UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

Professional Paper 207

GEOLOGY AND PALEONTOLOGY OF PALOS VERDES HILLS, CALIFORNIA

BY

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1946

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price $1.50

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By W. P. Woodring, M. N. Bramlette, and W. S. W. Kew

ABSTRACT

Stratigraphy and paleontology.—A metamorphic basement and formations of Miocene, Pliocene, and Pleistocene age are exposed in the Palos Verdes Hills. The Miocene and later deposits, about 3,000 feet thick, are much thinner than strata of the same age in the adjoining Los Angeles Basin and along the north border of the basin.

The oldest rocks are schists, assigned doubtfully to the Franciscan, and altered basic igneous rocks. Quartz-sericite schist, quartz-talc schist, and quartz-glaucophane schist are the most common rock types. The Franciscan (?) schist is considered of doubtful Jurassic age but may be older.

The Miocene strata are assigned to the Monterey shale, which has an exposed thickness of about 2,000 feet and is divided into three mapped local members—in ascending order the Altamira shale, the Valmonte diatomite, and the Malaga mudstone. The Altamira, the thickest of the three members, is divided into lower, middle, and upper parts, characterized, respectively, by the prevalence of silty shale, cherty shale, and phosphatic shale. The Valmonte consists chiefly of diatomite and diatomaceous shale; the Malaga is made up principally of mudstone containing Radiolaria. The Altamira shale member includes two named tuffs—a thick bentonitic tuff named the Portuguese tuff bed and a thin pumice tuff designated the Miraleste tuff bed. The Monterey overlaps the schist basement northward. According to the foraminiferal faunal zones represented, the Monterey of the Palos Verdes Hills is of late middle to late upper Miocene age, the division between middle and upper Miocene being between the middle and upper parts of the Altamira. Mollusks from sandstone resting on schist include several warm-water genera not found heretofore in the Coast Ranges.

The lower Pliocene Repetto siltstone overlies disconformably the Monterey shale. It consists of glauconitic foraminiferal siltstone having a maximum exposed thickness of about 150 feet. Much thinner than the Repetto of the Los Angeles Basin, it includes, nevertheless, the equivalent of a considerable part of the basin section, according to the foraminiferal zones. The Repetto contains deep-water fossils.

Lower Pleistocene strata cropping out on the north and east borders of the hills rest unconformably on the Repetto siltstone and lap up on different parts of the Monterey shale. They consist of 350 to 600 feet of sand, silt, and calcareous strata—the San Pedro sand, the Timms Point silt, and the Lomita marl, respectively. Wherever the Lomita marl is found, it is at the base of the section. The Timms Point silt is either at the base of the section or overlies the Lomita marl. The Lomita marl and Timms Point silt are interpreted as essential chronologic equivalents of each other and of the lower part of the San Pedro sand at localities where the marl and silt are absent.

Marine deposits on the platforms of marine terraces are assigned to the upper Pleistocene. The marine deposits on the extensive lowest terrace—the only terrace deposits named—constitute the Palos Verdes sand. The Palos Verdes sand rests unconformably on lower Pleistocene strata or on older formations.

The Pleistocene strata are exceptionally fossiliferous, Foraminifera and mollusks being most abundant in the lower Pleistocene and mollusks in the upper Pleistocene terrace deposits. The mollusks indicate several depth associations in the lower Pleistocene, ranging from shallow-water to moderate-depth (50 to 100 fathoms). Moderate-depth associations are prevalent in the Lomita marl, are the only associations recognized in the Timms Point silt, and are represented locally in the San Pedro sand. A rock-cliff and tide-pool association is characteristic of terrace deposits older than the Palos Verdes sand. An association indicating protected shallow water is prevalent in the Palos Verdes sand.

The marine Pleistocene strata are assigned to that epoch because their faunas are more modern than those of Coast Range Pliocene formations. The age assignments of the subdivisions of the Pleistocene are somewhat arbitrary. Though the Pleistocene deposits are presumably contemporaneous with Pleistocene glacial and interglacial stages, glacial-interglacial assignments based on the faunas are so involved, owing to possible effects produced by other factors, that such assignments are questionable.

Miocene igneous rocks.—Basaltic rocks, generally in the form of sills, penetrate the lower and middle parts of the Altamira shale member of the Monterey but are not known to occur in younger strata; that is, they are not known to be younger than middle Miocene.

Structure.—The structure of the Palos Verdes Hills is in general anticlinal. A deep-seated fault, not exposed at the surface, extends probably along the north border of the hills, and another may lie off shore to the south. The strongest deformation took place during the upper Pliocene, less marked deformation during the middle Pleistocene, and weaker deformation near the end of the upper Pleistocene. The effects of middle and upper Pleistocene deformation, other than uplift that took place repeatedly during upper Pleistocene time, are visible only along the north border of the hills, where the lower Pleistocene strata are moderately or strongly deformed and the upper Pleistocene lowest terrace platform and its deposits are mildly or moderately deformed.

In general the structure is relatively simple with the exception of a few areas—the north border and adjoining northwestern part of the hills, an area between San Pedro and Palos Verdes Drive East, and a small area near Whites Point—where the strata have been deformed by small folds and faults.

Physiography.—Thirteen main marine terraces considered of upper Pleistocene age are recognized. They are most clearly defined on the windward west slope, on part of the windward south slope, and on the lower part of the leeward east slope. Along the north border of the hills the lowest terrace has no longer the usual physiographic features of a terrace, owing to deformation since the terrace was formed. In the Palos Verdes Hills the effects on terrace development of lowering and rising sea level produced by Pleistocene glaciation and deglaciation are unrecognized.

The crest and upper slopes of the hills are characterized by a rolling upland rerpesenting an old erosion surface of moderate relief thought to have been formed during the period between the early Pliocene submergence and the late Pleistocene submergence.

Mineral resources.—Oil in commercial quantities has not been found so far in the Palos Verdes Hills. Eighteen wells have been drilled to depths greater than about 1,000 feet in the hills and close to the north border. Most of the wells located in the main part of the hills reached the schist basement at depths of about 900 to 3,900 feet below sea level. Wells drilled along and near the north border encountered greatly sheared steeply dipping Pliocene and Miocene formations, and in two wells part of the stratigraphic succession is reported to be inverted. The oil possibilities have not been tested thoroughly, however, at localities where the structure is favorable or where overlap may be effective.

Diatomite from the Valmonte diatomite member of the Monterey shale is mined and processed at a locality near the north border of the hills. The Valmonte diatomite is present along the north and east slopes, but material of the quality of that mined is not found there generally in commercial quantity. Sand and gravel from the San Pedro sand are mined at several localities along the north border of the hills. There are extensive deposits of such material in that area.

INTRODUCTION

SCOPE OF REPORT

During the early years of the present century a general study of the geology of California oil fields was undertaken under the auspices of the Geological Survey by G. H. Eldridge and after his death by Ralph Arnold.

As part of this program a report [1] was issued on the geology of the east end of the Santa Monica Mountains, the adjoining hills in the city of Los Angeles, and the Puente Hills—all along the north border of the Los Angeles Basin. (See fig. 1.) At the time when this program was started development of the oil fields was carried on by small companies, generally with the advice of practical oil prospectors. The intervening years have witnessed the rapid growth of the oil industry and the development of modern oil geology. As oil development progressed in the Los Angeles Basin the geology of the basin and its borders was studied intensively by many geologists. Inasmuch, however, as the results of the work of commercial geologists are not available for general use, it appeared desirable for the Geological Survey to continue the investigations begun in this area by Eldridge and Arnold. In 1926 a report [2] was issued on the Puente Hills and adjoining parts of the Santa Ana Mountains, and in a later publication [3] the geology of the eastern part of the Santa Monica Mountains was described.

The present report on the geology of the Palos Verdes Hills is part of the series of publications dealing with the geology of areas within and bordering the Los Angeles Basin. It describes the geology, paleontology, and mineral resources of the Palos Verdes Hills. The strata that crop out in the hills are penetrated in oil fields in the southern part of the Los Angeles Basin. Special emphasis is devoted to data that may aid in studying the subsurface section in the basin.

The illustrations of fossils from the different formations may be useful to both field geologists and laboratory paleontologists. According to the experience of California geologists, the illustrations of fossils in early reports of the Geological Survey on California oil fields are as useful now as at the time when the reports were issued, despite changes in paleontologic and stratigraphic nomenclature.

The Palos Verdes Hills include the San Pedro district, which has become a classic region in California geology as a result of Arnold's monograph [4] on the Pleistocene paleontology. About 150 collections of Pleistocene mollusks were made during the field work on which the present report is based. It was planned to identify a sufficient number of these collections to show the facies and geographic differentiation of the fossils in the different Pleistocene stratigraphic units. This plan was abandoned, however, for the identification of about 500 species of mollusks would have involved much work, and such a laborious undertaking would have delayed unduly completion of the report. Selected species were identified to serve as a basis for a discussion of the faunas. The omission of long lists of Pleistocene mollusks is not a great loss, as Arnold's collections were exhaustive and other paleontologists have contributed to the Pleistocene paleontology of the San Pedro district since the publication of Arnold's monograph. Arnold's collecting was limited, however, to a small area along the water front. One lithologic and faunal unit (Lomita marl) is not represented along the water front and consequently was not known by Arnold. Many species not recorded by Arnold have been found in that unit and in others.

[1] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, pp. 102–198, pls. 10–24, figs. 12–17, 1907.

[2] English, W. A., Geology and oil resources of the Puente Hills region, southern California: U. S. Geol. Survey Bull. 768, 110 pp., 14 pls., 3 figs., 1926.

[3] Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, pp. 83–134, pls. 16–34, figs. 7, 8, 1931.

[4] Arnold, Ralph, The Paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, 420 pp., 37 pls., 1903. (Reprint Leland Stanford Jr. Univ., Contr. Biol. Hopkins Seaside Lab., No. 31, 1903.)

FIELD WORK

The field work on which this report is based was started by W. S. W. Kew in 1921–22 and was continued by him at intervals until 1924. The geology of the area controlled at that time by the Palos Verdes Syndicate, comprising about the western two-thirds of the hills, was mapped on a topographic base (scale, 1:9,600; contour interval, 5 feet) supplied by the company. The geology of the remainder of the area was mapped on the topographic map of the Redondo quadrangle enlarged from a scale of 1:62,500 to a scale of 1:31,250. The geologic map of the entire area was compiled on the same enlarged map of the Redondo quadrangle. Kew completed the first draft of a report in 1925 after his resignation from the Geological Survey.

The topographic map available for publication at that time was unsuitable on account of the small scale, and the project was laid aside. By 1928 maps prepared on a scale of 1:24,000 by the Geological Survey in cooperation with Los Angeles County were available for the entire area (San Pedro Hill, Wilmington, and Torrance quadrangles). During the summer of 1930 the geology of the area lying outside the original holdings of the Palos Verdes Syndicate was mapped by W. P. Woodring on the new topographic maps enlarged to a scale of 1:12,000. In view of difficulties encountered in transferring the geology from one topographic map to another and in view of recent advances in stratigraphy, it later became evident that remapping of the entire area on a scale of 1:12,000 was desirable. This work was carried on by Woodring and M. N. Bramlette during the summer of 1933 and by Woodring during the summer of 1935. During the field season of 1933 particular attention was given to the Miocene Monterey shale, which had been studied previously by Bramlette at many other localities in the Coast Ranges.

The scale used in mapping is adequate for work of moderate detail. The results attained, however, cannot be regarded as more than a detailed reconnaissance, at least in the area underlain by Miocene strata. In that area, which embraces the greater part of the hills, exposures are generally poor, except along some of the deep canyons and along the sea cliff. Distinctive lithologic units seem to be rare in the Miocene section, strata evidently of the same age change in facies from place to place, and minor structural complications prevent generally a determination of stratigraphic position on a basis of regional structure. Nevertheless, the broad features of the Miocene stratigraphy and the succession of foraminiferal zones appear to be satisfactorily established.

It is difficult to show adequately on the geologic map (pl. 1) the distribution of rock types along the sea cliff, for at many places the cliff is vertical or almost vertical. Areas covered by talus along the cliff are not shown on the map, as it would be confusing rather than helpful to plot them.

Owing to more urgent matters, the preparation of the report was delayed until 1939. In the meantime a preliminary account [5] of the Miocene stratigraphy

[5] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., Miocene stratigraphy and paleontology of Palos Verdes Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 2, pp. 125–149, 3 figs., 1936.

and paleontology and a general account [6] of the fossils from the Pleistocene marine terraces were published.

ACKNOWLEDGMENTS

The Miocene Foraminifera, on which the age assignments and correlations of the Miocene strata are based, were determined by R. M. Kleinpell while he was on the staff of the Geological Survey. S. G. Wissler, of the Union Oil Co. of California, furnished notes based on an examination of a series of foraminiferal samples from the lower Pliocene Repetto siltstone at Malaga Cove. The late R. D. Reed, of the Texas Co. (California), offered much assistance dealing particularly with the Pleistocene calcareous strata now assigned to the Lomita marl. Hampton Smith, of the same organization, gave many helpful suggestions. A section of the Lomita marl in the canyon adjoining Hilltop quarry was measured with the assistance of J. M. Hamill, B. G. Laiming, and Mr. Reed. H. L. Driver, G. C. Ferguson, H. W. Hoots, and Mr. Wissler assisted in measuring and sampling the Repetto siltstone at Malaga Cove. Photographs were furnished by U. S. Grant, K. E. Lohman, Mr. Reed, and officials of the Palos Verdes Estates.

During construction of the Whites Point tunnel through the eastern part of the Palos Verdes Hills during 1935 and 1936 J. R. Schultz, then a graduate student at the California Institute of Technology, studied the geology of the tunnel under the auspices of the Geological Survey. Special acknowledgment is due A. M. Rawn, assistant chief engineer of Los Angeles County Sanitation Districts, and officials of the construction companies for facilities and courtesies that greatly aided Mr. Schultz's studies. The results of his work are included in this report.

