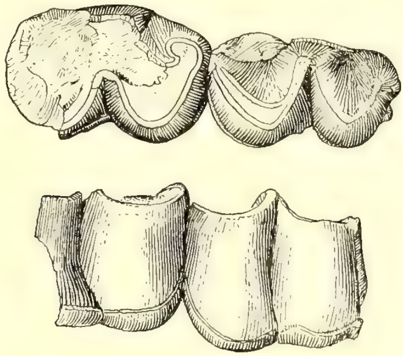

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Fig. 28. *Hypohippus*, near *affinis* Leidy. M_1 and M_2, no. 21215, natural size. Barstow Miocene, Mohave Desert, California.

A fragmentary upper molar, no. 21214, shows no characters more than that it is a large species of *Hypohippus*.

Measurements of no. 21215

M_1, approximate anteroposterior diameter	28.2 mm.
M_1, greatest transverse diameter	20
M_2, anteroposterior diameter	29.5
M_2, greatest transverse diameter	17.4
M_2, height of crown at middle of occlusal face	19.5

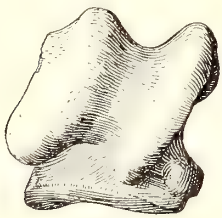
A number of phalanges of digit three, the distal end of a metapodial, several astragali, and a calcaneum from the Barstow collections apparently represent *Hypohippus*.

The phalanges (figs. 29 and 30) are larger and relatively much wider or flatter than those of members of the *Merychippus* group. In the proximal phalanges of the third digit, the median groove for the distal keel of the metapodial is limited to the posterior region of the articular face.

[30] Matthew, W. D., and Gidley, J. W., Bull. Am. Mus. Nat. Hist., vol. 22, p. 135, fig. 1, 1906.

A portion of a large, low, wide hoof, no. 21468, evidently represents *Hypohippus.*

A number of large astragali (fig. 31) show the wide and relatively shallow trochlea distinguishing this genus from *Merychippus,* in which the groove is narrower, deeper, and relatively sharper. A very large calcaneum evidently represents *Hypohippus.*



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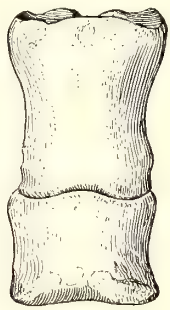

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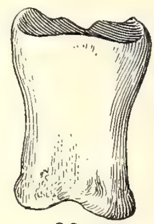

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Fig. 29. *Hypohippus,* near *affinis* (Leidy). Phalanges 1 and 2, no. 21216, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 30. *Hypohippus,* near *affinis* (Leidy). Phalanx 1, no. 21211, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 31. *Hypohippus,* near *affinis* (Leidy). Astragalus, no. 21467, × ½. Barstow Miocene, Mohave Desert, California.

Judging from the size of the limb elements *Hypohippus* furnished the largest members of the Equidae of the Barstow fauna.

Measurements

Phalanx 1, digit III, no. 21216	
Greatest length	49.3 mm.
Greatest proximal width	40.7
Phalanx 2, digit III, no. 21466	
Greatest length	30
Greatest proximal width	43
Astragalus, no. 21467	
Greatest length	54.5
Least width across trochlea	41
Calcaneum, no. 21465	
Greatest length	106

The proximal end of a very large metacarpal III (no. 21406, locality 2056, fig. 32) differs from the type of the Merychippus-like forms of the Barstow fauna and may represent *Hypohippus.* In addition to difference in size the large form is distinguished by greater width of the proximal face and by an anteroposteriorly longer unciform facet. One objection to referring it to *Hypohippus* is the fact that it is associated with the distal end of a metapodial quite unlike the better known forms of *Hypohippus* in possessing a complete distal keel.

Several relatively large proximal ends of metatarsal IV differ from the common specimens evidently representing *Merychippus* in the Barstow fauna, and are presumably to be referred to *Hypohippus.* These metapodials are distinguished from metatarsal IV specimens referred to *Merychippus* in much larger size; relatively wider cuboid facet, position of the median facet for contact with the metatarsal III more nearly transverse to the plane of lateral compression of the bone, and in apparent absence of a posterior facet for articulation with metatarsal III.

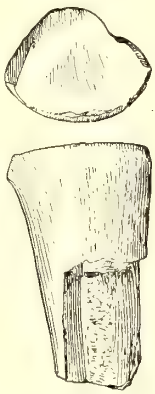


Fig. 32. *Hypohippus?*. Proximal end of metacarpal 3, no. 21406, × ½. Barstow Miocene, Mohave Desert, California.

PARAHIPPUS? MOURNINGI Merriam

Parahippus mourningi Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, p. 427, 1913.

A portion of a lower jaw with dentition (fig. 33) obtained by Mr. Baker in 1911 has been described by the writer as *Parahippus mourningi,* a horse with characters near *Parahippus* and *Hypohippus,* but with size and stage of evolution near *Archaeohippus.* The specimen differed, however, from the only lower jaw material referred to *Archaeohippus* in several characters, and especially in the absence of the strong internal cingulum shown on teeth referred to *Archaeohippus* by Gidley. In January, 1913, a second specimen, a maxillary (fig. 34) with Dm^3, Dm^4, and M^1, representing a very small brachyodont horse, was obtained in the Mohave region by Buwalda and Mourning. An approximation of the dimensions of the cheek-tooth series, as well as a comparison of individual teeth, shows that the upper and lower jaw specimens represent animals of very nearly the same size. The similarity of dimensions, considered with similarity of relationship to other forms and similarity of occurrence, leaves lttle room for doubt that the two jaws represent the same species.

In the specimen representing the upper jaw, the well-preserved, unworn, inner portion of M^1 shows the metaloph fully united with the ectoloph. The protoconule is distinctly separate from the protocone; it is considerably elongated and flattened and its inner end overlaps the protocone. The hypostyle is larger than in *Hypohippus* and *Archaeohippus,* and there is a more distinct cuplike depression behind it. There is no suggestion of a crochet, though several plate-

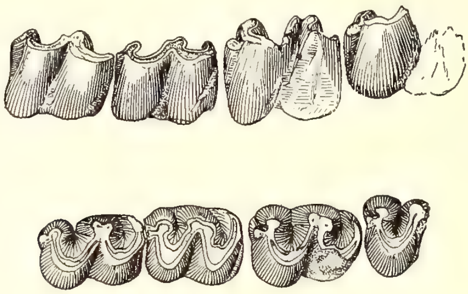
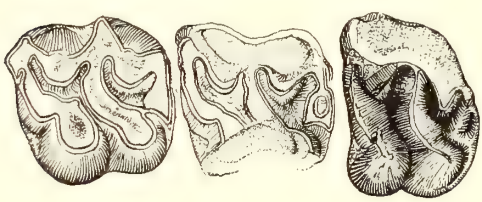


Fig. 33. *Parahippus? mourningi* Merriam. P_3 to M_2, no. 19764, natural size. Barstow Miocene, Mohave Desert, California.

like projections arise from the anterior side of the outer end of the metaloph. The cingulum is well developed on the posterior side, and less distinctly on the anterior side between the protocone and protoconule. There is no shelf of the cingulum on the inner or lingual side



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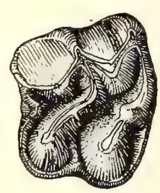

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Fig. 34. *Parahippus? mourningi* Merriam. Dm^3, Dm^4, and M^1, no. 19840, × 1½. Barstow Miocene, Mohave Desert, California.

Fig. 35. *Archaeohippus ultimus* (Cope). Upper molar, no. 1689, × 1½. Mascall Middle Miocene, John Day Region, Oregon.

of the tooth. The cusps or ridges of the crown are somewhat higher than in *Archaeohippus* or in *Hypohippus.* The surface shows a degree of rugosity more pronounced than seems characteristic of *Hypohippus* or of *Archaeohippus.* No trace of cement is evident upon the crown.

The crowns of the milk molars of the Barstow specimen were apparently somewhat shorter and slightly rougher than those of the permanent molars. As in the permanent dentition, the milk molars show the metaloph connected with the ectoloph, there is no internal or lingual shelf of the cingulum, and the hypostyle is large. A P^2 from the Mascall Miocene, considered by Gidley to represent *Archaeohippus,* differs from the milk molars of the Barstow specimen in showing much greater development of the longitudinal ribs on the outer side of the paracone and metacone. There is a very faint longitudinal rib on the outer face of the paracone in Dm^3 of the Barstow specimen. A longitudinal rib is barely perceptible on the outer side of the metacone of this tooth.

MEASUREMENTS	No. 19840	Archaeohippus ultimus Type specimen		Archaeohippus ultimus No. 1689
Dm^3, greatest anteroposterior diameter	13 mm.	P^3	12	......
Dm^3, transverse diameter	13.8	P^3	16	......
Dm^4, greatest anteroposterior diameter	13.7	P^4	13	......
Dm^4, transverse diameter	*a*14.5	P^4	17	......
M^1, anteroposterior diameter measured along middle of crown	13.7	M^1	11	......
M^1, approximate transverse diameter measured along anterior border	*a*16	M^1	15	......
M^3, anteroposterior diameter measured along middle of crown	......		11	11
M^3, transverse diameter along anterior border	......		14	14.8

a, approximate.

In the lower jaw specimen, no. 19764 (fig. 33), the cheek-teeth are brachyodont, without evidence of cement covering. The crowns of the molars and premolars are slightly rugose, and tend to be somewhat higher than in the average *Hypohippus.* P_4 is considerably larger than M_1 in both anteroposterior and transverse diameter. The metaconid and metastylid show a distinct tendency to separate at the summit, the separation being more marked than in typical *Hypohippus,* and less advanced than in typical *Parahippus.* The entostylid is well developed. The cingulum is well shown on the anterior and posterior sides of the crown, but shows no distinct shelf on the outer and inner sides.

The dentition of specimen 19764 differs from the lower teeth referred to *Archaeohippus* by Gidley in the absence of external and internal cingula, and apparently also in the proportions of the premolars.

The form represented by the lower jaw, no. 19764, shows a general resemblance to *Hypohippus*, but differs in its slightly higher and more rugose crowns, more clearly marked incipient separation of metaconid and metastylid columns, and absence of external basal cingulum.

This form differs from typical *Parahippus* in the very weak separation of the metaconid and metastylid columns, and in the absence of cement from the crowns. The separation of metaconid and metastylid in no. 19764 shows but little advance beyond the stage seen in the dentition of a *Hypohippus* specimen from Virgin Valley. In none of the cheek-teeth of no. 19764 are metaconid and metastylid pillars separated on the inner side by more than a faint groove at the summit.

Measurements

	No. 19764	Archaeohippus ultimus No. 1700
Length, anterior side of P_3 to posterior side of M_2	60 mm.	-----
P_2, approximate anteroposterior diameter	16	11.5
P_3, approximate anteroposterior diameter	15.8	12
P_3, transverse diameter across hypoconid	10.5	9.8
P_4, anteroposterior diameter	15	-----
P_4, transverse diameter across hypoconid	10.5	-----
M_1, greatest anteroposterior diameter	13.6	-----
M_1, transverse diameter across protoconid	9	-----
M_2, greatest anteroposterior diameter	13.6	-----
M_2, transverse diameter across protoconid	8.5	-----

The upper and lower jaw specimens (nos. 19840 and 19764) from the Barstow resemble each other in a number of important particulars. Their similarity in structure and their occurrence in the same region gave a reasonable assurance that they represent the same type. The two specimens show similarity in the following characters: (1) height of tooth crowns; (2) rugosity of enamel; (3) absence of cingulum on the protocone side; (4) stage of development, as seen in separation of metaconid and metastylid, in increase of size and compression of the protoconule, in complication of the metaloph, and in increase of size in hypostyle. The stage of evolution in the two specimens shows about equal advance beyond the dentition of the *Hypohippus*.

The Barstow type represented by specimens nos. 19840 and 19764 is evidently related to *Parahippus* in most characters, though distant from the typical form. The absence of a crochet in the upper teeth, and the very slight separation of metaconid and metastylid columns in the lower teeth, indicate a relatively undeveloped stage. Whether this form is too primitive to be included in *Parahippus* will be determined more clearly when better material is available for study.

Some significance may attach to the fact that this form, having a certain resemblance to *Parahippus*, but being relatively primitive, occurs in strata which were presumably deposited in a later period than the time of maximum development of the genus *Parahippus*. On the other hand, the Barstow form, being somewhat more advanced than *Archaeohippus* in most respects, and occurring in strata presumably younger, might be considered a product of modification from *Archaeohippus*. It is interesting to note that in the development of the crochet, in which one would expect advance, the Mohave form is more primitive than the Middle Miocene *Archaeohippus*.

The form represented by *Parahippus? mourningi* might be assigned tentatively to a place with *Archaeohippus*, as an advanced stage with protoconule and hypostyle more progressive, cingulum of the protocone side absent and complication of the metaloph not more advanced. It might be referred to *Parahippus*, as a primitive stage with crochet undeveloped, though the metaloph shows secondary folding, and with metaconid and metastylid in beginning separation. Its reference to one of the described genera depends somewhat upon the extent to which the limits of these groups may be expanded by later studies. A reference to *Parahippus* is apparently open to fewer definite objections than a reference to *Archaeohippus*.

MERYCHIPPUS Leidy

The remains of *Merychippus* are much the most common fossils throughout the Barstow wherever it has been examined. In the uppermost or Fossiliferous Tuff member of the Barstow syncline, mammalian remains are relatively much more abundant than in the other portions of the beds and *Merychippus* is the most common form. One zone, in which bones of this form were especially abundant was known in the field as the Merychippus bed. According to Baker, this stratum could be traced for a considerable distance. The presumption is that the Merychippus bed represents a deposit formed with unusual slowness, and possibly at a time when conditions bringing retardation of accumulation made the region an especially favorable habitat for animal life.

The *Merychippus* forms found in the Barstow seem to differ from the species of the Mascall and Virgin Valley, and also from all of the species in the Ricardo fauna. The Barstow forms are all more progressive than those of the Mascall stage, and with one possible exception they are all less progressive than the species of the Ricardo. Whatever be the ultimate position of these three faunal zones with reference to the palaeontologic or geologic scale in other regions, there seems no doubt that the horses of the Barstow fauna represent a stage intermediate in time between the Mascall Middle Miocene preceding and the Ricardo following.

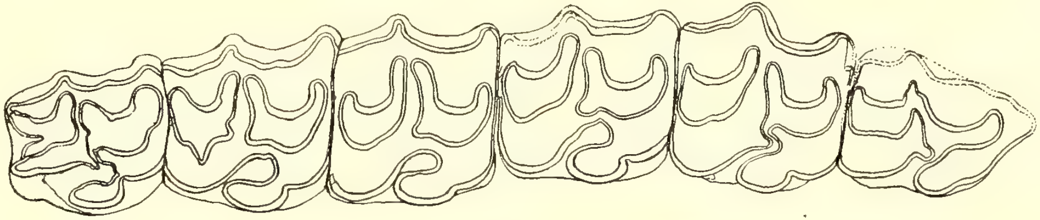
Upper Cheek-Teeth.—The numerous Merychippus-like specimens from the Barstow fauna resemble *Merychippus calamarius* (Cope) in many respects, but show a wide range of variation in the characters of the upper cheek-teeth. These teeth vary between small forms with discrete protocone and complex enamel folds bordering the fossettes on the one hand; and large, long-crowned forms with wide, simple fossettes, and protocone connected with the protoconule. The largest specimens are somewhat larger than the type of *Merychippus calamarius,* the smaller ones are considerably smaller. The difference in structure between the large and small forms may amount to more than specific distinction as ordinarily interpreted. It is comparable in general to the difference between the genera *Merychippus* and *Protohippus,* but the gradations between the forms are such that with the available material the writer finds it difficult to separate distinct groups of more than specific rank.

The largest form is separated as a species distinguished from *Merychippus calamarius* and approaching *Protohippus.* It has been described as *Merychippus* (*Protohippus*) *intermontanus*[31] (figs. 36 to 40). This species is characterized by relatively large size; long tooth crowns; curved, heavily cemented upper cheek-teeth with protocone uniting with protoconule, and with relatively simple enamel walls bordering the fossettes.

A small type has been set off as *Merychippus sumani.*[32] It is distinguished (figs. 41 and 42) by relatively small size and curved, well cemented, upper cheek-teeth with protocone tending to circular cross-section even in advanced stage of wear, and with relatively complicated enamel folds bordering the fossettes.

After separation of *M. sumani* and the large species included in *Merychippus intermontanus* there remains a type to some extent intermediate between these two and closely approaching typical *M. calamarius* (Cope), though the specimens seem rarely if ever to correspond exactly to the characters of that species as shown in Cope's

[31] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 50–51, 1915.
[32] *Ibid.*, pp. 49–50, fig. 1, 1915.



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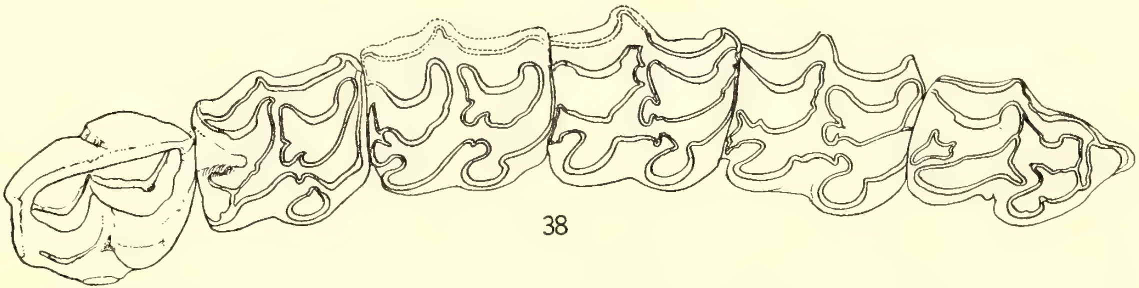

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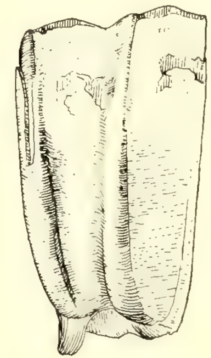

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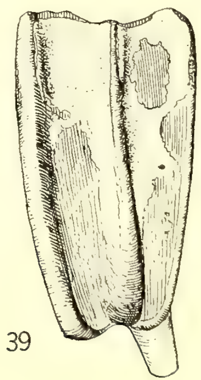

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Fig. 36. *Merychippus intermontanus* Merriam. Superior cheek-tooth series, no. 21399, natural size. Barstow Miocene, Mohave Desert, California.

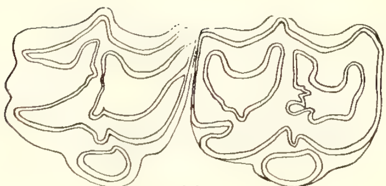
Fig. 37. *Merychippus intermontanus* Merriam. Type specimen, P^3, no. 21400, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 38. *Merychippus intermontanus* Merriam. Type specimen, superior cheek-tooth series, occlusal view, no. 21400, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 39. *Merychippus intermontanus* Merriam. Type specimen, M^2, outer view, no. 21400, natural size. Barstow Miocene, Mohave Desert, California.

type specimen. This form is described below as *M. calamarius stylodontus.* It is characterized (figs. 43 to 45) by relatively large size, approaching that of *M. intermontanus,* simple protocone nearly circular in cross-section and often separate from the protoconule until the crown is worn down to a height measuring much less than the width of the crown, and relatively simple enamel folds. The crowns are wide and well cemented.

42



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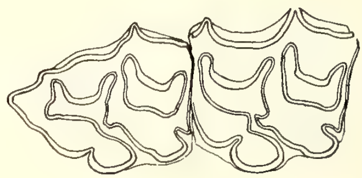

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Fig. 40. *Merychippus intermontanus?* Merriam. M^1 and M^2, no. 21409, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 42. *Merychippus sumani?* Merriam. P^2 to P^4, no. 21402, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 43. *Merychippus calamarius stylodontus,* n. var. Type specimen, M^2 and M^3, no. 21410, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 44. *Merychippus calamarius stylodontus,* n. var. P^2 and P^3, no. 22474, natural size. Barstow Miocene, Mohave Desert, California.

The *M. sumani* group comprises specimens much smaller than those referred to *M. c. stylodontus,* but apparently neither absolutely nor relatively shorter crowned. The enamel bordering the fossettes is commonly more complicated than in any of the larger *Merychippus* specimens of the Barstow.

The *M. c. stylodontus* form corresponds most nearly to Cope's type specimen of *M. calamarius* in dimensions and in proportions of the upper cheek-teeth in cross-section, but differs from the typical

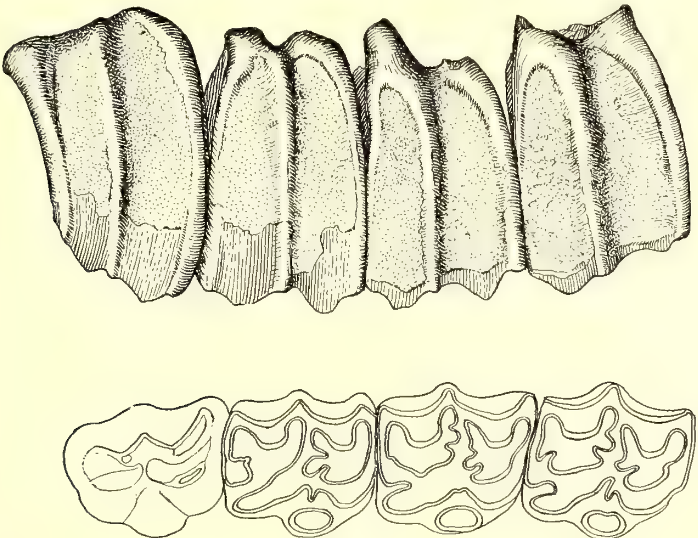

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Fig. 41. *Merychippus sumani* Merriam. Type specimen, P^4 to M^3, no. 21422, natural size. Barstow Miocene, Mohave Desert, California.

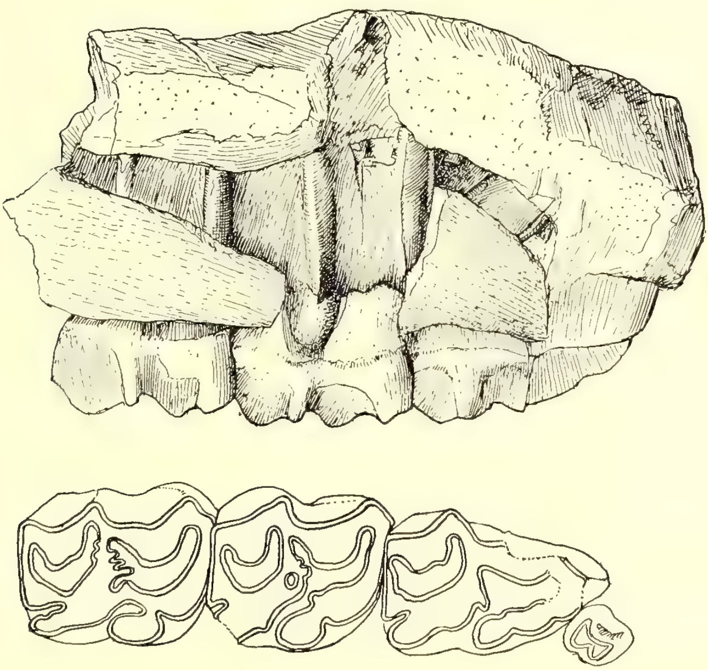

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Fig. 45. *Merychippus calamarius stylodontus,* n. var. Milk dentition, no. 19816, natural size. Permanent teeth also shown in side view. Barstow Miocene, Mohave Desert, California.

form in the relative simplicity of enamel folds of the walls bordering the fossettes. *M. sumani* resembles typical *M. calamarius* more closely in the folding of the enamel, and possibly in the relative length of the crown. It is considerably smaller than the typical form and the crowns seem narrower. The apparent difference in width may be due in part to difference in stages of wear of specimens compared, or to method of measurement. The teeth of Cope's type are apparently not in a very advanced stage of wear, but are uncommonly wide. If the stage of attrition is more advanced than the writer has assumed, the complication of the enamel folds becomes a relatively more important character.

The large *Merychippus intermontanus* closely approaches the *M. c. stylodontus* form through the medium of specimens like no. 21409 (fig. 40), in which the protocone unites with the protoconule in incipient wear and the fossettes have relatively simple borders. The crowns are, however, much larger in *M. intermontanus.*

While it is possible that additions to the material from the Barstow area now available may give sharper definition to boundary lines between the groups of *Merychippus* forms here described, or possibly between groups otherwise organized, it is also possible that fuller collections may serve rather to make separation more difficult. This may be true at least of structure of the cheek-teeth. In the series of *Merychippus* forms of the Barstow fauna as now known, the range of characters very nearly includes the range from *Merychippus* to *Protohippus* and to *Hipparion.* In the large *M. intermontanus* there is no clear separation from *Protohippus* on characters that have been used up to the present time. The cheek-teeth are large, long, heavily cemented, with heavy styles, comparatively simple fossettes, and the protocone unites with the protoconule in incipient wear. In the temporary dentition of a large specimen apparently representing *M. intermontanus* the milk molars are long and well cemented. In the *M. c. stylodontus* type the relatively short crowned character is present with the discrete protocone, and possibly thinner cementation.

In the small *M. sumani* form the characters of *Merychippus* range very near those of typical *Hipparion* as they appear in *H. mohavense* of the Ricardo fauna. The moderately cemented crowns may attain a length equalling twice the width. The borders of the fossettes are much crinkled, the protocone is discrete almost to the base and is nearly circular in cross-section. Characters separating this form from the Ricardo hipparions are seen in the smaller size, relative shortness

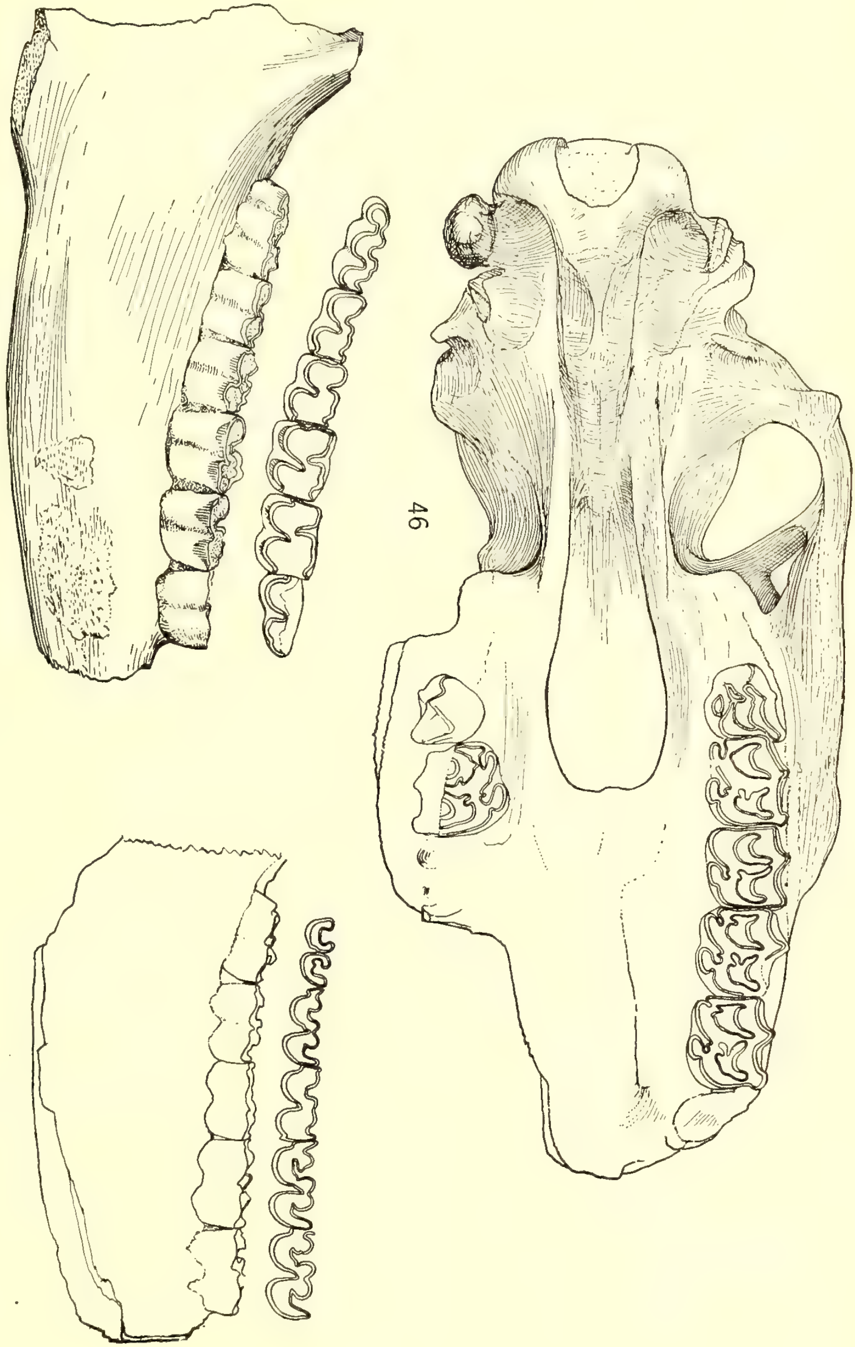


Fig. 46. *Merychippus calamarius stylodontus*, n. var. Skull, ventral view, no. 20039, × ½. Barstow Miocene, Mohave Desert, California.
Fig. 47. *Merychippus calamarius stylodontus*, n. var. Mandible, no. 20039, × ½. Barstow Miocene, Mohave Desert, California.
Fig. 48. *Merychippus intermontanus?* Merriam. Mandible, no. 21228, × ½. Barstow Miocene, Mohave Desert, California.

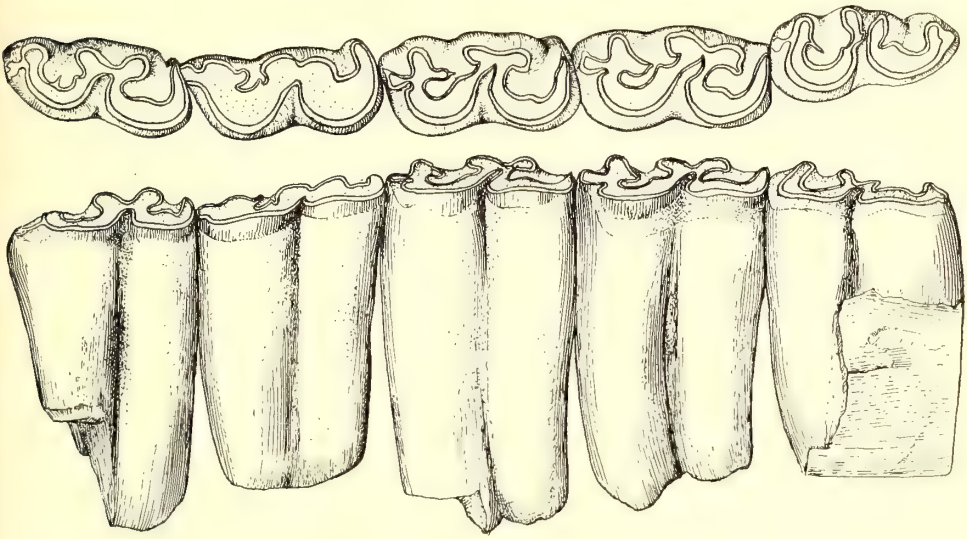
and greater curvature of crown, more gradual tapering of the mesostyles, and less advanced crinkling of the fossette borders. These characters in *Hipparion* may be due to continued specialization of the older Barstow form in the direction in which it was already moving. So far as the cheek-tooth structure is concerned, there appears to be a close relation between the *Merychippus sumani* form of the Barstow fauna and the *Hipparion* species of the Ricardo.

Lower Cheek-Teeth.—The lower molars and premolars of the *Merychippus* forms of the Barstow fauna are somewhat longer crowned than in the species of the Mascall and Virgin Valley beds, and tend generally to be well cemented. They vary considerably in size, corresponding to the difference between the large and small types of upper molars ranging between *Merychippus intermontanus* and the small *M. sumani* type.

In none of the *Merychippus* specimens from the Barstow fauna has the first lower premolar been observed though it is present in the upper dentition, and is seen as a peg-like tooth in the inferior milk dentition. In all of the forms of *Merychippus,* the metaconid-metastylid column is shorter anteroposteriorly than in *Hipparion.* The internal groove of this column is narrow and sharp. The parastylid commonly swings inward to a plane almost even with that of the inner side of the metaconid-metastylid column. Particularly in the smaller forms an antero-external ridge commonly appears on the protoconid.