During part of the time when this report was written, office and laboratory space in the quarters of the Division of Geological Sciences of the California Institute of Technology at Pasadena was available through the kindness of Prof. J. P. Buwalda.

EARLY HISTORY OF REGION

Juan Rodríguez Cabrillo was the first white navigator to explore the coast of California. During his voyage up the coast in 1542 he sailed past San Pedro Bay, which he named Bahía de los Fumos, from the smoke of Indian fires.[7] Late in 1602 Sebastian Vizcaíno explored this part of the California coast. Many of the names he gave to coastal features are still in use. One of Vizcaíno's ships evidently entered San Pedro Bay, which is designated Ensenada de San Andrés on a chart based on the results of his voyage.[8] In the manuscript coast-pilot written in 1603 by Franco de Bolaños and Father Antonio de la Ascension, two of Vizcaíno's assistants, the bay is called Ensenada de San Pedro—the first known usage of that designation. The bay and the Palos Verdes Hills are well described in the following extract from Wagner's translation [9] of the manuscript:

> From the Punta de la Conversión [Concepción] the coast trends east for more than fourteen leagues, very rough and rugged without any trees to a point which the land makes extending north-south, and with a hill of medium height bare on top which from afar looks like an island. To the east is a very good ensenada with shelter from the northwest, west, and southwest winds. It is named the "Ensenada de San Pedro" in 34½°, and in it there is a small island. Here are friendly Indians.

During the colonial period the open roadstead at San Pedro was used as a port for San Gabriel Mission, founded in 1771, and the village of Los Angeles, founded in 1781. The hide warehouse described by Dana [10] in chapter 14 of "Two years before the mast" was the first building erected at the port. It stood on the bluff about midway between Point Fermin and Timms Point. Point Fermin was named by Vancouver during his voyage of 1793 in honor of Fermín de Lausén, who succeeded Junipero Serra as head of the Franciscan missions in California.

The Palos Verdes Hills were used as grazing land for cattle and horses during the colonial period. The entire area of the hills, with the exception of a narrow strip along the east coast reserved for public use, and part of the adjoining Los Angeles Plain were included in the Rancho de los Palos Verdes, embracing an area of about 32,000 acres.[11] José Loreto Sepulveda and Juan Sepulveda, sons of José Dolores Sepulveda, received a provisional grant to this land in 1827 and a final grant from Governor Pio Pico in 1846. The elder Sepulveda was killed by Indians in 1824 during a journey to Monterey to petition for a patent. In 1882 the land was transferred from the Sepulveda family in a debt settlement.

NAME USED FOR THE HILLS

On current maps the hills are generally designated the San Pedro Hills. Most of the local residents, however, use the name "Palos Verdes Hills," and that name has been used by several writers and cartographers. In view of local usage and to avoid confusion with the name "San Pedro Hill," which is in usage for the highest hill in full view from the city of San Pedro, the United States Board on Geographical Names has adopted the name "Palos Verdes Hills." [12] This designation is particularly fitting, as it commemorates the name of the colonial ranch. The name Palos Verdes is said to have been based on willows growing along the small stream flowing southward into the present Bixby Slough.[13]

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Publications dealing with the geology, paleontology, and geography of the Palos Verdes Hills are included in the following bibliography. Abstracts covering the same ground as later publications are omitted.

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Bituminous shale [Monterey shale] of San Pedro district briefly described (pp. 24–26).

[6] Woodring, W. P., Fossils from the marine Pleistocene terraces of the San Pedro Hills, Calif.: Am. Jour. Sci., 5th ser., vol. 29, pp. 292–305, 1 fig., 1935.

[7] Wagner, H. R., Spanish voyages to the northwest coast of America in the sixteenth century: California Hist. Soc. Special Pub. 4, p. 334, 1929; The cartography of the northwest coast of America to the year 1800, vol. 1, p. 412, Berkeley, 1937.

Other writers have identified Santa Monica Bay as the Bahía de los Fumos. See Davidson, George, An examination of some of the early voyages of discovery and exploration on the northwest coast of America from 1539 to 1603: U. S. Coast and Geodetic Survey Rept. Supt., 1886, app. 7, p. 196, 1887; Bolton, H. E., Spanish exploration in the Southwest, 1542–1706: Original narratives of early American history, p. 7, New York, 1916.

[8] Wagner, H. R., op. cit. (California Hist. Soc. Special Pub. 4), p. 402; The cartography of the northwest coast of America to the year 1800, vol. 1, p. 412, Berkeley, 1937. For a reproduction of part of the chart see Bancroft, H. H., History of California, vol. 1 (Works of Hubert Howe Bancroft, vol. 18), p. 100, San Francisco, 1884.

[9] Wagner, H. R., op. cit. (California Hist. Soc. Special Pub. 4), p. 438, 1929. For a description of the manuscript see Wagner's publication, pp. 381–382.

[10] Dana, R. H., Two years before the mast, a personal narrative of life at sea, pp. 118–119, New York, 1840.

[11] For a brief summary of the history of the Palos Verdes Rancho see Robinson, W. W., Ranchos become cities, pp. 18–25, Pasadena, 1939.

[12] U. S. Board on Geog. Names, Decisions rendered between July 1, 1934, and June 30, 1935, p. 19, 1936.

[13] Robinson, W. W., op. cit., p. 19.

1855. Conrad, T. A., Note on the Miocene and post-Pliocene deposits of California, with descriptions of two new fossil corals: Philadelphia Acad. Nat. Sci. Proc., vol. 7, p. 441. (Reprinted in U. S. Geol. Survey Prof. Paper 59, p. 172, 1909.)

Five species of post-Pliocene [Pleistocene] mollusks are listed from localities "near Santa Barbara and San Pedro."

1855. Blake, W. P., Preliminary geological report [Williamson's reconnaissance in California]: In U. S. Pacific R. R. Expl., U. S. 33d Cong., 1st sess., H. Ex. Doc. 129, 80 pp.

Bituminous shale [Monterey shale] of San Pedro district mentioned (p. 69).

1855. Conrad, T. A., Report on the fossil shells collected in California by Wm. P. Blake, geologist of the expedition under the command of Lieutenant R. S. Williamson, United States Topographical Engineers: Idem, app., pp. 9–20. (Reprinted in U. S. Geol. Survey Prof. Paper 59, pp. 163–171, 1909.)

Twelve species of mollusks described from "Recent formation" at San Pedro [Palos Verdes sand].

1855. Blake, W. P., Remains of the mammoth and mastodon in California: Am. Jour. Sci., 2d ser., vol. 19, p. 133.

Mammoth tooth from San Pedro [evidently from Palos Verdes sand].

1855. Trask, J. B., [Description of fossil shells from the Tertiary deposits of Santa Barbara and San Pedro, California]: California Acad. Nat. Sci. Proc., vol. 1, pp. 41–43. (2d ed., pp. 40–42, 1873.)

Description of *Fusus robustus* and *Fusus rugosus* from strata at San Pedro [presumably San Pedro sand or Timms Point silt].

1856. Blake, W. P., Observations on the physical geography and geology of the coast of California from Bodega Bay to San Diego: U. S. Coast and Geodetic Survey Rept. Supt. 1855, app. 65, pp. 376–398.

Geology of San Pedro district described (pp. 393–395).

1856. Trask, J. B., Description of three new species of the genus *Plagiostoma* from the Cretaceous rocks of Los Angeles: California Acad. Nat. Sci. Proc., vol. 1, p. 86, 1 pl. (2d ed., pp. 93–94, pl. 3, 1873.)

Description of *Plagiostoma pedroana*, *P. annulatus*, and *P. truncata* from strata on east coast of Palos Verdes Hills considered Cretaceous [upper part of Altamira shale member or Valmonte diatomite member of Monterey shale].

1857. Blake, W. P., Geological report [Williamson's reconnaissance in California]: U. S. Pacific R. R. Expl., vol. 5, pt. 2, 370 pp., 11 pls., maps, sections.

Description of strata at and near landing in San Pedro (pp. 129–130), of post-Pliocene deposits [Palos Verdes sand] and fossils near mouth of Los Angeles River (p. 186), including illustration of mammoth molar, and of Miocene siliceous shale (pp. 178–179). Analysis of siliceous rock from San Pedro (p. 341).

1857. Conrad, T. A., Descriptions of the fossil shells: Idem, app., art. 2, pp. 317–329, pls. 2–9.

Same data as in preliminary report (1855) with addition of illustrations.

1857. Antisell, Thomas, Geological report [Parke's surveys in California and near thirty-second parallel]: Idem, vol. 7, pt. 2, 204 pp., 14 pls., 2 maps, 1856 (1857).

Two sections of terrace deposits at San Pedro (p. 118), one of which is shown graphically (pl. 5, fig. 4). Bituminous rock at San Pedro mentioned (p. 77).

1865. Gabb, W. M., Description of new species of marine shells from the coast of California: California Acad. Nat. Sci. Proc., vol. 3, pp. 182–190.

Description of three species from post-Pliocene at San Pedro [evidently Timms Point silt at Deadman Island].

1866. Gabb, W. M., Tertiary invertebrate fossils: California Geol. Survey, Paleontology, vol. 2, sec. 1, pt. 1, pp. 1–38, pls. 1–13.

Description of 6 species of mollusks from post-Pliocene at San Pedro, one of which (*Conchocele disjuncta*) is specifically recorded from Deadman Island [Timms Point silt].

1869. Gabb, W. M., Tertiary invertebrate fossils: Idem, sec. 1, pt. 2, pp. 39–63, pls. 14–18.

Pecten pedroanus, considered Cretaceous by Trask, is assigned to upper Miocene (p. 60), as in this report. Three additional species of mollusks are recorded from post-Pliocene at San Pedro.

1869. Gabb, W. M., Synopsis of the Tertiary invertebrate fossils of California: Idem, sec. 1, pt. 3, pp. 65–124.

Earliest comprehensive record of fossils from post-Pliocene [Pleistocene], of San Pedro—86 species of mollusks and one echinoid, many of which were not recorded earlier. *Conchocele disjuncta* is the only species that has definite locality record—Deadman Island [Timms Point silt].

1888. Cooper, J. G., Catalogue of California fossils: California Min., Bur., 7th Ann. Rept. State Mineralogist, pp. 223–308.

Includes records of Pleistocene fossils from San Pedro.

1892. Dall, W. H., and Harris, G. D., Correlation papers; Neocene: U. S. Geol. Survey Bull. 84, 349 pp., 3 pls., 43 figs.

Three formations are recognized on Deadman Island (p. 216), "the uppermost of which [presumably San Pedro sand] is certainly Pleistocene, while the others are Neocene, and the middle layer [Timms Point silt] probably Pliocene."

1893. Lawson, A. C., The post-Pliocene diastrophism of the coast of southern California: California Univ. Dept. Geol. Bull., vol. 1, pp. 115–160.

Marine Pleistocene terraces of Palos Verdes Hills are described (pp. 122–128). Fossiliferous strata assigned to lower Pleistocene in present report considered Pliocene.

1894. Cooper, J. G., Catalogue of California fossils, pt. 3, Additions to the catalogue of Californian fossils obtained since 1888: California Min. Bur. Bull. 4, pp. 23–33.

Includes records of Pleistocene fossils from San Pedro.

1895. Ashley, G. H., Studies in the Neocene of California: Jour. Geology, vol. 3, pp. 434–454, pls. 8–10.

"Pliocene" [Pleistocene] and Pleistocene strata of San Pedro district mentioned (pp. 451–452).

1895. Ashley, G. H., The Neocene stratigraphy of the Santa Cruz Mountains of California: California Acad. Sci. Proc., 2d ser., vol. 5, pp. 273–367, pls. 22–25. (Also issued as Leland Stanford Jr. Univ. Pubs., Geology and Paleontology, No. 1.)

Strata in San Pedro district assigned to Pliocene [Pleistocene] described, and 103 species of mollusks listed (pp. 339–346). The fauna is considered of northern aspect. [Nevertheless one of the localities included in the "Pliocene" is evidently Arnold's Crawfish George's locality, where the Palos Verdes sand is the only fossiliferous formation exposed.] Thirteen species of mollusks listed from Quaternary strata at San Pedro (pp. 355–356) [evidently Palos Verdes sand].

1896. Arnold, Delos, An interrogation regarding the fossil shells of San Pedro Bay: Nautilus, vol. 10, pp. 33–34.

It is pointed out that some of the mollusks of the San Pedro district, which are no longer living there or are scarce, are living or are more abundant farther north. [The list includes, however, "*Venus*" (*Chione*) *gnidia* and "*Hemicardium*" *biangulatum*, which are southern species.]

1897. Arnold, Delos, Fossils of Deadman's Island: Idem, pp. 140–142.

Fossiliferous strata described and some of the fossil mollusks mentioned. Arnold feared that the island would soon be destroyed by wave erosion. [It has been destroyed by steamshovel and dredge.]

1898. Dall, W. H., A table of the North American Tertiary horizons, correlated into one another and with those of western Europe, with annotations: U. S. Geol. Survey 18th Ann. Rept., pt. 2, pp. 323–348. (First published as H. Doc. 5, U. S. 55th Cong., 2d sess., 1897.)

The term "San Pedro beds" is proposed for Pleistocene strata of San Pedro district (p. 335). As proposed, includes probably both San Pedro sand and Palos Verdes sand of present terminology.

1900. Vaughan, T. W., A new fossil species of *Caryophyllia* from California and a new genus and species of turbinolid coral from Japan: U. S. Nat. Mus. Proc., vol. 22, pp. 199–203, pl. 16.

Caryophyllia arnoldi from the Pleistocene of "San Pedro Hill."

1901. Watts, W. L., Oil and gas yielding formations of California: California Min. Bur. Bull. 19, 236 pp., 26 figs., 35 photographs, 13 maps.