The small, inferior, cheek-tooth series which evidently correspond to the *M. sumani* type of upper teeth are generally characterized by somewhat shorter crowns than the large form, and by somewhat less increase in the width of the series in the region of P_3 and P_4. In the small forms, the greatest width of the crushing surface of the lower dentition lies at the posterior end of P_3 and anterior end of P_4, as in the large form, but the increase in width in this region seems noticeably less. In such material as it available there is a suggestion that the anteroexternal angle of the protoconid appears more commonly in the small form than in the large.

In a general way, the lower cheek-teeth of *Merychippus intermontanus* (figs. 48, 49) resemble *Protohippus,* and might lead toward *Pliohippus.* Those of the small *M. sumani* form are nearer to *Hipparion* than is the larger type, but do not seem to approach the characters of that genus as closely as do the upper teeth.



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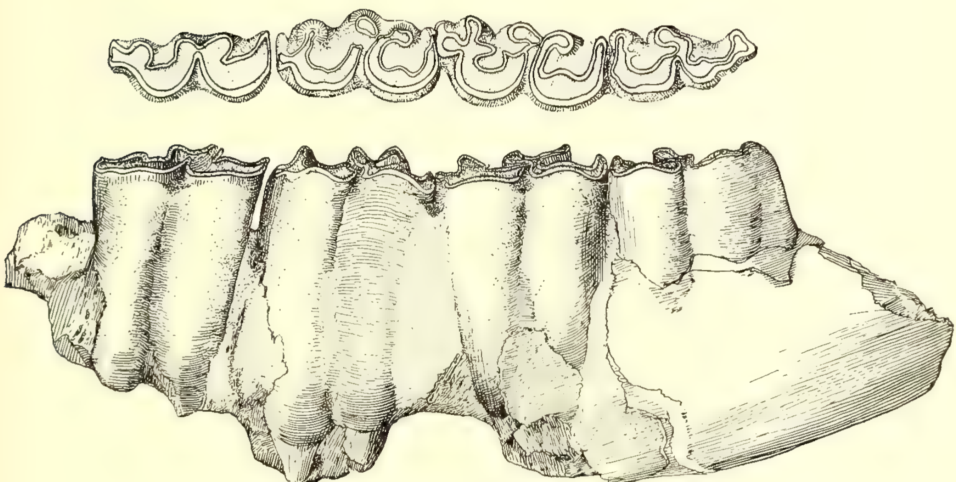

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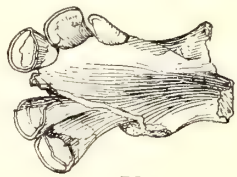
Fig. 49. *Merychippus intermontanus* Merriam. P_2 to M_2, no. 21459, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 50. *Merychippus calamarius stylodontus?*, n. var. P_2 to M_1, no. 19819, natural size. Barstow Miocene, Mohave Desert, California.

Incisors and Canines.—The incisors are well shown in specimen 21463, which is associated with teeth of the *Merychippus c. stylodontus* type. All of the incisors of the upper dentition (figs. 51*a*, 51*b*) are clearly cupped, and cement fills the valleys of the middle incisors to a considerable depth. I_3 is distinctly cupped.

Specimen 21776 shows I_1 and I_2 with distinct cupping. On I_3 there is a marked infolding of the posterior wall and an incipient posterior ridge begins to enclose a median pit.

The upper canines of no. 21463 are of moderate size and slightly flattened laterally. In no. 1349, apparently a form of the same specific type, the superior canine is somewhat larger and apparently is markedly flattened laterally. The inner face shows a median ridge flanked anteriorly and posteriorly by shallow longitudinal grooves.



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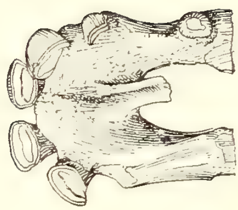
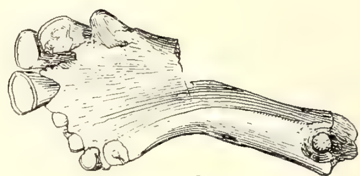
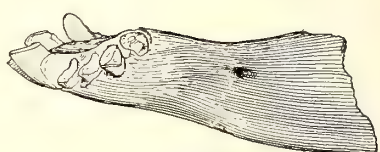


51a



52a

51b



52b

Figs. 51*a* and 51*b*. *Merychippus calamarius stylodontus?*, n. var. Superior incisors and canine, no. 21463, × ½. Fig. 51*a*, inferior view; fig. 51*b*, lateral view. Barstow Miocene, Mohave Desert, California.

Figs. 52*a* and 52*b*. *Merychippus calamarius stylodontus?*, n. var. Inferior incisors and canine, no. 21569, × ½. Fig. 52*a*, dorsal view; fig. 52*b*, lateral view. Barstow Miocene, Mohave Desert, California.

Fig. 53. *Merychippus calamarius stylodontus?*, n. var. Inferior incisors and canines, no. 21776, dorsal view, × ½. Barstow Miocene, Mohave Desert, California.

In a considerable number of specimens exhibiting the symphysial region the lower canine is a large prominent tooth with nearly circular cross-section (fig. 52*a*) and the root is much larger than that of I_3. In no. 21776 the small inferior canine is situated immediately behind I_3. The root is approximately one-half as large as that of I_3. This is possibly a female.

COMPARATIVE MEASUREMENTS OF SUPERIOR DENTITION OF MERYCHIPPUS FORMS*

	Merychippus calamarius Type specimen	M. c. stylodontus, Type specimen, no. 21411 beginning wear	M. c. stylodontus no. 21410 moderate wear	M. c. stylodontus no.21404 considerably worn	M. c. stylodontus no. 20039	M. c. stylodontus no. 21405 beginning wear	M. c. stylodontus? no. 21403 much worn	M. c. stylodontus no. 21463	M. c. stylodontus no. 21386	M. intermontanus Type, no. 21400 moderately worn	M. intermontanus no. 21399 much worn	M. sumani Type, no. 21422 moderate wear	M. sumani no. 21401 much worn	M. sumani? no. 21402 beginning wear	M. sumani no. 21385 much worn
Length, anterior side I^1 to posterior side M^3	......	......	......	......	......	......	......	......	*a*198	......	......	......	......	......	......
Length, anterior side P^2 to posterior side M^3	134 mm.	......	......	......	......	......	......	......	*a*112	146	139	......	......	......	*a*107
Length, anterior side P^2 to posterior side P^4	......	......	......	......	......	......	......	......	55.7	78.8	73.5	......	......	......	54.8
Length, anterior side M^1 to posterior side M^3	62	56.5	......	......	63	......	......	......	*a*58	67	65.8	57	......	......	*a*52.5
Length of crown, P^3	30	36.5	27.5	21.5	......	*a*32	......	......	......	44	30	......	16	*a*31	*a*5
Length of crown, M^2	......	......	......	......	......	......	......	......	......	43	33	32.8	20	......	6
P^1, greatest anteroposterior diameter	......	7	......	......	......	......	......	......	*a*11	......	......	......	......	......	......
P^1, greatest transverse diameter	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
P^2, anteroposterior diameter	25	......	......	28.9	......	25.9	......	......	......	27.8	*a*27	......	......	25.4	22.8
P^2, transverse diameter	21	......	......	24.2	......	18.8	......	......	......	18.5	......	......	......	17	22
P^3, anteroposterior diameter	21.5	24.7	24.4	23.3	22.9	23.3	21.4?	......	20	24.5	23.6	......	20	22.6	16
P^3, transverse diameter	24	24.7	23.6	27.8	22.3	22.8	......	......	*a*23	22.7	24.2	......	21.9	......	......
P^4, anteroposterior diameter	21	......	23.4	22.2	23	22	21.6?	......	......	24.9	23.4	22	20	22.4	17
P^4, transverse diameter	23	......	23.8	25.9	23.2	20.8	......	......	......	21	24.8	20.8	21.6	20.5	*a*25.4
M^1, anteroposterior diameter	20	......	......	......	21	......	19.2	......	18	24	22	19	17.4	......	15.5
M^1, transverse diameter	22	......	......	......	22.4	......	28.1	......	......	......	26	19.4	20.6	......	......
M^2, anteroposterior diameter	21	......	......	......	23	......	20.1	......	19.3	24	21.9	20.8	20	......	16
M^2, transverse diameter	21	......	......	......	20.7	......	25	......	*a*23	21.7	25	18.1	19.3	......	22
M^3, anteroposterior diameter	20	......	......	......	18.5	......	21.4	......	......	*a*22	22.7	19.7	......	......	......
M^3, transverse diameter	?17	......	......	......	19	......	22.7	......	......	*a*18	19.5	15.5	......	......	21
Length, anterior side I^1 to anterior side P^2	......	......	......	......	......	......	......	......	86	......	......	......	......	......	......
C, anteroposterior diameter	......	......	......	......	......	......	......	7.3	6.4	......	......	......	......	......	......
I^1, anteroposterior diameter	......	......	......	......	......	......	......	8.2	8	......	......	......	......	......	......
I^1, greatest width	......	......	......	......	......	......	......	13.2	9.9	......	......	......	......	......	......
I^2, anteroposterior diameter	......	......	......	......	......	......	......	7.2	7.5	......	......	......	......	......	......
I^2, greatest width	......	......	......	......	......	......	......	13.2	9.7	......	......	......	......	......	......
I^3, anteroposterior diameter	......	......	......	......	......	......	......	......	6.2	......	......	......	......	......	......
I^3, greatest width	......	......	......	......	......	......	......	12.8	10.8	......	......	......	......	......	......

* All measurements without cement. For system of measurements see Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, p. 409, 1913.

a, approximate.

Comparative Measurements of Inferior Dentition of Merychippus Forms*

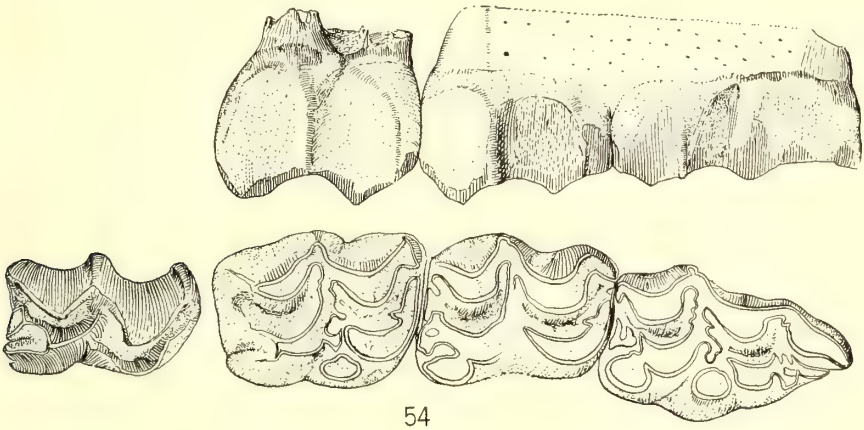
	M. c. stylodontus no. 20039 worn	M. c. stylodontus no. 21392 moderately worn	M. c. stylodontus no. 19919 moderately worn	M. intermontanus no. 21459 moderately worn	M. intermontanus no. 21228 well worn	M. sumani? no. 21389
Length, anterior side P_2 to posterior side M_3	......	120.5	......	......	123	......
Length, anterior side P_2 to posterior side P_4	......	60.5	64	75	62	......
Length, anterior side M_1 to posterior side M_3	45.2 mm.	60	......	......	61	57.6
P_2, anteroposterior diameter	......	21.8	20.5	25.1	21.2	*a*18.5
P_2, transverse diameter	......	10.6	9	10.8	......	......
P_3, anteroposterior diameter	22.2	20.4	22.5	25.1	20.4	18.9
P_3, transverse diameter	11.2	12	10.4	12.2	14.2	......
P_4, anteroposterior diameter	23.5	20	21.8	24.7	20.4	19.8
P_4, transverse diameter	11.6	12.2	10.5	12	14.3	......
M_1, anteroposterior diameter	20.4	18.8	21.6	25.4	18.2	17.5
M_1, transverse diameter	10.6	10.8	9.5	10.1	12.8	......
M_2, anteroposterior diameter	20.9	21.1	......	25.6	18.5	18.2
M_2, transverse diameter	9.4	10	......	9.7	11.5	9.5
M_3, anteroposterior diameter	23.3	21.1	......	......	25	22.1
M_3, transverse diameter	7.8	8	......	......	9.3	8.8
Length of crown, P_4	......	......	38	44	......	......
Length of crown, M_2	......	......	......	*a*41	......	......
	No. 21569			No. 21776		
I_1, anteroposterior diameter	8	......	......	7.7	......	......
I_1, transverse diameter	10.3	......	......	......	......	......
I_2, anteroposterior diameter	8	......	......	7.7	......	......
I_2, transverse diameter	10.7	......	......	11.6	......	......
I_3, anteroposterior diameter	*a*6	......	......	*a*5.7	......	......
I_3, transverse diameter	*a*10.4	......	......	5.9	......	......
C, anteroposterior diameter	7	......	......	3.9	......	......
C, transverse diameter	6.8	......	......	4.3	......	......

* All measurements without cement. For system of measurements see Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, p. 409, 1913.

a, approximate.

Milk Dentition.—The milk teeth of *Merychippus* forms are well shown in a number of specimens from the Barstow beds, but it is not possible to make certain in every case which of the several species is represented.

In specimen 19816 (fig. 45, p. 483) a complete upper cheek-tooth dentition is shown with the permanent premolars partly formed in the jaw above. The well worn milk teeth have a pattern suggesting *Merychippus calamarius stylodontus.* They are well cemented and the degree of cementation suggests *Protohippus.* The premolars forming in the jaw are large and might represent either *M. c. stylodontus* or *M. intermontanus.*



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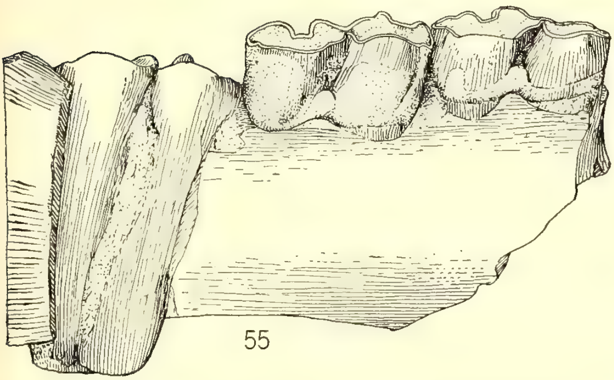

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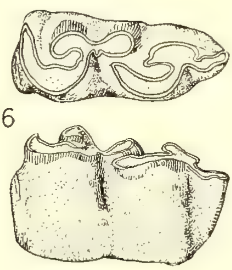

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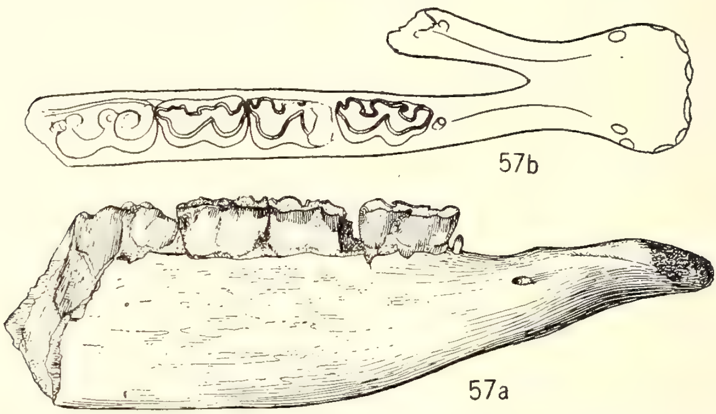
Fig. 54. *Merychippus intermontanus?* Merriam. Superior milk dentition with occlusal view of M^1, no. 21460, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 55. *Merychippus intermontanus* Merriam. Inferior milk dentition with permanent M_1, no. 21398, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 56. *Merychippus intermontanus* Merriam. Dm_3, no. 21461, natural size. Barstow Miocene, Mohave Desert, California.

In no. 21460 the upper milk molars (fig. 54) are somewhat larger than in no. 19816 though of much the same form. In no. 21460 the slightly worn crowns are high and well cemented. They seem as advanced as in *Protohippus.* In no. 21460 M^1 is a large tooth comparable in general to M^1 of *M. intermontanus,* and it is not improbable that this specimen represents that species. The teeth in this specimen differ from those of certain forms referred to *Pliohippus* in the Ricardo fauna in the more clearly separate protocone and slightly less cementation.

A complete series of lower milk molars (no. 20029, figs. 57*a* and 57*b*) represents a relatively small form of the *Merychippus* group. The crowns are about as advanced as in *M. isonesus* of the Mascall, but are more heavily cemented. Dm_1 is a very small peg-like tooth. M_1 is a long tooth. This specimen represents either *M. sumani* or the *M. c. stylodontus* form. The incisors and canines are missing from



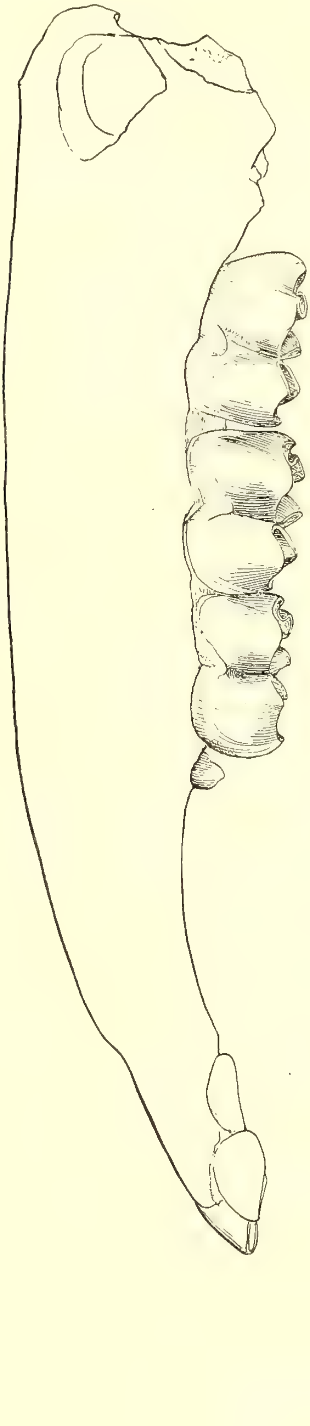
Figs. 57*a* and 57*b*. *Merychippus sumani?* Merriam. Mandible with milk dentition, no. 20029, × ½. Fig. 57*a*, lateral view; fig. 57*b*, dorsal view. Barstow Miocene, Mohave Desert, California.

this specimen. The alveolus for the inferior canine is very small, and is situated close behind I_3.

A lower jaw with milk teeth somewhat larger than in no. 20029 was associated with the upper milk dentition of no. 21460, and probably represents the same specimen. The crowns are high and well cemented, much as in *Protohippus*. This specimen presumably represents *Merychippus intermontanus*.

In all of the lower milk teeth of the *Merychippus* forms of the Barstow fauna the anteroexternal fold on the protoconid, and the external tubercle between protoconid and hypoconid tend to develop.

Comparison with a fine specimen, evidently representing *Merychippus isonesus* (no. 1678, figs. 58 and 59) from the Mascall Miocene in Oregon shows that the difference between the milk molars of the Mascall and Barstow forms is not large. The crowns of the Barstow species are possibly a little longer and the cementation somewhat



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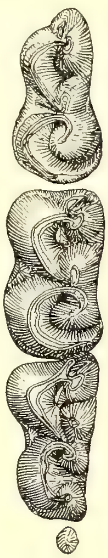

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Fig. 58. *Merychippus isonesus* (Cope). Mandible with milk dentition, no. 1678, natural size. Mascall Middle Miocene, John Day Region, Oregon.

Fig. 59. *Merychippus isonesus* (Cope). Inferior milk dentition, occlusal view, no. 1678, natural size. Mascall Middle Miocene, John Day Region, Oregon.

heavier. So far as known P_1 is larger in the Mascall species. The difference between the temporary teeth seems less than between the permanent cheek-teeth of the Mascall and Barstow forms. As shown in figs. 57*a* and 58 there is a wide difference between the Mascall and Barstow species in the form of the lower jaw. In the Barstow species, the mandible is much higher and heavier than the slender horizontal ramus of the Mascall species.

Comparative Measurements of Milk Dentition

	No. 19816	No. 21460	No. 1678 Mascall	
Length, anterior side Dm^2 to posterior side Dm^4	*a*77.5 mm.	82.5	*a*71	
Dm^1, anteroposterior diameter	10.4	......	......	
Dm^1, transverse diameter	7.9	......	......	
Dm^2, anteroposterior diameter	30.2	32.5	27	
Dm^2, transverse diameter	18.3	21.5	17.5	
Dm^2, height of crown	......	......	......	
Dm^3, anteroposterior diameter	22.5	24.8	20.5	
Dm^3, transverse diameter	21.7	......	18.4	
Dm^4, anteroposterior diameter	23.9	25.9	21.3	
Dm^4, transverse diameter	21	21.4	......	
Dm^4, height of crown	8.5	17	......	
M^1, anteroposterior diameter	......	23.8	22.2	
	No. 20029	No. 21461		No. 21398
Length, anterior side Dm_2 to posterior side Dm_4	72.5	*a*78	66	......
Dm_1, anteroposterior diameter	2.8	......	4.6	......
Dm_2, anteroposterior diameter	24.5	......	22.8	......
Dm_2, transverse diameter	......	......	11.8	......
Dm_3, anteroposterior diameter	......	25.1	21.8	23.7
Dm_3, transverse diameter	11.8	12.5	12.1	......
Dm_4, anteroposterior diameter	24.6	27.9	23	*a*26
Dm_4, transverse diameter	12.2	*a*12	11.9	15
Dm_4, height of crown	13	16.8	15	12.5
M_1, anteroposterior diameter	24.5	......	20	*a*26
M_1, height of crown	*a*39	......	23	*a*43

a, approximate.

Skull.—Three specimens show the greater part of the cranium and two others represent portions of the anterior region not well preserved in the better skulls. The several specimens taken together exhibit practically all of the essential characters of the skull. These specimens agree quite closely in comparable measurements and seem all to represent the *Merychippus calamarius* group. No. 20039 (fig. 61), the specimen showing the teeth in the best stage of preservation, seems to belong to the *M. c. stylodontus* type. No. 21385 (fig. 64*a*) possibly belongs to *M. sumani*.

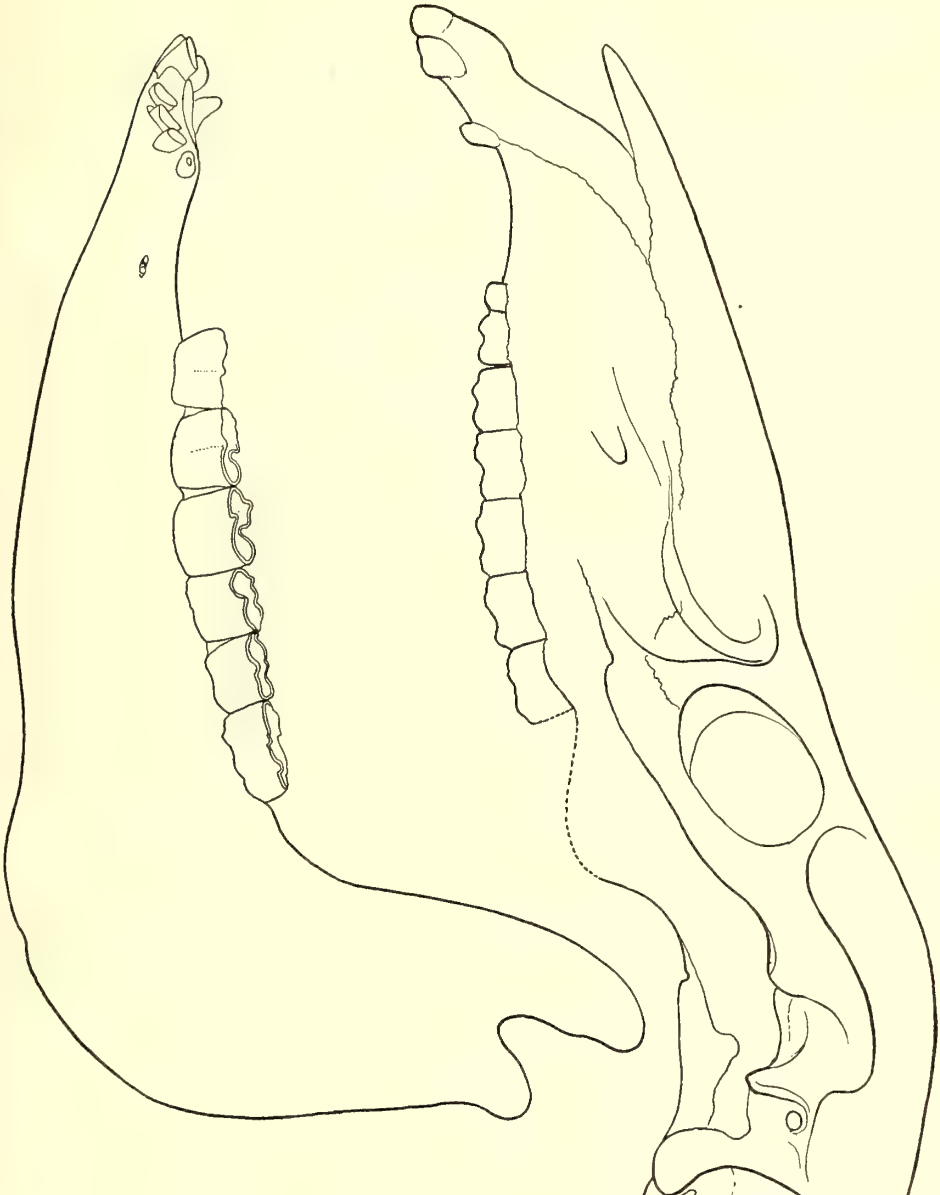
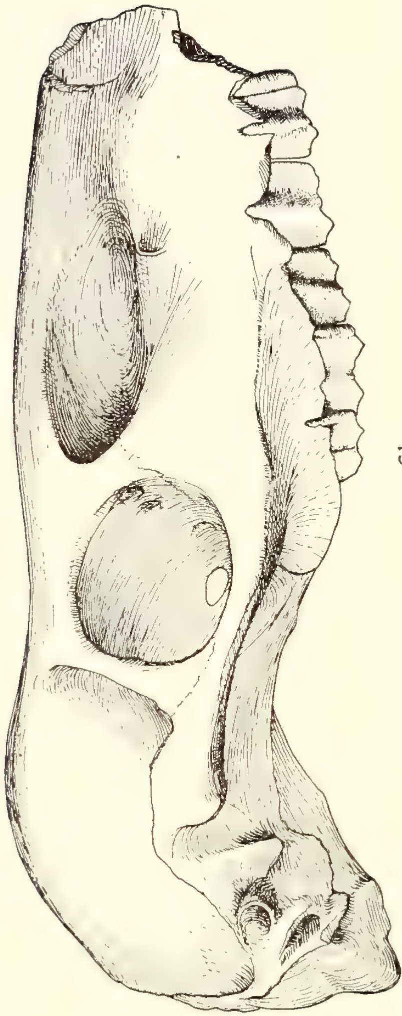


Fig. 60. *Merychippus*, like *calamarius* (Cope). Reconstruction of skull based on specimens from Barstow Miocene, Mohave Desert, California.



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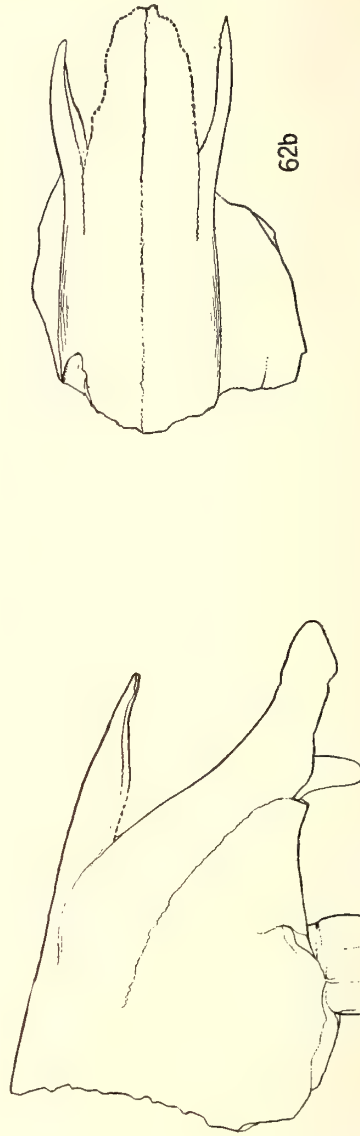


62a

62b

Fig. 61. *Merychippus calamarius stylodontus?*, n. var. Cranium, lateral view, no. 20039, × ½; anterior end broken away and occipital region damaged. Barstow Miocene, Mohave Desert, California.

Fig. 62*a* and 62*b*. *Merychippus*, sp. Nasal region of cranium, no. 1349, × ½. Fig. 62*a*, lateral view; fig. 62*b*, dorsal view. Barstow Miocene, Mohave Desert, California.

The length of the skull is a little greater than the measurements of *Merychippus* material from the Great Plains region available for comparison, and is greater than in a specimen of *Protohippus sejunctus* (no. 8291, Am. Mus. Nat. Hist.).

The brain case is large, wide, and strongly arched anteroposteriorly in the median line (fig. 60). The anterior slope of the dorsal surface extends downward to the wide, flat or slightly concave frontal area, producing in specimen no. 20039 a peculiar convex form in the parietal region.

The rostral region is rather narrow anterior to the cheek-teeth. Very large lateral or lachrymal fossae originate immediately anterior to the orbits and extend forward as very marked depressions almost to a point opposite P^3. In less marked form they may reach almost to the anterior end of the cheek-tooth series. The long narrow nasal elements extend forward over the nasal openings to a point somewhat in advance of the superior canines.

The anterior ends of the large oval orbits are situated above the posterior region of M_3. The zygomatic arch and postorbital bar are rather slender. The postglenoid process is of moderate length. The paroccipital process is long and slender.

Fig. 63. *Merychippus calamarius stylodontus?*, n. var. Cranium, lateral view, no. 21386, × ½. Barstow Miocene, Mohave Desert, California.

The occipital condyles are large and wide. The occiput is strongly convex immediately above the foramen magnum, but shows a marked depression, apparently with a median ridge for muscular attachment, just below the marked overhang of the inion.

The posterior palatine opening is wide anteriorly, its anterior end being opposite the anterior region of M^2 in no. 21385, an individual of advanced age of the *Merychippus sumani* type. In no. 20039, a younger individual probably of the *M. c. stylodontus* type, the anterior end of the opening is opposite the middle of M^2.

The infraorbital foramen is above the posterior region of P^4 in no. 20039. The postpalatine foramina are opposite the middle of M^2 in the same specimen.

The reconstruction of the skull shown in figure 60 is based in considerable part on specimen 21386, presumably a representative of *M. c. stylodontus*, with restoration according to the characters of the other skulls available. This restoration may be taken as representing the type like *Merychippus calamarius* in the Barstow fauna.

The form of the skull in the Barstow specimens is in general similar to that of *Merychippus* as known to the writer. In most respects it approaches the type seen in *Protohippus sejunctus* so closely that no generic distinctions are apparent. Such differences as exist are apparently of specific value.

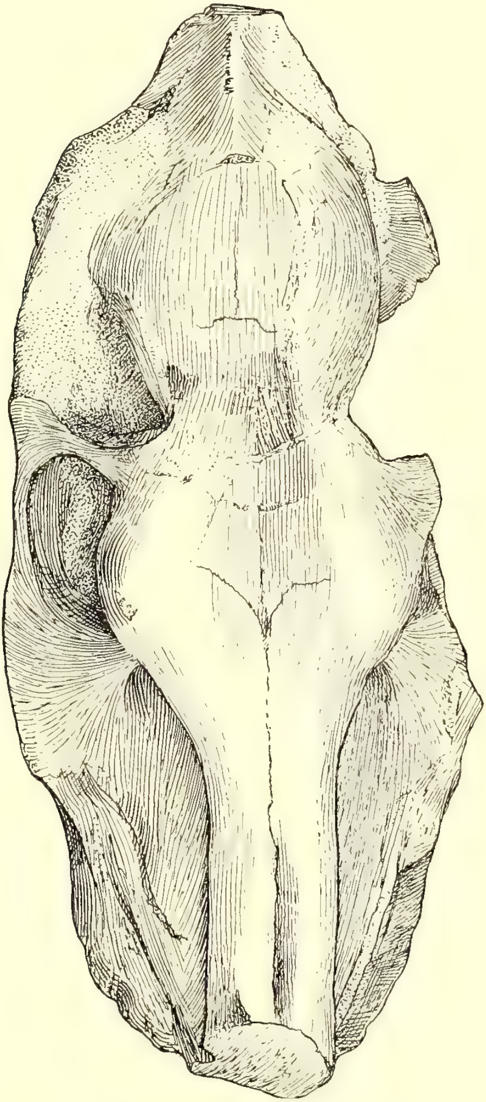
Measurements of Skull

	No. 20039	No. 21386	No. 21387	No. 21385
Length, anterior end premaxillary to posterior end occipital condyles	......	336 mm.	......	......
Length, anterior end P^2 to anterior end premaxillary	......	82	......	......
Length, anterior side of orbit to anterior end of premaxillary	......	*a*194	......	......
Length, anterior side M^1 to posterior side of occipital condyles	199	196	......	196
Length, anterior side M^1 to anterior end of premaxillary	......	138	......	......
Width, between inner sides of M^1	52.5	......	crushed *a*46	44
Least width between orbits	96	*a*90	......	*a*83
Least width across nasal ridge above lachrymal fossae	*a*31	crushed 25.3	*a*36	......
Greatest width across zygomatic arches	*a*142	......	......	120
Greatest width of occipital condyles	52.5	*a*57	......	51.8
Greatest anteroposterior diameter of orbit	49.5	......	......	*a*50

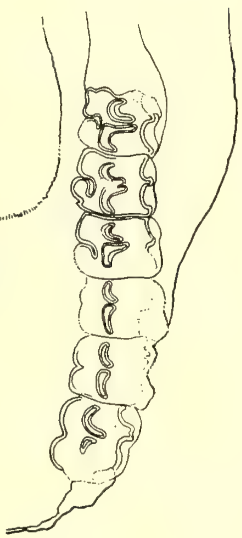
	No. 21389	No. 21228			
Height of mandible below anterior end of M_2	47	51	......	......	......

	No. 20029				
Height of mandible anterior end of M_1	41	......	......	......	......

a, approximate.



64a



64b

Figs. 64*a* and 64*b*. *Merychippus*, sp. Cranium, no. 21385, × ½. Fig. 64*a*, dorsal view; fig. 64*b*, view of palate with teeth. Barstow Miocene, Mohave Desert, California.

The mandible is not shown complete in any specimen. In no. 20029 (figs. 57*a* and 57*b*), a young individual with M_1 not yet in function, the horizontal ramus is seen to be much higher than in a young specimen of *Merychippus isonesus* from the Mascall Miocene. The symphysial region is not greatly widened, and the very small canine is close behind I_3.

A lower jaw (fig. 47) associated with the skull no. 20039 does not show the outlines of the ramus. In no. 21228 the form of the mandible in the adult is seen to be much as in the young specimen represented in no. 20029 (fig. 57*a*).

Limbs.—Large numbers of skeletal parts found in the beds of the Barstow syncline represent a *Merychippus* species corresponding approximately to *M. calamarius* in stage of development and in size.

The range of variation in the material extends from elements representing small forms near the size of specimens of *Merychippus isonesus* of the Mascall up to elements from individuals evidently about double the size of the smaller type. In the absence of good associated skeletal material it is not possible to make a thoroughly satisfactory determination of the systematic position of the species represented by the skeletal elements, but it is reasonable to assume that the smallest represent *Merychippus sumani* as known from the dentition, and that the largest specimens are from the *M. intermontanus* type.

In general the type of foot structure is similar to that of the genus *Merychippus* as seen in *M. isonesus*. The metapodials are slender, the lateral digits small and scarcely functional. The hoofs of digit III are narrow, and with a marked terminal cleft. The narrow astragalus has a deep subacute trochlear groove.

The abundant proximal phalanges of digit III (figs. 66 and 67) are much more slender than those of *Hypohippus* (fig. 29) and show a marked median constriction. There is a suggestion of less flattening and more distinct rounding of the shaft than in a number of specimens presumably representing *Merychippus isonesus* from the Virgin Valley Miocene. The groove for the trochlear ridge of the metapodials is commonly not well marked at the anterior side of the proximal articular face; but in a few of the largest specimens (fig. 68) it is strongly marked on the anterior side corresponding to the development of the metapodial keel.

The second phalanges of digit III are easily distinguished by their narrower form from the wide, relatively short phalanges of *Hypohippus*.

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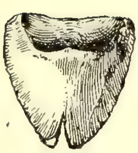

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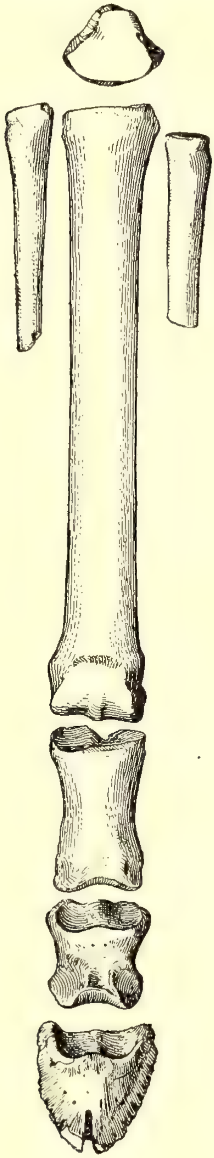

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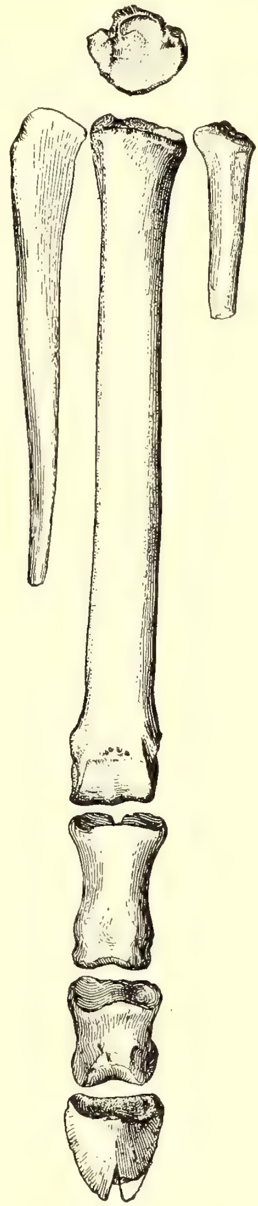

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Fig. 65. *Merychippus,* sp. Ungual phalanx, no. 23131, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 66. *Merychippus,* sp. Third metacarpal and digit with proximal ends of metacarpals 2 and 4, no. 22372, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 67. *Merychippus,* sp. Third metatarsal and digit with fragments of metatarsals 2 and 4, no. 19817, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 68. *Merychippus,* sp. Third metacarpal with splint bones, no. 21470, × ½. Barstow Miocene, Mohave Desert, California.

The ungual phalanges of digit III of even the smallest form (fig. 67) in the Barstow fauna are relatively somewhat wider than in one perfect specimen of a Merychippus-like horse from the Mascall available for comparison, but have nearly the same size and proportions as another Mascall specimen. The difference between the smallest and largest forms in the Barstow collection is mainly one of size. In all of the specimens the anterior end is subacute, with the terminal cleft well marked. The postero-lateral wings project slightly behind the inferior margin of the proximal articular face.

69

70

Fig. 69. *Merychippus*, sp. Third metatarsal, no. 21407, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 70. *Merychippus*, sp. Distal end of third metatarsal with first phalanx, no. 21468, × ½. Barstow Miocene, Mohave Desert, California.

Compared with casts of the feet of *Protohippus sejunctus* from the American Museum, the largest ungual phalanges in the Barstow collections have nearly the same size, but seem to show slightly smaller lateral wings, and are possibly a little higher posteriorly.

MEASUREMENTS OF METAPODIAL III

	Length	Least transverse diameter of shaft	Greatest transverse diameter of proximal end of shaft	Greatest transverse diameter of distal end of shaft
Anterior, no. 22372	165.2 mm.	17	25	25.5
Posterior, no. 19817	180.5	17.3	23.6	24.2
Posterior, no. 23130	183	16	25.4	25

Metapodial III of the *Merychippus* species of the Barstow fauna varies considerably in size, but the general outlines of the shaft do not vary greatly in either front or hind limb. The distal keel is well developed in all specimens. In some individuals the keel is scarcely visible on the anterior side of the distal articular face of even the posterior metapodial III, but careful examination will show a faint ridge reaching the proximal end of the anterior face. On some of the large specimens, as in no. 21269, the keel is strongly marked up to the proximal end of the anterior side of the distal articulation.

In metacarpal III the angle between the magnum and unciform facets ranges from near 112° to a little more than 121°. In the smaller, more slender specimens there appears a tendency toward a sharper angle than in the larger individuals. There are, however, small specimens in which the angle is 121°. It is probable that the smaller, more slender specimens of metacarpal III with the more acute magnum-unciform angle represent *Merychippus sumani.* The larger, heavier specimens with the tendency toward a wider angle presumably belong to *M. intermontanus.* In metatarsal III the cuboid facet may be nearly transverse to the long axis of shaft. It is commonly separated from the ectocuneiform facet by a sharp ridge, but the larger part of the cuboid facet may be inclined away from the ectocuneiform facet only a few degrees. In most specimens there appears to be no facet for the mesocuneiform. In others, as in no. 21206, a distinct mesocuneiform articulation lies almost in the plane of the ectocuneiform surface.

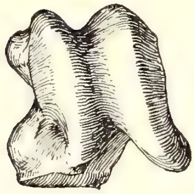
The astragalus in all of the *Merychippus* specimens shows a deep, narrow trochlear groove. The cuboid facet is well developed. The astragali vary much in size as shown in figures 77 to 79, and may well represent two or more specific types ranging from *M. intermontanus* to *M. sumani.*

The calcaneum, as shown in many specimens, seems not to differ particularly from that in other *Merychippus* forms.

Metacarpals II and IV are shown in a number of specimens (figs. 66, 68, and 72). They are quite small in comparison with metacarpal III. Compared with a cast of the foot of *Protohippus sejunctus* kindly furnished by the American Museum they are not relatively larger, and the fourth metacarpal seems somewhat smaller. Very small lateral facets are present on both metacarpal II and IV. Judging by the size of these lateral facets, the rudiments of metacarpals I and V must have been smaller than the small nodules seen in *P. sejunctus.*

The lateral metapodials of the hind foot (figs. 67 and 71) are, so far as known, not larger and possibly smaller than in *Protohippus sejunctus.* The complete form is not known but in at least one case, as shown in figure 67, the distal region of the lateral metatarsal is much reduced.

All of the specimens representing distal ends of the lateral metapodials found in the Barstow are small and slender (fig. 74). The lateral phalanges known are also small (figs. 76*a* and 76*b*). All of the evidence available shows that the lateral toes were small.



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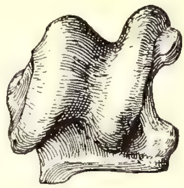

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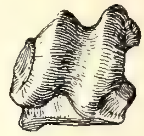

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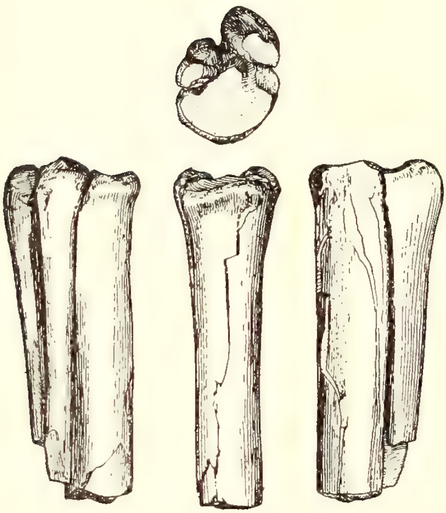

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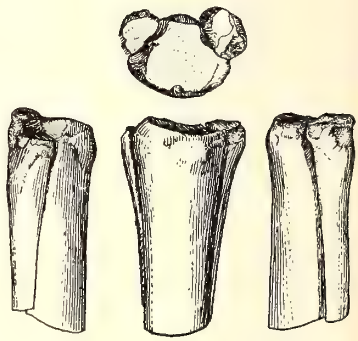

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76a

76b

Figs. 71 to 79. *Merychippus*, sp., from Barstow Miocene, Mohave Desert, California.

Fig. 71, *Merychippus*, sp., metatarsals two to four, no. 22479, × ½.

Fig. 72, *Merychippus*, sp. Metacarpals two to four, no 22370, × ½.

Fig. 73. *Merychippus*, sp. Carpus with proximal ends of metapodials, no. 21570, × ½.

Fig. 74. *Merychippus*, sp. Distal end of lateral metapodial, no. 22475, × ½.

Fig. 75. *Merychippus*, sp. Lower sesamoid or navicular, third digit, no. 22476, proximal view, × ½.

Figs. 76*a* and 76*b*. *Merychippus*, sp. Lateral digit, no. 22490, × ½. Fig. 76*a*, lateral view; fig. 76*b*, anterior view.

Fig. 77. *Merychippus*, sp. Astragalus, no. 23122, × ½.

Fig. 78. *Merychippus*, sp. Astragalus, no. 23123, × ½.

Fig. 79. *Merychippus*, sp. Astragalus, no. 23124, × ½.

The variations shown above between the large and small forms of metapodials may well be comparable to the difference between *Merychippus intermontanus* and *M. sumani.*

Certain forms of foot structure seen in the *Merychippus* types of the Barstow fauna might be transformed into those of horses in the Ricardo, without extraordinary modifications.

MERYCHIPPUS INTERMONTANUS Merriam

Merychippus intermontanus, n. sp. Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 50, 52, figs. 2, 3, 1915.

Type specimen, no. 21400. An upper cheek-tooth dentition from locality 1401 in the Barstow Miocene of the Mohave Desert, California.

Cheek-teeth large (figs. 36–39); crowns long, strongly curved, heavily cemented. Protocone of upper cheek-teeth uniting early with protoconule. Enamel walls bordering the fossettes comparatively simple.

MERYCHIPPUS CALAMARIUS STYLODONTUS, n. var.

Type specimen an upper cheek-tooth dentition, no. 21410, from locality 2057, in the Barstow Miocene of the Mohave Desert, California.

Upper cheek-tooth dentition (figs. 43–46) much as in typical *Merychippus calamarius* (Cope). Crowns larger and relatively shorter than in *M. sumani.* Protocone nearly circular in cross-section and often separate from protoconule until the crown is reduced to a height measurement less than the width. Enamel folds bordering the fossettes apparently simpler than in typical *M. calamarius.*

MERYCHIPPUS SUMANI Merriam

Merychippus, near *calamarius.* Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 168, pl. 29, figs. 1*a*–1*c,* 1911.

Merychippus sumani, n. sp. Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 49, 50, fig. 1, 1915.

Type specimen, no. 21422. Barstow Miocene, Mohave Desert, California.

Upper cheek-teeth (fig. 41) much smaller than in typical *Merychippus calamarius* or in *M. intermontanus.* Crowns of cheek-teeth considerably elongated, markedly curved, and well cemented; height of the crowns often equal approximately to twice their width. Protocone round, tending toward circular form in cross-section, and discrete up to a stage of very advanced wear. Enamel bordering the fossettes commonly more complicated than in any of the larger *Merychippus* forms of the Barstow Miocene.

PROTOHIPPUS? or PLIOHIPPUS?, sp.

A single upper molar, no. 21423 (figs. 80 and 81), represents a form apparently more advanced than the type of *Merychippus intermontanus.* It is closely allied to *Protohippus,* but better material might indicate its affinity with *Pliohippus.* This specimen was associated with the type specimen of *M. intermontanus* from locality 1401 in the Barstow syncline.

The characters of this tooth are near those of *M. intermontanus,* but it differs from that form in greater width and its much more compressed and anteriorly longer protocone.

The form represented by no. 21423 (figs. 80, 81) may be a species distinct from *M. intermontanus* or may be a more advanced stage of

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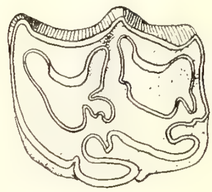

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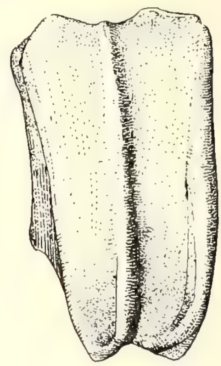


82

Figs. 80 and 81. *Protohippus?* or *Pliohippus?,* sp. Superior cheek-tooth, no. 21423. Fig. 80, outer view; fig. 81, occlusal view. Barstow Miocene, Mohave Desert, California.

Fig. 82. *Protohippus* or *Pliohippus?,* sp. Superior cheek-tooth, no. 21424, natural size. Barstow Miocene, Mohave Desert, California.

that species. Specimen no. 21423 represents the maximum of advance of the Equidae in the Barstow fauna. It differs from all three of the *Pliohippus* forms of the Ricardo. It is smaller, and less advanced than *Pliohippus fairbanksi.* It differs from *P. tantalus* in the smaller fossettes, and is also somewhat smaller and apparently less advanced. A single tooth from the Ricardo, representing a form near *Pliohippus mirabilis* is smaller in cross-section than no. 21423 from the Barstow fauna, but the Ricardo specimen is considerably worn and may originally have been the longer crowned and more progressive of the two.

Two other upper cheek-teeth, nos. 21424 and 21425, from localities in the Barstow represent forms near that seen in no. 21423 described above. No. 21424 (fig. 82) is little worn and is the longest molar found in the Barstow. The pattern of the crown and of the protocone, so far as known, suggests that of no. 21423. No. 21425 is a much worn tooth and may represent *Merychippus intermontanus.*

MEASUREMENTS

	No. 21423	No. 21424	No. 21425
M^1, anteroposterior diameter	24.2 mm.	*a*23.5	24
M^1, transverse diameter	23.8	*a*19	24
M^1, height of crown	39	42.6	37

a, approximate.

The large protohippine horses of the Barstow fauna represented in *Merychippus c. stylodontus*, *M. intermontanus*, and the *Protohippus* or *Pliohippus* described above, are antecedent types such as we might expect to find in the ancestors of the Ricardo and Etchegoin *Protohippus* and *Pliohippus* species. *Pliohippus fairbanksi* of the Ricardo fauna and *P. coalingensis* of the Etchegoin may either or both be derivations of *Merychippus intermontanus* of the Barstow. *Pliohippus tantalus* is as yet imperfectly known, but may be a derivative of a form near one of the Barstow types.

SUIDAE

A single astragalus of a suilline form, no. 22469 (fig. 83), from locality 1398 in the Barstow beds represents a dicotyline form, but a generic determination seems doubtful. This specimen shows the presence in this fauna of the peccary-like forms so well represented elsewhere in the American Miocene.

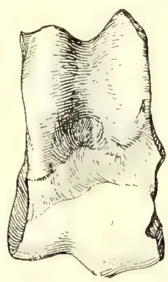


Fig. 83. *Prosthennops?*, sp. Astragalus, no. 22469, natural size. Barstow Miocene, Mohave Desert, California.

OREODONTIDAE

MERYCOCHOERUS? BUWALDI, n. sp.

Type specimen, no. 21350, an upper dentition from locality 2057, Barstow beds, Barstow syncline, north of Barstow, California.

Fragmentary oreodont remains representing a form near *Merycochoerus* were found sparingly by Baker in the Barstow region in 1911. In 1913 Buwalda and Mourning found more abundant material showing a complete upper cheek-tooth series, and a considerable part of the lower dentition.

This species is near *Merycochoerus* in general characters of the dentition and skull. It is at least as advanced as that genus in specialization of the premolars and in relative proportions of the molar and premolar series.

Only small portions of the skull are present in the type specimen, no. 21350 (fig. 84). The anterior portion of the base of the zygomatic arch arises above M^1. Anterior to the root of the zygomatic arch the maxillary appears to be somewhat flattened superiorly in a plane nearly parallel with the palate. The infraorbital foramen is situated at the posterior end of this flattened area, and above the anterior half of M^2. In specimen 21485 (figs. 85*a* and 85*b*), the base of the zygomatic arch is shown more satisfactorily. The lower jaw as seen in several quite fragmentary specimens has approximately the form shown in *Merycochoerus.* It is high anteriorly and on one specimen seems to increase in height rapidly below the posterior molars. It does not seem to show the unusual elevation of the posterior region of the mandible exhibited in *Pronomotherium.*

The dentition is characterized by height of the crowns of the cheek-teeth, relatively great length of the molar series compared with the premolars, advanced specialization of the premolars, and a tendency to crowding of the premolars anteriorly.

The stage of complication of the premolars is near that of *Merycochoerus proprius,* and not more advanced than in that species. In the Barstow species the elongation of the cheek-tooth crowns seems to have advanced farther and the external anterior and posterior styles in P^3 and P^4 seem better developed than in *M. proprius.* In the Barstow form the outer faces of P^3 and P^4 are nearly flat with a faint longitudinal rib, which the writer has not seen on *M. proprius.*

There are suggestions of external paracone and metacone ribs on the upper molars of the type specimen of *M. buwaldi.* These ribs are not clear on no. 21485.

On P^2 of *M. proprius* there is a small anterior pocket in the enamel which does not appear on the only Barstow specimen showing this tooth. An internal basal cingulum is clearly shown on the upper premolars of the Barstow form. It is faint or absent on the upper molars.

The upper canine is triangular in outline. The upper incisors are very small.

In the lower dentition the degree of complication is approximately as in *M. proprius,* and not more advanced. P_1 is relatively smaller, or the other premolars relatively larger than in *M. proprius.*

P_3 and P_4 of *M. buwaldi* are both less complicated than in *M. rusticus* of the Pawnee Creek beds of Colorado (Am. Mus. Nat. Hist., no. 9115, now in collections of University of California). The antero-

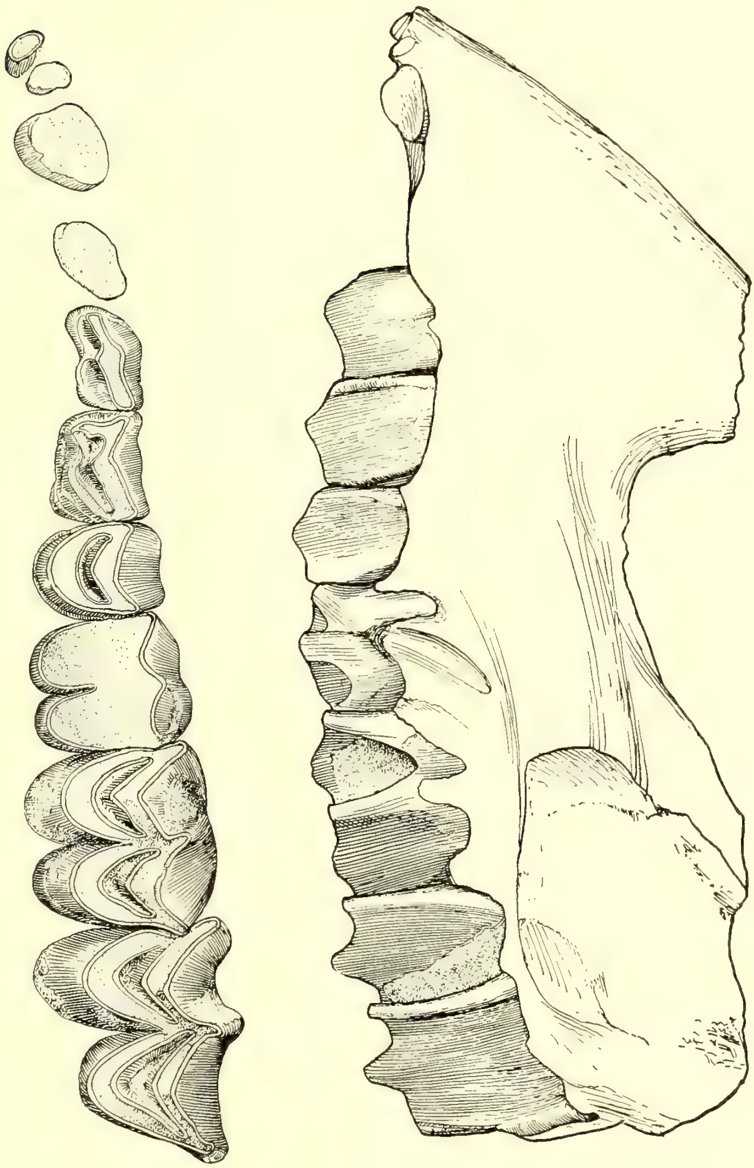
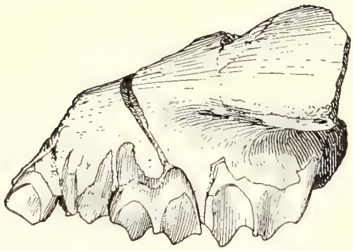


Fig. 84. *Merycochoerus? buwaldi*, n. sp. Skull fragment with superior dentition, type specimen, no. 21350, natural size. Barstow Miocene, Mohave Desert, California.



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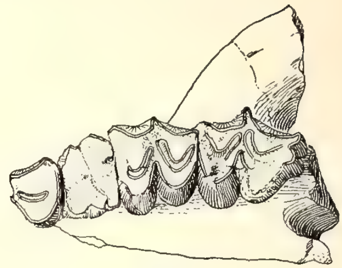

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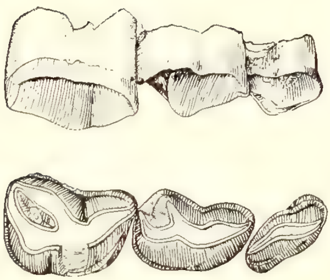

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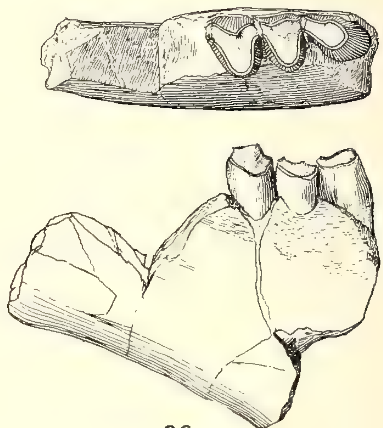

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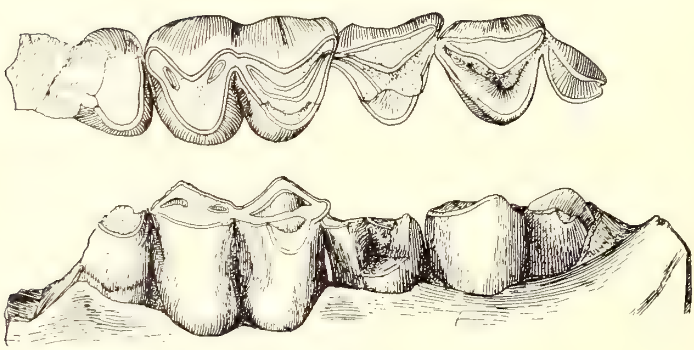


88

Figs. 85*a* and 85*b*. *Merycochoerus? buwaldi*, n. sp. Skull fragment with P^4 to M^3, no. 21485, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 86. *Merycochoerus? buwaldi*, n. sp. Fragment of mandible, outer and dorsal views, with M_3, no. 21485, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 87. *Merycochoerus? buwaldi*, n. sp. Inferior premolars, no. 21354, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 88. *Merycochoerus? buwaldi*, n. sp. M_1 to M_3, no. 21487, natural size. Barstow Miocene, Mohave Desert, California.

internal fold is more prominent on both P_3 and P_4 in *M. rusticus* than in the Barstow species. The internal cingula are strong on the premolars. The external cingula are fairly marked. The lower molars have moderately elongated crowns on the specimens available for study. There are faint internal ribs on the metaconid and entoconid columns.

A single astragalus, no. 21486 (fig. 89), from the Barstow may represent an oreodont form.

MEASUREMENTS OF SKULL AND DENTITION

	No. 21350	No. 21485
Length, anterior side of superior canine to posterior side of M^3	142 mm.	......
Length of superior molar-premolar series	128.5	......
Length of superior premolar series	53.5	......
Length of superior molar series	75	......
I^2, greatest transverse diameter	5.3	......
I^3, greatest transverse diameter	7.4	......
Superior canine, greatest transverse diameter	14.7	......
P^1, anteroposterior diameter	*a*12.2	......
P^2, anteroposterior diameter	15.8	......
P^2, transverse diameter	10.5	......
P^3, anteroposterior diameter	14.8	......
P^3, transverse diameter	14	......
P^4, anteroposterior diameter	13	12.8
P^4, transverse diameter	17.8	16.4
M^1, anteroposterior diameter	19.6	15
M^1, transverse diameter	22	20.6
M^2, anteroposterior diameter	26.3	24
M^2, transverse diameter	26.4	24
M^3, anteroposterior diameter	34.5	29.7
M^3, transverse diameter	27.8	30.7
	No. 21354	
P_2, anteroposterior diameter	12.8	......
P_2, transverse diameter	6	......
P_3, anteroposterior diameter	15.5	......
P_3, transverse diameter	10.4	......
P_4, anteroposterior diameter	17.2	......
P_4, transverse diameter	12.1	......
	No. 21487	No. 21485
M_2, anteroposterior diameter	24.8	*a*24
M_2, transverse diameter	16.1	*a*16
M_3, anteroposterior diameter	37.2	38
M_3, transverse diameter	13.2	17.2

a, approximate.

CAMELIDAE

Remains of camels are among the most common fossils found in the Barstow beds. Unfortunately the teeth do not resist destructive processes as well as those of the horses, and in absence of complete skeletal material little but scattered foot bones remain for study. Almost the only basis for comparative study of the camels seems to be furnished by the astragali. Of these there are at least four types, graded according to form and size. One is a small form (compare fig. 98), of which the astragalus is a little more than 40 mm. in greatest diameter; others are much larger (compare figs. 100 and 101) ranging to a length between 80 and 90 mm. It is possible that the smallest of these is merely a diminutive type of the next in size, but a considerable number of specimens seem not to show an intergradation. The largest of the Barstow forms are much smaller than the largest forms in the Ricardo fauna. At least two of the Barstow types (compare figs. 98 and 99) evidently represent the genus *Procamelus*, as nearly as can be judged by the dentition and the metapodials referred to this group. The largest forms of the Barstow fauna presumably represent the genera *Alticamelus* and *Pliauchenia* (compare figs. 100 and 101). The broader specimens of the larger group are presumably *Pliauchenia*, the narrower ones *Alticamelus*.

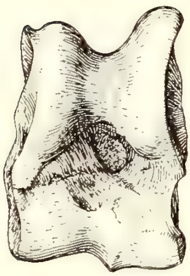
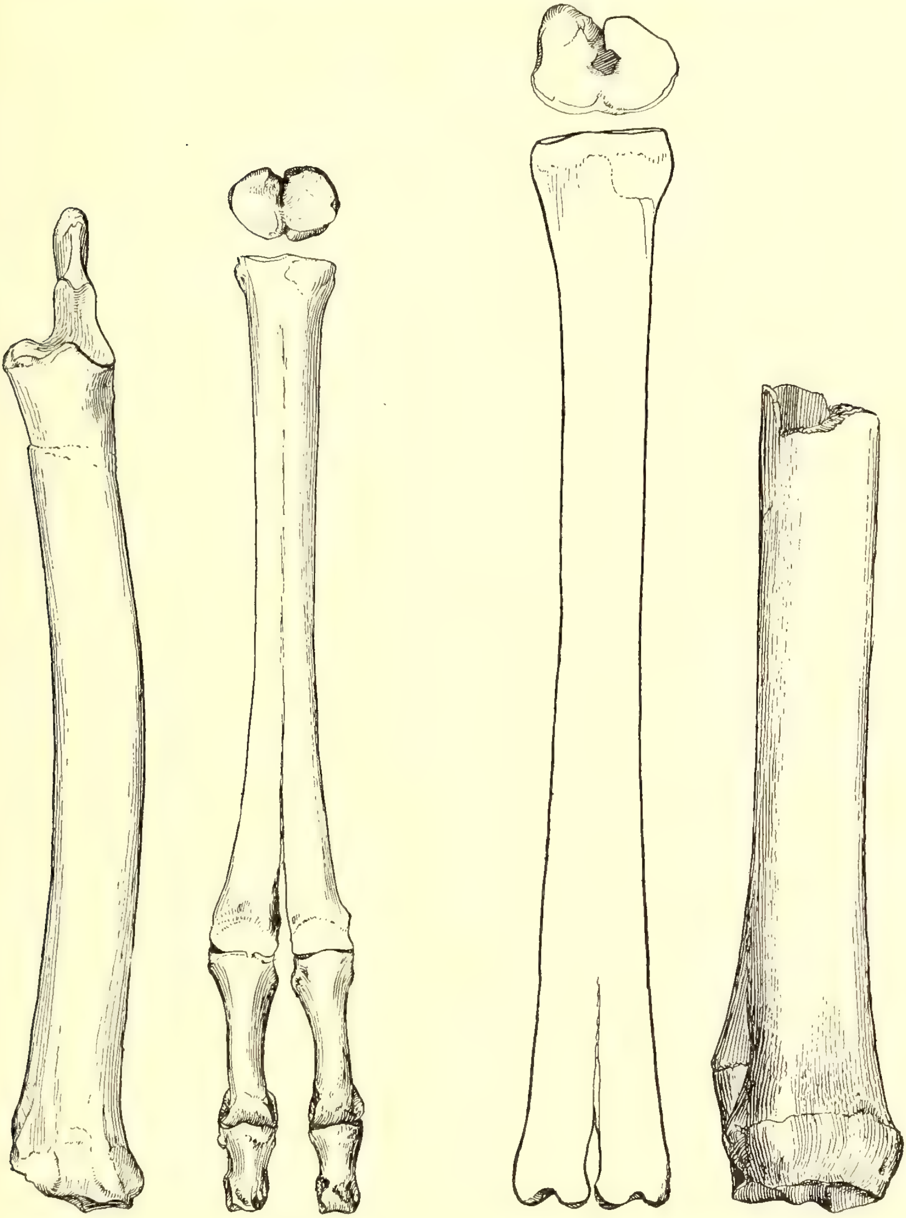


Fig. 89. *Merycochoerus? buwaldi*, n. sp.? Astragalus, no. 21486, natural size. Barstow Miocene, Mohave Desert, California.