Geology of Palos Verdes Hills is described (pp. 53–56, fig. E (map), photographs 10–12).

1902. Arnold, Delos, and Arnold, Ralph, The marine Pliocene and Pleistocene stratigraphy of the coast of southern California: Jour. Geology, vol. 10, pp. 117–138, pls. 1–5, 6 figs.
Pleistocene strata of San Pedro district are described and terms "lower San Pedro series" and "upper San Pedro series" are proposed (pp. 119–129). [For remarks concerning stratigraphic nomenclature see following entry.]

1903. Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, 420 pp., 37 pls. (Reprint Leland Stanford Jr. Univ., Contr. Biol. Hopkins Seaside Lab., No. 31, 1903.)
Monographic treatise on stratigraphy and paleontology of Pleistocene strata exposed on San Pedro water front and Deadman Island. Includes descriptions of 4 species of corals, 3 echinoids, undetermined Bryozoa, 2 brachiopods, 395 mollusks, a barnacle, a crab, and a sting ray, many of which are figured. Arnold's Pliocene is Timms Point silt of this report, his lower San Pedro series is San Pedro sand, and his upper San Pedro series is Palos Verdes sand and nonmarine deposits on first terrace.

1904. Rivers, J. J., Descriptions of some undescribed fossil shells of Pleistocene and Pliocene formations of the Santa Monica Range: Southern Calif. Acad. Sci. Bull., vol. 3, pp. 69–72.
Description and only record of *"Chrysodomus" arnoldi* from Arnold's Crawfish George's locality.

1906. Arnold, Ralph, The Tertiary and Quaternary pectens of California: U. S. Geol. Survey Prof. Paper 47, 264 pp., 53 pls., 2 figs.
Lists of fossils from Pliocene of Deadman Island [Timms Point silt] and from the "San Pedro formation" [San Pedro sand and Palos Verdes sand] (pp. 30–37). Systematic part includes descriptions and illustrations of the pectens.

1906. Raymond, W. J., The west American species of *Pleurotoma*, subgenus *Genota:* Nautilus, vol. 20, pp. 37–39, pl. 2.
Includes records of Pleistocene forms from San Pedro district.

1907. Bartsch, Paul, The west American mollusks of the genus *Triphoris:* U. S. Nat. Mus. Proc., vol. 33, pp. 249–262, pl. 16.
Includes Pleistocene species from San Pedro district.

1909. Dall, W. H., and Bartsch, Paul, A monograph of west American Pyramidellid mollusks: U. S. Nat. Mus. Bull. 68, 258 pp., 30 pls.
Includes Pleistocene species from San Pedro district.

1911. Bartsch, Paul, The Recent and fossil mollusks of the genus *Alabina* from the west coast of America: U. S. Nat. Mus. Proc., vol. 39, pp. 408–418, pls. 61–62.
Includes Pleistocene species from San Pedro district.

1911. Bartsch, Paul, The Recent and fossil mollusks of the genus *Cerithiopsis* from the west coast of America: Idem, vol. 40, pp. 327–367, pls. 36–41.
Includes Pleistocene species from San Pedro district.

1911. Bartsch, Paul, The Recent and fossil mollusks of the genus *Bittium* from the west coast of America: Idem, pp. 383–414, pls. 51–58.
Includes Pleistocene species from San Pedro district.

1911. Bartsch, Paul, The Recent and fossil mollusks of the genus *Alvania* from the west coast of America: Idem, vol. 41, pp. 333–362, pls. 29–32.
Includes Pleistocene species from San Pedro district.

1912. Bagg, R. M., Jr., Pliocene and Pleistocene Foraminifera from southern California: U. S. Geol. Survey Bull. 513, 153 pp., 28 pls., 3 figs.
Description of 105 species and varieties of Foraminifera from "Pliocene" at Timms Point [Timms Point silt], 39 of which are figured from San Pedro material. Discussion of paleoecology.

1912. Miller, L. H., Contribution to avian paleontology from the Pacific Coast of North America: California Univ. Dept. Geol. Bull., vol. 7, pp. 61–115, 1912.
Three species of birds listed from Arnold's upper San Pedro (p. 115).

1913. Rivers, J. J., A new species of *Bathytoma* from the upper Pleistocene of San Pedro, Calif.: Southern California Acad. Sci. Bull., vol. 12, p. 29, unnumbered pl.
"Bathytoma" clarkiana, based on worn imperfect specimen, evidently a form of *Megasurcula carpenteriana.*

1913. Prutzman, P. W., Petroleum in southern California: California Min. Bur. Bull. 63, 430 pp., unnumbered illustrations, maps.
Wells drilled for oil in and near Palos Verdes Hills described (pp. 327–329), and locations shown on small-scale map of southern California (in pocket).

1914. Martin, Bruce, Descriptions of new species of fossil Mollusca from the later marine Neocene of California: California Univ. Dept. Geol. Bull., vol. 8, pp. 181–282, pls. 19–22.
Description and only record of *Tritonofusus riversi* from Timms Point (p. 190).

1914. Rivers, J. J., A new form of *Bathytoma* from the upper Pleistocene of San Pedro, Calif.: Nautilus, vol. 28, pp. 64–65, pl. 3, figs. B, C.
Same data as in Rivers, 1913.

1914. Miller, L. H., Bird remains from the Pleistocene of San Pedro, Calif.: California Univ. Dept. Geol. Bull., vol. 8, pp. 31–38.
Sixteen species of birds from Arnold's upper San Pedro at his lumber yard locality [locality 113 of present report.]

1914. McLaughlin, R. P., and Waring, C. A., Petroleum industry of California: California Min. Bur. Bull. 69, 519 pp., 78 figs., 13 unnumbered illustrations, map folio of 18 pls.
Oil possibilities in Palos Verdes Hills briefly discussed (pp. 366–367). Map folio plate 1 includes 5 species of Pleistocene mollusks from San Pedro; plate 2 includes a small-scale geologic map of Palos Verdes Hills.

1917. Bartsch, Paul, A monograph of west American melanellid mollusks: U. S. Nat. Mus. Proc., vol. 53, pp. 295–356, pls. 34–49.
Includes Pleistocene species from San Pedro district.

1919. Chace, E. P. and E. M., An unreported exposure of the San Pedro Pleistocene: Lorquinia, vol. 2, No. 6, pp. 41–43.
List of mollusks from marine deposits on second terrace near Point Fermin [locality 94 of present report], where chitons were exceptionally abundant; discussion of paleoecology and age.

1919. Smith, J. P., Climatic relations of the Tertiary and Quaternary faunas of the California region: California Acad. Sci. Proc., 4th ser., vol. 9, pp. 123–173, pl. 9.
Includes discussion of cool-water aspect of Arnold's Pliocene (pp. 150–151) and lower San Pedro (pp. 136–137) faunas, and of warm-water aspect of Arnold's upper San Pedro fauna (pp. 137–138).

1919. Nelson, J. W., and others, Soil survey of the Los Angeles area, Calif.: U. S. Bur. Soils Field Operations Advance Sheets, 78 pp., 3 pls., map. (18th Rept., 1916, pp. 2347–2420, 3 pls., map, 1921.)
Includes Palos Verdes Hills.

1920. Kew, W. S. W., Cretaceous and Cenozoic Echinoidea of the Pacific coast of North America: California Univ. Dept. Geol. Bull., vol. 12, pp. 23–236, pls. 3–42, 5 figs.
Includes Pleistocene species from San Pedro district.

1921. Oldroyd, T. S., New Pleistocene mollusks from California: Nautilus, vol. 34, pp. 114–116, pl. 5.
Three forms of mollusks from Arnold's lower San Pedro, one of which (*Vermetus nodosus*) is not considered in Oldroyd's 1924 account.

1921. Vander Leck, Lawrence, Petroleum resources of California, with special reference to unproved areas: California Min. Bur. Bull. 89, 186 pp., 6 pls., 12 figs., 6 unnumbered photographs.
Oil possibilities in Palos Verdes Hills discussed (p. 141).

1922. Berry, S. S., Fossil chitons of western North America: California Acad. Sci. Proc., 4th ser., vol. 11, pp. 399–526, pls. 1–16, figs. 1–11.
Includes Pleistocene species from San Pedro district, the largest number (350 specimens of 15 species and varieties) being from the Chaces' chiton bed locality on the second terrace near Point Fermin.

1922. Jordan, D. S., Some sharks' teeth from the California Pliocene: Am. Jour. Sci., 5th ser., vol. 3, pp. 338–342, 3 figs.
Description of shark's teeth, assigned to 4 species, from Pleistocene of Palos Verdes Hills [presumably Lomita marl].

1922. Kellogg, Remington, Pinnipeds from Miocene and Pleistocene deposits of California: California Univ. Dept. Geol. Sci. Bull., vol. 13, pp. 23–132, 6 figs.
Undetermined seal (*Phoca* sp. B, p. 120) recorded from Arnold's upper San Pedro.

1923. Jordan, D. S., and Hannibal, Harold, Fossil sharks and rays of the Pacific slope of North America: Southern California Acad. Sci. Bull., vol. 22, pp. 27–63, 65–68, 11 pls., 4 figs.
Shark teeth, assigned to 7 species, from Lomita quarry [Lomita marl], a ray from Oldroyd's Nob Hill locality [San Pedro sand], and a ray from Arnold's upper San Pedro [Palos Verdes sand]. Marine and land vertebrates from Lomita quarry.

1923. Hanna, G. D., Results of preliminary examination of seven samples of sediments from near Lomita: Idem, p. 64.
Paleoecology and age of fossils from Lomita quarry.

1923. Canu, Ferdinand, and Bassler, R. S., North American later Tertiary and Quaternary Bryozoa: U. S. Nat. Mus. Bull. 125, 302 pp., 47 pls., 38 figs.
Includes species from Pleistocene of Deadman Island [evidently Timms Point silt].

1924. Oldroyd, T. S., The fossils of the lower San Pedro fauna of the Nob Hill cut, San Pedro, Calif.: U. S. Nat. Mus. Proc., vol. 65, art. 22, 39 pp., 2 pls.
Stratigraphy, paleontology, and paleoecology of a locality in San Pedro now destroyed. Records 242 species and varieties of mollusks, 22 of which are described as new.

1924. Oldroyd, I. S., Description of a new fossil species of a clam of the genus *Crassatellites:* Southern Calif. Acad. Sci. Bull., vol. 23, p. 10, 1 fig.
"*Crassatellites*" *lomitensis* from Pleistocene beds near Lomita [Lomita marl].

1924. Woodford, A. O., The Catalina metamorphic facies of the Franciscan series: California Univ. Dept. Geol. Sci. Bull. vol. 15, pp. 49–68, pls. 5–7, 2 figs.
Includes description of schist basement in Palos Verdes Hills and its rock types.

1925. Cushman, J. A., and Hughes, D. D., Some later Tertiary Cassidulinas of California: Cushman Lab. Foraminiferal Research Contr., vol. 1, pp. 11–16, pl. 2.
Includes description of species from Timms Point and Lomita quarry.

1925. Stock, Chester, Cenozoic gravigrade edentates of western North America, with special reference to the Pleistocene Megalonychinae and Mylodontidae of Rancho La Brea: Carnegie Inst. Washington Pub. 331, 206 pp., 47 pls., 120 figs.
List of land mammals from Arnold's upper San Pedro and brief discussion of relations to Rancho La Brea fauna (pp. 118–119).

1925. Woodford, A. O., The San Onofre breccia, its nature and origin: California Univ. Dept. Geol. Sci. Bull., vol. 15, pp. 159–280, pls. 23–35, 11 figs.
Description of blue-schist sandstone and breccia in Miocene strata at Point Fermin and record of fossils (pp. 210–211).

1926. Kew, W. S. W., Geologic and physiographic features in the San Pedro Hills, Los Angeles County, Calif.: Oil Bull., vol. 12, No. 5, pp. 513–518, 590, 3 figs.
General account of geology and physiography.

1926. Rathbun, M. J., The fossil stalk-eyed Crustacea of the Pacific slope of North America: U. S. Nat. Mus. Bull 138, 155 pp., 39 pls.
Descriptions of 25 species from Pleistocene at San Pedro, 6 of which are new. Those from Oldroyd's Nob Hill lower San Pedro locality represent San Pedro sand. Horizon of others not designated.

1927. Cushman, J. A., and Grant, U. S., IV. Late Tertiary and Quaternary Elphidiums of the west coast of North America: San Diego Soc. Nat. History Trans., vol. 5, No. 6, pp. 69–82, pls. 7, 8.
Includes record of *Elphidium crispum?* from "Pliocene" [Pleistocene] of San Pedro district.

1927. Galloway, J. J., and Wissler, S. G., Pleistocene Foraminifera from the Lomita Quarry, Palos Verdes Hills, Calif.: Jour. Paleontology, vol. 1, pp. 35–87, pls. 7–12.
Description of 79 species and varieties of Foraminifera from calcareous strata [Lomita marl] at Lomita quarry.

1927. Galloway, J. J., and Wissler, S. G., Correction of names of Foraminifera: Idem, p. 193.
New names for homonyms proposed in preceding account.

1927. Hay, O. P., The Pleistocene of the western region of North America and its vertebrated animals: Carnegie Inst. Washington Pub. 322B, 346 pp., 21 maps, 12 pls.
Arnold's lower San Pedro is assigned to Nebraskan glacial stage and his upper San Pedro to Aftonian interglacial stage (pp. 166–174).

1927. Kellogg, Remington, Fossil pinnipeds from California: Idem, Pub. 346, pp. 25–37, 8 figs.
Description of sea lion radius (*Zalophus* sp.?) from Arnold's upper San Pedro at his lumber yard locality (pp. 33–35) [locality 113 of present report].

1928. Hanna, G. D., The age of the diatom-bearing shales at Malaga Cove, Los Angeles County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 12, pp. 1109–1111.
The diatoms are considered upper Miocene and are thought to furnish conclusive evidence that the material accumulated in shallow water. [It is not known whether the diatoms are from Valmonte diatomite member or Malaga mudstone member of the Monterey shale. A shallow-water depositional environment for either is doubtful.]

1928. Reed, R. D., A siliceous shale formation from southern California: Jour. Geology, vol. 36, pp. 342–361, 4 figs.
Petrology and organic constituents of nonforaminiferal siliceous shale [Valmonte diatomite member and Malaga mudstone member of Monterey shale] and foraminiferal rock [Repetto siltstone] at Malaga Cove.

1929. Crickmay, C. H., On a new pelecypod, *Calyptogena gibbera:* Canadian Field Naturalist, vol. 43, p. 93, 1 fig.
This species is from the lower part of the strata of Deadman Island now assigned to Timms Point silt.

1929. Crickmay, C. H., The anomalous stratigraphy of Deadman's Island, Calif.: Jour. Geology, vol. 37, pp. 617–638.
Stratigraphy and paleontology of Pleistocene formations of Deadman Island, with special reference to temperature facies of different zones.

1929. Nicholson, G. F., Variations in levels, 1929 to 1927, in Los Angeles harbor: Seismol. Soc. America Bull., vol. 19, pp. 200–205, 3 figs.
Relative uplift of as much as 0.2 foot, attributed to movement along inferred fault.

1930. Miller, Loye, Further bird remains from the upper San Pedro Pleistocene: Condor, vol. 32, pp. 116–118, fig. 45.
Ten species from Arnold's upper San Pedro at his lumber yard locality, including the extinct diving goose *Chendytes lawi.*

1931. Clark, Alex, The cool-water Timms Point Pleistocene horizon at San Pedro, Calif.: San Diego Soc. Nat. History Trans., vol. 7, No. 4, pp. 25–42, 2 figs.
Stratigraphy and paleontology of strata at Timms Point, for which term "Timms Point" is proposed. List of 137 species of mollusks, 2 brachiopods, 13 Bryozoa, an undetermined barnacle, an undetermined crab, and a fish tooth.

1931. Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, 1,036 pp., 32 pls., 15 figs.
Part I (by Gale) includes discussion of stratigraphy and temperature facies of marine Pleistocene formations in San Pedro region and assignment of them to glacial and interglacial stages (pp. 40–45, 60–76). Part II assembles records of marine mollusks from those formations and includes illustrations of some species based on material from that region.

1931. Miller, J. M., The landslide at Point Firmin, Calif.: Sci. Monthly, vol. 32, pp. 464–469, 5 figs.
Attributed to seaward sliding along slippery shale on flank of anticline.

1931. Reed, R. D., Petrology of the calcareous beds of San Pedro Hills, Calif. (abstract): Geol. Soc. America Bull., vol. 42, pp. 310–311, 1931.
Petrology of calcareous strata assigned in present report to Lomita marl.

1932. Hadding, Assar, The pre-Quaternary sedimentary rocks of Sweden; IV, Glauconite and glauconitic rocks: Lunds Geol.-Mineralog. Inst. Meddel., No. 51, 174 pp., 73 figs.
Analysis of glauconite from Pleistocene strata at San Pedro (p. 124) [presumably from Lomita marl].

1932. Woodring, W. P., San Pedro Hills: 16th Internat. Geol. Cong. Guidebook 15, pp. 34–40, figs. 4–6.
Geologic features of an excursion in Palos Verdes Hills. Designations for Miocene units superseded in later accounts.

1932. Hoots, H. W., Excursion in Los Angeles Basin and Santa Monica Mountains: Idem, pp. 43–48, pl. 9.
Geologic features of an excursion including Palos Verdes Hills (p. 45).

1933. Davis, W. M., Glacial epochs of the Santa Monica Mountains, Calif.: Geol. Soc. America Bull., vol. 44, pp. 1041–1133, pls. 40–56, 26 figs.

Marine terraces of Palos Verdes Hills mentioned (p. 1105).

1933. Livingston, Alfred, Jr., and Putnam, W. C., Geological journeys in southern California: Los Angeles Junior Coll. Pub. 1, 104 pp., 56 unnumbered illustrations.

Includes an enthusiastic account of geologic features in Palos Verdes Hills (pp. 17–21).

1933. Reed, R. D., Geology of California, 355 pp., 60 figs., Tulsa, Am. Assoc. Petroleum Geologists.

Petrology and other features of Miocene (pp. 195–196), Pliocene (pp. 238–239), and Pleistocene (pp. 258–261) formations of Palos Verdes Hills.

1934. Eckis, Rollin, South Coastal Basin investigation; Geology and ground water storage capacity of valley fill: California Dept. Public Works, Water Resources Div. Bull. 45, 279 p., 24 pls., 6 maps.

Contains much information that has direct or indirect bearing on geologic history of Palos Verdes Hills, especially in discussion of Pleistocene formations and history (pp. 48–62). Geologic map (scale 1:142,560) is largest scale geologic map now available of Los Angeles Basin and borders, including Palos Verdes Hills.

1934. Howe, M. A., Eocene marine algae (Lithothamnieae) from the Sierra Blanca limestone: Geol. Soc. America Bull., vol. 45, pp. 507–518, pls. 52–56.

Mesophyllum(?) recorded from Lomita quarry (pp. 515, 517).

1934. Leypoldt, Harry, Earth movements in California determined from apparent variation in tidal datum planes: Seismol. Soc. America Bull., vol. 24, pp. 63–68, 3 figs.

Records of tide gages in outer and inner harbors at San Pedro indicate relative subsidence in inner harbor from 1922 to 1928, relative uplift from 1928 to 1930, and relative subsidence beginning in 1930.

1935. Miller, Loye, New bird horizons in California: California Univ. at Los Angeles, Pub. Biol. Sci., vol. 1, No. 5, pp. 73–80, 2 figs.

Description of three sea birds from Miocene strata in Palos Verdes Hills [Valmonte diatomite member of Monterey shale] and record of a small cetacean.

1935. Smith, Hampton, Origin of some siliceous Miocene rocks of California (abstract): Geol. Soc. America Proc., 1934, p. 334.

Siliceous cement of cherty shales in Palos Verdes Hills thought to have been derived principally from decomposition of bentonitic clay and perhaps of volcanic ash.

1935. Woodring, W. P., Fossils from the marine Pleistocene terraces of the San Pedro Hills, Calif.: Am. Jour., Sci., 5th ser., vol. 29, pp. 292–305, 1 fig.

Preliminary account of marine terraces and fossils.

1936. Raup, H. F., Land-use and water-supply problems in southern California; market gardens of the Palos Verdes Hills: Geog. Rev., vol. 26, pp. 264–269, 4 figs.

Factors controlling raising of vegetable crops without irrigation.

1936. Reed, R. D., and Hollister, J. S., Structural evolution of southern California, 157 pp., 9 pls., 57 figs., Tulsa, Am. Assoc. Petroleum Geologists. (Also issued in Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 1529–1704.)

Palos Verdes Hills included in discussion of geology and structural history of Los Angeles Basin (pp. 112–135).

1936. Schenck, H. G., Nuculid bivalves of the genus *Acila:* Geol. Soc. Am. Spec. Paper 4, 149 pp., 18 pls., 15 figs.

Includes records and illustrations of *Acila castrensis* from Pleistocene strata in San Pedro district.

1936. Woodring, W. P., Bramlette, M. N., and Kleimpell, R. M., Miocene stratigraphy and paleontology of Palos Verdes Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 125–149, 3 figs.

Preliminary account of stratigraphy and paleontology of Monterey shale in Palos Verdes Hills.

1937. Howell, B. F., and Mason, J. F., Reef-forming serpulid from the Pleistocene of San Pedro, Calif.: Wagner Free Inst. Sci. Bull., vol. 12, No. 1, pp. 1–2, 2 figs.

Description of "*Serpula*" *saxistructoris*, from the San Pedro sand of Deadman Island. Packard (Jour. Paleontology, vol. 16, p. 778, 1942) suggested that this is the Recent cirratulid *Dodecaceria fistulicola* and implied that the reported occurrence as a fossil needs confirmation.

1937. Reinhart, P. W., Three new species of the pelecypod family Arcidae from the Pliocene of California: Jour. Paleontology vol. 11, pp. 181–185, pl. 28.

Arca sisquocensis recorded from Hilltop quarry [Lomita marl].

1937. Thompson, W. O., Original structures of beaches, bars, and dunes: Geol. Soc. America Bull., vol. 48, pp. 723–752, 8 pls., 6 figs.

Cross-laminated sand in San Pedro sand at San Pedro interpreted as lower foreshore deposits superimposed on upper foreshore deposits (pp. 742–744).

1937. Walker, E. F., Sequence of prehistoric material culture at Malaga Cove, Calif.: Masterkey, vol. 11, No. 6, pp. 210–214, 2 figs.

Stratigraphy and typology of four human culture levels, the lowest in uppermost 3 feet of alluvium [nonmarine cover on lowest terrace] and the others in overlying dune sand.

1937. Willett, George, Additions to knowledge of the fossil invertebrate fauna of California: Southern California Acad. Sci. Bull., vol. 36, pp. 61–64, pls. 24–25.

Comments on 19 species of mollusks, 2 of which are new, from lower part of strata exposed at Timms Point heretofore not recorded from that locality.

1938. Natland, M. L., New species of Foraminifera from off the west coast of North America and from the later Tertiary of the Los Angeles Basin: California Univ. Scripps Inst. Oceanography Bull., tech. ser., vol. 4, No. 5, pp. 137–164, pls. 3–7.

Two species (*Virgulina seminuda* and *Cibicides spiralis*) recorded from Repetto siltstone at Lomita quarry.

1938. Grant, U. S., IV, and Hertlein, L. G., The West American Cenozoic Echinoidea: Calif. Univ. at Los Angeles Pub. Math. Physical Sci., vol. 2, 225 pp., 30 pls., 17 figs.

Includes Pleistocene species from San Pedro district.

1938. Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, California, and their inferred environment: U. S. Geol. Survey Prof. Paper 190, 67 pp., 9 pls., 2 figs.

Brief description of Repetto formation in Palos Verdes Hills (pp. 4–5) and records of *Lima hamlini* from that area (pp. 47–49).

1938. Kleinpell, R. M., Miocene stratigraphy of California, 450 pp., 22 pls., 14 figs., Tulsa, Am. Assoc. Petroleum Geologists.

Includes correlation of Miocene strata in Palos Verdes Hills (see fig. 14), records of Foraminifera from those deposits, and illustrations of 23 species based on material from that area, 13 of which are new.

1938. Lyon, G. M., *Megalonyx milleri*, a new Pleistocene ground sloth from southern California: San Diego Soc. Nat. History Trans., vol. 9, No. 6, pp. 15–30, pl. 1, figs. 1–7.

Description of ground sloth remains, including skull, from nonmarine cover of lowest terrace at Second and Beacon Streets, San Pedro.

1939. Macdonald, G. A., An intrusive peperite at San Pedro Hill, Calif.: California Univ. Dept. Geol. Sci. Bull., vol. 24, pp. 329–338, 6 figs.

Structural relations and petrography of basalt near Point Vicente. Intruded on sea floor under thin cover of contemporaneous sediments.

1939. Willett, G., A new species of mollusk from the San Pedro Pleistocene: Southern California Acad. Sci. Bull., vol. 38, pp. 202–203, pl. 54.

Description of *Alabina effiae* from strata assigned in present report to Lomita marl.

1940. Berry, S. S., New Mollusca from the Pleistocene of San Pedro, Calif.; I: Bull. Am. Paleontology, vol. 25, No. 94a, 18 pp., 2 pls.

Description of 6 species from lower Pleistocene strata and one from upper Pleistocene strata.

1941. Berry, S. S., New Mollusca from the Pleistocene of San Pedro, Calif.; II: Idem, vol. 27, No. 101, 18 pp., 1 pl.

Description of 7 species and 1 subspecies from Hilltop quarry [Lomita marl].

1941. Lyon, G. M., A Miocene sea lion from Lomita, Calif.: California Univ., Pub. Zoology, vol. 47, pp. 23–42, pls. 2–6, 2 figs.
Description of sea lion remains, assigned to *Pontolis magnus*, from diatomite [Valmonte diatomite member of Monterey shale] at quarry of Dicalite Co.

1941. Wissler, S. G., Stratigraphic formations [relations] of the producing zones of the Los Angeles Basin oil fields: California Div. Mines Bull. 118, pt. 2, pp. 209–234, pl. 5, figs. 88–94, 1 table.
Includes discussion of Repetto siltstone at Malaga Cove (pp. 217–218) and of correlation of Miocene strata of Palos Verdes Hills with subsurface Miocene section of Los Angeles Basin (p. 222).

1942. Miller, Loye, and DeMay, Ida, The fossil birds of California: California Univ., Pub. Zoology, vol. 47, No. 4, pp. 47–142.
Includes records and discussion of Miocene and Pleistocene birds from Palos Verdes Hills.

1943. David, L. R., Miocene fishes of southern California: Geol. Soc. America Spec. Paper 43, 193 pp., 16 pls., 39 figs.
Includes description and discussion of 5 species of fish from the Altamira member of the Monterey shale at a locality near Whites Point (pp. 81–88).

1943. LeRoy, L. W., Pleistocene and Pliocene Ostracoda of the costal region of southern California: Jour. Paleontology, vol. 17, pp. 354–373, pls. 58–62.
Includes descriptions of species from Lomita marl, Timms Point silt, and San Pedro sand.

1943. Reinhart, P. W., Mesozoic and Cenozoic Arcidae from the Pacific slope of North America: Geol. Soc. Am. Spec. Paper 47, 117 pp., 15 pls., 3 figs.
Includes records of Pleistocene species from San Pedro district.

1944. Willett, George, Northwest American species of *Glycimeris:* Southern California Acad. Sci. Bull., vol. 42, pt. 3, pp. 107–114, pls. 11, 12, 1943 (1944).
Specimens of *Glycymeris profunda* from Hilltop quarry are described and figured.