A small astragalus with a portion of the dentition, no. 21554 (figs. 96 and 98), representing the smallest form known from the Barstow seems to represent *Procamelus*. The astragalus is small and narrow. The dentition represents the last two milk molars. The form is evidently a young individual of one of the two species smaller than *Alticamelus* and presumably to be referred to *Procamelus*.

The largest specimen representing the limbs is no. 21552, fig. 92, and is a very large and slender anterior metapodial about 70 per cent longer than the anterior metapodial of a Recent camel. This specimen presumably represents a form of *Alticamelus*. The largest specimen representing the dentition in the Barstow fauna is a mandible (fig. 104), no. 21553, with two posterior molars, the roots of the premolars, and the canine. On this specimen all of the four premolars have been present. This mandible may belong also to *Alticamelus*.

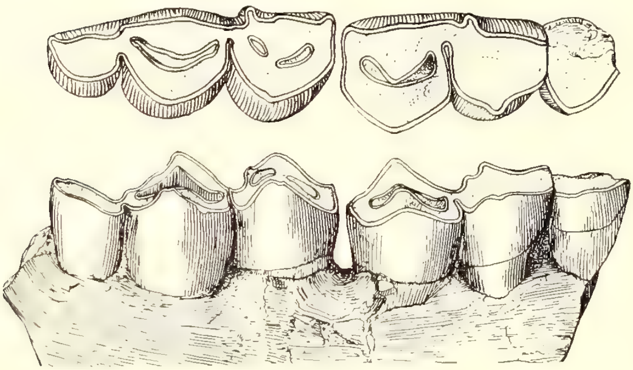


90 91 92 93

Figs. 90 to 93. Camel remains from Barstow Miocene, Mohave Desert, California.

Fig. 90, *Procamelus*, sp., radius and ulna, no. 22492, × ¼; fig. 91, *Procamelus*, sp., cannon bone and phalanges, anterior limb, no. 22491, × ¼; fig. 92, *Alticamelus?*, sp., cannon bone, no. 21552, × ¼; fig. 93, *Alticamelus?*, sp., distal half of radius, no. 22493, × ¼.

In the posterior metapodials of the Barstow forms there are two distinct types of articulation at the proximal end. One is shown in no. 21555 (fig. 107), in which the area for articulation with the cuboid and ectocuneiform is narrow transversely and the posterior hook is relatively large and high. This type evidently represents *Procamelus*, and is to be associated with one of the two intermediate types of astragalus. It corresponds very closely to the type seen in the proximal end of some of the Procamelus-like forms of the Miocene



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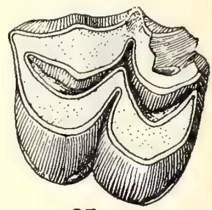

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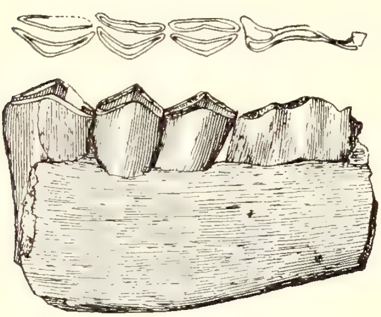

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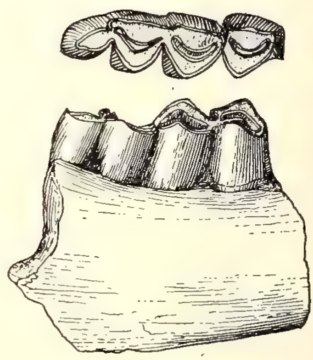


97

Fig. 94. *Procamelus?*, sp. Inferior dentition, no. 22482, natural size. Barstow Miocene, Mohave Desert, California.

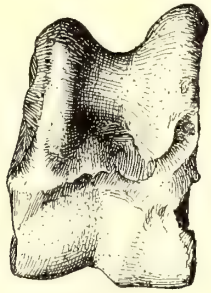
Fig. 95. *Procamelus?* sp. Superior molar, no. 23129, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 96. *Procamelus?*, sp. Inferior milk teeth, no. 21554, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 97. *Procamelus*, sp. Fragment of mandible with M_2 and M_3, no. 21562, $\times \frac{1}{2}$. Barstow Miocene, Mohave Desert, California.

98

99



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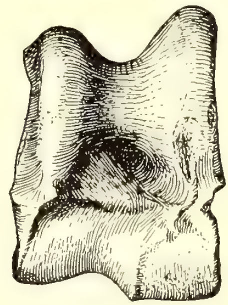

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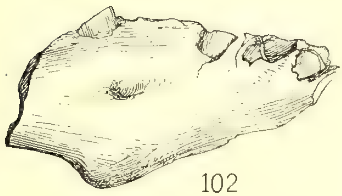

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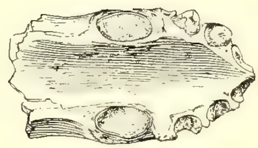

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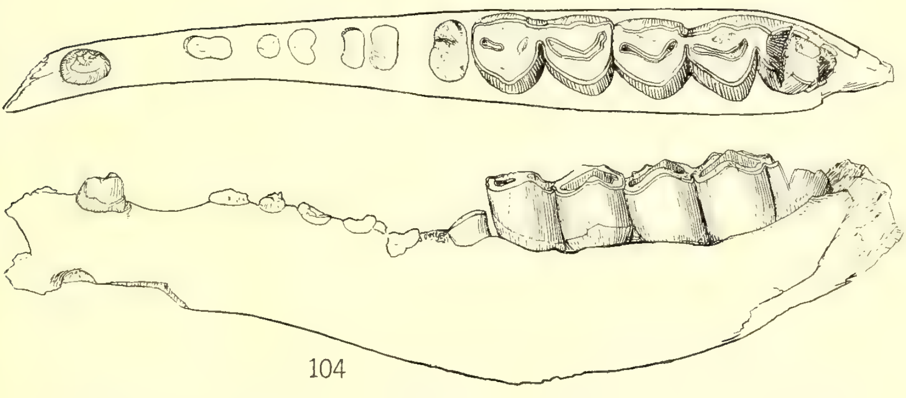


104

Fig. 98. *Procamelus,* sp. Astragalus, no. 21554, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 99. *Procamelus,* sp. Astragalus, no. 22481, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 100. *Alticamelus* or *Pliauchenia?,* sp. Astragalus, no. 23125, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 101. *Pliauchenia?,* sp. Astragalus, no. 21559, × ½. Barstow Miocene, Mohave Desert, California.

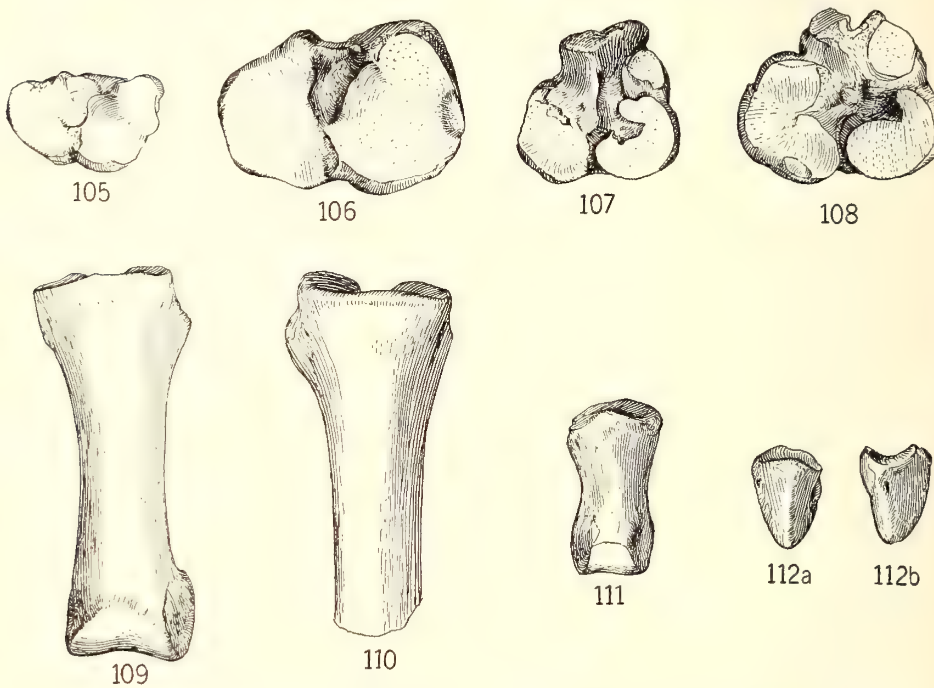
Fig. 102. *Pliauchenia?,* sp. Anterior end of mandible, no. 22484, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 103. *Procamelus?,* sp. Anterior end of mandible, no. 22483, dorsal view, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 104. *Alticamelus?,* sp. Mandible, no. 21553, × ½. Barstow Miocene, Mohave Desert, California.

in the Great Plains region. In the other form, no. 21556 (fig. 108), the proximal articular area is relatively much wider and the posterior hook is smaller. This is possibly *Pliauchenia.*

In the form of the phalanges there is also a wide variation corresponding in general to the grade of difference in astragali. The form



Figs. 105 to 112*b*. Camel remains from Barstow Miocene, Mohave Desert, California.

Fig. 105, *Procamelus,* sp., proximal end of cannon bone, anterior limb, no. 22489, × ½; fig. 106, *Pliauchenia,* sp., proximal end of cannon bone, anterior limb, no. 22488, × ½; fig. 107, *Procamelus,* sp., proximal end of cannon bone, posterior limb, no. 21555, × ½; fig. 108, *Pliauchenia?,* sp., proximal end of cannon bone, posterior limb, no. 21556, × ½; fig. 109, *Alticamelus?* or *Pliauchenia,* sp., first phalanx, no. 21558, × ½; fig. 110, *Alticamelus?,* sp., first phalanx, no. 22487, × ½; fig. 111, *Procamelus* or *Pliauchenia,* sp., second phalanx, no. 22486, × ½; figs. 112*a* and 112*b*, *Procamelus?,* sp., ungual phalanx, no. 22485, × ½, fig. 112*a*, dorsal view; fig. 112*b*, side view.

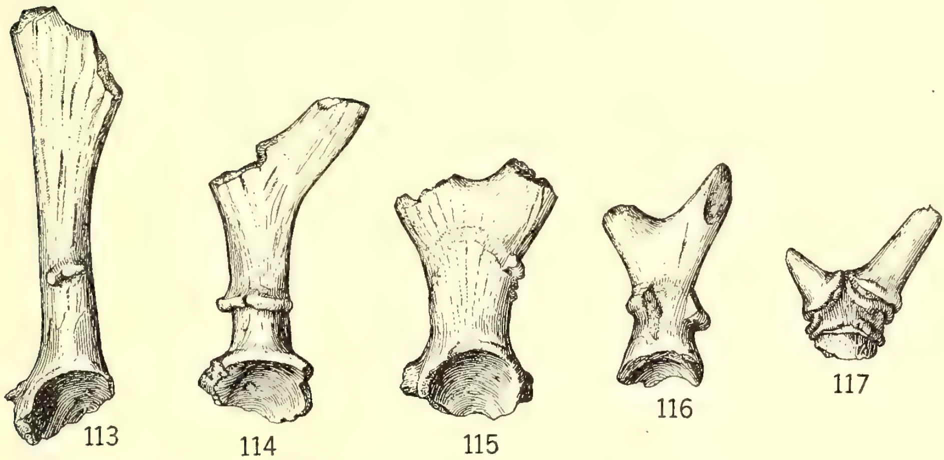
represented by no. 21558 (fig. 109) may represent *Alticamelus.* Smaller forms seen in no. 21557 evidently belong to *Procamelus.*

A fine specimen, no. 21569, shows the greater portion of the anterior limb of an individual of approximately the same dimensions as in *Alticamelus* or *Procamelus leptocolon* of the Pawnee Creek Miocene in the Great Plains region.

The upper dentition is not well shown in any of the Barstow specimens. No. 23129 (fig. 95) represents a single upper molar and no. 21562 (fig. 97) a portion of a lower jaw.

BOVIDAE

Remains of *Merycodus* are among the most common fossils found in the Miocene of the Barstow syncline. Fragments of horns or antlers are the most commonly recognized parts, and several hundred have been collected in the work on the Barstow fauna.



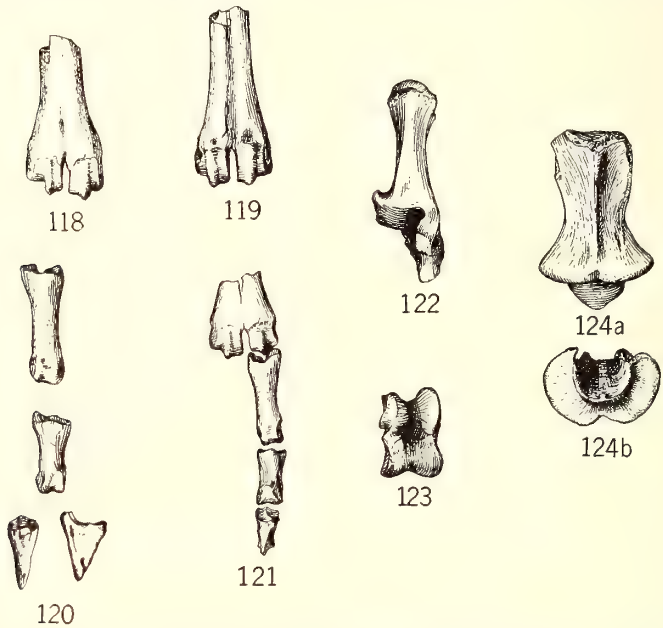
Figs. 113 to 117. *Merycodus necatus?* Leidy. Antlers, × ½. A second species possibly represented. Fig. 113, no. 22496; fig. 114, no. 22497; fig. 115, no. 22495; fig. 116, no. 22498; fig. 117, no. 21488. Barstow Miocene, Mohave Desert, California.

The forms commonly seen correspond most closely to *Merycodus necatus* described by Leidy from the Upper Miocene of the Great Plains region and figured by Cope from the Santa Fé region. A second form, *Merycodus(?) coronatus* found in the Barstow represents a peculiar type which seems to the writer to be nearest to *Merycodus.* It may represent a distinct genus or is possibly a sport.

MERYCODUS NECATUS? Leidy

This species is one of the common and characteristic forms of the Barstow fauna. It is known by abundant antlers, a large portion of a skull, numerous parts of jaws with teeth, and many portions of the skeleton.

The antlers, as shown in figures 113 to 117, vary from large specimens with the tines dividing nearly evenly and relatively high above the base, to specimens in which the antler forks only a short distance above the base. Though two types, the long antlers and the short antlers, can be recognized they intergrade and evidently represent one species. The beam is commonly much flattened below the point of division. Only rarely in the highest antlers is the shaft nearly circular in cross-sections well above the base. In many cases the two tines are nearly equal. Usually there is a noticeable difference.



Figs. 118 to 120. *Merycodus*, sp. Metapodials and digit, no. 22502, × ½. Fig. 118, distal end of anterior cannon bone; fig. 119, distal end of posterior cannon bone; fig. 120, phalanges of digit. Barstow Miocene, Mohave Desert, California.

Fig. 121. *Merycodus*, sp. Distal end of anterior cannon bone and digit, no. 22499, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 122. *Merycodus*, sp. Calcaneum, no. 22501, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 123. *Merycodus*, sp. Astragalus, no. 22500, × ½. Barstow Miocene, Mohave Desert, California.

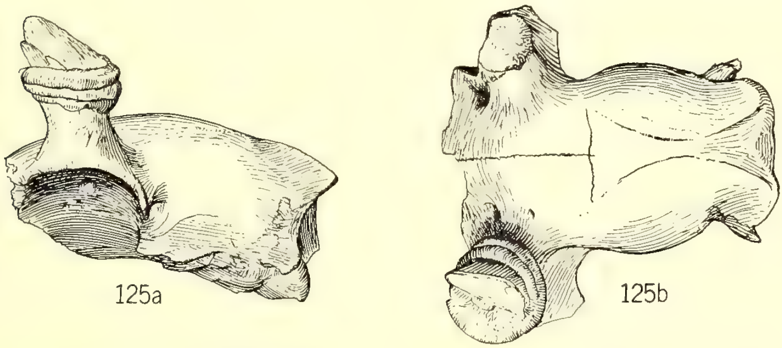
Fig. 124*a* and 124*b*. Bovid. Axis, no. 21499, × ½. Fig. 124*a*, ventral view; fig. 124*b*, anterior view. Barstow Miocene, Mohave Desert, California.

The burr is present in many specimens. It is commonly near the base of the horn. In some of the forms with the longest, most slender beam it may be more than an inch above the base. It is absent from many specimens. It may be situated immediately below the forks or may be far below them. In one specimen, no. 21488 (fig. 117), there is a burr on each tine above the division. In the specimen showing the skull the portion of a horn attached shows the burr about one-half an inch above the orbit.

In skull specimen no. 21551 (figs. 125*a*, 125*b*) the characters are near those of the fine specimen of *Merycodus osborni*, figured and described by Matthew.[33]

In the Barstow species the brain case seems narrower, the orbits a little less prominent, and the antlers are situated a little farther forward on the orbit than in *M. osborni*.

The frontoparietal suture in *M. osborni* is almost identical in position with a line connecting the posterior sides of the antler bases. In the Barstow species the suture bows far back of the antler bases.



Figs. 125*a* and 125*b*. *Merycodus*, sp. Skull, no. 21551, × ½. Fig. 125*a*, lateral view; fig. 125*b*, dorsal view. Barstow Miocene, Mohave Desert, California.

The mandible of the Barstow form has approximately the dimensions of the forms figured by Cope[34] and referred to *M. necatus*, and the dimensions of the inferior cheek-tooth series are also similar. The maxillary is known only by small fragments.

The degree of hypsodonty of the molars is greater than in the Virgin Valley forms, so far as known, and much less than in the Pleistocene *Capromeryx*. M_3 has a strong hypoconulid lobe, which in some cases (no. 21490, fig. 130) approaches the size of the second or hypoconid-entoconid segment of the tooth. No suggestion of division of the posterior lobe of M_3 has been noted more than the presence of a faint concavity on the posteroexternal side of the third lobe (figs. 129, 130). The inferior premolars (figs. 128 and 131*a*) are moderately hypsodont. The postero-external fold is generally strongly marked almost to the base of the tooth.

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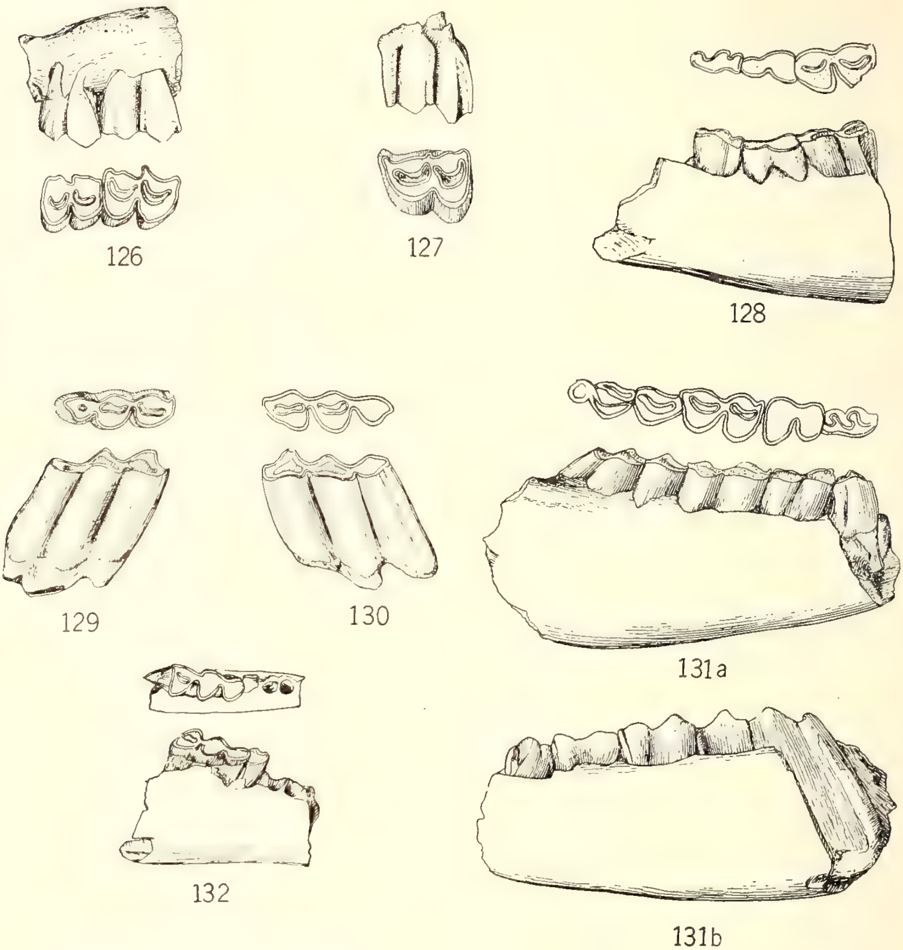
33 Matthew, W. D., Bull. Am. Mus. Nat. Hist., vol. 20, p. 106, 1904.

34 Cope, E. D., U. S. Geog. Surv. West of 100th Meridian, vol. 4, p. 82, 1877.

The upper cheek-tooth dentition is represented only by scattered teeth (figs. 126, 127) which do not differ materially from those of the form from the Santa Fé beds referred to *M. necatus* by Cope.



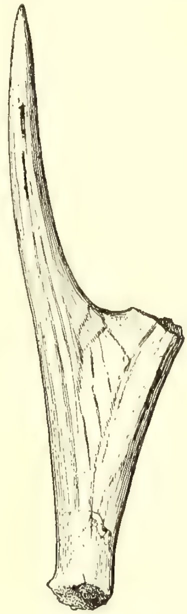
Figs. 126 to 132. *Merycodus necatus?* Leidy. Superior and inferior teeth, natural size. Fig. 126, M^1 and M^2, no. 22504; fig. 127, M^2, no. 22506; fig. 128, jaw fragment with P_3 to M_1, no. 22507; fig. 129, M_3, no. 22505; fig. 130, M_3, no. 21490; figs. 131*a* and 131*b*, fragment of mandible with inferior molars and P_4, outer and inner views of mandible and teeth, no. 22503; fig. 132, fragment of mandible with Dm_4, no. 21491. Barstow Miocene, Mohave Desert, California.

In the milk dentition Dm_4 possesses a large anterior lobe at least equaling that of *Capromeryx* in relative size compared with the middle lobe.

The limb elements are represented by numerous scattered bones of the manus and pes with portions of the larger bones.

The metapodials are not distinctly different from those of *Merycodus osborni* figured by Matthew.[35] The ungual phalanges are sharply pointed anteriorly, and do not show the Roman-nose form seen in the Pliocene antelopes of Thousand Creek and to some extent in *Capromeryx.*

133



134

Fig. 133. *Merycodus necatus?* Leidy. Antler, no. 19832, × ½. Barstow Miocene, Mohave Desert, California.

Fig. 134. *Merycodus necatus?* Leidy. Antler, no. 22494, × ½. Barstow Miocene, Mohave Desert, California.

An axis, no. 21499 (figs. 124*a*, 124*b*), from the Barstow is nearly identical in form and dimensions with the axis of *Capromeryx* from the Pleistocene of Rancho La Brea. The spout of the Barstow specimen is extended almost as far up on the sides as in *Capromeryx*, the Barstow form being in this respect possibly a trifle less advanced.

MERYCODUS? CORONATUS Merriam

M(?). coronatus Merriam. Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 335–339, 1913.

The type specimen, consisting of a single fragmentary horn or antler, no. 20052, found by Buwalda and Mourning in 1913, represents a horn or antler of peculiar type, unlike any form known to the writer.

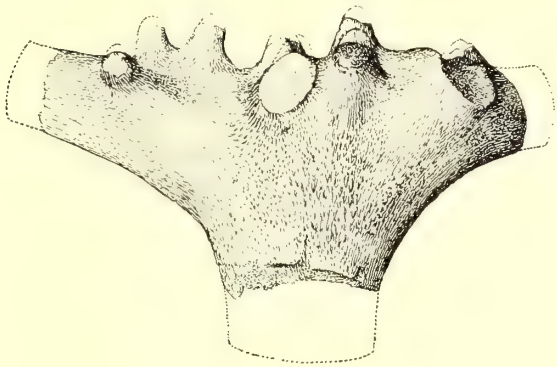
[35] Matthew, W. D., Bull. Am. Mus. Nat. Hist., vol. 20, pp. 117, 120. 1904.

Specimen 20052 consists of a part of the beam, which divides into two nearly equal branches diverging almost horizontally. Upon the nearly even superior surface of the branches are a considerable number of small spikes or papillae. Of the two branches, one is projected approximately in the plane of the flattened beam. The other branch curves rather sharply away from this plane (fig. 135*b*). The branch bending away from the plane of the beam is the smaller. A number of the superior spikes or papillae bend out at a low angle from the convex side of the curve formed by the two branches. It seems probable that the plane of the beam was anteroposterior rather than transverse to the skull, and that the papillae on the convex side of the bow are on the outer or lateral, rather than on the inner side of the horn. If the smaller of these two horizontal branches is the anterior, this is the right horn.

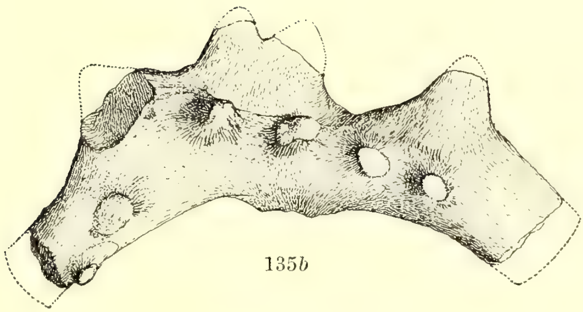
The spikes or papillae on the upper side of the horn are in two rows. There are six on the concave side, and four on the convex side. The inner six are arranged in three pairs. Of the outer four there is a single large spike opposite the posterior inner pair and a similar one opposite the space between the anterior and middle inner pairs, and a pair of papillae arising from a common base opposite the middle inner pair. The inner papillae are nearly erect, excepting the most anterior one. The papillae on the outer side are directed outward at a low angle. Judging from the single specimen available, the anterior branches of the right and left horns of this animal curved in toward each other over the face, the other branches extended backward and slightly inward, making a crown-like or horseshoe-like structure above the head.

Specimen 20052 resembles most nearly the horn or antler of *Merycodus*, which it also approaches in size, and to some extent in the texture of the horn. It differs from *Merycodus* in the form of branching, and in the presence of the double row of superior spikes. The texture of the surface of specimen 20052 differs somewhat from that of any of the numerous *Merycodus* horns available from the Barstow Miocene. It is possible that the contrast is due in part to condition of weathering, but it seems partly due to difference in structure.

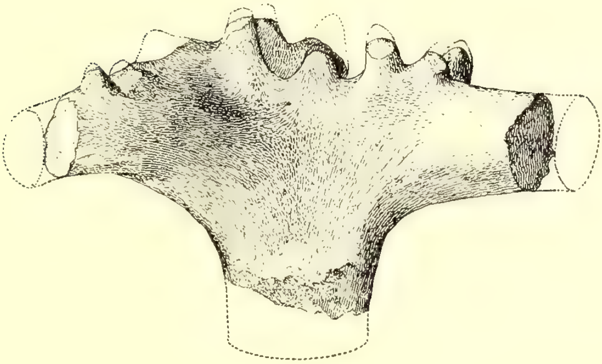
The peculiarities of specimen 20052 may be accounted for on the assumption that it is a "sport" or "monstrosity" of *Merycodus necatus*, a common form in the Mohave region. A large number of *Merycodus* horns have been found in the Barstow, but on no other



135*a*



135*b*



135*c*

Figs. 135*a* to 135*c*. *Merycodus? coronatus* Merriam. Antler, no. 20052, natural size. Fig. 135*a*, outer side; fig. 135*b*, dorsal view; fig. 135*c*, medial side. Barstow Miocene, Mohave Desert, California.

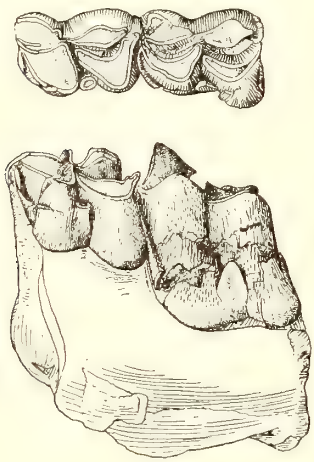
specimen has there been noted any suggestion of the form seen in no. 20052, so that there was no common tendency to develop this type of horn.

For the present it is desirable to recognize this form as distinct from other species and probably nearest to *Merycodus*.

CERVIDAE

DROMOMERYX or CERVUS?, n. sp.

Two jaw fragments with teeth from locality 2057, in the Barstow syncline, represent a form near *Dromomeryx*, but apparently more advanced than any described American form.



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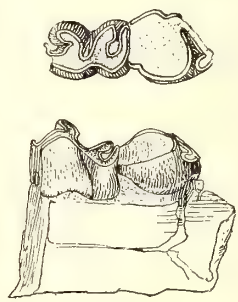


137

Fig. 136. *Dromomeryv* or *Cervus?*, n. sp. Dm$_4$ and M$_1$, no. 21218, natural size. Barstow Miocene, Mohave Desert, California.

Fig. 137. *Dromomeryx* or *Cervus?*, n. sp. Inferior teeth, no. 21219, natural size. Barstow Miocene, Mohave Desert, California.

A fragmentary specimen, no. 21218 (fig. 136), shows Dm$_4$ and M$_1$. Both teeth resemble *Dromomeryx* in general form. They have the exceedingly rough enamel, the inner cusp between the protoconid and hypoconid pillars, and the shelf of the cingulum found in *Dromomeryx*. The dimensions of M$_1$ are near those of specimens of *Dromomeryx* from the Snake Creek beds of Nebraska. They differ from *Dromomeryx* in entire absence of the palaeomeryx fold, and in the greater length of M$_1$ than in the *Dromomeryx* specimens known to the writer.

This specimen may conceivably be a representative of the *Dromomeryx* group with relatively high crown and reduced palaeomeryx fold. Matthew and Cook[36] describe a somewhat similar form from the Snake Creek beds of Nebraska.

MEASUREMENTS OF NO. 21218

Dm_4, anteroposterior diameter along middle of crown	14.6 mm.
Dm_4, transverse diameter across hypoconid	12
M_1, anteroposterior diameter along middle of crown	18
M_1, transverse diameter across hypoconid	14.1
M_1, height of crown on slightly worn protoconid pillar	19

RICARDO FAUNA

Reptilia
- Testudinate remains

Carnivora
- Canid, small, near Canis? vafer Leidy
- Aelurodon? aphobus, n. sp.
- Aelurodon?, possibly aphobus, n. sp.
- Aelurodon?, n. sp. *a*
- Aelurodon?, n. sp. *b*
- Aelurodon or Tephrocyon, sp. *c*
- Aleurodon or Tephrocyon, sp. *d*
- Mustela? buwaldi, n. sp.
- Ischyrosmilus osborni, n. gen. and sp.
- Felid, large
- Felid, small, not Ischyrosmilus

Rodentia
- Lepus?, sp.

Proboscidea
- Tetrabelodon?, sp.

Equidae
- Hipparion mohavense Merriam
- Hipparion mohavense callodonte Merriam
- Hipparion, sp. *a*
- Hipparion, sp. *b*
- Pliohippus tantalus Merriam
- Pliohippus fairbanksi Merriam
- Pliohippus, sp. near mirabilis (Leidy)

Oreodontidae
- Merycochoerus? (Pronomotherium?) californicus, n. sp.

Camelidae
- Procamelus, sp. *a*
- Procamelus, sp. *b*.
- Pliauchenia, sp.
- Alticamelus?, sp.