1944. Campbell, A. S., and Clark, B. L., Miocene radiolarian faunas from southern California: Geol. Soc. Am., Special Paper 51, 76 pp., 7 pls.
Most of the Radiolaria described are from the Valmonte diatomite and Malaga mudstone of the Palos Verdes Hills.

GEOGRAPHY

GEOGRAPHIC RELATIONS

The Palos Verdes Hills constitute an isolated upland peninsula projecting into the ocean at the southwest border of the Los Angeles Basin, which is a gently sloping lowland extending seaward from Los Angeles. (See pl. 2.) In general features this peninsula resembles the islands off the coast of southern California; indeed during parts of Pleistocene time it was an island. Northwest of the Palos Verdes Hills a belt of irregular dune-sand topography extends inland from the coast and overlaps the lowland and the northwestern border of the hills.

Industrial, agricultural, and residential districts are located throughout the Los Angeles Basin. The oil industry holds an important position. Los Angeles Basin fields have produced almost half of California's oil.[14] In 1936–37 two new fields were discovered in the southern part of the basin, El Segundo and Wilmington. As shown in figure 1, the Wilmington field is in the harbor district close to the northeastern border of the Palos Verdes Hills. The Torrance field occupies a large area on an ill-defined ridge extending eastward from the belt of dune sand near the coast. The El Segundo field is located farther north at the eastern edge of the dune-sand area. The Playa Del Rey field is at the seaward end of the wide, flat valley now occupied by Ballona Creek and extends southeastward into the area of dune sand. In stratigraphic succession and in general geologic history these 4 fields resemble the Palos Verdes Hills more closely than other fields in the Los Angeles Basin. They are also the most recently discovered fields in the basin, with the exception of the Torrance, a relatively old field, where, however, new activity has resulted from development of the other 3 fields.

SURFACE FEATURES

The Palos Verdes Hills represent a miniature Coast Range mountainous area of low altitude. They have a maximum northwest-southeast length of about 9½ miles and a width of 4 to 5 miles. San Pedro Hill, the highest hill, has an altitude of 1,480 feet above sea level.

The crest and the greater part of the upper slopes of the hills form a rolling upland, characterized by smoothly rounded hills and wide, gently sloping valleys. The lower slopes are marked by a series of coastal terraces. Deep canyons advancing inland across the terraces are destroying the rolling upland.

The west and south coasts are bordered by a sea cliff that has in general a height of 100 to 150 feet. At Long Point, on the south coast, the height of the cliff is exceptionally low, 50 feet, whereas at Bluff Cove and Malaga Cove, on the west coast, it is exceptionally high, 300 and 200 feet, respectively. The sea cliff along the east coast in the city of San Pedro has a height of about 50 feet.

LAND USE

Areas in the Palos Verdes Hills, like those in the Los Angeles Basin, are used for agricultural, residential, and industrial purposes.

San Pedro has grown rapidly since the construction of a deep-water harbor in 1910–14. Shipyards, docks, warehouses, and establishments for handling fish are located along the water front and nearby. Sand and gravel pits and plants for treating the products from them are located along the north border of the hills. A diatomite quarry and plant are located in the same region, near the mouth of Agua Negra Canyon. These plants are the only industrial establishments at a considerable distance from the water front, and they also represent the only industries utilizing the mineral resources of the hills.

The residential district of San Pedro has spread from the flat coastal terrace along the water front westward to the lower slopes of the hills. The Palos Verdes land grant, comprising essentially the western two-thirds of the hills, is being held for residential and estate development. Most of the development so far is in the Malaga Cove, Valmonte, Margate, and Miraleste districts, which are under the control of the Palos Verdes Estates, and in the Rolling Hills district.

Most of the arable land outside the residential and estate districts, both within and outside the Palos Verdes grant, is now used for agricultural purposes. Agriculture as practiced in this region depends on a balance between factors involving topography, soil, and climate, which have been discussed recently by Raup.[15] San Pedro has a mean annual precipitation of 10½ inches, and Los Angeles, 20 miles inland, has 15 inches.[16]

[14] For a brief account of oil development in the Los Angeles Basin see Hoots, H. W. Oil development in the Los Angeles Basin: 16th Internat. Geol. Congress Guidebook 15, pp. 26–30, pls. 6–8, 1932.

[15] Raup, H. F., Land-use and water-supply problems in southern California; market gardens of the Palos Verdes Hills: Geog. Rev., vol. 26, pp. 264–269, 4 figs., 1936.

[16] Los Angeles (length of record 53 years) and San Pedro (length of record 20 years for precipitation and 11 years for temperature) data from Climatic Summary of the United States, section 18: U. S. Weather Bur., pp. 2–3, 23, 28, 1932. Point Vicente data (length of record 11 years) from Raup, H. F., op. cit., p. 266.

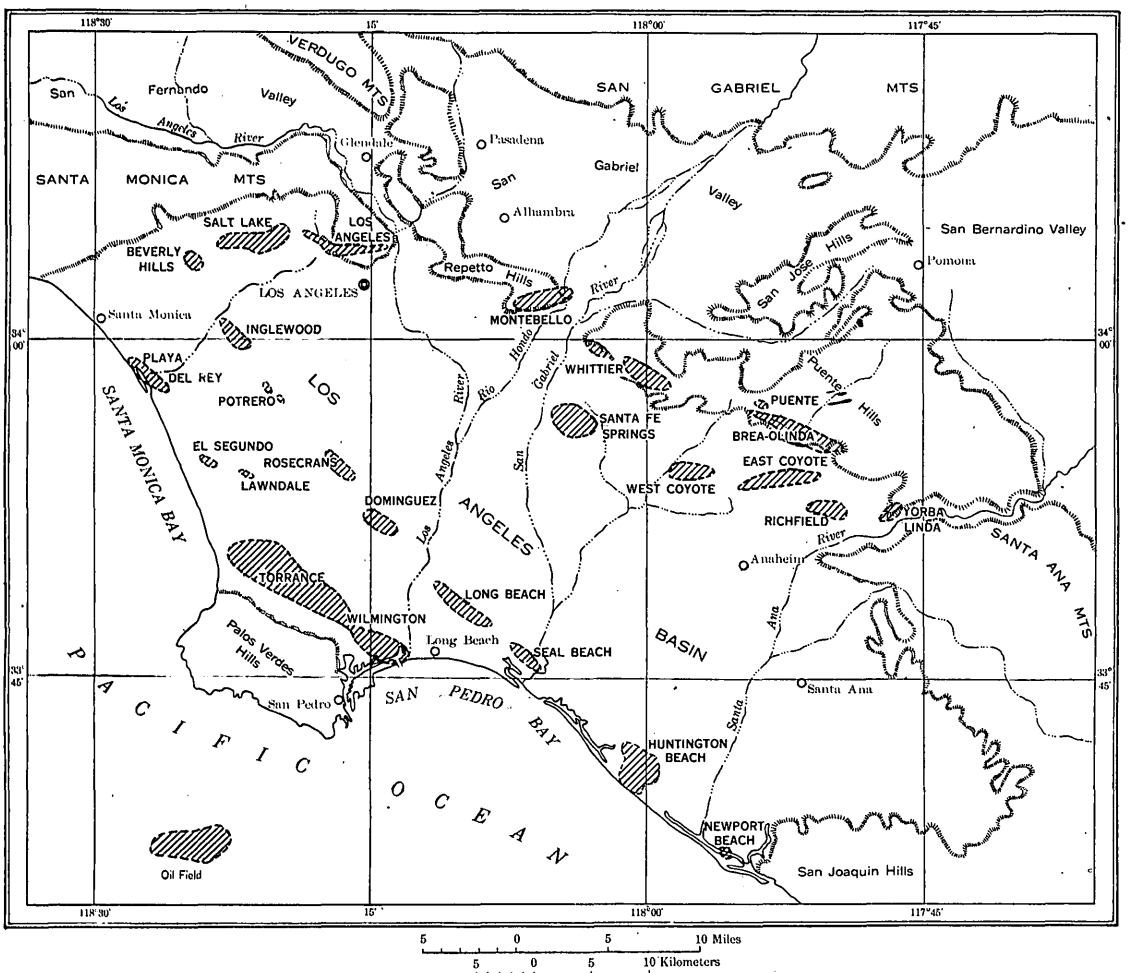

FIGURE 1.—Sketch map of Los Angeles Basin and borders showing location of Palos Verdes Hills with reference to other geographic features. Adapted from Hoots and Kew (16th Internat. Geol. Cong. Guidebook 15, pl. 6, 1932).

Crops are grown in the Palos Verdes Hills without irrigation, but farther inland the same crops need irrigation for successful maturing, despite the greater rainfall. The maturing of crops without irrigation in the Palos Verdes Hills is controlled by higher relative humidity and more equable temperatures, owing to proximity of the ocean. Point Vicente on the south coast of the hills has a mean relative humidity of 71 percent; at Los Angeles the noon mean relative humidity is 51 percent.[17] August, the warmest summer month, has a mean temperature of 66.5° F. at Point Vicente, 67° at San Pedro, and 71° at Los Angeles. The high fogs that are prevalent in the morning along the coast during the spring and early summer are an important factor, as they reduce evaporation during the growing season of most of the crops. The soils under cultivation in the Palos Verdes Hills consist principally of clay loam and clay adobe,[18] which retain moisture. The soil is plowed under proper moisture conditions soon after the first winter rains. In the vegetable-growing districts it is frequently cultivated to reduce evaporation.

The soils of the lower part of the Monterey shale are generally brownish and contain numerous stones, composed of hard cherty shale, and larger pieces of limestone. In cultivated areas the largest pieces of limestone are usually gathered and dumped on steep slopes between terrace treads or into ravines. (See pl. 24, *D*.) The soils of the upper part of the Monterey shale are darker, dark gray to black, and generally contain few stones. The residual basalt soils and the nonresidual terrace-cover soils are reddish brown, but the terrace-cover soil is more sandy than the basalt soil.

The lower part of the southwest, south, and southeast slopes and small areas along the lower course of George F Canyon and on the north slope, east of the Palos Verdes golf course, are leased to tenants living on small tracts. Fresh vegetables, principally tomatoes and squash, but also beans, peas, cucumbers, and corn are grown in these districts. The lower terrace treads are most accessible and most readily tilled. Some rises that are not too steep and a few terrace treads and flats high on the south slope are under cultivation. The rolling upland along the crest and upper slopes and most of the north slope are leased to tenants living on large ranches. Lima beans, which are dried for the market, are grown on areas of gentle declivity along the western part of the crest and on adjoining parts of the north and south slopes, mostly on the dark soils of the upper part of the Monterey shale. Barley, generally used for hay, is grown on part of the rolling upland and on gentler declivities of the north slope, and wild oats are cut for hay on some of the steeper slopes.

Part of the northeast slope near San Pedro is used for dairy pasturing. Sheep are grazed during part of the

[17] The time of day is not specified for the Point Vicente records, but is presumably noon. At Los Angeles the mean relative humidity is 77 percent at 8 a. m., 51 percent at noon, and 61 percent at 8 p. m.

[18] Nelson, J. W., and others, Soil survey of the Los Angeles area, Calif.: U. S. Bur. Soils Field Operations Advance Sheets, 78 pp., 3 pls., map, 1919 (18th Ann. Rept., pp. 2347–2420, 3 pls., map, 1921).

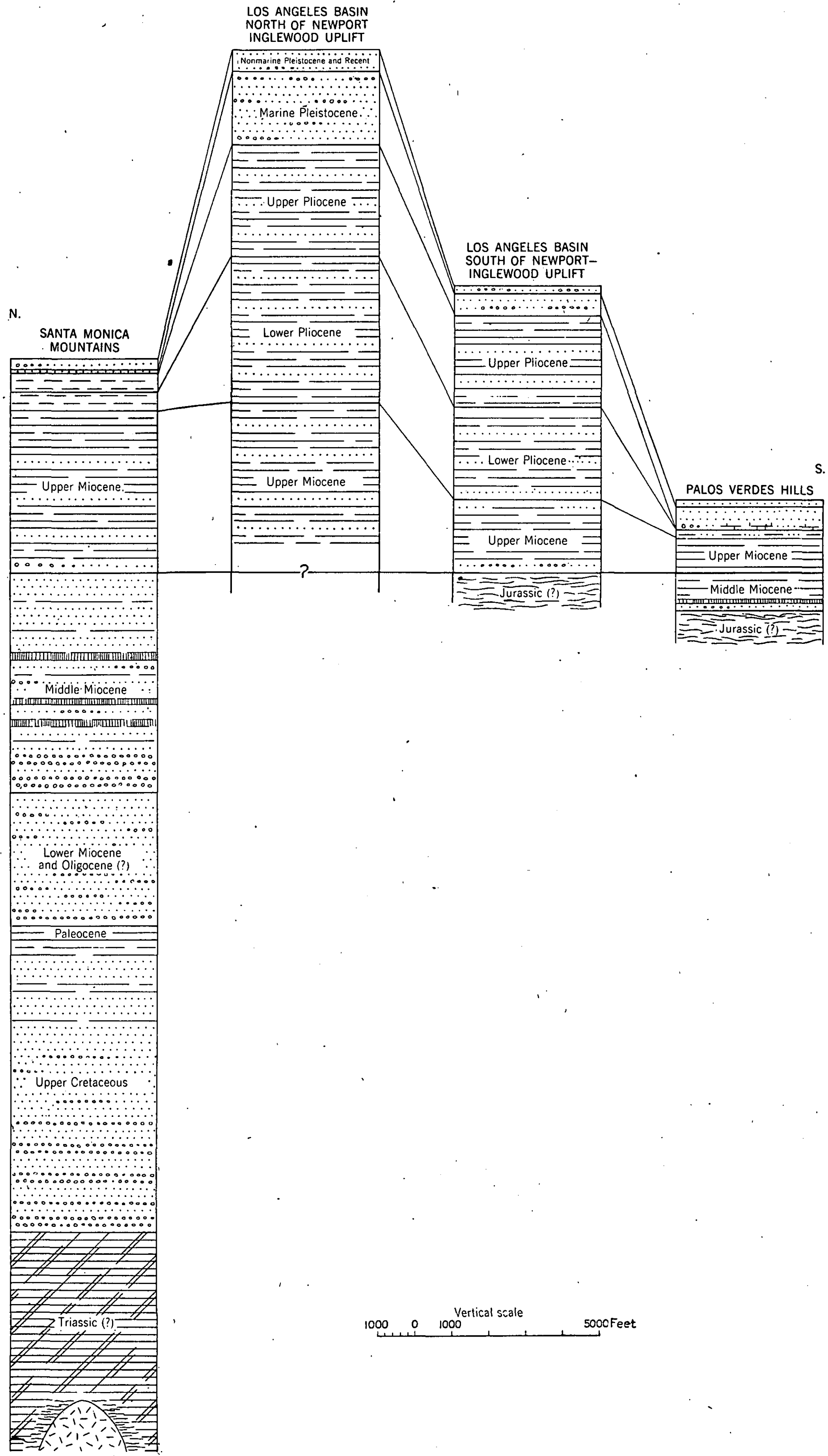

FIGURE 2.—Generalized stratigraphic sections in western part of Los Angeles Basin and its borders. Santa Monica Mountains section after Hoots (U. S. Geol. Survey Prof. Paper 165-C); Los Angeles Basin sections compiled from various sources.

year on the north slope, and small areas along or near the crest are used for ranch pasturing.

STRATIGRAPHY AND PALEONTOLOGY

OUTLINE OF STRATIGRAPHY

The stratigraphic section in the Palos Verdes Hills is greatly abbreviated and incomplete as compared with sections along the north border and in the northern part of the Los Angeles Basin. (See figs. 1, 2.) In the Santa Monica Mountains, which lie along the northwest border of the basin, and also in the Santa Ana Mountains, at the southeast border, the oldest formation consists of argillite, phyllite, and slate intruded by granitic rocks. Triassic fossils have been found in the argillite of the Santa Ana Mountains, but in both mountain areas the argillite and associated rocks may include deposits of Jurassic age. In both mountain areas these basement rocks are overlain by a thick succession of Upper Cretaceous and Tertiary formations. A similar section underlies presumably the northern part of the Los Angeles Basin. Thousands of oil wells have penetrated the upper part of this section and have revealed a succession of Pleistocene and Pliocene formations that are much thicker than corresponding formations along the foot of the Santa Monica Mountains. Many wells in the northern part of the basin have also reached the upper Miocene.

In the southern part of the basin, south of the Newport-Inglewood uplift, which extends from Newport Beach to and beyond Inglewood, the basement consists of Franciscan (?) schist of doubtful Jurassic age. Resting on the schist are deposits of Miocene age, upper Miocene in most of the area and middle Miocene in the Palos Verdes Hills and at the seaward margin of the basin east of the hills; that is, the Upper Cretaceous, Paleocene, Eocene, Oligocene (?), and lower Miocene formations of the Santa Monica and Santa Ana Mountains, representing a thickness of 12,000 feet in the Santa Monica Mountains, are missing. The Pliocene and Pleistocene formations in the southern part of the basin are similar to those in the northern part but are considerably thinner, and in many areas parts of the Pliocene section are missing. The Newport-Inglewood uplift is thought by many geologists to mark a deep-seated fault. It has been suggested that if a deep-seated fault lies along the uplift, the fault probably represents the boundary between the areas of schist and granitic basement.[19]

The section exposed in the Palos Verdes Hills represented on a larger scale in figure 3, is essentially the same as the subsurface section south of the Newport-Inglewood uplift. As in the subsurface section, Franciscan (?) schist forms the basement. The Pliocene section is, however, more condensed than the subsurface Pliocene, and parts of the subsurface Pliocene are not represented. The Miocene section is thicker than it is in the Playa del Rey, El Segundo, and Torrance anticlinal areas north of the hills but is thinner than in the syncline between the El Segundo and Torrance fields and in the Wilmington field—an anticlinal area east of the hills. (See fig. 1.) The Miocene section in the hills includes older strata than is found in any of the nearby subsurface area so far explored. On the north slope of the hills, however, the oldest strata are of the same age as those resting on schist in the Wilmington field.

The Miocene of the Palos Verdes Hills has an exposed thickness of about 2,000 feet. Subsurface data indicate that the maximum thickness of the Miocene

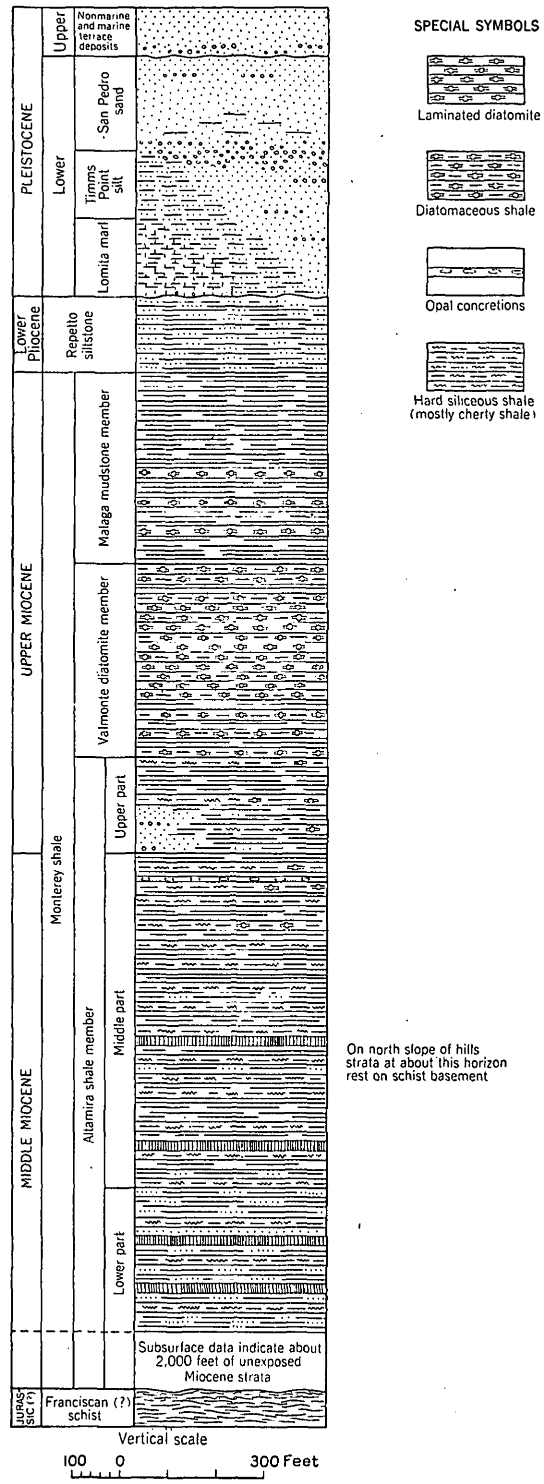

FIGURE 3.—Generalized stratigraphic section in Palos Verdes Hills.

is at least 4,000 feet, but the schist surface is irregular. The exposed part of the Miocene section is assigned to the Monterey shale, which is subdivided into the following members in ascending order: Altamira shale member, Valmonte diatomite member, and Malaga

[19] Reed, R. D., and Hollister, J. S., Structural evolution of Southern California. Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 1678-1679, 1936: Am. Assoc. Petroleum Geologists, pp. 132-133, Tulsa, Okla., 1936.

mudstone member. The lower and middle parts of the Altamira member are assigned to the middle Miocene and the upper part and the Valmonte and Malaga members to the upper Miocene. Basalt, generally in the form of sills, is found in the lower and middle parts of the Altamira.

The Monterey shale is overlain disconformably by the Repetto siltstone of lower Pliocene age. The maximum exposed thickness of the Repetto siltstone is about 150 feet, the top being marked by an uncomformity. It represents a greatly condensed section of parts of the Repetto formation of the Los Angeles Basin, which has a thickness of 2,000 to 5,000 feet. The upper Pliocene, represented in the basin by a thickness of 2,000 to 3,000 feet of strata assigned to the Pico formation, is missing.

Uncomformably overlying the Repetto siltstone and overlapping different parts of the Monterey shale are 350 to 600 feet of deposits assigned to the lower Pleistocene. In most areas these strata consist chiefly of sand, designated the San Pedro sand. At places a calcareous facies, the Lomita marl, is at the base of the section. A silt facies, either at the base of the lower Pleistocene strata or between the Lomita and San Pedro is designated the Timms Point silt. These three formations are the thin marginal equivalent of an undetermined lower part of the Pleistocene of the Los Angeles Basin, which has a thickness of as much as 2,000 feet.

Marine deposits, generally a few feet thick, have been found on 9 of the 13 main marine terraces, all of which are considered younger than the lower Pleistocene strata and are assigned to the upper Pleistocene. The most extensive marine terrace deposits are those on the lowest terrace. They overlie unconformably the lower Pleistocene or older formations and are designated the Palos Verdes sand. Nonmarine deposits, constituting the nonmarine terrace cover, overlie the marine sediments on the terraces or rest directly on the terrace platform. They are considerably thicker than the marine deposits. The marine and nonmarine terrace deposits are the equivalent of an undetermined upper part of the thick Pleistocene section in the basin. The nonmarine cover on the lowest terrace merges into the upper part of the older alluvium of the basin.

JURASSIC (?) SYSTEM

FRANCISCAN (?) SCHIST

DISTRIBUTION AND LITHOLOGY

Schists of doubtful Franciscan age are the oldest rocks that crop out in the Palos Verdes Hills. These rocks were noticed by Watts,[20] and some of the lithologic types have been described by Woodford.[21] They were not examined carefully during the present investigation, and their structure was not studied.

The metamorphic rocks are exposed along a wide anticline modified by minor folds in George F Canyon and its tributaries and nearby. The upper surface of the schist, which forms the floor on which the Miocene strata rest, is evidently irregular, though it conforms in a general way to the folds in the Miocene rocks. The schistosity or foliation is generally at fairly low angles and is roughly parallel to the strike and dip of the overlying Miocene strata, as observed by Woodford.[22]

The metamorphic rocks include a variety of schists. Green to greenish gray quartz-sericite schist, red-weathering to lavender-weathering quartz-talc schist containing much hematite, and bluish schist consisting principally of quartz and glaucophane or crossite are the most common. Woodford [23] described quartz schist, quartz-albite schist, and blue schist in which crossite is more abundant than glaucophane.

A saussuritized basic igneous rock is associated with the schists. This rock was probably a diabase or gabbro, but augite is apparently the only unaltered original constituent. Lawsonite is common in some of this altered rock, and much chlorite and glaucophane are developed along shear planes. At places the altered igneous rock is cut by quartz veins.

A small area of quartz schist, exposed on the crest of an anticline in a canyon east of Palos Verdes Drive East, about three-quarters of a mile southeast of George F Canyon, represents an outcrop of schist or an exceptionally large boulder in the Miocene strata close to the schist contact. A little farther down the canyon, but apparently within the outcrop of Miocene sandstone, are two smaller poorly exposed masses of schist, one 5½ by 4 feet and the other 4 by 2 feet, that may represent large boulders or small outcrops of schist. Such large boulders were not recognized, however, in the main schist area, where the relations between Miocene rocks and schist are clearer, and these apparent masses may be a further indication of the irregular schist surface.

Schist was penetrated in the Whites Point tunnel on the crest of an anticline that appears to be the southeastward extension of the anticline just mentioned. (See section *E—E'*, pl. 1.) On the north limb of the anticline the schist is decomposed at the contact with the Miocene strata, forming a layer of green clay about a foot thick. Most of the schist in the core of the anticline is altered. It contains plates of glaucophane 1 to 2 inches in diameter and minor amounts of talc and chloritic minerals. Near the contact with the Miocene strata on the south limb of the anticline the schistosity is vertical; 50 feet farther north it is nearly horizontal. On the crest of the anticline the rock is made up of fragments of micaceous and schistose minerals that form a matrix in which are embedded angular to slightly rounded fragments of quartz. Toward the north this breccia is in contact with a nearly vertical ledge of schist that strikes at right angles to the tunnel line. The breccia may represent material that accumulated along a cliff, but slickensides suggest that the ledge of schist marks a fault and that the breccia is a fault breccia. The schist is cut by two systems of joints. The joints of one system are virtually vertical and strike almost at right angles to the tunnel line; those of the other system are approximately horizontal. In both systems the joints are spaced about 8 feet apart.

Six wells drilled in the hills penetrated schist. The subsurface altitude of the schist in the Palos Verdes Hills is discussed under the heading "Oil possibilities," page 119.

AGE

The age of the schist is unknown other than that it is obviously pre-Miocene. The occurrence of glaucophane schist and altered basic igneous rocks suggests

[20] Watts, W. L., Oil and gas yielding formations of California: California Min. Bur. Bull. 19, p. 54, 1901.
[21] Woodford, A. O., The Catalina metamorphic facies of the Franciscan series: California Univ., Dept. Geol. Sci., Bull., vol. 15, pp. 49–68, pls. 5–7, 2 figs., 1924.

[22] Woodford, A. O., op. cit., p. 52.
[23] Woodford, A. O., op. cit., pp. 54, 57, pl. 7.

correlation with the Franciscan of the Coast Ranges. The Franciscan, an extensive description of which has been published recently by Taliaferro,[24] consists chiefly, however, of arkosic sandstone, shale, radiolarian chert, limestone, and volcanic rocks. Glaucophane schist and other metamorphic rocks are local and relatively rare rock types associated with intrusive igneous rocks. In view of these relations Woodford [25] designated the metamorphic rocks of the Palos Verdes Hills and the similar more extensive rocks of Santa Catalina Island as the Catalina metamorphic facies of the Franciscan. The absence of unaltered sedimentary rocks indicates that the metamorphics of the Palos Verdes Hills and Santa Catalina Island are older than the Franciscan, an alternative considered by Woodford.[26] This matter has been emphasized by Taliaferro,[27] who objected to including these metamorphics in the Franciscan. It may be advantageous to designate them as the Catalina schist.