Bovidae
- Merycodus, near necatus Leidy

RELATION OF THE RICARDO FAUNA TO ITS ENVIRONMENT

The beds in which the Ricardo fauna occurs were evidently deposited on plains lying at the eastern base of a late Tertiary Sierra Range rising to a height of several thousand feet above the level of the Mohave area. The elevation of the region as a whole was probably not greater than at present and may have been somewhat less. The Ricardo deposits are probably in part land-laid, and in part water-

[36] Matthew, W. D., and Cook, H. J., Bull. Am. Mus. Nat. Hist., vol. 26, p. 409, 1909.

laid. The volcanic materials which they contain may at times have accumulated rapidly, but seem in general to have been deposited so slowly that the region was nearly continuously habitable.

The Ricardo fauna consists largely of forms that would naturally prefer to inhabit plains areas, or might thrive in partly open, level regions at least as well as in other environment. *Hipparion, Pliohippus,* the camels, and *Merycodus* would find this a favorable habitat. The carnivores associated with them would not necessarily find the surroundings unfavorable provided sufficient cover were available. The mastodons and oreodonts might inhabit the plains or frequent the border of the mountain area to the west. There are no elements in the Ricardo fauna which are necessarily considered as representatives of a forest or mountain assemblage washed or carried out to the plains.

The Ricardo fauna suggests climatic conditions permitting the development of vegetation suitable for grazing animals. This indicates a somewhat heavier growth of grass than is found in this region at the present time. There is nothing in the constitution of the fauna to suggest conditions radically different from those obtaining in this region today, but the presumption is in favor of less extreme aridity than is now known on the western border of the Mohave Desert. The conditions prevailing in this region in Ricardo time were probably not widely different from those now obtaining in the southern portion of the Great Valley of California.

Stage of Evolution and Relationships of the Ricardo Fauna

Relation to Tertiary Faunas of the Great Basin Province

The fauna of the Ricardo beds is widely different from that of the Middle Miocene Mascall and Virgin Valley, and is distinctly more progressive or later than that of the Upper Miocene Barstow. It is quite different from the Pliocene of Thousand Creek and is evidently less advanced. It differs also so far as known from the Rattlesnake Pliocene, and is presumably somewhat older.

Comparison of the Ricardo and Barstow faunas as shown in the following table shows almost complete specific separation of the two life assemblages, and considerable difference in the genera, especially in the Equidae, the best known group.

COMPARATIVE TABLE OF RICARDO AND BARSTOW FAUNAS

Ricardo Fauna	Barstow Fauna
Testudinata	Testudinata
Fragments, indet.	Testudo mohavense, n. sp.
	Aves
	Buteo, sp.
Carnivora	Carnivora
Canid, small, near Canis? vafer Leidy	Canid (Canis?), sp. small
Aelurodon? aphobus, n. sp.	Tephrocyon, near temerarius (Leidy)
Aelurodon?, possibly aphobus, n. sp.	Aelurodon, near wheelerianus Cope
Aelurodon?, n. sp. *a*	Aelurodon, Dinocyon, or Amphicyon, sp.
Aelurodon?, n. sp. *b*	Canid, indet.
Aelurodon or Tephrocyon, sp. *c*	Machaerodont, sp. *a*
Aelurodon or Tephrocyon, sp. *d*	Machaerodont, sp. *b*
Mustela? buwaldi, n. sp.	Machaerodont, sp. *c*
Ischyrosmilus osborni, n. gen. and sp.	Felid?, indet.
Felid, large	Pseudaelurus, sp.
Felid, small, not Ischyrosmilus	
Rodentia	Rodentia
Lepus?, sp.	Lepus?, sp.
Proboscidea	Proboscidea
Tetrabelodon?, sp.	Tetrabelodon?, sp.
Equidae	Equidae
Hipparion mohavense Merriam	Hypohippus, near affinis (Leidy)
Hipparion mohavense callodonte Merriam	Parahippus? mourningi Merriam
Hipparion, sp. *a*	Merychippus (Protohippus) intermontanus Merriam
Hipparion, sp. *b*	Merychippus calamarius stylodontus, n. var.
Pliohippus tantalus Merriam	Merychippus sumani Merriam
Pliohippus fairbanksi Merriam	Protohippus? or Pliohippus?, sp.
Pliohippus, sp. near mirabilis (Leidy)	
	Suidae
	Prosthennops?, sp.
Oreodontidae	Oreodontidae
Merycochoerus? (Pronomotherium?) californicus, n. sp.	Merycochoerus? buwaldi, n. sp.
Camelidae	Camelidae
Procamelus, sp. *a*	Procamelus, sp. *a*
Procamelus, sp. *b*	Procamelus, sp. *b*
Pliauchenia, sp.	Pliauchenia, sp.
Alticamelus?, sp.	Alticamelus?, sp.
	Cervidae
	Dromomeryx or Cervus?, sp.
Bovidae	Bovidae
Merycodus, near necatus Leidy	Merycodus necatus(?) Leidy
	Merycodus? coronatus Merriam

In nearly all cases in which it has been possible to make a satisfactory comparison of forms representing similar groups in the two faunas, the Ricardo types are seen to be more specialized. In the Carnivora the common *Tephrocyon* of the Barstow seems to have disappeared. Specimens showing some resemblance to *Tephrocyon* are not clearly comparable to any Barstow species. The aelurodons, which are the characteristic canids of the Ricardo fauna, seem to be mainly, if not entirely distinct, and are generally more specialized.

In the Equidae the abundant *Merychippus* fauna accompanied by rare *Hypohippus, Parahippus,* and possibly *Protohippus* or *Pliohippus* of the Barstow is replaced in the Ricardo by a group consisting of specialized *Hipparion* and *Pliohippus* species which may, in part, be derived from the earlier Barstow types.

The only oreodont of the Ricardo is a Merycochoerus-like form specifically distinct from that of the Barstow and more advanced. The Ricardo camels include larger forms than those of the Barstow. The known difference between the *Merycodus* forms is small, as only fragmentary comparative material is available, but so far as determinable the Ricardo species seems more specialized.

The general correspondence in groups but difference in species between the Ricardo and Barstow leads one to consider as probable the derivation of a considerable part of the Ricardo fauna from stocks near those represented in the Barstow. If this is true the difference in stage of evolution indicates that a considerable time must have elapsed between the deposition of the beds in which these faunas occur. The amount of difference shown in comparison of these faunas does not represent less than one-third of the change ordinarily taking place within the limits of a geological period. If the Barstow is recognized as Upper Miocene, which seems unavoidable, it is difficult to consider placing the Ricardo lower than the base of the Pliocene, or at the lowest, in the extreme upper limit of the Miocene.

In comparison with the Cedar Mountain or Esmeralda fauna of western Nevada the Ricardo shows much the same relationship as to the Barstow. A few very fragmentary horse teeth from the Cedar Mountain region suggest the presence of a type more advanced than those of the Barstow and nearer the Ricardo forms, but the evidence is as yet unsatisfactory. It is possible that in addition to the typical Cedar Mountain fauna a later faunal stage is present in the Cedar Mountain region.

Comparison of the Ricardo and Thousand Creek faunas is difficult because of absence of comparable material. The known Carnivora of the Ricardo seem at least as progressive as those of Thousand Creek. In the Equidae the Ricardo *Pliohippus* species seem near the stage of evolution of the forms from Thousand Creek. The Ricardo hipparions differ generally from what we know of the Thousand Creek representatives in less compression of the protocone of the upper cheek-teeth. In this respect the Thousand Creek forms appear more progressive than those of Ricardo.

Merycodus, so well represented in the Miocene, is known in the Ricardo but not at Thousand Creek. In the place of *Merycodus,* and possibly derived from it, we find in the Thousand Creek several advanced types of antelopes all unknown in the Ricardo. The oreodont group represented in the Ricardo is not known to be represented at Thousand Creek.

As a whole, the Thousand Creek fauna seems more advanced than that of the Ricardo. The difference may be due to geographic variation or to earlier appearance in the Thousand Creek region of immigrants reaching North America in Pliocene time. It is probable that the difference between the Ricardo and Thousand Creek faunas is due in part to difference in stage of evolution, with the Ricardo as the earlier stage. It is not probable that this difference amounts to more than a small portion of a geological period.

The relationship of the Ricardo and Rattlesnake faunas is presumably similar to that between Ricardo and Thousand Creek, as the Rattlesnake and Thousand Creek faunas seem in general closely related. Such comparison as can be made suggests placing the Rattlesnake somewhat later than the Ricardo and near the position of the Thousand Creek.

Within the Great Basin province the relationships of the Ricardo fauna so far as known seem somewhat nearer to the Rattlesnake than to any other fauna. The Ricardo represents a stage between the Upper Miocene Barstow and the Lower Pliocene Rattlesnake and Thousand Creek.

COMPARISON WITH FAUNAS OF THE PACIFIC COAST PROVINCE

In the sequence of late Tertiary faunas of the Pacific Coast province the Ricardo assemblage shows relationship to the faunas of the Chanac formation at the lower end of the San Joaquin Valley, the Lower Etchegoin or Jacalitos and the Middle Etchegoin of the North Coalinga region, and the Pinole Tuff-Orinda fauna of the San Francisco Bay region.

The Chanac fauna includes hipparions, *Merycodus,* a rhinocerotid, rare remains of *Protohippus,* and possibly *Pliohippus.* As yet no horses have been found in the Chanac which seem to correspond specifically to Ricardo forms, but the dominance of hipparions approaching in characters one of the Ricardo species suggests similar time stage of the two faunas. As rhinoceroses are unknown in the Ricardo the presence of a member of this group in the Chanac may mean considerable separation of these two faunas in time, or may indicate difference in habitat.

The presence of *Hipparion* in the lower Etchegoin and its failure to appear in the Middle Etchegoin may be taken to indicate closer approximation of the Ricardo to the lower division than to the middle or *Pliohippus coalingensis* zone. In the character of the *Pliohippus* species the *P. coalingensis* zone fauna is not widely removed from that of Ricardo, but there seems in general reason for considering the Middle Etchegoin as near the Rattlesnake-Thousand Creek stage of the Great Basin province, and it is not improbable that a fuller knowledge of the fauna may reveal types more advanced than those of the Ricardo.

The Pinole Tuff-Orinda fauna as known by the best representation from San Pablo Bay comprises an assemblage of forms suggesting the Thousand Creek, Rattlesnake, and Middle Etchegoin stages. It appears to be somewhat later than the Ricardo. In beds considered to represent a stage of the Orinda in the Contra Costa Hills *Hipparion* remains have been obtained representing a form specifically not distinguishable from *Hipparion mohavense* of Ricardo. Another assumed Orinda specimen, the type of *Hipparion platystyle,* closely approaches one of the large Ricardo *Hipparion* forms with somewhat compressed protocone. It is possible that the beds containing these Ricardo-like forms of the Orinda are older than those on San Pablo Bay containing *Pliohippus* species without associated *Hipparion.*

In general the Ricardo stage is not far from that of the Pinole Tuff-Orinda, but may be somewhat earlier.

COMPARISON OF THE RICARDO FAUNA WITH THAT OF THE AMERICAN TERTIARY OUTSIDE THE GREAT BASIN AND PACIFIC COAST PROVINCES

The faunas outside the Great Basin and Pacific Coast provinces of western North America with which the Ricardo is most closely comparable are the Snake Creek, Republican River, Alachua, and Blanco.

The Blanco Pliocene fauna of Texas resembles the Ricardo in the absence of horses of more primitive stage than *Protohippus,* and in the progressive stage of the carnivores and camels. The Blanco horses of the *Pliohippus* type appear more advanced than those of the Ricardo. Of the known Canidae *Borophagus* of the Blanco represents a very advanced stage, probably more progressive than any Ricardo form. No machaerodont cats are known in the Blanco, the only representative of the Felidae being a typical *Felis.* The only camels of the Blanco are referred to *Pliauchenia,* while the Ricardo forms seem to include *Procamelus, Pliauchenia,* and *Alticamelus.* The introduction of several edentates, including *Glypotherium* and *Megalonyx,* in the Blanco presumably indicates a later stage than the Ricardo, but the difference may be due to failure of southern edentate immigrants to reach California as early as they appeared in Texas.

The absence from the Blanco of typical aelurodons, machaerodonts, oreodonts, and merycodonts, taken with the presence of a variety of edentates, and general advanced stage of the fauna indicates that the Blanco is distinctly younger than the Ricardo. As the Blanco seems also younger than the Rattlesnake and Thousand Creek, which appear younger than the Ricardo, there is presumably a considerable gap between these two southern faunas of Pliocene age.

The Snake Creek fauna of western Nebraska contains many elements which correspond closely to those of the Ricardo. In the Carnivora two forms of *Aelurodon* are represented which are near the stage of evolution of certain species in the Ricardo. With *Aelurodon* there are, however, at Snake Creek, several *Tephrocyon* species corresponding to types of the Great Basin Upper or Middle Miocene. The Snake Creek Equidae comprise *Protohippus, Pliohippus,* and *Neohipparion* of advanced types not less progressive than the Ricardo species. At Snake Creek there is also found abundant representation of the more primitive *Merychippus,* with *Parahippus* and *Hypohippus.* The remains of *Merychippus* make up over half of the collection of equid remains known from the Snake Creek. One of the common species of *Merychippus* is closely related to *M. calamarius* of the Santa Fé Upper Miocene.

The oreodonts of Snake Creek and Ricardo are not easily comparable, but may be near the same stage of evolution. The camels are also not widely different so far as can be determined. *Dromomeryx* present at Snake Creek is not more advanced than a Barstow form, as is also the *Merycodus* of Snake Creek. *Blastomeryx* is present at Snake Creek and unknown in both the Ricardo and Barstow. The bovid form, *Neotragocerus* at Snake Creek is not known at Ricardo, and approaches more nearly the stage of the Thousand Creek antelopes.

If it should appear that the Snake Creek represents more than a single faunal stage, one assemblage may be near the stage of the Ricardo or younger and one older.[37a]

The Republican River fauna of northwestern Kansas represents a stage recognized as near the beginning of the Pliocene. Matthew and Cook, who have made a most careful comparison of this assemblage with the Snake Creek, consider that modernization is more apparent in the latter.[37b] The Republican River canid fauna contains only advanced forms of the *Aelurodon* or *Dinocyon* type. The felid forms are presumed to be machaerodont. The Equidae include *Hypohippus, Protohippus,* and *Neohipparion.* Two oreodonts, *Merycochoerus* and *Merychyus,* are present, with camels of the genera *Procamelus* and *Pliauchenia. Dromomeryx* and *Blastomeryx* are not represented. Considering that the two areas discussed are widely separated geographically, it would seem to the writer that the Republican River may not be far from the stage of faunal evolution shown by the Ricardo.

Relationship of the Ricardo to the Alachua of Florida is suggested especially by similarity of the *Hipparion* species. The American species most resembling the Ricardo hipparions include *H. plicatile* and *H. ingenuum* of the Archer beds, and *H. venustum* from Ashley River, South Carolina. This resemblance may be purely incidental, but possibly indicates a close genetic relationship, and approximately the same stage of early Pliocene for the beds in which these forms are found.

[37a] See Matthew, W. D., recently published review of Snake Creek fauna appearing while present article is in proof. Bull. Amer. Mus. Nat. Hist., vol. 38, pp. 183–185, 1918.

[37b] Matthew, W. D., and Cook, H. J., Bull. Amer. Mus. Nat. Hist., vol. 26, p. 368, 1909.

Description of Fauna

TESTUDINATE REMAINS

Fragments of the shell of a large tortoise found in the Ricardo beds represent a form approximating the size of the large tortoises of the Barstow fauna. Several fragments of peripheral bones differ from those of *Testudo mohavense* of the Barstow in that the sulci between the dermal scutes are situated on prominent ridges, whereas in the Barstow form the sulci are sharply impressed and do not follow ridges.

CARNIVORA

The Carnivora of the Ricardo are in general quite distinct from those of the Barstow, and are also as a rule more progressive. The two faunas seem to have no forms in common, unless it be one of the canids and possibly one large cat. The genus *Tephrocyon* which forms an important part of the Barstow fauna is not certainly known in the Ricardo.

The Candidae are represented by a considerable variety of forms. These include a very small species like *Canis? vafer;* an Aelurodon-like form near *A. wheelerianus,* but with heavier carnassial; a second Aelurodon-like type near *A. wheelerianus,* but with different proportions of the mandible; a third very large Aelurodon-like form with massive molars; and species which may represent *Tephrocyon* or small Aelurodons.

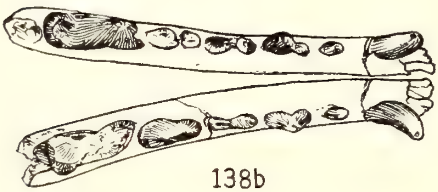
The cats include at least three types, one a machaerodont of the new generic group *Ischyrosmilus;* the other two forms are imperfectly known.

A new mustelid constitutes the only other known carnivore of this fauna.

CANID, small, near CANIS? VAFER Leidy

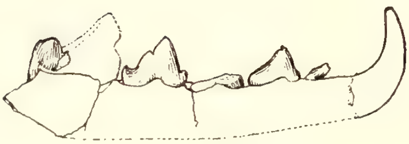
Specimen no. 22319 (figs. 138*a*, 138*b*) from locality 2731 in the lower portion of the Ricardo represents a small slender-jawed dog not unlike *Canis? vafer* Leidy of the Fort Niobrara formation, and represented by a similar type in the Snake Creek Pliocene of Nebraska.

The jaw is slender and the premolar teeth are fairly spaced. The lower canines are long and slender, the premolars are narrow. P_2 has a minute posterior basal tubercle. P_4 has a high, sharp principal cusp, with a prominent posterior cusp, a well developed basal tubercle or shelf, and a minute anterior basal tubercle. Unfortunately the molars are all imperfect. On M_1 the metaconid is well developed, the hypoconid is large and distinctly compressed laterally, the entoconid is relatively small but prominent. A fragment of a jaw apparently representing this species contains a portion of M_2, and a small, two-tubercled M_3.

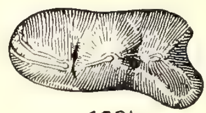


138b

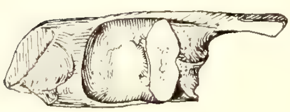
139a



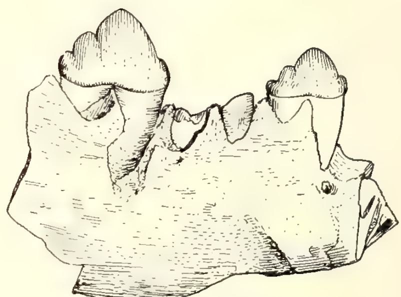
138a



139b



139d



139c

Figs. 138*a* and 138*b*. Canid, small, near *Canis? vafer* Leidy. Mandible, no. 22319, natural size. Fig. 138*a*, lateral view; fig. 138*b*, dorsal view. Ricardo Pliocene, Mohave Desert, California.

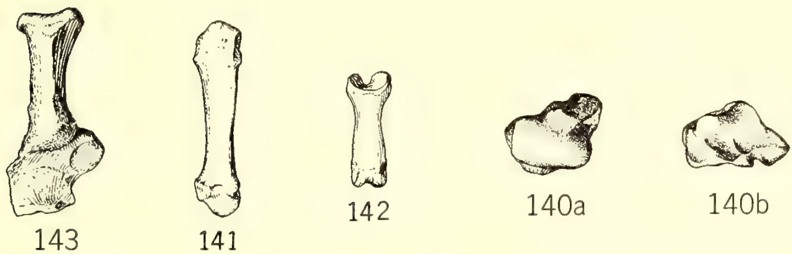
Figs. 139*a* to 139*d*. *Aelurodon* or *Tephrocyon*, sp. D. Upper and lower teeth, no. 22320, natural size. Fig. 139*a*, P^4, outer view; fig. 139*b*, P^4, occlusal view; fig. 139*c*, jaw fragment with P_2 and P_4; fig. 139*d*, heel of M_1. Ricardo Pliocene, Mohave Desert, California.

Until we can examine material with complete lower carnassial, and showing more fully the structure of the other molars, it does not seem possible to make a close reference of this interesting little canid.

MEASUREMENTS OF NO. 22319

Length anterior side of canine to posterior side of M_1	47.8 mm.
P_1, anteroposterior diameter	3.3
P_2, anteroposterior diameter	6.2
P_4, anteroposterior diameter	7.9
M_1, anteroposterior diameter	*a*13
M_1, anteroposterior diameter of heel	4.6

a, approximate.



Figs. 140*a* to 143. Canid?, indet. Limb elements, no. 22321, × ½. Fig. 140*a*, scaphoid, dorsal view; fig. 140*b*, scaphoid, ventral view; fig. 141, metacarpal 5; fig. 142, first phalanx; fig. 143, calcaneum. Ricardo Pliocene, Mohave Desert, California.

AELURODON? APHOBUS, n. sp.

Type specimen, an upper jaw with P^4, M^1, M^2, and a portion of P^3, no. 21507, from locality 2281 in the upper portion of the Ricardo beds in the Western El Paso Range, California.

This specimen (figs. 144*a*, 144*b*) represents a very large canid with heavy crushing teeth.

M^1 is large with heavy protocone, and only moderately developed protoconule ridge. M^2 is a heavy tooth with large protocone ridge. This tooth seems larger than in most specimens referred to *Aelurodon.*

P^4 is a heavy tooth with much reduced deuterocone. The protocone and tritocone are broken so that the form can not be clearly seen. When the type specimen was first examined by the writer, shallow external and internal grooves on the anterior region of the protocone seemed to show the separation of a well marked protostyle. In preparation of this tooth for study the region of the carnassial was damaged somewhat, and the grooves separating the protostyle region are no longer apparent. The construction of the anterior portion of the tooth is, however, much as in upper carnassials possessing an anterior style.

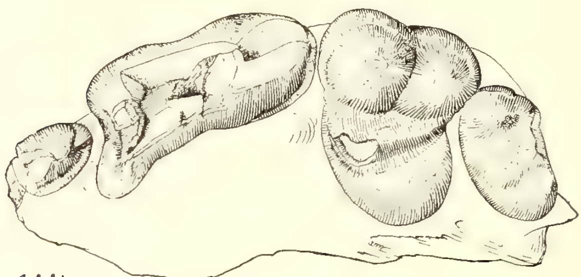
The portion of P^3 present shows that this was a heavy tooth.

The maxillary fragment shows no important characters. The infraorbital foramen is immediately over the anterior border of P^4.

MEASUREMENTS OF NO. 21507

P^3, transverse diameter of heel	9 mm.
P^4, anteroposterior diameter	32.3
P^4, transverse diameter across protocone	15
M^1, anteroposterior diameter	21.4
M^1, transverse diameter	28.7
M^2, transverse diameter	18.2

144a



144b

Figs. 144*a* and 144*b*. *Aelurodon? aphobus*, n. sp. Upper jaw with P^4, M^1, and M^2, no. 21507, natural size. Fig. 144*a*, lateral view; fig. 144*b*, occlusal view of teeth. Ricardo Pliocene, Mohave Desert, California.

This form shows some resemblance to *Dinocyon*, but M^2 is smaller and P^4 narrower. It differs from *Aelurodon wheelerianus* in the larger size, less prominent protostyle and deuterocone of P^4; larger inner lobe of M^1; and larger M^2. From *A. saevus* it differs in the much smaller deuterocone of P^4; longer and heavier protocone lobe of M^1; and larger M^2.

Canis? ursinus described by Cope,[38] from a lower jaw obtained from the Santa Fé marl is a canid with large M_2 and M_3. The upper

[38] Cope, E. D., U. S. Geol. Surv. West of 100th Meridian, vol. 4, p. 304, pl. 69, figs. 1 to 1*b*, 1877.

molars of the Ricardo specimen, no. 21507, are large and heavy and must have opposed a well developed crushing area on the heel of M_1 and on the tubercular lower molars. It may be that *C.? ursinus* and the Ricardo form are related or it is possible that, as Matthew[39] has suggested, *C. ursinus* is really an *Amphicyon.* It is improbable that the Ricardo form is an *Amphicyon.* Though M^2 is a large tooth the form of the maxillary posterior to M^2 makes the presence of a M^3 improbable.

AELURODON?, possibly APHOBUS, n. sp.

A large lower jaw, no. 22470 (fig. 145), represents an Aelurodon-like canid from locality 2769 in the upper portion of the Ricardo

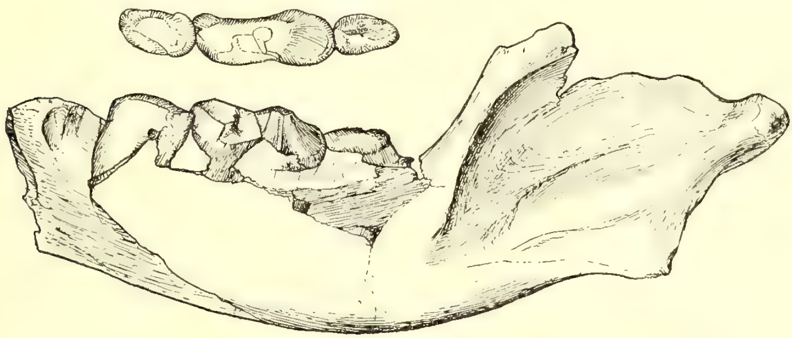


Fig. 145. *Aelurodon?*, possibly *aphobus*, n. sp. Mandible, no. 22470, × ½. Ricardo Pliocene, Mohave Desert, California.

beds. This specimen includes the greater part of the mandible with P_4, M_1, and M_2, the teeth being badly worn and imperfect.

The lower jaw is short, heavy, and the inferior side below the posterior end of the molar series is markedly convex. The teeth are massive and thick transversely. The heel of M_1 is short and wide. M_2 is considerably longer anteroposteriorly than the heel of M_1.

The size and proportions of the dentition of specimen no. 22470 suggest those of *Aelurodon? aphobus* and it is not impossible that this mandible represents an animal of the same type, possibly of the same species.

The Ricardo jaw resembles *Canis? ursinus* Cope to some extent in massiveness of jaw and dentition, but the mandible may differ in proportions and the tooth proportions are quite different. In *C.? ursinus* the masseteric fossa extends forward to a point below the

39 Matthew, W. D., Bull. Am. Mus. Nat. Hist., vol. 16, p. 130, 1902.

posterior end of M_1, whereas in the Ricardo specimen this fossa does not reach farther forward than the posterior end of the alveolus of M_3. In the Ricardo mandible the last premolar and the carnassial are larger than in the type of *C.? ursinus,* whereas M_2 is smaller, and M_3 was presumably smaller judging from the alveolus.

The Ricardo form represented in no. 22470 was evidently a type with dentition specialized in a direction which gave relatively more emphasis to function of P_4 and the carnassial, although the crushing area of the molar series was large; while in *C.? ursinus* the use of the crushing area of the tubercular molars was relatively more important.

In the importance of P_4 with M_1 in the lower cheek-tooth series, in the tendency to especial massiveness of P_4, and to some extent in the form of the posterior half of the mandible, the Ricardo jaw, no. 22470, suggests the late Pliocene *Hyaenognathus.* The Ricardo jaw is considerably longer than that of *Hyaenognathus,* but the most marked difference is found in the more specialized form of P_4 of *Hyaenognathus.* In the Ricardo specimen P_4 is apparently not radically different from a heavy *Canis* or *Aelurodon* tooth of this position. In *Hyaenognathus* P_4 is greatly broadened posteriorly, and the principal cusp is extraordinarily enlarged. It is possible that *Hyaenognathus* is derived from the group to which the Ricardo species belonged. It may be noted that the upper dentition of *A.? aphobus,* to which it has been suggested that the Ricardo mandible, no. 22470, may be referred, is quite different from that of *Hyaenognathus* (*Porthocyon*) *dubius* with which the mandible of the type of *Hyaenognathus* has been compared.

COMPARATIVE MEASUREMENTS

	No. 22470	C?. ursinus type
Height of mandible below posterior end of M_1	44 mm.	45
Length of dentition from anterior side of P_4 to posterior side of M_2	73	*a*64.5
P_4, anteroposterior diameter	22.2	*a*17
M_1, anteroposterior diameter	36.5	31
M_1, anteroposterior diameter of heel	*a*9	.....
M_1, greatest transverse diameter of heel	13.7	.....
M_2, anteroposterior diameter	15.8	20

a, approximate.

AELURODON?, n. sp. A

A portion of a lower jaw, no. 21225 (figs. 146*a*, 146*b*), represents a heavy-jawed canid of a type similar to *Aelurodon wheelerianus* of the Barstow fauna but heavier, with much heavier and larger carnassial, and with smaller M_2. This form is quite certainly a new species of the *A. wheelerianus* type, but the writer prefers not to make this imperfect specimen the type.

M_1 of no. 21225 is very large, exceeding the Barstow specimens considerably in anteroposterior diameter. M_2 is represented by a small alveolus for the anterior root, and a very minute pit behind it which probably held the posterior root. There is no alveolus for M_3.

Comparative Measurements

	No. 21225 Ricardo	A. wheelerianus? No. 19455 Barstow
Height of mandible below posterior end of M_1	32.7 mm.	*a*35.5
Thickness of mandible below posterior end of M_1	20.2	18
M_1, anteroposterior diameter	*a*35.7	28.4
M_2, anteroposterior diameter	*a*9.6	10.3

a, approximate.

AELURODON?, n. sp. B

A fragment of a lower jaw, no. 21317 (fig. 148), without teeth represents a canid species different from any of those reported from this fauna. This form is smaller and with lighter mandible than *Aelurodon wheelerianus* of the Barstow, and larger than *Tephrocyon* near *temerarius* of that fauna. It most nearly resembles *A. wheelerianus,* and is tentatively referred to *Aelurodon.*

Comparative Measurements

	No. 21317 Ricardo	No. 19455 Barstow
Height of mandible below protoconid of M_2	29.6 mm.	*a*35.5
Thickness of mandible below protoconid of M_2	12.7	18
Anteroposterior diameter of alveolus of M_2	12.8	10.3

a, approximate.

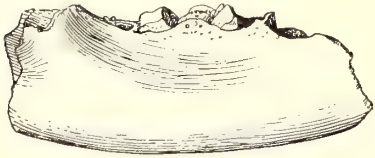
AELURODON or TEPHROCYON, sp. C

A portion of a lower jaw, no. 21226 (figs. 147*a*, 147*b*), represents a canid form much smaller than the three types referred tentatively to *Aelurodon,* and certainly specifically different. The mandible is heavy and thick, and the fragment of the carnassial present seems to have a heavy crushing heel. The form is probably an *Aelurodon* or *Tephrocyon* as yet undescribed.

Measurements of no. 21226

Height of mandible below heel of M_1	23.7 mm.
Thickness of mandible below heel of M_1	11.9
M_1, anteroposterior diameter	*a*23.5
M_1, transverse diameter of heel	9.1

a, approximate.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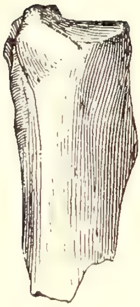
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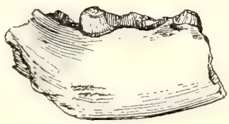
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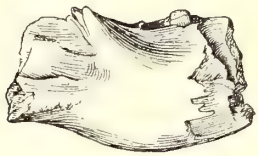
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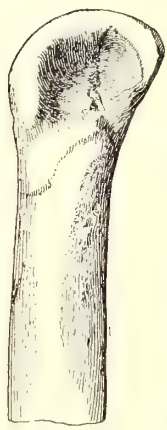
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153b

Figures 146*a* to 153*b* represent forms from the Ricardo Pliocene, Mohave Desert, California.

Figs. 146*a* and 146*b*. *Aelurodon?*, n. sp. A, fragment of mandible, no. 21225, × ½, fig. 146*a*, lateral view, fig. 146*b*, dorsal view; figs. 147*a* and 147*b*, *Aelurodon* or *Tephrocyon*, sp. C, fragment of mandible, no. 21226, × ½, fig. 147*a*, lateral view, fig. 147*b*, dorsal view; fig. 148, *Aelurodon?*, n. sp. B, fragment of mandible, no. 21317, × ½; figs. 149 and 150, Canid, indet., metapodials, natural size, fig. 149, no. 22509, fig. 150, no. 21312; fig. 151, *Aelurodon?*, sp., metapodial, no. 21497, natural size; figs. 152 to 153*b*, *Aelurodon?*, sp., metapodials, natural size, fig. 152, no. 19809; figs. 153*a* and 153*b*, no. 19810.

AELURODON or TEPHROCYON, sp. D

An interesting specimen, no. 22320, from locality 2733, in the lower portion of the Ricardo formation includes fragments of the skull with a portion of the dentition including the upper carnassial, P_2, P_4, and the heel of M_1. The upper carnassial is of the typical *Aelurodon* type with large, sharply separated protostyle. It represents a form smaller than the better known *Aelurodon* forms, the animal having approximately the dimensions of the average specimens of *Tephrocyon*. The lower premolars (fig. 139*c*) are heavy, thick transversely, and with well developed cingulum. P_2 has a prominent posterior cusp with small but well marked anterior and posterior basal tubercles. P_4 has a prominent posterior cusp with well marked anterior and posterior basal tubercles. The heel of M_1 (fig. 139*d*) shows the hypoconid and entoconid of approximately the same size. Both tubercles are low, and the heel has distinctly a crushing function.

This specimen may represent a type of animal known in other material from this region and referred to *Aelurodon* in the descriptions above.

LIMB ELEMENTS

A number of limb elements representing canid forms from the Ricardo beds are presumably to be referred to some of the species described above from jaws and teeth.

Two very large specimens, nos. 21312 and 22509 (figs. 149, 150), possibly represent *Aelurodon? aphobus*. A smaller specimen, no. 21497 (fig. 151), is possibly the undescribed form *Aelurodon*, n. sp A.

The distal end of a femur no. 21314 may represent an *Aelurodon* or *Tephrocyon* species.

In specimen no. 22321 (figs. 140*a* to 143), found associated with parts of a skull and dentition, no. 22320, at locality 2733, there is represented a considerable portion of a foot with short, rather heavy, strongly curved, cat-like metacarpals. In this specimen the proximal end of metacarpal III shows characters not unlike those of specimen no. 22289 from the Cedar Mountain Miocene of Nevada. Only a proximal end is preserved. The facet for articulation with the magnum is not as deeply curved as in the puma, but the median proximal facet for articulation with metacarpal II is raised relatively high, and has nearly the same position as this facet in the puma. This facet is, however, not as large as in the puma and is not as well developed on the posterior side. Behind the excavation below the median facet for articulation with metacarpal II there is a small round facet also for contact with metacarpal II. The writer has not seen this facet in the Canidae. It is not present in the puma, the sabre-tooth, or in *Felis atrox*. On the external side the lower excavated face for contact with metacarpal IV is not as deeply cut as in the cats, but is deeper than in *Aenocyon dirus*. The upper portion of the facet for contact with metacarpal IV is broken anteriorly. Unfortunately the writer has not had good material of *Aelurodon* immediately available for comparison.

MUSTELA? BUWALDI, n. sp.

Type specimen a lower jaw with P_1 to M_1, no. 21323, from locality 2282, Ricardo beds, Mohave Desert, California.

A lower jaw with the carnassial and all of the premolars from the Ricardo beds (fig. 154) represents a mustelid not known elsewhere in the Tertiary of the Great Basin province.

P_1 to P_3 are simple cones without accessory tubercles. P_4 has a posterior cusp.

M_1 has a low mustelid or musteline type of crown. The protoconid and paraconid are nearly equal. The metaconid is prominent and sharply separated from the protoconid. The heel is long and basin-shaped. The hypoconid is fairly prominent. A long, curved postero-internal ridge connects posteriorly with the hypoconid and internally with the base of the metaconid. The external cingulum of M_1 is faintly marked on the heel, but is not visible on the outer side of the protoconid, although the teeth are but little worn.

Measurements of no. 21323

Length, anterior side P_1 to posterior side M_1	26.9 mm.
P_1, anteroposterior diameter	2.4
P_2, anteroposterior diameter	4.5
P_3, anteroposterior diameter	5
P_4, anteroposterior diameter	6.1
M_1, anteroposterior diameter	9.9
M_1, length of heel on outer side	3
M_1, width of heel	3.9

ISCHYROSMILUS Merriam

ἰσχυρός, strong; σμιλη, knife.

Machaerodus? J. C. Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 4, p. 171, 1905.

Ischyrosmilus Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, p. 524, 1918.

Type species *Machaerodus? ischyrus* Merriam from beds near McKittrick on the western border of the San Joaquin Valley, California. The type is known only by the mandible and inferior dentition.

Mandible massive; flange clearly marked, relatively wide anteroposteriorly, slightly deeper than in *Smilodon*, not as strongly developed as in typical *Machaerodus;* length of diastema much as in *Machaerodus*, but shorter than in *Smilodon*. P_3 very small, and with one root. P_4 with a single posterior cusp or with incipient division of this cusp. M_1 without metaconid and heel. The group is known only from beds referred to the Pliocene.

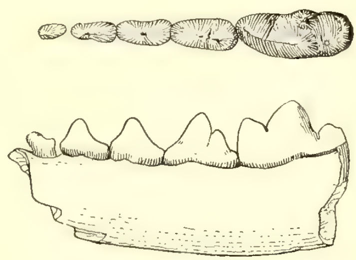


Fig. 154. *Mustela? buwaldi*, n. sp. Mandible with P_1 to M_1, no. 21323, × 1½. Ricardo Pliocene, Mohave Desert, California.

Ischyrosmilus differs from the *Dinictis* group in the absence of M_2, absence of heel and metaconid of M_1, great reduction of P_3, and in the relatively large size of the flange below the diastema. From *Hoplophoneus* it differs in the absence of heel and metaconid of M_1, and in the somewhat greater anteroposterior diameter of the relatively shallow flange. From typical *Machaerodus* it differs in the greater reduction of P_3, and in the greater anteroposterior diameter of the relatively shallow flange. From *Smilodon* it differs in the shorter diastema, larger flange, and more simple form of the posterior lobe of P_4. This group is nearest *Machaerodus,* and may be considered as a subgenus under that division. The fact that two forms are found which resemble each other in the general characters through which they differ from other groups, though they are evidently different specifically, seems to require recognition in the classification; particularly is this desirable when the species thus distinguished are in a geographic province from which other *Machaerodus* species of similar age are not known.

This genus approaches the Pleistocene *Smilodon* more closely than does any American Tertiary machaerodont thus far described. The characters of the lower dentition differ from those of *Smilodon* only in the less advanced development of the second posterior cusp of P_4.

The presence of a small P_3 in *Ischyrosmilus* is not a distinguishing character, as this tooth may be present and fully as large in *Smilodon californicus.* The mandibles of the two genera are distinguished by the greater elongation of the diastema region and the slightly smaller flange in *Smilodon.* This difference is presumed to represent correlation with the large upper canine in *Smilodon.*

Although *Smilodon* is presumed to be derived from *Machaerodus,* as yet the former has been found only in the New World and the latter in the Old World, and no described form of *Machaerodus* fur-

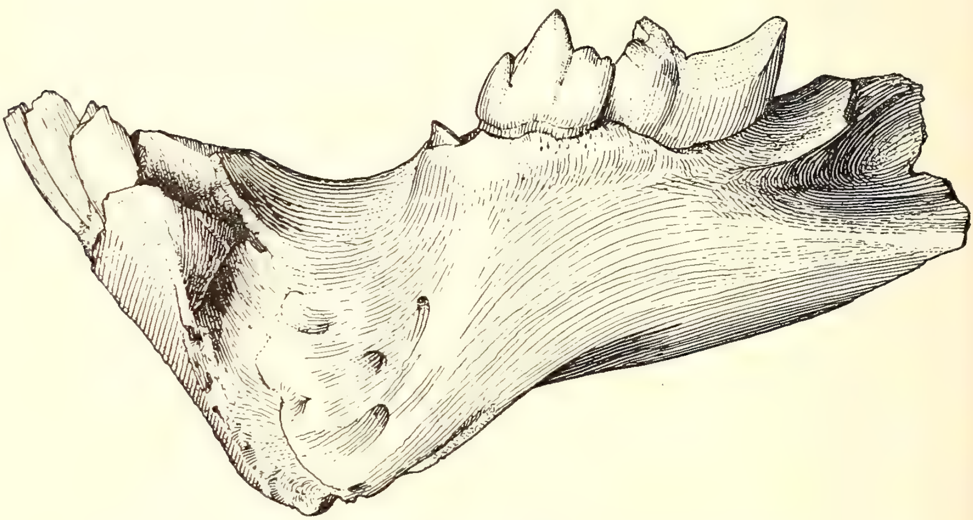


Fig. 155. *Ischyrosmilus osborni,* n. sp. Type specimen, mandible with dentition, no. 19476, natural size. Ricardo Pliocene, Mohave Desert, California.

nishes the characters required in the ancestor of *Smilodon.* As *Smilodon* is an American genus, and the sabre-tooth is characteristic of America rather than of the Old World, this genus might be presumed to be derived from an American Pliocene form. Of the known American forms *Ischyrosmilus* most nearly approaches *Smilodon,* and the similarity of the two genera is closer than is the resemblance of any Old World representative of the genus *Machaerodus* to *Smilodon.* This does not mean that *Smilodon* is derived immediately from *Ischyrosmilus.* The gap between the two is wide, and it is not improbable that *Ischyrosmilus* represents only one specialized branch of a large division leading toward *Smilodon.*

ISCHYROSMILUS OSBORNI, n. sp.

Type specimen, a portion of a left lower jaw with dentition, no. 19476, Univ. Calif. Col. Vert. Palae. From the Ricardo beds near Red Rock Cañon, California.

The type specimen (fig. 155) represents a species most nearly related to *Ischyrosmilus ischyrus* from McKittrick, on the western side of the San Joaquin Valley, California. The specimen of *I. osborni,* represents the same portion of the mandible shown in the type of *I. ischyrus,* so that a close comparison can be made. This species differs from *I. ischyrus* in its smaller size, somewhat flatter anterior face of the symphysial region, much thinner or transversely narrower cheek-teeth, and in the division of the posterior lobe of P_4 into two cusps.

The anterior end of the masseteric fossa in the specimen of *I. osborni* is much narrower vertically than in the type of *I. ischyrus,* and suggests that the form of the jaw in this region may be found to be different in the two species.

The incisors have lost the greater part of their crowns, but seem smaller and narrower transversely than in *I. ischyrus.* The canine is not represented.

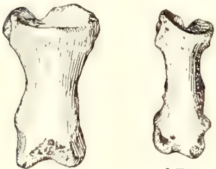
P_3 is known only by the root with a small portion of the crown. The root is small and round in cross-section, with no suggestion of division.

P_4 resembles the corresponding tooth of *I. ischyrus,* excepting in the slightly larger size of the posterior lobe, and in its beginning division into two cusps.

Comparative Measurements	I. ischyrus no. 8140 Tulare?	I. osborni no. 19476 Ricardo
Length from anterior side of I_1 to posterior side of M_1	123 mm.	101
Length from anterior side of canine to posterior side of M_1	107	81
Width of anterior face of symphysial region	52	*a*36
Depth of jaw across the middle of the flange	58	44
Depth of mandible below posterior end of P_4	37.5	32.3
Length of inferior diastema	33.5	26.5
Width of I_1 transversely	4	2.5
Width of I_2 transversely	6.5	4
Anteroposterior diameter of inferior canine	14.5	*a*10
Anteroposterior diameter of P_3	7.2	*a*6.4
Anteroposterior diameter of alveolus of P_3	8.1	7
Anteroposterior diameter of P_4	20	16.7
Anteroposterior diameter of M_1	28.5	24
Transverse diameter of M_1	15	11

a, approximate.

M_1 is relatively large compared with P_4. This tooth and P_4 are both much thinner transversely than in the other species. There is no suggestion of a posterior heel or of a metaconid. A peculiar character exists in the extension of the concave face between the bases of the protoconid and paraconid on the inner side of M_1 downward to the cinculum. There is no alveolus for M_2, and as the specimen represents a relatively young animal without heel or metaconid on M_1 it is to be presumed that the second lower molar was not normally present.



156 157

Figs. 156 and 157. Felid, indet. Phalanges, × ½. Fig. 156, no. 21222; fig. 157, no. 21313. Ricardo Pliocene, Mohave Desert, California.

As in the case of *Ischyrosmilus ischyrus,* the Ricardo species shows resemblance to *Machaerodus palaeindicus* of the Indian Siwaliks in form of the mandible, shape of the flange, and length of the diastema. The Ricardo specimen and the type of *I. ischyrus* differ from the Siwalik form in the much reduced P_3. In *Macherodus palaeindicus* according to Lydekker P_4 possesses but a single posterior cusp as in *I. ischyrus.* In the Ricardo form the posterior cusp is divided by a sharp groove on the inner side, but the size of the two cusps combined in the posterior lobe of this tooth in the Ricardo specimen is scarcely greater than that of the single posterior lobe in the type of *I. ischyrus.*

FELID LIMB ELEMENTS

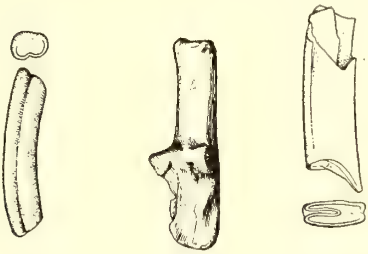
Two phalanges, nos. 21222 and 21313 (figs. 156, 157), presumably represent different species. The former represents a large cat probably a machaerodont. No. 21313 is much more slender and may belong to a feline form.

Measurements of Phalanges

	No. 21222	No. 21313
Greatest length	37.5 mm.	36.5
Greatest width at proximal end	22.5	15
Least transverse diameter	13.5	9.1

FELID?, indet.

A fragment, no. 21696, representing the posterior end of a mandible from Ricardo is from a large form of the type represented in the Barstow fauna by a similar fragment, no. 21571. The Ricardo specimen is almost identical in its character with the form known from the Barstow fauna, but is slightly larger. The position of the angle indicates a character of the feline rather than a machaerodine group if this form is a felid. The angle is farther removed from the condyle than in the more specialized machaerodine forms. It is also



158a 159 158b

Figs. 158*a* to 159. *Lepus?* or *Hypolagus?*, sp. Fig. 158*a*, incisor, no. 22337, × 2. Fig. 158*b*, upper tooth, no. 22338, × 2; fig. 159, calcaneum, no. 22336, natural size. Ricardo Pliocene, Mohave Desert, California.

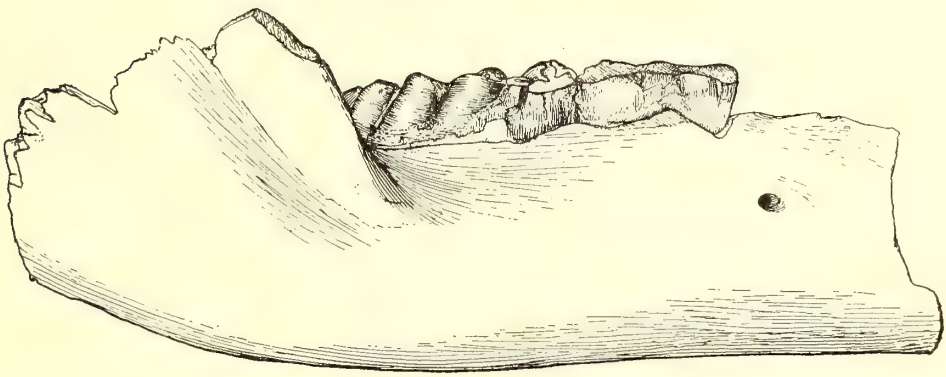


Fig. 160. *Tetrabelodon?*, sp. Mandible, no. 22681, lateral view, × ¼. Ricardo Pliocene, Mohave Desert, California.

almost immediately below the posterior side of the base of the coronoid process, whereas in the specialized machaerodine forms the angle is situated below the outer end of the condyle.

RODENTIA

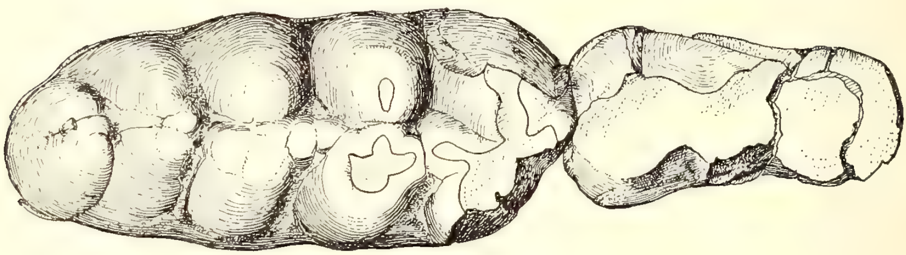
A small astragalus, no. 21496, like that of a jackrabbit, from locality 1805 in the Ricardo, represents a rodent type near *Lepus* or *Hypolagus*. Other material, possibly of this form, is shown in figures 158*a* to 159.

PROBOSCIDEA

TETRABELODON?, sp.

A number of fragments of a large mastodontine form were obtained in the Ricardo beds.

A considerable portion of a lower jaw, no. 22681 (fig. 160), shows the character of the lower molar teeth, and a portion of the symphysial region. The symphysis is elongated and the cross-section of the lower tusk indicates that it was of considerable size. The pattern of the lower cheek-teeth is that of an early Pliocene or late Miocene type with comparatively simple outlines of the tubercles or



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Figs. 161 and 162. *Tetrabelodon?*, sp. Lower cheek-teeth and incisor, × ½. Fig. 161, no. 22681; fig. 162, no. 21318. Ricardo Pliocene, Mohave Desert, California.

transverse ridges, but with secondary tubercles in the space between the transverse ridges. A piece of an upper tusk shows a portion of an enamel covering. A small lower incisor (no. 21318, fig. 162) has a portion of the enamel band still intact.

EQUIDAE

The horse group is known in the Ricardo fauna by several clearly marked species representing the genera *Hipparion* and *Pliohippus*. The Ricardo horses are as a group much more advanced than the Barstow species. A single Pliohippus-like specimen from Ricardo is to be considered as possibly not more progressive than a relatively very rare form from the Barstow, otherwise all of the Ricardo forms seem more advanced than those of the Barstow.

The *Pliohippus* species of the Ricardo resemble in structure a number of early Pliocene or late Miocene forms appearing in various faunas of western North America. The *Hipparion* forms of the Ricardo show at least as close a resemblance to the species of Asia and Europe as to any in the known American faunas.

HIPPARION MOHAVENSE Merriam

Figures 163 to 170*b*

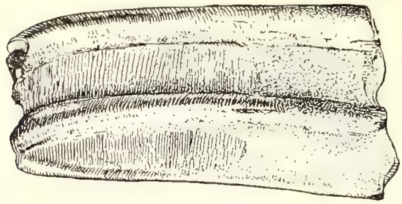
Hipparion? mohavense Merriam. Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, p. 436, figs. 1*a* to 3*b*, 1913.

Type specimen an upper premolar three, no. 19787 (fig. 167), associated with M^1 and M^2, from the Ricardo beds, in the El Paso Range, northwestern border of the Mohave Desert, California.

Upper cheek-tooth crowns nearly straight, length a little more than twice the transverse diameter in unworn specimens. Protocone small, subcircular or slightly compressed laterally in the type material, separate from protoconule almost to the base of the crown. Enamel bordering the fossettes with numerous plications which commonly show rounded rather than angular terminations. Middle region of outer side of paracone and metacone commonly flat. Mesostyle narrowing very gradually beyond the base. Cement covering well developed.

Lower cheek-teeth with metaconid-metastylid column long anteroposteriorly, narrow transversely, and showing a wide longitudinal inner furrow. The small fold commonly seen on the anteroexternal angle of the lower cheek-teeth of *Hipparion* forms is present in several specimens. The enamel of the lower cheek-teeth shows a tendency to form secondary plications especially on the inner side of the parastylid ridge. The greatest transverse diameter of the lower cheek-tooth series is seen in P_4, and commonly at the posterior end of that tooth. The crowns are all heavily cemented.

Since the description of the type specimen the amount of material representing *Hipparion mohavense* has been much increased through the efforts of the parties working under J. P. Buwalda in December 1913 to May 1915, and by several other parties. One fine specimen discovered by Chester Stock includes the complete upper cheek-tooth dentition (no. 21320, figs. 163, 164). This specimen is evidently specifically identical with the typical form. The dimensions are nearly the same as those of the type, the crowns of no. 21320 being relatively narrow due to less advanced wear. The plications of the enamel in no. 21320 are less marked than in the type, though the latter specimen is from an older individual. There is also seen in specimen no. 21320 a tendency to the formation of a slightly different pattern of the enamel folds at the posterointernal angle of the prefossette, and



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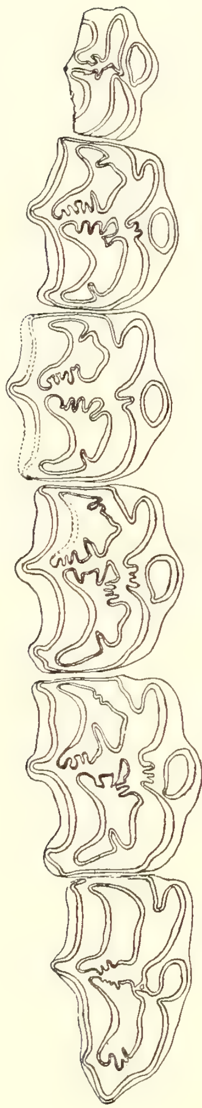

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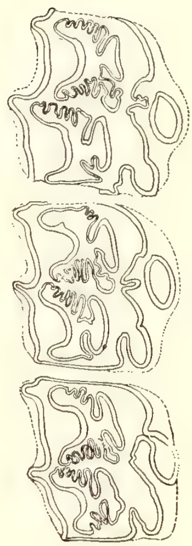

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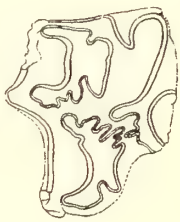

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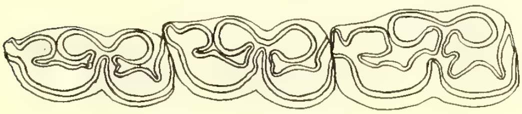
Figs. 163 and 164. *Hipparion mohavense* Merriam. Upper cheek-teeth, P^2 to M^3, no. 21320, natural size. Fig. 163, occlusal view; fig. 164, P^4, outer view. Ricardo Pliocene, Mohave Desert, California.

Fig. 165. *Hipparion*, near *mohavense* Merriam. P^2, no. 19438, natural size. Ricardo Pliocene, Mohave Desert, California.

Fig. 166. *Hipparion*, near *mohavense* Merriam. Upper cheek-tooth, no. 19843, natural size. Ricardo Pliocene, Mohave Desert, California.

Fig. 167. *Hipparion mohavense* Merriam. Type specimen, upper cheek-teeth, no. 19787, natural size. Ricardo Pliocene, Mohave Desert, California.

on the inner wall opposite the protocone. The type specimen was found to differ from *Hipparion richthofeni* of China in the presence of a single fold in the enamel wall opposite the protocone, while in *H. richthofeni* a double fold may appear at this point. In the specimen no. 21320 the fold may be double as in *H. richthofeni.*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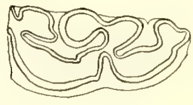
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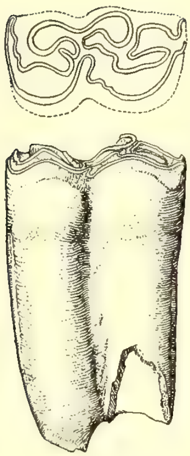
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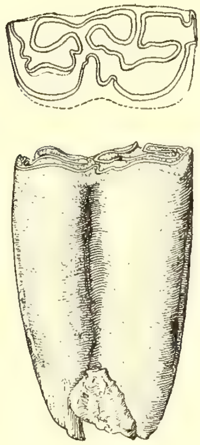
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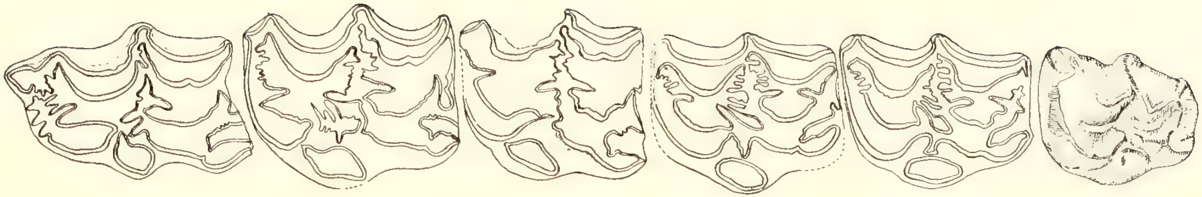
Figs. 168*a* and 168*b*. *Hipparion mohavense* Merriam. Inferior cheek-teeth associated with type specimen, no. 19787?, natural size. Fig. 168*a*, P_4; Fig. 168*b*, P_3. Ricardo Pliocene, Mohave Desert, California.

Fig. 169. *Hipparion mohavense* Merriam. M_2, no. 21209, natural size. Ricardo Pliocene, Mohave Desert, California.

Figs. 170*a* and 170*b*. *Hipparion mohavense* Merriam. Lower cheek-teeth, no. 21348, natural size. Fig. 170*a*, P_2; fig. 170*b*, P_4 to M_2. Ricardo Pliocene, Mohave Desert, California.

Several lower cheek-teeth associated with the type specimen (figs. 168*a*, 168*b*) of *H. mohavense* are Hipparion-like in form and cementation of the crowns, in the form of the metaconid-metastylid column, in the plications of the enamel, and in the occasional presence of the



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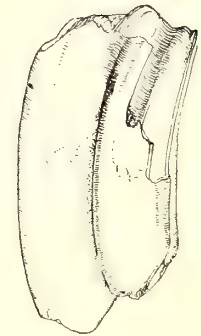

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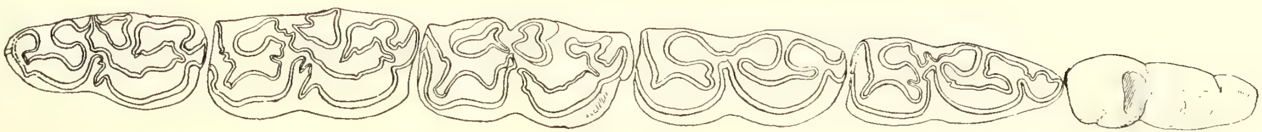


173

Figs. 171 to 173. *Hipparion mohavense callodonte* Merriam. Cheek-tooth series, type specimen, no. 21311, natural size. Fig. 171, superior cheek-teeth, occlusal view; fig. 172, M^3, outer view; fig. 173, inferior cheek-teeth, occlusal view. Ricardo Pliocene, Mohave Desert, California.

small antero-external fold. Several other specimens from the Ricardo show approximately the characters seen in this type.

The Ricardo specimens exhibit considerable variation in size and form. The extremes of difference are probably those separating the type specimen from the complete dentition represented in no. 21311 described below as *Hipparion mohavense callodonte.* The gaps are partly bridged, but it is not improbable that two or more distinct species are represented.

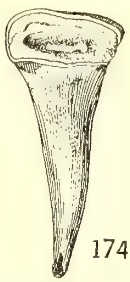
HIPPARION MOHAVENSE CALLODONTE Merriam

Figures 171 to 175

H. m. callodonte Merriam. Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, p. 54, figs. 5–7, 1915.

Type specimen no. 21311, a practically complete upper and lower dentition from locality 2281, in the upper portion of the Ricardo Pliocene, near Ricardo Post Office, California.

A finely preserved specimen (no. 21311, figs. 171–175) representing all of the elements of the cheek-tooth dentition, and several incisors was discovered by E. M. Butterworth in 1913. This specimen shows the dentition very slightly worn, with M^3 not yet in function. The upper cheek-teeth are slightly larger than those of the *Hipparion mohavense* specimen no. 21320. The protocone shows more marked transverse flattening, the enamel pattern exhibits more numerous folds, but fewer which are deep and well rounded. Much of the difference to which attention has just been directed is evidently due to the fact that the teeth of *H. m. callodonte* are in a less advanced stage of wear. The difference in complication of the enamel folds may not be explained on this basis.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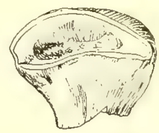
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Figs. 174 to 175. *Hipparion mohavense callodonte* Merriam. Incisor teeth, no. 21311, natural size. Ricardo Pliocene, Mohave Desert, California.

In specimen 21311 the complete lower cheek-tooth series is present with the upper series. P_4 shows incipient wear; M_3 was not yet in function. These teeth represent an individual somewhat larger than the type specimen of *H. mohavense.* The enamel is markedly folded, though not as strongly as in some specimens of *H. gracile.*

Incisor teeth associated with specimen 21311 (figs. 174, 175) show a strongly developed cupping of the enamel.

Measurements of no. 21311

P^2, anteroposterior diameter	29.9 mm.
P^2, transverse diameter	20.2
P^3, anteroposterior diameter	27.4
P^3, transverse diameter	23.2
P^4, anteroposterior diameter	24.8
P^4, transverse diameter	21.5
P^4, height of mesostyle	45.5
M^1, anteroposterior diameter	24.5
M^1, transverse diameter	22.6
M^2, anteroposterior diameter	24
M^2, transverse diameter	20.4
M^2, height of mesostyle	41
M^3, anteroposterior diameter	21
M^3, transverse diameter	18
P_2, Anteroposterior diameter	28.4
P_2, greatest transverse diameter	12
P_3, anteroposterior diameter	27
P_3, greatest transverse diameter	13.7
P_4, anteroposterior diameter	27.4
P_4, greatest transverse diameter	13
P_4, height of protoconid	51
M_1, anteroposterior diameter	25.8
M_1, greatest transverse diameter	11.4
M_2, anteroposterior diameter	27.3
M_2, greatest transverse diameter	10.8
M_2, height of protoconid	44.4
M_3, height of protoconid	44.4
M_3, greatest transverse diameter	10.4

HIPPARION, sp. A

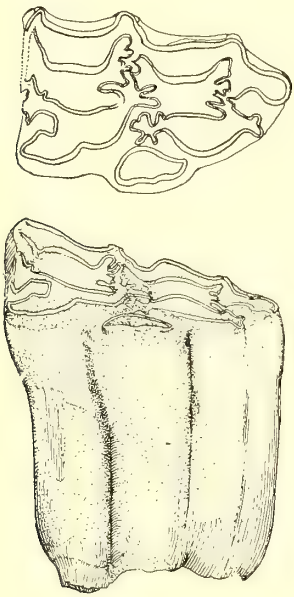
A very large *Hipparion* P^2, no. 22303 (fig. 176), found in the Ricardo beds between the uppermost and the second basalt flows differs so much from the typical *H. mohavense* in its large size that it may represent a distinct species. The pattern of the enamel suggests in some respect the *Hipparion mohavense callodonte* form.

Measurements of no. 22303

P^2, anteroposterior diameter	35.6 mm.
P^2, transverse diameter	22.8

HIPPARION, sp. B

In the collection of Professor James Perrin Smith of Stanford University there is a M^2 (fig. 177) of a *Hipparion* from the upper portion of the Ricardo. This tooth is much narrower than M^2 of the type specimen of *H. mohavense,* while the enamel folds are less complicated and the protocone is more strongly compressed. This form may be as near to the Tejon Hills *Neohipparion*, near *molle*,[40] as it is to *Hipparion mohavense*. It shows characters which possibly set it off as a species distinct from other forms of this genus known in the Mohave area.



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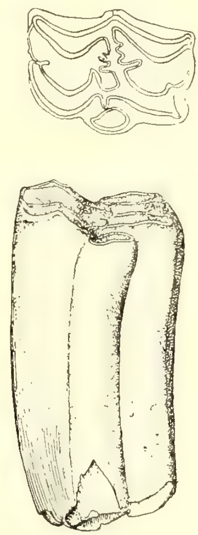

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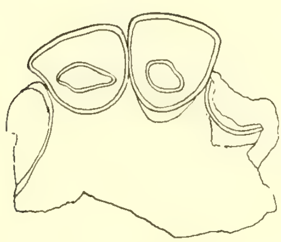

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Fig. 176. *Hipparion*, sp. A. P^2, no. 22303, natural size. Ricardo Pliocene, Mohave Desert, California.

Fig. 177. *Hipparion*, sp. B. M^2, natural size. Ricardo Pliocene, Mohave Desert, California.

Fig. 178. *Pliohippus?*, sp. Incisor teeth, no. 22510, natural size. Ricardo Pliocene, Mohave Desert, California.

40 Merriam, J. C., Mammalian remains from the Chanac Formation of the Tejon Hills, California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, p. 120, 1916.

COMPARATIVE MEASUREMENTS

	Hipparion sp. B	Neohipparion near molle No. 21781 Chanac	H. mohavense No. 21320
M^2, anteroposterior diameter	21.3 mm.	17.8	22.3
M^2, transverse diameter at summit	15.8	*a*12.8	20.2
M^2, height of slightly worn crown	*a*42	*a*40.5	45.6

a, approximate.

RELATIONSHIPS OF RICARDO HIPPARIONS

The affinities of the Ricardo *Hipparion* species to the Old World forms cannot be determined with full satisfaction on the basis of dentition alone, but the relation between dentition and limb structure in the Ricardo material is as yet so indefinite as to make comparisons based upon dentition less dangerous than when combined with discussion of limbs of doubtful relationship.