If the metamorphics of the Palos Verdes Hills are older than Franciscan, they are Jurassic or older. On the basis of stratigraphic relations in southern Oregon and less satisfactory evidence in the California Coast Ranges, Taliaferro [28] concluded that the age of the Franciscan can be restricted to narrow limits in the late Upper Jurassic—Tithonian (used in the broad sense to include Portlandian) and possibly uppermost Kimmeridgian.

MIOCENE SERIES

MONTEREY SHALE

GENERAL RELATIONS

Strata of Miocene age rest directly on the Franciscan (?) schist. The Miocene deposits overlap the schist basement northward, the strata overlying the schist on the north slope of the hills being younger than those on the south slope of the central part of the hills, where the base of the Miocene section is not exposed.

The Miocene deposits include a variety of rocks, but hard silica-cemented shale and soft shale containing siliceous microfossils are the thickest and most conspicuous constituents. Early investigators of the geology of this region recognized that these unusual rocks are similar lithologically to those elsewhere in the Coast Ranges designated at that time the Miocene bituminous shale and later the Monterey shale. The stratigraphic nomenclature of the Miocene section in coastal southern California became confused, however, at a later date by the introduction of two local formation names for Miocene strata including shale of Monterey type—Modelo formation proposed for strata in the Santa Clara Valley in the Ventura Basin northwest of the Palos Verdes Hills, and Puente formation proposed for strata in the Puente Hills on the north border of the Los Angeles Basin northeast of the Palos Verdes Hills— and by the raising of Monterey to group rank to include the underlying Vaqueros sandstone. The Miocene strata in the Palos Verdes Hills have been assigned generally to the Modelo formation and the corresponding Miocene subsurface section in the adjoining Los Angeles Basin to the Puente formation. It has been proposed recently to restore the name "Monterey shale" as a formation name for Coast Range Miocene strata including shale of Monterey type regardless of varying stratigraphic position within the Miocene.[29] According to this proposal, the Miocene strata in the Palos Verdes Hills are assigned to the Monterey shale.

The Monterey shale of the Palos Verdes Hills is of middle to upper Miocene age. It has a maximum exposed thickness of about 2,000 feet. The underlying schist does not crop out, however, in the area where the oldest strata are found. Outcrop data show a southward increase in thickness through the addition of older strata at the base of the section. Subsurface data in the Point Fermin and Long Point areas indicate that the maximum thickness of the Miocene is at least 4,000 feet.

LITHOLOGY

Details of the stratigraphy and lithology of the Monterey shale were not determined in many areas, owing to meager exposures, to the apparent absence of distinctive lithologic units throughout hundreds of feet of strata, to minor structural complications that prevent determination of stratigraphic position on a basis of regional structure, and to changes in thickness and facies. The main features of the stratigraphic and lithologic succession seem to be well defined in some areas, but in other areas recognition of the main units is difficult, owing to lateral variations. On the basis of the succession in areas where the relations are fairly certain, the Monterey shale of the Palos Verdes Hills is divided into three named and mapped members, the principal features of which are summarized in the following table:

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[24] Taliaferro, N. L., Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 109–219, 7 pls., 7 figs., 1943.

[25] Woodford, A. O., op. cit., p. 49.

[26] Woodford, A. O., op. cit., p. 62.

[27] Taliaferro, N. L., op. cit., pp. 122–125.

[28] Taliaferro, N. L., Geologic history and structure of the central Coast Ranges of California, in Jenkins, O. P., and others, Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, pt. 2, pp. 125–126, 1941; Geologic history and correlation of the Jurassic of Southwestern Oregon and California: Geol. Soc. America Bull., vol. 53, pp. 85–87, 1942; Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., vol. 27, pp. 190–195, 1943.

[29] Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, Calif.; stratigraphy, paleontology, and structure: U. S. Geol. Survey Prof. Paper 195, pp. 122-123, 1940 [1941]. (The history of the name "Monterey" and the arguments involved in the proposal to use Monterey shale as a formation name are discussed in this publication.) Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., Miocene stratigraphy and paleontology of Palos Verdes Hills, Calif. Am. Assoc. Peteroleum Geologists Bull., vol. 20, No. 2, pp. 127, 131, 1936.

Subdivisions and principal features of Monterey shale in Palos Verdes Hills

Subdivision	Thickness (feet)	Principal lithologic constituents	Minor lithologic constituents	Fossils
Malaga mudstone member	300-600	Radiolarian mudstone	Diatomite, diatomaceous shale, siltstone, limestone, volcanic ash.	Foraminifera of *Bolivina obliqua* zone [1]. Radiolaria, diatoms, and other siliceous microfossils.
Valmonte diatomite member	300-500	Diatomite, diatomaceous shale, diatomaceous mudstone.	Mudstone, phosphatic shale, limestone, black chert, cherty shale, volcanic ash.	Foraminifera of *Bolivina hughesi* zone, including *Bolivina decurtata* and *Bolivina goudkoffi* sub zones. Diatoms and other siliceous microfossils. *Hyalopecten* aff. *H. peckhami*.
Altamira shale member:				
Upper part	100-300	Phosphatic shale, bituminous shale.	Cherty shale, porcelaneous shale, silty shale, limestone, diatomaceous silt, diatomaceous shale, sandstone (locally thick), local brecciated shale, bentonitic tuff, volcanic ash.	Foraminifera of *Bolivina modeloensis* and *Bulimina uvigerinaformis* zones. Diatoms and other siliceous microfossils.
Middle part	400-675	Cherty shale, porcelaneous shale, chert, limestone.	Silty shale, siltstone, diatomite, diatomaceous shale, phosphatic shale, sandstone, conglomerate, bentonitic tuff, pumice tuff (Miraleste tuff bed).	Foraminifera of *Siphogenerina reedi*, *Siphogenerina nuciformis*, and *Siphogenerina collomi* zones. Fish scales. Diatoms and other siliceous microfossils generally rare. *Turritella ocoyana* and other mollusks locally in sandstone.
Lower part	275+	Silty shale, sandy shale	Cherty shale, porcelaneous shale, limestone, sandstone, bentonitic tuff (including Portuguese tuff bed), local breccia composed of schist debris.	Foraminifera of *Siphogenerina branneri* zone. Fish scales. Diatoms generally only in limestone concretions.

[1] See footnote, p. 39.

Bramlette's terminology [30] for the siliceous rocks of the Monterey is adopted in the present report. The terms used are defined briefly as follows:

Chert: Hard massive dense vitreous rock composed principally of silica.
Laminated chert: Laminated but nonplaty rock similar to the chert mentioned above.
Cherty shale: Hard platy dense vitreous rock composed principally of silica. The most common type in the Palos Verdes Hills.
Porcelaneous mudstone: Hard massive nonlustrous rock composed of silica and fine-grained clastics.
Porcelaneous shale: Hard laminated platy nonlustrous rock composed of silica and fine-grained clastics.
Diatomite: Soft massive or laminated rock containing abundant diatoms.
Diatomaceous mudstone: Soft massive rock composed of fine-grained clastic material containing diatoms.
Diatomaceous shale: Soft layered or laminated rock composed of fine-grained clastic material containing diatoms.
Radiolarian mudstone: Soft massive rock composed of fine-grained clastic material in which Radiolaria are more conspicuous than diatoms.

Diatomite, diatomaceous mudstone, and diatomaceous shale are loosely defined field terms. There are, of course, gradations between the three types. The term "diatomite" is used for rock at least 50 percent of which consists of diatoms.

Rhythmically bedded shale refers to alternations of different rock types in units several feet or several inches thick. A finer lamination consisting of alternations of the same types is superimposed generally on the coarser units. Rhythmic bedding is characteristic of the fine-grained Monterey rocks, the term being used in the descriptive matter only for striking examples. The term "phosphatic shale" is used for shale containing layers and nodules of phosphatic material, probably impure collophane. The phosphatic shale in the upper part of the Altamira member and in the Valmonte member is soft. Phosphatic shale or siltstone in the middle part of the Altamira is generally hard and siliceous or calcareous. The term "bituminous shale" is used for tough, brown shale rich in organic matter.

The three divisions of the Altamira member include coarse-grained clastic rocks—sandstone, conglomerate, and breccia—which are locally thick. Such material was not observed in the other two members of the Monterey shale. Many of the sandstones contain a notable quantity of blue soda amphibole derived from blue schist containing glaucophane or other soda amphiboles. Blue-schist sandstone is a convenient term for such sandstone.

Limestone, presumably more or less dolomitic, occurs throughout the Monterey but is much more abundant in the Altamira member than in the others. In many Altamira areas the only natural outcrops are ledges of limestone, and the ground is strewn with pieces of limestone. The limestone occurs as lenses, ranging in thickness from a few inches to several feet, and as concretions. In the Altamira member the thickest limestone beds are massive; the thinner beds are massive or laminated, and some of the laminated limestone is siliceous. In the Valmonte and Malaga members concretions are more abundant than lenses. Concretions in laminated rock are laminated or massive. The Altamira member contains also thin beds made up largely of dolomite grains having the texture of coarse-grained sand.

Volcanic material is likewise common throughout the Monterey. It occurs generally as distinct beds containing virtually no other material. In the Altamira shale the beds of volcanic material consist of more or less bentonitic tuff and pumiceous tuff, with the local exception of vitric ash near the top of the member, whereas in the Valmonte and Malaga members they consist of vitric ash. Owing to their stratigraphic importance two beds of tuff are named: the Portuguese tuff, a thick bentonitic tuff at the top of the lower part of the Altamira and the Miraleste tuff, a thin pumiceous tuff in the middle part of the Altamira.

As in many other areas, the lower part of the Monterey shale is characterized by hard silica-cemented shale, much of which contains molds of diatoms, and the upper part by softer rocks containing abundant preserved diatoms. This distinction affords the most obvious basis for a lithologic subdivision and might be expected to prove useful in mapping. That this lithologic change does not take place even approximately at the same horizon in different areas in the Palos Verdes Hills is indicated by tracing the Miraleste tuff, as well as by other lithologic data and the foraminiferal faunas. Despite the varying stratigraphic position of the lithologic change, it would ordinarily be regarded as a satisfactory basis for the recognition and mapping of members. Such procedure is beset with special difficulties, however, in the Palos Verdes Hills, owing

[30] Bramlette, M. N., The Monterey formation of California and the origin of its siliceous rocks: U. S. Geol. Survey Prof. Paper (in preparation).

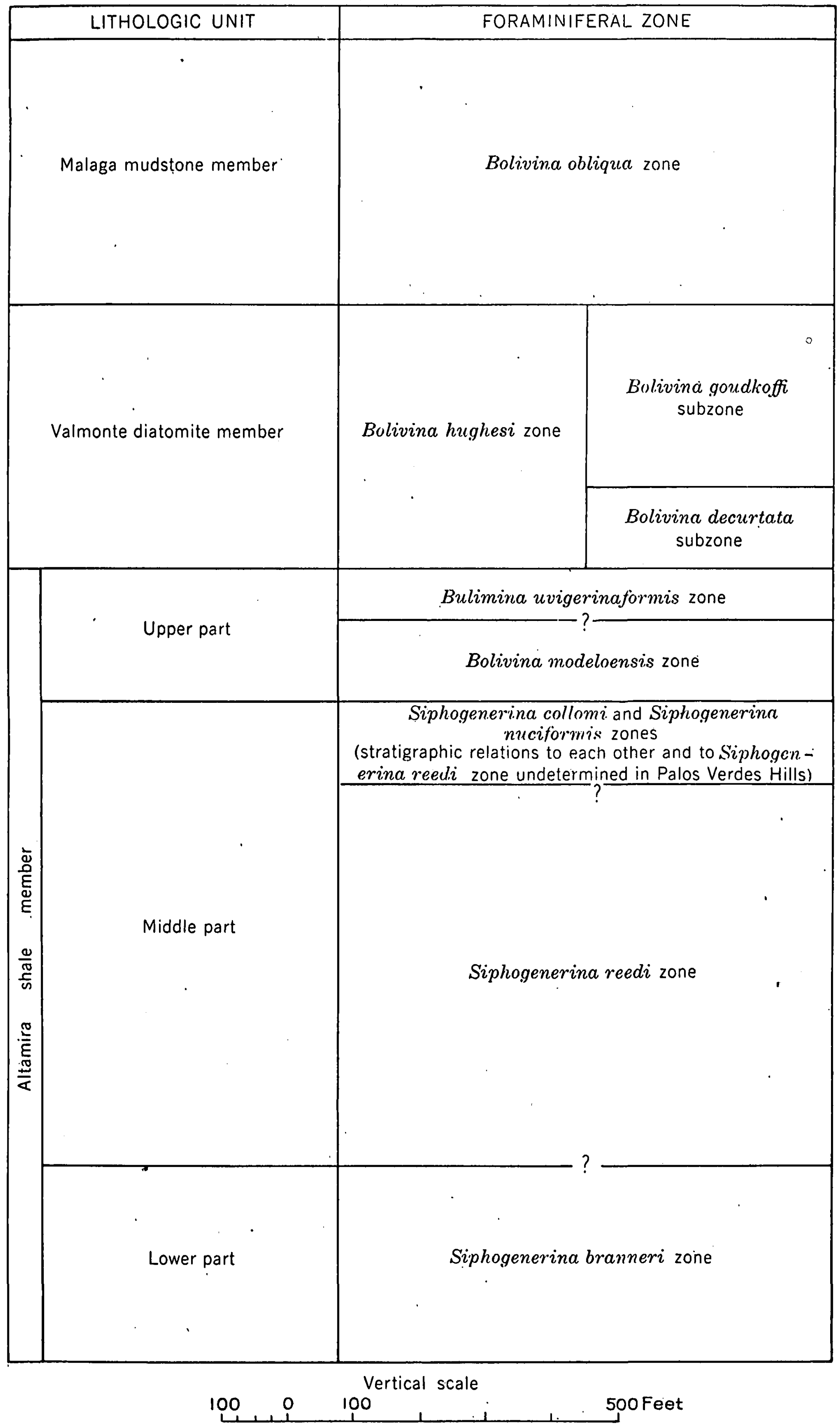


FIGURE 4.—Chart showing relation between lithologic units and foraminiferal zones in Monterey shale of Palos Verdes Hills.

to intricate minor structural features in areas of the most extensive interfingering of these two main rock types. In view of these relations an attempt to subdivide and map the formation on the basis of this lithologic change was abandoned.