The hipparions from the Ricardo do not seem to correspond exactly in specific characters to any described American species known east of the Great Basin region. The nearest forms are found in the group of species including *Hipparion plicatile* and *H. ingenuum* of the Florida Pliocene, *H. venustum* of Ashley River, South Carolina, and *Neohipparion occidentale* of the Great Plains region. Of these *H. venustum* and *H. ingenuum* represent much smaller forms than those of the Ricardo. *H. plicatile* is slightly smaller than *H. mohavense*, the crowns seem somewhat shorter anteroposteriorly, the fossettes are smaller, and the outer faces of the paracone and metacone pillars are much more distinctly concave than in the Ricardo species. On the whole these three Atlantic Coast species differ more widely from the Old World hipparions than do the Ricardo forms.

Of the American species grouped by Gidley under *Neohipparion*, *N. occidentale* shows tooth dimensions approaching those of the Ricardo specimens, but probably ranges to larger size than the Ricardo forms. Compared with *H. mohavense* the protocone of *N. occidentale* is commonly much longer anteroposteriorly and much more compressed laterally, and the enamel bordering the fossettes generally shows less marked plications. The type of *H. mohavense callodonte* from Ricardo approaches the American *Neohipparion* more closely than does the typical material of *H. mohavense*. The protocone is somewhat flatter, the enamel may show somewhat shallower plication in the upper molars, and the folds may be more distinctly angular. This specimen is not however referable to any previously described American species, and it is near an Old World type.

The closest affinities of *Hipparion mohavense* are evidently with the Old World species of the East Asiatic *H. richthofeni*, and the European *H. gracile* type, rather than with the typical American species grouped in *Neohipparion*. Even the form seen in *H. plicatile* of Florida is not as near the Ricardo species as are the Chinese and European representatives of this genus.

According to Schlosser[41] the upper cheek-teeth of *H. gracile* are commonly distinguished from those of *H. richthofeni* by a relatively short and broad posterior valley, a smaller and more nearly circular protocone, and by the form of the small fold of the inner wall opposite the protocone. In all of these characters *H. mohavense* is nearer to *H. richthofeni* than to *H. gracile*.

In the original description of *Hipparion mohavense* the writer suggested that diagnostic characters separating it from the Chinese hipparions in the upper molars were found in the form of the small fold opposite the protocone, and in the length of the molars. Additional material now available shows that the small enamel fold opposite the protocone may have approximately the same form in the two species, though it probably tends to be more complex in the Chinese form. The new material available for study indicates also that the difference in length of the cheek-teeth is very small. Measurements of the largest specimens of *H. richthofeni* are somewhat greater in length of crown than in the Ricardo material, but the difference is slight. More noticeable than contrast in length of crown is the excess in area of the cross-section of the largest cheek-teeth of *H. richthofeni*.

With the collections now available few if any clearly diagnostic characters in form or pattern of the Ricardo teeth designated as *H. mohavense* appear which may be considered as certainly separating them from the Chinese *H. richthofeni*. The most suggestive differences between the two are in dimensions, but this variation is inconsiderable. Were the specimens examined not found so widely separated geographically as to make specific identity seem highly improbable, the writer would be inclined to include the Ricardo forms in the *H. richthofeni* group. Geographic situation and the suggested differences in dimensions make it practically certain that the Ricardo species is distinct from *H. richthofeni*, but the marvel is that the two approach so closely. It should be remarked in passing over this subject that some of the characters which have been used to separate *H. richthofeni* from *H. gracile* seem to disappear with the study of large collections.

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41 Schlosser, M., Abh. d. Mat. Phys. Kl. Bayr. Akad. Wiss., Bd. 22, S. 84, 1906.

It is probable, however, that as these characters disappear others not previously observed will present themselves.

In many respects *Hipparion mohavense callodonte* of the Ricardo *Hipparion* group resembles a type from the island of Samos, which has been referred to *H. gracile*. In this Samos form the protocone is much more strongly compressed than in typical *H. gracile,* and exceeds the degree of flattening in *H. m. callodonte*. The enamel folds are complicated much as in *H. gracile, H. richthofeni,* and *H. mohavense.*

ORIGIN OF RICARDO HIPPARIONS

The close similarity of the Ricardo hipparions to the types in existence at approximately the same time in Asia and Europe is probably not to be explained on any hypothesis other than that of common origin. As the gap between *Hipparion* and the brachyodont horses seems more clearly bridged in America than in Europe, there is good reason for looking to America or some intermediate region for the ancestors of this group. Among the species assembled in the North American genus *Merychippus* there are a number of forms that are very close to *Hipparion,* and that seem in their evolution to trend directly toward that type. From available evidence it appears probable that *Hipparion* is derived from the *Merychippus* group.

With special reference to the origin of the Ricardo species it seems worth noting that there is present in the Upper Miocene Barstow fauna of the Barstow syncline an advanced form of *Merychippus* differing but little from *Hipparion.* In the Barstow *Merychippus* the crowns are a little shorter, they are more strongly curved, the mesostyle is relatively heavier at the proximal end, the enamel folds are less complex, and the cement is a little less abundant than in *H. mohavense.* While it is improbable that the known *Hipparion* forms of the Ricardo fauna are descended directly from any known Hipparion-like species of *Merychippus* of the Barstow fauna, the proximity of the two in morphologic characters, geographic situation, and in time, strongly suggest close relationship. Very much of the palaeontologic history of the Great Basin and Pacific Coast regions is still unknown. The portions that are not yet known vastly exceed the material available, and much of the Miocene record is still to be discovered. In the present state of our knowledge we may consider as reasonable the view that a line of descent may yet be traced from a form near a Barstow *Merychippus* to a Ricardo *Hipparion.*

COMPARATIVE MEASUREMENTS OF HIPPARION DENTITION

	H. mohavense, no. 21320, moderately worn, M^3 in function	H. mohavense callodonte, no. 21311, slightly worn, M^3 not in function	H. mohavense, Type, no. 19787	H. richthofeni, after Schlosser	H. richthofeni, after Schlosser	H. richthofeni, after Schlosser	H. gracilis, after Weithofer	H. ingenuum, Florida Pliocene	H. plicatile, Florida Pliocene
P^2, anteroposterior diameter	29 mm.	29.9	......	34	29	31	......	......	......
P^2, transverse diameter	19.6	20.2	......	24	22	22	......	......	......
P^3, anteroposterior diameter	25	27.4	22	27	24	23	23.8	......	......
P^3, transverse diameter	22.4	23.2	23	28	24	23	23	......	......
P^3, height of mesostyle	43	......	......	40	......	......	......	......	......
P^4, anteroposterior diameter	24	24.8	......	......	......	mid. age 22.5	22.2	......	......
P^4, transverse diameter	22	21.5	......	......	......	23	21	......	......
P^4, height of mesostyle	47.5	45.5	......	......	......	......	......	......	......
M^1, anteroposterior diameter	22.3	24.5	21.4	27.5	23.5	20	20.5	......	M^1? 20
M^1, transverse diameter	21.5	22.6	22	22	20	19	20.7	......	M^1? 23
M^2, anteroposterior diameter	22.3	24	21.6	27.5	23.5	20	20.5	18.5	......
M^2, transverse diameter	20.2	20.4	20	22	20	19	17.2	16.5	......
M^2, height of mesostyle	44	41	33.5	56	......	......	......	43	......
M^3, anteroposterior diameter	19.7	21	......	24	19	29	......	......	......
M^3, transverse diameter	16.9	18	......	19.5	18	22	......	......	......

Comparative Measurements of Hipparion Dentition—(*Continued*)

	H. m. callodonte, no. 21311, beginning wear, M_3 not in function	Associated with H. mohavense, no. 19787, Type	H. mohavense, no. 21348	H. richthofeni, after Schlosser	H. richthofeni, after Schlosser	H. richthofeni, after Schlosser	H. gracile, after Weithofer	H. gracile, after Weithofer
P_2, anteroposterior diameter	28.4 mm.	......	23.8	*a*29.3	25	24	23	30.7
P_2, greatest transverse diameter	12	......	11.4	15	12	11	12	12.1
P_3, anteroposterior diameter	27	23.5	......	27	22	21	27	26.7
P_3, greatest transverse diameter	13.7	11.7	......	16.5	14.5	12	12.8	13.7
P_3, height of protoconid	......	......	......	46	......	......	......	......
P_4, anteroposterior diameter	27.4	23.8	24.2	25	19.5	20	25	25.1
P_4, greatest transverse diameter	13	11.9	12.9	16.5	13	12	cut end 11	cut end 13.8
P_4, height of protoconid	51	32	44	47	......	......	......	......
M_1, anteroposterior diameter	25.8	......	21.5	28	22	20	25.8	24.6
M_1, greatest transverse diameter	11.4	......	12.1	15	14	13	10.8	12.2
M_2, anteroposterior diameter	27.3	......	22	no. 21209 26.2	27	23	25	23.1
M_2, greatest transverse diameter	10.8	......	11.3	11	13	11	9.9	10.1
M_2, height of protoconid	44.4	......	......	50	56	54	......	......
M_3, anteroposterior diameter	25	......	......	no. 19849 24.3	24	31	24	27.9
M_3, greatest transverse diameter	10.4	......	......	10	11	13	*a*8	9.8
I, anteroposterior diameter	8	......	......	......	......	......	......	......
I, greatest transverse diameter	15	......	......	......	......	......	......	......

a, approximate.

While we are as yet very far from a situation in which we can hope to establish anything like a fully satisfactory time correlation between the West American Tertiary formations and those of Europe or even of Asia, there are reasons for believing that the Ricardo fauna represents a time near the beginning of the Old World Pliocene, and the Barstow fauna an epoch corresponding approximately to Upper Miocene. If these suggestions are approximately correct there is a possibility that the Old World hipparions are derived from an American stock of which the Ricardo group was a part. Or it may be that the Ricardo fauna was only a surviving remnant of this stock occupying a limited area on the Pacific border of the continent. The great number of American forms grouped under *Neohipparion* may be derived from an original typical *Hipparion* group, or they may have originated independently from another branch of *Merychippus.* The forms of the Florida Pliocene, including *Hipparion plicatile,* may be an Atlantic survival of the original American *Hipparion* group differing from the western forms partly because of geographic separation.

PLIOHIPPUS TANTALUS Merriam

Protohippus? tantalus Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, p. 440, figs. 4*a* and 4*b,* 1913.

Type specimen (fig. 189) an upper premolar, no. 19434, Ricardo beds, Mohave Desert, California.

Crowns of upper cheek-teeth moderately curved. Unworn crowns probably with a longitudinal diameter exceeding twice the transverse measurement. Protocone connected with protoconule. Anterior and posterior fossettes wide, with enamel moderately folded on their adjacent borders. Mesostyle narrowing very slightly above the base, apparently somewhat heavier than in *Pliohippus mirabilis* and *P. supremus.*

A complete but somewhat worn, upper cheek-tooth dentition (no. 22308, fig. 179) from locality 2065 in the middle portion of the Ricardo section represents a *Pliohippus* form in which the protocone is relatively narrower transversely than in *P. fairbanksi,* and the fossettes are wider. While these characters may be due in a considerable part to wear, the specimen suggests *P. tantalus* rather than *P. fairbanksi.*

Two practically complete series of lower cheek-teeth (figs. 180–182) from the lower half of the section at Ricardo represent a *Protohippus* or *Pliohippus* form, the relationship of which to the described upper cheek-teeth has not as yet been certainly determined. This species is apparently distinct from a larger, heavier type tentatively deter-

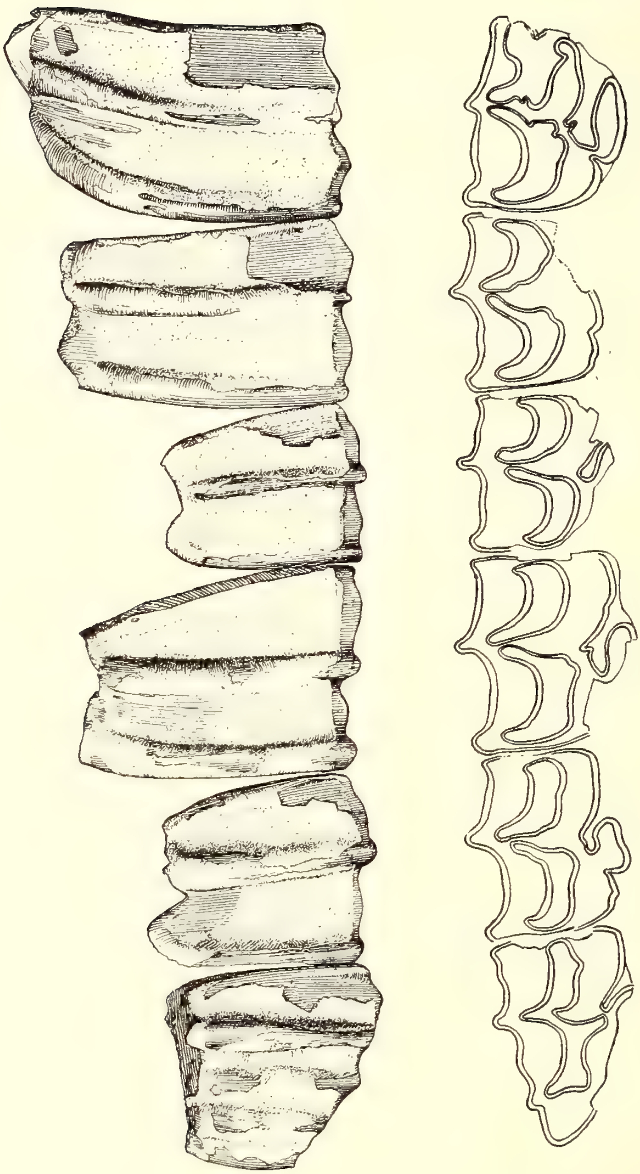
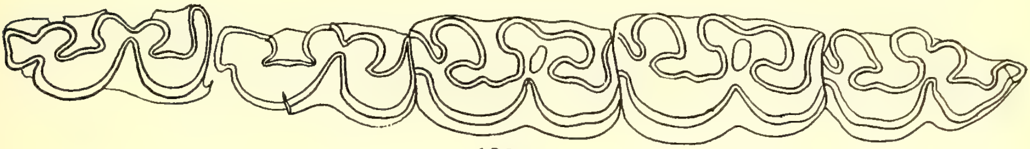


Fig. 179. *Pliohippus tantalus?* (Merriam). Superior cheek-tooth series, no. 22308, lateral and occlusal views, natural size. Ricardo Pliocene, Mohave Desert, California.

mined as *P. fairbanksi.* These less massive teeth, in which the metaconid-metastylid column is somewhat longer anteroposteriorly and the inner gutter wider than in the larger form, are referred tentatively to *Pliohippus tantalus.* Of the two lower dentitions referred to *P. tantalus,* no. 21789 was found between the uppermost and the second basalt flows 2½ miles north of Ricardo Post Office; no. 21790



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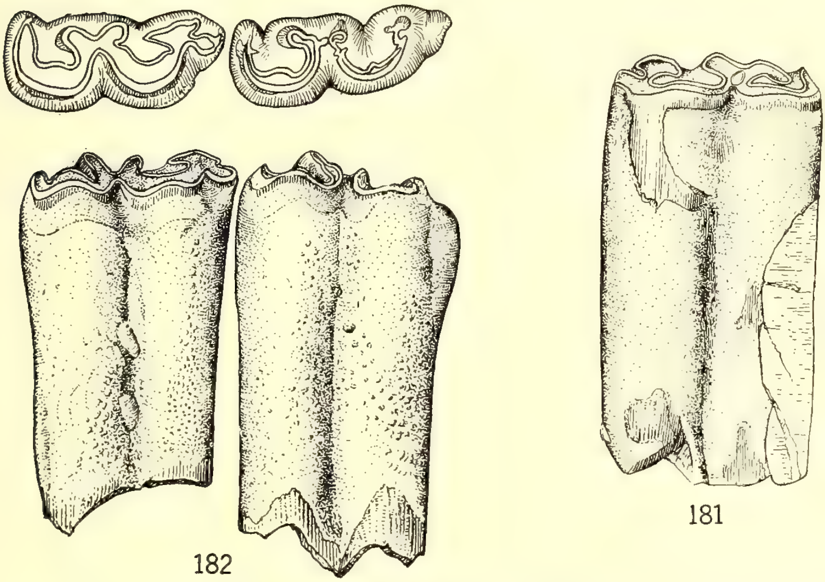

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Figs. 180 to 182. *Pliohippus tantalus?* (Merriam). Inferior cheek-teeth, natural size. Fig. 180, P_2 to M_2, no. 21789, occlusal view; fig. 181, P_4, no. 21789, outer view; fig. 182, M_1 and M_2, no. 21790, outer and occlusal views. Ricardo Pliocene, Mohave Desert, California.

was found by J. P. Buwalda about 500 feet below the lowest basalt flow and 400 feet above the base of the Ricardo beds, two miles above the mouth of Iron Cañon.

In no. 21789 (figs. 180, 181) the moderately worn tooth crowns are long and heavily cemented. Compared with no. 21346, a large *Pliohippus* specimen from a much higher situation in the Ricardo, the crowns are relatively much narrower with approximately the same anteroposterior diameter. The metaconid-metastylid column in no. 21789 is noticeably narrower than in the later form.

In no. 21790 (fig. 182) the characters seem much as in no. 21789, but the permanent teeth are shown by wear only in the case of M_1. In no. 21790 the milk premolars are still in position, though almost worn away. The temporary teeth show a clearly marked cement deposit on the best preserved individuals.

Pliohippus tantalus is near *P. supremus,* in character of upper cheek-teeth, but seems to have wider fossettes with a different type of enamel folds. The mesostyle of the Ricardo type appears slightly heavier than that of the type specimen of *P. supremus,* which is a tooth of approximately the same size and of similar situation in the dental series.

Upper cheek-teeth of *Pliohippus* from the Thousand Creek Pliocene are near the stage of evolution in this Ricardo form, but the material from Thousand Creek is fragmentary, and a better representation of the species is needed before a thoroughly satisfactory comparison can be made.

The *Pliohippus* forms from the Lower Etchegoin and Jacalitos of the Great Valley of California all have narrower upper cheek-teeth with smaller fossettes than in *P. tantalus.*

PLIOHIPPUS FAIRBANKSI Merriam

Pliohippus fairbanksi Merriam. Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, p. 55, figs. 8*a*–8*c*, 1915.

Type specimen (fig. 185) an upper cheek-tooth, P^4?, no. 19789, from the Ricardo Pliocene near Ricardo Post Office, California.

Crowns of upper cheek-teeth heavily cemented and strongly curved. Protocone small, nearly circular in cross-section in premolars. Anterior notch between protocone and protoconule sharp. Union of metaloph and protoloph commonly effected by confluence of the posterior horn of the protoconule and a crochet external to it. Borders of fossettes simple.

This species differs from *Pliohippus tantalus* mainly in form of protocone and fossettes. The protocone is of the short, round type seen in *P. interpolatus,* while that of *P. tantalus* is presumed to show more compression. The fossettes in the type specimen are narrow and more distinctly lunate than in *P. tantalus,* and do not show less marked plications of their walls.

Specimen no. 21346 (fig. 183) representing the greater part of a *Pliohippus* lower cheek-tooth dentition from the upper portion of the Ricardo shows the crowns larger and heavier than those from the lower and middle portion of the section referred to *P. tantalus,* and the metaconid-metastylid column presents a sharper, narrower, inner gutter. The form represented by no. 21346 is presumably distinct from the specimens referred to *P. tantalus.* It may be referred tentatively to *P. fairbanksi,* but possibly represents a third type in the Ricardo fauna.

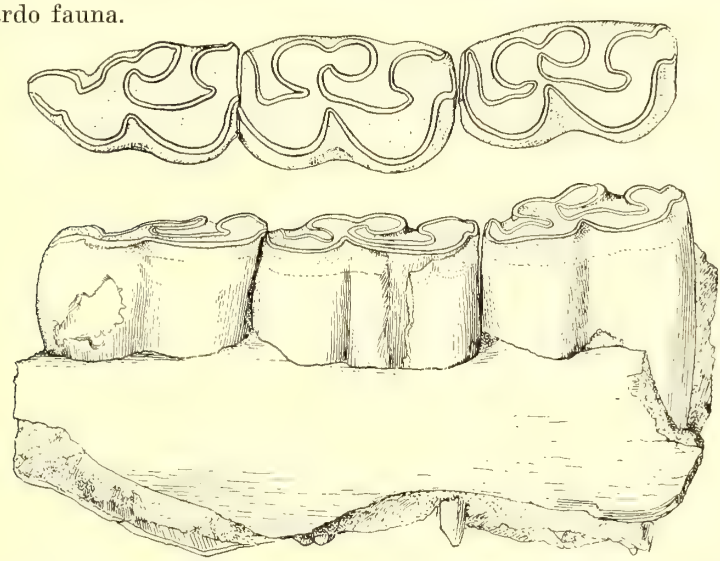


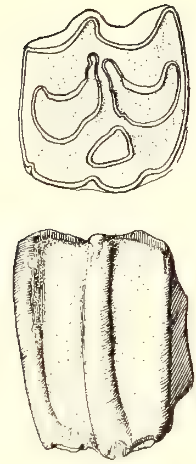
Fig. 183. *Pliohippus fairbanksi?* Merriam. P_2 to P_4, no. 21346, natural size. Ricardo Pliocene, Mohave Desert, California.

Comparative Measurements

	P. fairbanksi, Ricardo, Type, no. 19789	P. fairbanksi, no. 22307	P. fairbanksi, J. P. Smith specimen	P. coalingensis, Etchegoin, no. 21341	P. tantalus, Type, no. 19434
P^3, anteroposterior diameter	......	......	25.2	......	......
P^3, transverse diameter	......	......	26	......	......
P^4, height of crown, outer side	55 mm.	51.5	......	53	48
P^4, anteroposterior diameter	25	25.6	24.8	27.2	24.8
P^4, transverse diameter	26.4	25	26.7	24.4	24
M^1, anteroposterior diameter	......	......	22	......	......
M^1, transverse diameter	......	......	25.2	......	......

Measuremnts of no. 21346

Length anterior border P_2 to posterior border P_4	85.5 mm.
P_2, anteroposterior diameter	29
P_2, transverse diameter	15.2
P_3, anteroposterior diameter	27.9
P_3, transverse diameter	15.2
P_4, anteroposterior diameter	29.6
P_4, transverse diameter	15.5
M_1?, anteroposterior diameter	25.5
M_1?, transverse diameter	14.2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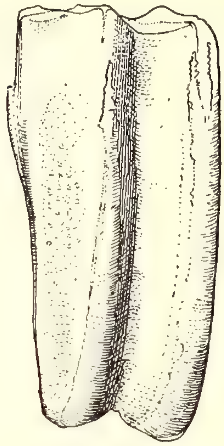
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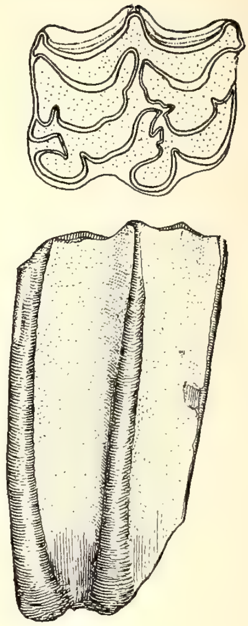
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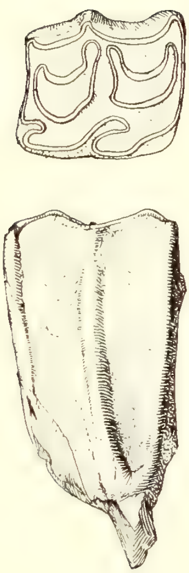
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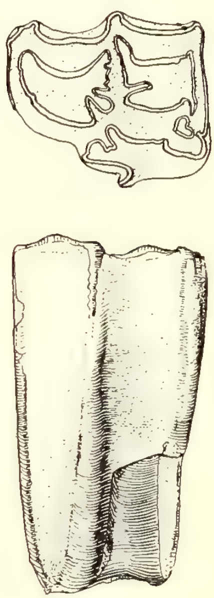
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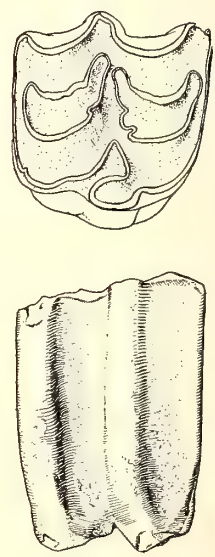
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Figs. 184 to 187. *Pliohippus fairbanksi* Merriam. Superior cheek-teeth, outer and occlusal views, natural size. Fig. 184, P^4, no. 22307; fig. 185, type specimen, P^4?, no. 19789; fig. 186, M^1; fig. 187, P^4. Ricardo Pliocene, Mohave Desert, California.

Fig. 188. *Pliohippus*, sp. *a*, near *mirabilis* (Leidy). M^1, no. 21323, natural size. Ricardo Pliocene, Mohave Desert, California.

Fig. 189. *Pliohippus tantalus* (Merriam). P^4?, type specimen, no. 19434, natural size. Ricardo Pliocene, Mohave Desert, California.

The upper cheek-teeth of *Pliohippus coalingensis* from the Lower Etchegoin on the western border of the San Joaquin Valley show rather narrow fossettes, a very small, round protocone, and a weak connection of protoloph and metaloph. The Etchegoin species has considerably narrower and less curved teeth than the Ricardo form, and is presumably specifically different.

The crowns of upper cheek-teeth of *Pliohippus* from the Thousand Creek Pliocene show about the same curvature as in no. 19789, and the size is approximately the same. The fossettes are larger in the Thousand Creek form, but there is not sufficient material available for a fully satisfactory comparison. The protocone is not well shown in the Thousand Creek specimens.

PLIOHIPPUS, sp. A, near MIRABILIS (Leidy)

A single tooth, M^1 (no. 21323, fig. 188), from Ricardo represents a form presumably to be assigned to *Pliohippus,* but not certainly identical with either *P. tantalus* or *P. fairbanksi.* Compared with the described forms from the Ricardo, the crown of no. 21323 is smaller and narrower, the fossettes are simpler, and the mesostyle is a little lighter than in *P. tantalus.* As this specimen is evidently M^1 considerably worn, while the *P. tantalus* type may be a P^4 in a less advanced stage of wear, it is possible that position, wear, and individual variation may account for the difference between no. 21323 and the type of *P. tantalus.* On the other hand the smaller size suggests that later collections from Ricardo should be carefully examined for a species smaller than *P. tantalus.* The form represented by no. 21323 evidently possessed characters verging on those of *Pliohippus mirabilis.*

Measurements of no. 21323

M^1, anteroposterior diameter	21.4 mm.
M^1, transverse diameter	21.7
M^1, height of portion of crown remaining, measured along mesostyle	36

PLIOHIPPUS MILK DENTITION

Several milk teeth of *Pliohippus* are present in the collection from the Ricardo. The crowns are subhypsodont and heavily cemented. Even in very slightly worn specimens the small protocone is lightly connected with the protoconule. The enamel bordering the fossettes shows very few plications in a moderately worn tooth. These teeth resemble in general the form of milk premolars in *Pliohippus supremus.* It is not certain which of the Ricardo species of *Pliohippus* these teeth represent.

Measurements of Upper Milk Molars

	No. 21199
Dm^4, anteroposterior diameter	26.5 mm.
Dm^4, height of slightly worn crown, measured on protocone	14
	No. 19443
Dm^3?, anteroposterior diameter	24.5
Dm^3?, height of somewhat worn crown, measured on protocone	9

In a large lower milk molar (no. 21315, fig. 190), the crown is high and narrow and shows a thick cement layer. The parastylid extends inward beyond the metaconid. The metaconid-metastylid column is narrow transversely in the section exposed, and the gutter is narrow. This specimen probably represents the same species as the large lower teeth no. 21346 referred to *P. fairbanksi.*

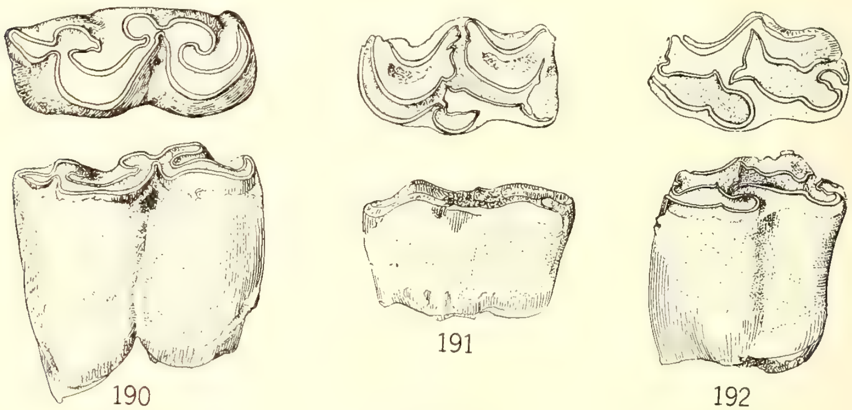


Fig. 190. *Pliohippus fairbanksi?* Merriam. Dm_4, no. 21315, natural size. Ricardo Pliocene, Mohave Desert, California.

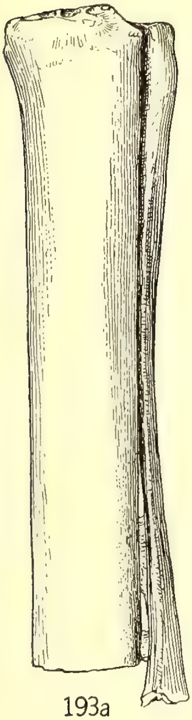
Figs. 191 and 192. *Pliohippus fairbanksi?* Merriam. Superior milk molars, natural size. Fig. 191, Dm^4, no. 21199; fig. 192, no. 21210. Ricardo Pliocene, Mohave Desert, California.

Measurements of no. 21315

Dm_4, anteroposterior diameter	32 mm.
Dm_4, transverse diameter	12
Dm_4, height of crown	26.6

EQUID SKELETAL ELEMENTS

A number of limb bones from Ricardo represent horses considerably larger and of more advanced type than those from the beds of the Barstow syncline. The phalangeal elements and the metapodials represent at least two horse types. In no. 21200 (fig. 195) the proximal phalangeal element is larger and more slender than in any of the *Merychippus* or *Protohippus* forms from the Barstow. It is longer and much more slender than in *Hypohippus.* It is smaller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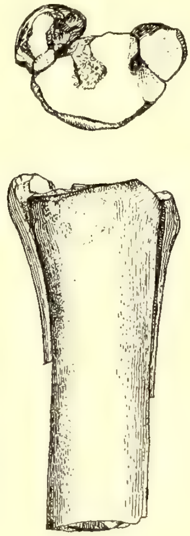
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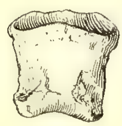
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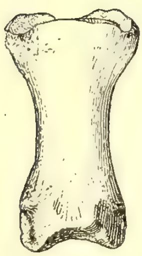
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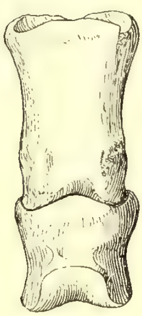
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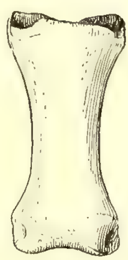
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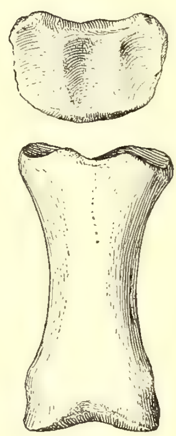
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Figs. 193*a* and 193*b*. *Pliohippus?*, sp. Third metacarpal and lateral metacarpal, no. 21203, × ½. Fig. 193*a*, anterior view; fig. 193*b*, side view. Ricardo Pliocene, Mohave Desert, California.

Fig. 194. *Pliohippus?*, sp. Third metacarpal with lateral metacarpals, no. 21202, × ½. Ricardo Pliocene, Mohave Desert, California.

Figs. 195 to 199. *Hipparion* and *Pliohippus*. Phalanges, × ½. Fig. 195, first phalanx, no. 21200; fig. 196, first and second phalanges, no. 21197; fig. 197, second phalanx, no. 22255; fig. 198, first phalanx, no. 23126; fig. 199, first phalanx, no. 23127. Ricardo Pliocene, Mohave Desert, California.

and much more slender than in *Equus*. It closely resembles the proximal phalanges of *Pliohippus pernix,* the type of the genus *Pliohippus*. It is somewhat more slender and much larger than the corresponding element in *Neohipparion whitneyi.* Whether the specimen is to be referred to *Hipparion, Neohipparion,* or *Pliohippus* is uncertain, but the relation to *Pliohippus* seems close.

201

200

202

Fig. 200. *Pliohippus?,* sp. Third metatarsal, no. 21201, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 201. *Pliohippus?,* sp. Fourth metatarsal?, no. 21480, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 202. *Pliohippus?,* sp. Distal end of third metapodial, no. 21478, × ½. Ricardo Pliocene, Mohave Desert, California.

In no. 21197 (fig. 196) the proximal phalangeal element is shorter and much less slender than in no. 21200. It is also larger than in any of the forms like *Protohippus* or *Merychippus* from the Barstow beds, and is relatively wider than the Barstow forms. This element is nearer the form of the corresponding element in *Hypohippus,* but is longer and more slender than any proximal phalanx of *Hypohippus* known to the writer, and much more slender than elements from the Barstow fauna which are apparently to be referred to *Hypohippus* (see figs. 29, 30). This element is near the form of the proximal phalanx in *Hipparion theoboldi* of the Siwalik beds, but is more slender and smaller than in *H. theoboldi.*

Several metapodials represent a species much larger than any form from the Barstow. A second and somewhat smaller form is possibly represented by a single specimen, no. 21201. The distal end of a single metapodial, no. 21478 (fig. 202), represents a form possibly larger and distinct from the others.

In the more common form the shaft of metapodial III is considerably larger than in any specimen from the Barstow beds, and is much heavier than in the average *Merychippus* or *Protohippus* species.

In two specimens representing metacarpal III (nos. 21202, fig. 194, and 21203, fig. 193*a*, 193*b*) lateral elements are shown. In the proximal articulation the large unciform facet on metacarpal III meets the magnum facet at an angle ranging from 128° to 131°. The magnum-unciform angle is from ten to twenty degrees wider than that in the Barstow horses and seems uniformly to separate the Ricardo forms from the less progressive Barstow species. Metacarpal II stands relatively higher at the proximal end than in *Equus,* and the facet between magnum and metacarpal II is inclined about twenty degrees away from a plane normal to the distal facet of the magnum.

If a rudimentary metacarpal I was present it was exceedingly minute, as there is scarcely a suggestion of a face of contact on the inner side of the proximal end of metacarpal II. Metacarpal IV is represented for at least two-thirds of its length in specimen no. 21203. The lateral side of the proximal end shows a distinct facet for a metacarpal V.

In a metatarsal III (no. 21198, figs. 203*a*-203*d*) the beveled postero-lateral regions with large contact faces show that lateral metatarsals II and IV extend as fairly large elements down almost to the distal end of this element. A portion of the large metatarsal IV is coössified with the shaft of metatarsal III near the middle of this specimen. The median distal keel extends over the anterior portion of the distal articular face as a clearly defined ridge, reaching quite to its proximal border. The distal keel is more strongly marked in this form than in any of the numerous specimens from the Barstow.

On the proximal end of a metatarsal III (no. 21198, fig. 203*b*), the cuboid facet is large, and is only slightly inclined away from the plane of the ectocuneiform facet. There is a well marked facet for the mesocuneiform showing but little more inclination away from the plane of articulation of the metapodial and ectocuneiform than is shown in the facet between cuboid and metapodial. The lunate posterior portion of the articulation between metapodial and ectocuneiform is separated from the larger anterior surface by a deeply pitted area.

A single metatarsal III, no. 21201 (fig. 200) represents a type somewhat different from that seen in no. 21198. The shaft in specimen 21201 is more slender and evidently smaller. The proximal end is relatively narrower anteroposteriorly. The facet for the mesocuneiform is slightly larger and more nearly parallel with the plane of the ectocuneiform facet. The posterior articulation with the ecto-

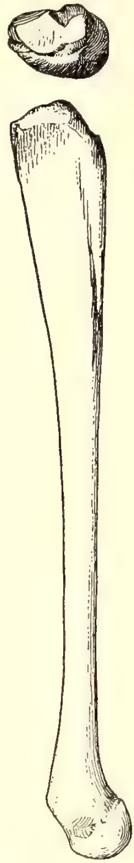

203a


203b


205


203c


203d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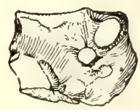
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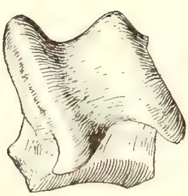
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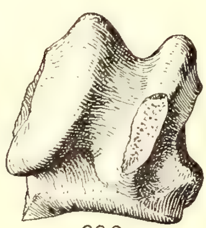
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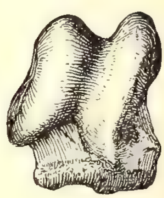
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Figs. 203*a* to 203*d*. *Hipparion* or *Pliohippus*, sp. Third metatarsal, no. 21198, × ½. Fig. 203*a*, anterior view of proximal end; fig. 203*b*, articular facets of proximal end; fig. 203*c*, anterior view of distal half; fig. 203*d*, posterior view of distal half. Ricardo Pliocene, Mohave Desert, California.

Figs. 204 and 205. *Pliohippus* or *Hipparion*, sp. Second and fourth metatarsals, lateral views, × ½. Fig. 204, metatarsal IV, no. 21475; fig. 205, metatarsal 2, no. 21479. Ricardo Pliocene, Mohave Desert, California.

See legend for figures 206 to 210, foot of page 573.

cuneiform is not separated as a distinct lunate facet as in no. 21198, but is connected with the anterior portion of the articulation at its inner or medial end.

Metatarsal IV is shown complete in no. 21475 (fig. 204). It is considerably shorter and heavier than in *Neohipparion whitneyi.* The distal end has a large facet for support of a phalanx. This specimen evidently belongs with a metatarsal III as large as that seen in no. 21198. In no. 21476, a metatarsal IV is seen associated with a metatarsal III apparently of the same type as that in no. 21198. In no. 21476, the proximal end of metatarsal IV is somewhat thinner than in 21475 and the proximal articulation with the cuboid is divided into two facets instead of being a single facet, as shown in no. 21475. This difference may have some significance in specific or generic diagnosis or may be merely individual.

Metatarsal II is seen in no. 21479 (fig. 205). It is much smaller than metatarsal IV. There is no evidence indicating the presence of metatarsals I and V.

A single specimen, no. 21480 (fig. 201), seems to represent a metatarsal IV nearly twice the size of the other specimens from the Ricardo region. It differs from those of the large horses in the marked concavity of the surface of articulation for the cuboid. This surface curves upward sharply to the summit of a sharp spine or prominence on the inner side of the proximal end of the bone and immediately behind the facet for articulation with metacarpal III. There is also a possible difference from metatarsal IV of the horses described in the absence of a posterior inner face for articulation with metatarsal III. The relationship of this specimen is uncertain.

The equid astragali from the Ricardo region are larger than any from the Barstow excepting a large Barstow specimen presumably representing *Hypohippus.* Of the specimens available for comparison the Ricardo astragali most nearly resemble certain specimens from the Thousand Creek Pliocene which represent a *Pliohippus* or a Hipparion-like form. The range in size among the Ricardo astragali is considerable (figs. 208–210), and it is probable that two species

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Fig. 206. *Pliohippus?,* sp. Distal end of metapodial, no. 22325, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 207. *Pliohippus* or *Hipparion,* sp. Cuboid, no. 21198, inner view, × ½. Ricardo Pliocene, Mohave Desert, California.

Figs. 208 and 209. *Pliohippus* or *Hipparion,* sp. Astragali, × ½. Fig. 208, no. 21495; fig. 209, no. 21213. Ricardo Pliocene, Mohave Desert, California.

Fig. 210. *Hipparion* or *Pliohippus,* sp. Astragalus, no. 22326, × ½. Ricardo Pliocene, Mohave Desert, California.

or two genera are represented by this range, which seems also to be indicated by a difference in form.

The proximal end of metatarsal III, no. 21198, in its dimensions resembles that of *Hipparion*, as figured by Weithofer.[42] In specimens of metatarsal III available from Ricardo the middle portion of the

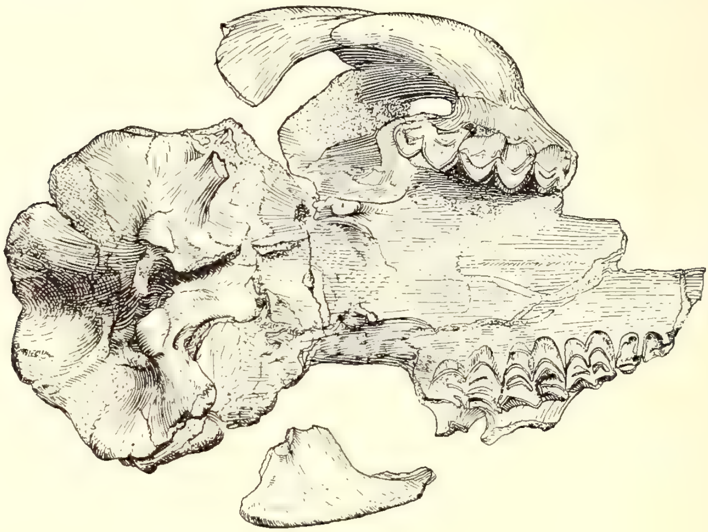

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Fig. 211. *Merycochoerus? (Pronomotherium?) californicus*, n. sp. Skull, type specimen, no. 21351, ventral view, × ¼. Ricardo Pliocene, Mohave Desert, California.

proximal face is more deeply indented than in metapodials of the European form, and there is a separation of the posterior region of the ectocuneiform facet as a distinct lunate articular area. In *Hipparion* the posterior area is not separated from the anterior.

The proximal face of metacarpal III in no. 21202 (fig. 194) seems to differ from that of *Hipparion* in possessing a small notch in the middle of the unciform facet. The dimensions are near those of the European form.

The slender proximal phalanx from Ricardo seems more slender than in *Hipparion* forms of the Old World and approaches the type of *Pliohippus*. In some cases, proximal phalanges of *Hipparion* may be heavier than the wider form from Ricardo seen in no. 21197 (fig. 196).

[42] Weithofer, A., Beiträge zur Kenntniss der Fauna von Pikermi bei Athen, Beitr. Palae. Geol. Oest-Ung., Bd. 6, Taf. 13, figs. 14 and 15, 1888.

The nature of the lateral metapodials in the Ricardo specimens can be nearly duplicated in *Hipparion* of the Old World or in *Protohippus* or *Pliohippus* of America.

A cuboid, no. 21204, from the Ricardo differs from that of *Hipparion* as figured by Weithofer mainly in the separation of the posterior facets for navicular and ectocuneiform. In *Hipparion,* as shown by Weithofer, these facets are contiguous as in *Equus.* This specimen differs from the cuboid in the Barstow *Merychippus* forms in the position of the posterior facet for the navicular somewhat nearer the proximal end of the element, and in its slightly less prominent tuberosity.

OREODONTIDAE

MERYCOCHOERUS? (PRONOMOTHERIUM?) CALIFORNICUS, n. sp.

Type specimen, no. 21351, a fragmentary skull with molar dentition, from locality 1755, Ricardo beds, Mohave Desert, California.

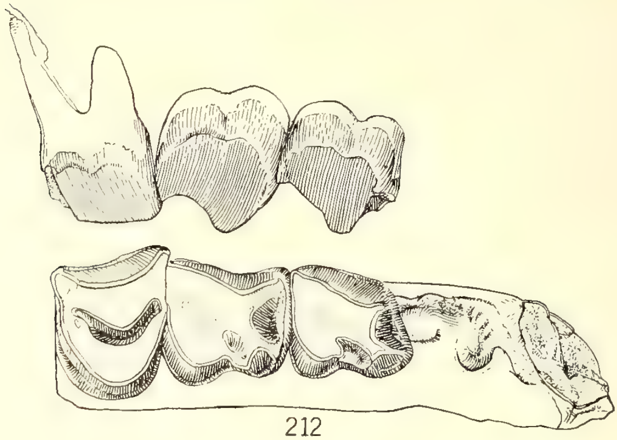
A large, highly specialized oreodont is represented by the type material and several other more imperfect specimens from the beds near Ricardo. So far as known this form is one of the largest and most highly specialized of the oreodonts. Its characters are near those of *Merycochoerus* and approach those of the bizarre *Pronomotherium* from the Madison Valley beds of Montana.

The skull is very badly crushed, but shows some of the general outlines. It seems short and the facial region appears depressed. The orbits are small. The zygomatic arch is deep below the orbit, and is widely expanded. The occipital region (fig. 211) is extremely wide as in *Merycochoerus.* The widely spreading mastoid plates merge into the heavy paroccipital processes below. The sagittal crest is low. The palate is wide; the processes are relatively heavy and project relatively far inferiorly.

The premaxillaries are closely united with the maxillaries, and the superior margin of the premaxillaries slopes backward at a low angle indicating a low, wide anterior nasal opening. The infraorbital foramen is situated over the anterior region of M^1.

The cheek-teeth are large and seem to show a very advanced stage of development in relative length of the molar series, in hypsodonty, and in complication of the premolars.

The molars are large, the crowns are long, and the styles prominent. The internal cingulum is faint on the type specimen, but is strongly marked on no. 21353 (fig. 214) from the Ricardo beds. The



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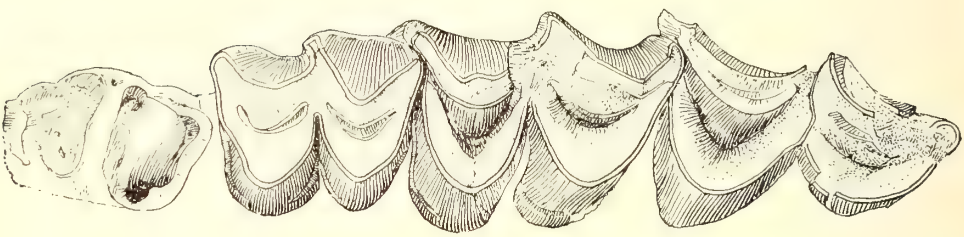

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Fig. 212. *Merycochoerus? (Pronomotherium?) californicus?,* n. sp. Upper premolars, no. 23128, natural size. Ricardo Pliocene, Mohave Desert, California.

Fig. 213. *Merycochoerus? (Pronomotherium?) californicus,* n. sp. Upper molars, occlusal view, natural size. Type specimen, no. 21351. Ricardo Pliocene, Mohave Desert, California.

molars do not differ greatly from those of *Merycochoerus buwaldi* of the Barstow beds excepting in their larger size.

The premolars of the type specimen are imperfect. On a specimen (no. 23128) associated with the type the premolars are well preserved and have approximately the same dimensions as those imperfectly represented on the type specimen. It is presumed that no. 23128 represents the same form as the type though this cannot be proved with the material available.

All of the premolars in no. 23128 show external and internal cingula. They are at least as hypsodont as in *Merycochoerus proprius,* and were probably longer than in that form. In the state of wear shown in the material available it is not evident that the premolars were more hypsodont than in *M. buwaldi* of the Barstow. The external faces are flatter than in *M. proprius,* but do not show the suggestion of median longitudinal ribs seen in *M. buwaldi.* P^4 shows approximately the form seen in *M. buwaldi.* P^3 seems slightly more advanced, and P^2 is decidedly more progressive than in *M. proprius* or *M. buwaldi.* In P^2 the diameter of the crown is greater transversely and the anterior pocket is much larger.

The upper canine is possibly a little smaller than in *M. proprius* compared with the size of the skull. It is somewhat larger relative to the size of the skull than in *Pronomotherium altiramum.*

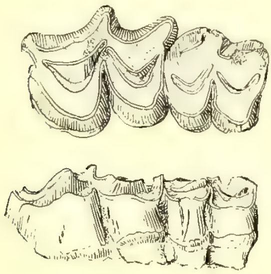

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Fig. 214. *Merycochoerus? (Pronomotherium?) californicus?,* n. sp. M^1 and M^2, no. 21353, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 215. *Merycochoerus? (Pronomotherium?) californicus?,* n. sp. Symphysis of mandible, no. 21567, × ½. Ricardo Pliocene, Mohave Desert, California.

Measurements of Skull, no. 21351

Width across occipital region including expansion of mastoid plates	175	mm.
Height of inion above upper border of foramen magnum	*a*92	
Width of palate between inner borders of M^2	74	
Width of posterior narial opening between processes	49	
Height of zygomatic arch immediately below orbit	45	

a, approximate.

Measurements of Dentition

Length of upper molar-premolar series, no. 21351 and no. 23128 combined	167.5 mm.
Length of premolar series, no. 23128	63.5
Length of molar series, no. 21351	*a*104
	No. 23128
Anteroposterior diameter of superior canine at base	14.3
P^2, anteroposterior diameter	16.5
P^2, greatest transverse diameter	13.5
P^3, anteroposterior diameter	16
P^3, transverse diameter	17.2
P^4, anteroposterior diameter	16
P^4, transverse diameter	21.1

a, approximate.

Measurements of Dentition—(*Continued*)

	No. 21351
M^1, anteroposterior diameter	28.3
M^1, transverse diameter	25.2
M^2, anteroposterior diameter	36.8
M^2, transverse diameter	*a*31.3
M^3, anteroposterior diameter	45.5
M^3, transverse diameter	*a*28.5

a, approximate.

Measurements of no. 21353, an Individual with Well Worn Teeth, and M^3 Well Worn

M^2, anteroposterior diameter	*a*27 mm.
M^2, transverse diameter	*a*28
M^3, anteroposterior diameter	41.2
M^3, transverse diameter	33.2

a, approximate.

The dentition of the Ricardo oreodont shows an unusually long molar series and relatively great length of this series compared with the premolars. The length of the premolar series seems to be about 61% that of the molars, while in a *Merycochoerus* specimen available for comparison the length is greater. In Leidy's type of *M. proprius*, it is 85%. In the *Pronomotherium* specimens described by Douglass, the length is 70% for *P. laticeps*, and 77% for *P. altiramum*. In *M. buwaldi* from the Barstow beds the corresponding percentage is 71.3%.

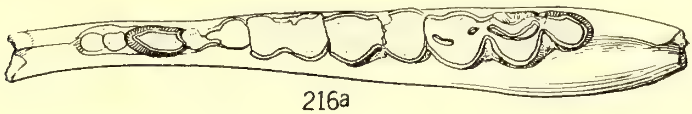
The whole assemblage of characters in the Ricardo specimen seems to distinguish it as a member of the *Merycochoerus* group, and one of the most advanced forms in the group.

Comparative Measurements of Upper Molar and Premolar Series

	Length of premolar series	Length of molar series
Merycochoerus proprius, type	68 mm.	80
Merycochoerus buwaldi	53.5	75
Merycochoerus? californicus*	63.5	104
Pronomotherium laticeps	56	80
Pronomotherium altiramum	70	90

* In *M.? californicus* the molar and premolar dentition are not completely represented in one specimen.

Compared with *Pronomotherium altiramum* the Ricardo form seems to have at least as progressive teeth, but the canine is smaller. The final test of relationship will depend on appearance of good skull material for comparison.



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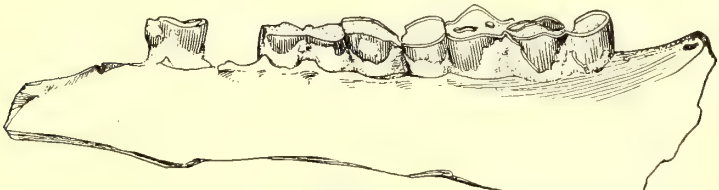

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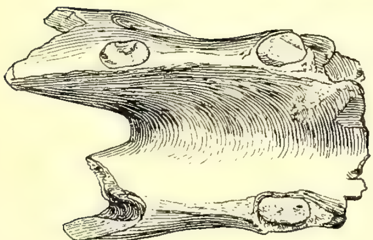

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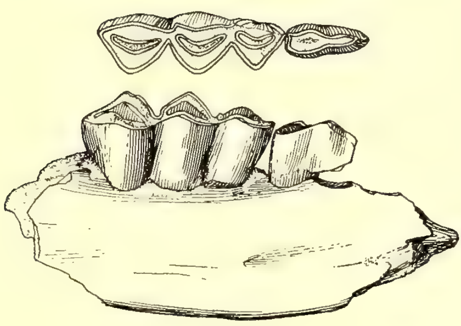

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Figs. 216*a* and 216*b*. *Procamelus?* or *Alticamelus?*, sp. Mandible, no. 22516, × ½. Fig. 216*a*, dorsal view; fig. 216*b*, lateral view. Ricardo Pliocene, Mohave Desert, California.

Fig. 217. *Pliauchenia?* or *Alticamelus?* sp. Symphysis of mandible, no. 23115, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 218. *Procamelus?*, sp. Symphysis of mandible, no. 21305, dorsal view, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 219. *Procamelus?*, sp. Dm_3 and Dm_4, no. 21504, natural size. Ricardo Pliocene, Mohave Desert, California.


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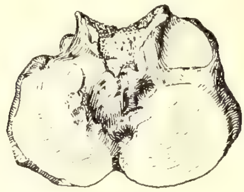
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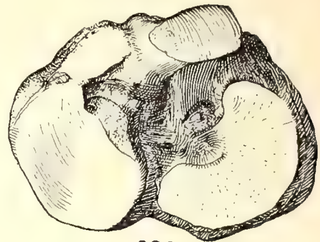
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Fig. 220. *Procamelus?*, sp. Proximal facets of cannon bone of posterior limb, no. 23117, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 221. *Alticamelus* or *Pliauchenia?*. Proximal facets of cannon bone of posterior limb, no. 23116, × ½. Ricardo Pliocene, Mohave Desert, California.

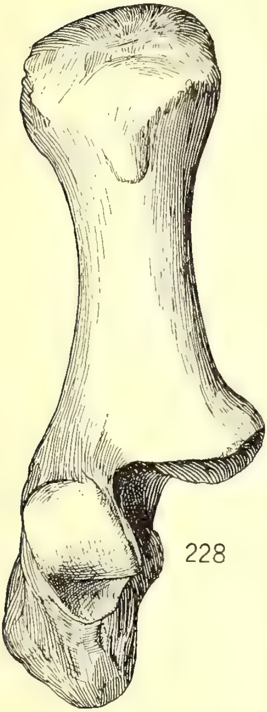
Fig. 222. *Pliauchenia* or *Alticamelus?* Proximal facets of cannon bone of posterior limb, no. 23118, × ½. Ricardo Pliocene, Mohave Desert, California.

Figs. 223 to 227. First phalanges, × ½. Fig. 223, *Alticamelus?*, sp., no. 21563; fig. 224, *Pliauchenia?*, sp., no. 21564; figs. 225 and 226, *Alticamelus* or *Procamelus*, sp., no. 23119 and no. 23114; fig. 227, *Procamelus*, sp., no. 22517. Ricardo Pliocene, Mohave Desert, California.

CAMELIDAE

The camel remains from the Ricardo beds consist almost exclusively of limb bones. Only a few jaw fragments are known, of which a mandible with several molar teeth (no. 22516, figs. 216*a*, 216*b*) is the most important specimen.

At least two camel types are represented in jaw fragments found at Ricardo. One, a small form represented by fig. 218, presumably belonging to the genus *Procamelus*; a larger form, fig. 217, is possibly *Alticamelus*.



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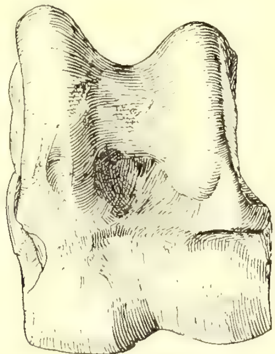

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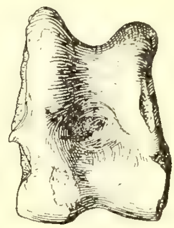

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Fig. 228. *Alticamelus?* or *Pliauchenia?*, sp. Calcaneum, no. 21567, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 229. *Alticamelus?*, sp. Astragalus, no. 23113, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 230. *Alticamelus?*, sp. Astragalus, no. 22519, × ½. Ricardo Pliocene, Mohave Desert, California.

Fig. 231. *Pliauchenia?*, sp. Astragalus, no. 22521, × ½. Ricardo Pliocene, Mohave Desert, California.

Figs. 232 and 233. *Procamelus?*, sp. Astragali, × ½. Fig. 232, no. 22518; fig. 233, no. 22520. Ricardo Pliocene, Mohave Desert, California.

The mandible no. 22516 with dentition shows three premolars of which the anterior tooth is small, but two-rooted. This tooth is moderately hypsodont. This specimen evidently represents *Procamelus* or *Alticamelus*.

A small specimen, no. 21504 (fig. 219), shows the milk dentition. Dm_4 is long and narrow and the anterior lobe is well displayed.

Among the foot bones there are at least four types represented. No. 22521 (fig. 231) belongs to a very large form with relatively wide astragalus. This form is presumably *Pliauchenia*. No. 23113 (fig. 229) with a large but narrow astragalus is apparently *Alticamelus*. No. 22519 (fig. 230) may represent *Alticamelus*. No. 22518 (fig. 232) and no. 22520 (fig. 233) are presumably forms of *Procamelus*.

BOVIDAE

MERYCODUS, near NECATUS Leidy

A considerable number of parts of jaws, horns, and limb elements representing a *Merycodus* species near the Barstow form referred to *M. necatus* have been found at Ricardo. Horns and antlers found in the lower portion of this section are not materially different from those of the Barstow species determined as *M. necatus*, as is seen in no. 22448 (fig. 235). In no. 22449 (fig. 234) the horn has a longer, more slender shaft or beam. In the Barstow fauna forms with the longer beam grade into those with the shorter, flatter beam of the *M. necatus* type.

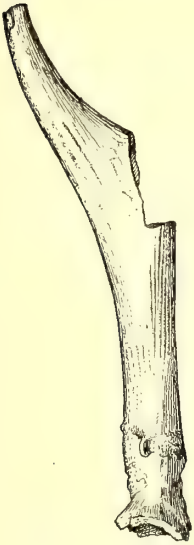
The jaws and teeth of the Ricardo specimens (figs. 236–245) do not differ greatly from those referred to *Merycodus necatus* in the Barstow fauna, and evidently represent a species near that form.

In the Ricardo form the lower molars seem in some cases slightly narrower. In M_3 the posterior lobe may be large showing in some cases an incipient division on the outer side (fig. 242), or it may be relatively small and simple (fig. 241). Some of the specimens with the largest lobes are found low down in the section and below the basalt, while specimens with relatively small lobes are known above the basalt. The premolars may be considerably compressed laterally (fig. 240). The characters mentioned may warrant specific separation from the Barstow species when the form is better known.

In the milk dentition Dm_4 (fig. 239) has a large anterior lobe.

A number of limb elements (figs. 246–252) of *Merycodus* found in the Ricardo have not as yet shown characters distinguishing them clearly from the Barstow form.

The Ricardo form of *Merycodus* in some respect approaches *Capromeryx* of the Pleistocene a little more closely than the Barstow species. The tendency to grooving or division of the third lobe of M_3 is a progressive character. The degree of hypsodonty of the Ricardo species is still much less than in *Capromeryx*, but the difference separating the two is not more than would be expected in an ancestor of *Capromeryx* as far removed in time as the Ricardo species is removed from that of Rancho La Brea.



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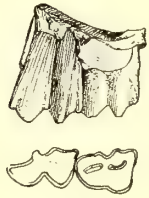

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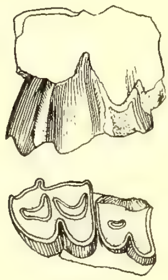

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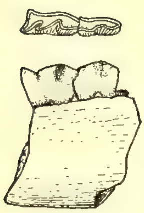

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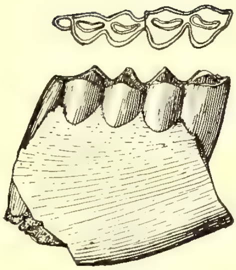

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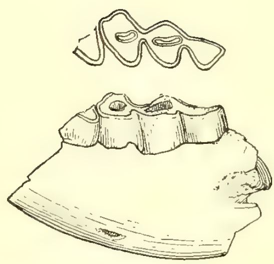

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Figs. 234 to 241 represent specimens from the Ricardo Pliocene, Mohave Desert, California.

Figs. 234 and 235. *Merycodus,* near *necatus* Leidy. Antlers, × ½. Fig. 234, no. 22449; fig. 235, no. 23448.

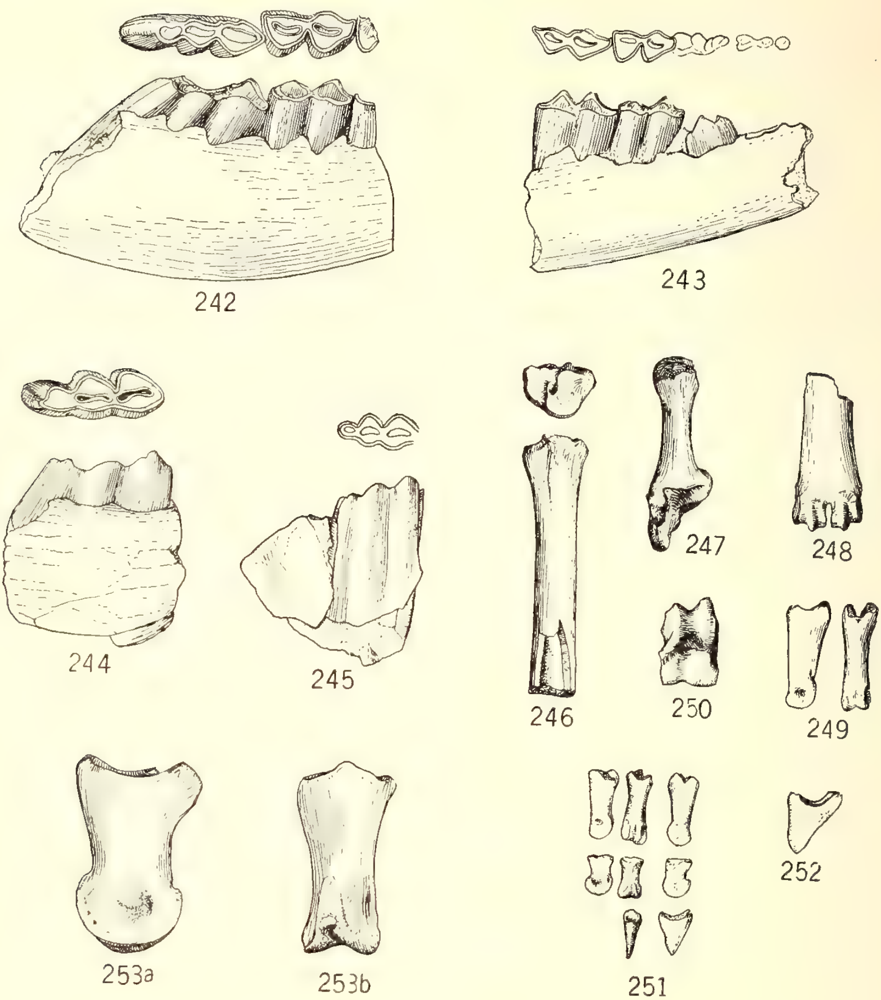
Figs. 236 and 237. *Merycodus,* near *necatus* Leidy. Superior molars, natural size. Fig. 236, no. 22452; fig. 237, no. 22455.

Fig. 238. *Merycodus,* near *necatus* Leidy. M_3 no. 22327, natural size.

Fig. 239. *Merycodus,* near *necatus* Leidy. Dm_4, no. 22453, natural size.

Fig. 240. *Merycodus,* near *necatus* Leidy. P_2 and P_3, no. 22456, natural size.

Fig. 241. *Merycodus,* near *necatus* Leidy. M_2 and M_3, no. 22454, natural size.



Figs 242 to 245. *Merycodus,* near *necatus* Leidy. Inferior dentition, natural size. Fig. 242, M_2 and M_3, no. 21322; fig. 243, P_4, M_1, and M_2, no. 22450; fig. 244, M_3, no. 22457; fig. 245, M_3, no. 22451. Ricardo Pliocene, Mohave Desert, California.

Figs. 246 to 252. *Merycodus,* near *necatus* Leidy. Limb elements, × ½. Fig. 246, anterior cannon bone, no. 22515; fig. 247, calcaneum, no. 21321; fig. 248, distal end of cannon bone, no. 22513; fig. 249, first phalanx, no. 22513; fig. 250, astragalus, no. 22514; fig. 251, phalanges, no. 22512; fig. 252, ungual phalanx, no. 22512. Ricardo Pliocene, Mohave Desert, California.

Figs. 253*a* and 253*b*. Bovid or cervid, indet. Second phalanx, no. 22458, natural size. Fig. 253*a,* lateral view; fig. 253*b,* dorsal view. From beds referred to the Ricardo Pliocene, locality 2578, two miles south of Warren, a station on the Southern Pacific Railroad at eastern end of Tehachapi Pass, Mohave Desert, California.

BOVID or CERVID, indet.

A single second phalanx (no. 22458, figs. 253*a*, 253*b*) from locality 2578, two miles south of Warren on the Southern Pacific Railroad at the eastern foot of the Tehachapi Pass represents an antelope or deer differing both from *Dromomeryx* and from the antelopes of the Thousand Creek fauna. It is much larger than *Merycodus,* smaller than *Dromomeryx,* and approaches the Thousand Creek forms in size. The articulation surfaces differ somewhat from those of the Thousand Creek forms. It is hoped that more material may be secured from this locality.

Transmitted, April, 1915.

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