In the western half of the hills and on the south slope the change from hard cherty shale to softer diatomaceous rocks takes place approximately at the top of the phosphatic upper part of the Altamira member. The change in that area forms the basis for recognition and designation of the overlying Valmonte diatomite member. In the northeastern and eastern parts of the hills the change takes place at varying horizons in the middle part of the Altamira member. In those areas the Valmonte member was differentiated by the ocurrence of relatively pure diatomaceous rocks, the diatomaceous strata in the Altamira member including phosphatic shale, and blue-schist sand and silt.

The Malaga mudstone member is characterized by the prevalence of massive mudstone. That member includes, however, diatomaceous shale, and the Valmonte includes mudstone of the massive type. At Malaga Cove, where these members are well exposed, they are well differentiated. Owing to meager exposures it is not known whether the distinction is as well defined in other areas. It is not known also whether the change from diatomaceous shale to massive mudstone takes place at the same horizon from place to place.

FOSSILS

Foraminifera were found in the three members of the Monterey, and the age assignments are based on them. The material collected was identified by R. M. Kleinpell, and the zonal assignments were made by him. A discussion of the foraminiferal zones of the California Miocene recognized by Kleinpell may be found in his publication.[31] The stratigraphic position of some collections of Foraminifera from the Palos Verdes Hills, particularly in the middle part of the Altamira member, was not determined, owing to insufficient field data. The relation between lithologic units and foraminiferal zones, according to present interpretations, is shown in figure 4.

Diatoms are more abundant than Foraminifera in the Monterey, especially in the Malaga and Valmonte members and in the diatomite and diatomaceous shale in the middle and upper parts of the Altamira member. They were observed also in limestones and limestone concretions in the lower part of the Altamira. The extensive collections made during the field work have not, however, been examined. Other siliceous microfossils—Radiolaria, silicoflagellates, and sponge spicules—occur with the diatoms and in some beds are more abundant than diatoms. Radiolaria from the Valmonte and Malaga members have been described recently by Campbell and Clark.[32]

Mollusks are rare in the Monterey, and none were observed in most of the fine-grained rocks. At a few localities shallow-water forms were found in sandstone in the middle part of the Altamira shale. The deep-water scallop *Delectopecten* occurs in the Valmonte diatomite but appears to be rare.

Fish scales are the most abundant fossils, or the only ones observed, in much of the hard silica-cemented shale. In some areas they may be found in almost any hand specimen. Fish skeletal remains are not abundant, though local collectors have found some well-preserved specimens in both hard cherty shale and soft diatomite. At numerous localities fragmentary cetacean remains, or fragmentary large bones that are presumably cetacean remains, were observed in hard limestone in the middle part of the Altamira member. Those observed include a fragmentary skull suggestive of a whalebone whale, and local collectors have found fragmentary skulls and jaws of toothed whales or dolphins. A small cetacean has been recorded from the Valmonte diatomite, and three sea birds from that member have been described.

[31] Kleinpell, R. M., Miocene stratigraphy of California, pp. 103–135, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938.

[32] Campbell, A. S., and Clark, B. L., Miocene radiolarian faunas from southern California: Geol. Soc. Am., Special Paper 51, 76 pp., 7 pls., 1944.

ALTAMIRA SHALE MEMBER

The oldest member of the Monterey is designated the Altamira shale member.[33] The type region is on the south slope of the hills adjoining Altamira Canyon (see pl. 4). The Altamira is thicker than the overlying members and covers a much larger area. In the type region it has an exposed thickness of about 1,000 feet. On the north slope of the hills the thickness decreases to about 600 feet, owing to overlap on the schist basement.

As shown in the table on page 14, the Altamira is divided into lower, middle, and upper parts characterized, respectively, by the prevalence of silty and sandy shale, cherty shale, and phosphatic shale. Each of these subdivisions, however, includes other rock types, and locally other rock types are prevalent; consequently in some areas differentiation of the three parts is not well defined, and no attempt was made to map them. Each part of the Altamira member has a coarse-grained detrital facies. The lower part includes a breccia composed of schist debris. Sandstone and conglomerate are included in the middle part in the area where that division rests on the schist basement and elsewhere. At Point Fermin the upper part includes thick beds of coarse-grained blue-schist sandstone.

Basalt, generally in the form of sills, is not known to penetrate strata above the middle part of the Altamira. In areas where basalt is present its distribution, therefore, shows roughly the distribution of the lower and middle parts of the Altamira. In extensive areas on the north slope of the hills, however, basalt is absent in the middle part.

Sections of the Altamira in different parts of the hills are shown on plate 3. The most complete sections are exposed in canyons in the type region inland from Portuguese Point and Inspiration Point. A section including most of the middle part and all of the upper part is exposed in the sea cliff extending from Bluff Cove to Lunada Bay, but in that area the base of the middle part is not certainly identified, and the structure is complicated by minor folds.

LOWER PART, INCLUDING PORTUGUESE TUFF BED

The lower part of the Altamira shale member is exposed in the Portuguese Canyon area and nearby on the south slope of the central part of the hills, where it has an exposed thickness of at least 280 feet. Strata in the Miraleste and Bluff Cove areas appear to represent the lower part of the Altamira.

In the Portuguese Canyon area the lower part of the Altamira consists chiefly of silty shale and sandy shale. Highly siliceous rocks are less abundant than in the middle part and consist mostly of silty porcelaneous

[33] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), p. 131, 1936.

shale and porcelaneous mudstone rather than cherty shale; that is, most of it is less siliceous than that in the middle division of the member. A thick bentonitic tuff is chosen as the top of the lower part of the Altamira. This tuff is designated the Portuguese tuff bed, a name derived from Portuguese Bend. The type region is along Klondike Canyon, near Portuguese Bend. In the preliminary paper [34] Portuguese Canyon was erroneously cited as the type locality. Owing to inadequate exposures and the tendency of the tuff to slump and slide, the tuff was not continuously traced, except in small areas. The strata immediately below and above the Portuguese tuff show no sharp lithologic change. Silty shale and sandy shale are, however, more abundant below that bed, and cherty shale is more abundant above it.

In the Bluff Cove area strata assigned to the lower part of the Altamira consist of silty sandstone, sandy siltstone, and a schist-debris breccia facies not found in any other area in the hills.

STRATIGRAPHY AND LITHOLOGY

PORTUGUESE CANYON AREA

The lower part of the Altamira shale crops out in the area adjoining the extensive landslide inland from Portuguese Point and Inspiration Point. The best exposures were found in Portuguese Canyon and the unnamed canyon between Portuguese and Klondike canyons. Silty shale and sandy shale are the prevailing rocks in that area. Porcelaneous silty shale, porcelaneous mudstone and siltstone, altered tuffaceous material, limestone, and sandstone are the principal minor constituents. Hard cherty shale and sandstone are less abundant than in the middle part of the Altamira.

The following section (column 5, pl. 3) was measured in the unnamed canyon a quarter of a mile east of Portuguese Canyon:

Section of lower part of Altamira shale member of Monterey shale in unnamed canyon a quarter of a mile east of Portuguese Canyon

	Ft.	*in.*
46. Thin-bedded silty shale; upper part not exposed	5+	0
45. Sandy tuff		8
44. Thin-bedded silty shale	1	8
43. Sandy limestone containing blue-schist shreds		8
42. Thin-bedded silty shale		6
41. Lenticular laminated limestone	1	2
40. Silty shale		4
39. Rusty fine-grained altered tuff (?)		2
38. Poorly exposed thin-bedded silty shale	10±	0
37. Rhythmically bedded silty shale; units of sandy shale at base and shale at top, each about 2 inches thick	2	0
36. Thin-bedded silty shale including some sandy lenses	8	8
35. Impure altered tuff		6
34. Hard brown mudstone containing altered pumiceous fragments and small glass shards; limy concretions about a foot thick in basal part	4	4
33. Poorly exposed thin-bedded silty shale	7	8
32. Thin-bedded silty shale and fine-grained sandy shale	10	10
31. Altered tuff containing a few poorly preserved Foraminifera	1	8
30. Hard porcelaneous mudstone and siltstone containing a few molds of Foraminifera; some layers tuffaceous	3	2
29. Coarse-grained sandy tuff, finer-grained at top; contains "bentonitized" glass shards that have a maximum length of a quarter of an inch or more	2	6

[34] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op cit., p. 132.

Section of lower part of Altamira shale member of Monterey shale in unnamed canyon a quarter of a mile east of Portuguese Canyon—Continued

	Ft.	*in.*
28. Hard porcelaneous mudstone		10
27. Thin-bedded silty and sandy shale	2	0
26. Altered tuff		6
25. Hard thin-bedded porcelaneous silty shale; a zone of diatom-bearing calcareous concretions 2½ feet above base	7	8
24. Thin-bedded silty shale	6	0
23. Altered sandy tuff; upper 2 inches fine-grained		6
22. Silty shale and mudstone	5	7
21. Altered sandy tuff		10
20. Limestone	1	
19. Unexposed	12±	0
18. Limestone		9
17. Thin-bedded silty shale	5	0
16. Hard limy siltstone	1	0
15. Thin-bedded silty shale	1	9
14. Lenticular limestone		8
13. Hard silty porcelaneous shale	6	8
12. Lenticular limestone	1	0
11. Thin-bedded silty shale and clay; lower half hard and porcelaneous	7	0
10. Limestone	1	11
9. Rhythmically bedded silty and porcelaneous shale; units of more silty and more porcelaneous shale, each having an average thickness of 1 to 2 inches	7	2
8. Impure sandy altered tuff	2±	0
7. Unexposed	6±	0
6. Hard black baked limestone	1	0
5. Basalt sill	5	6
4. Baked siliceous limestone		9
3. Thin-bedded silty and porcelaneous shale; not so hard nor so siliceous as unit 9	7	4
2. Limestone	1	3
1. Thin-bedded silty shale	2	0
Basalt in core of pitching anticline.		
Approximate thickness of section, excluding unit 46	152	0

The following section (column 4, pl. 3), measured in Portuguese Canyon, is an upward continuation of the preceding section. Unit 46 was matched in the two sections by a comparison of lithology, with special reference to the tuffs and the thickness.

Section of lower part of Altamira shale member of Monterey shale in Portuguese canyon

[Upward continuation of preceding section]

	Ft.	*in.*
56. Portuguese tuff bed, poorly exposed, thickness approximate	40±	0
55. Poorly exposed tuffaceous, sandy, silty, and porcelaneous shale; thickness estimated	25±	0
54. Poorly exposed silty shale	9±	0
53. Thin-bedded sandstone; top not exposed	5±	0
52. Massive sandstone	8	6
51. Hard sandy limestone or calcareous sandstone	1	10
50. Massive fine-grained to medium-grained sandstone containing blue-schist shreds	7	0
49. Rhythmically bedded thin-bedded fine-grained sandstone at base and silty sandstone at top, each about 2 inches thick	4	0
48. Poorly exposed thin-bedded silty shale and sandy shale, the latter containing blue-schist shreds	10±	0
47. Yellow altered tuff		6
46. Thin-bedded silty shale. Foraminifera of *Siphogenerina branneri* zone (locality 1) [35] collected from a limy bed lower in section corresponding to unit 34 of preceding section	14	0
Approximate thickness of this section	125	0
Approximate thickness of section in canyon a quarter of a mile east of Portuguese Canyon	152	0
	277	0

[35] The fossil localities are plotted on the geologic maps (pls. 1, 14, 21) and are described on pp. 120-125.

Foraminifera, generally represented by poorly preserved material or molds, were observed at different horizons in this area. The best material, assigned to the *Siphogenerina branneri* zone, was collected at locality 1 in Portuguese Canyon, as noted in the preceding section.

The Portuguese tuff bed consists of light-colored bentonitic tuff. As shown in the view on plate 6, *A*, it is well exposed in the type region, where it has a thickness of 55 feet. At the landward end of Inspiration Point the tuff is abruptly upturned on the south limb of an anticline (see pl. 5) and is about 60 feet thick. On the west side of Abalone Cove tuffaceous material is exposed through a thickness of 30 feet, and the debris indicates that it continues upward through an additional thickness of about 30 feet. The scattered outcrops of the Portuguese tuff that were recognized are shown on the geologic map (pl. 1). In addition to these outcrops, tuff debris, doubtless derived from this bed, was found at many localities along the north margin of the extensive landslide in the Portuguese Canyon district and in stream cuts within the landslide area. Inasmuch as the strata, including the tuff, dip toward the landslide along its east, north, and northwest margins, this bentonitic tuff probably acted as a lubricant for a mass of rocks that slid down dip into a structural basin and moving seaward overrode the lower marine terraces.

The lower part of the Altamira shale probably crops out in other areas along anticlines on the lower part of the south slope of the Palos Verdes Hills east and west of the Portuguese Canyon area. The stratigraphic relations in those areas are doubtful, however, as exposures are generally poor and the Portuguese tuff was not certainly recognized. Tuff debris, possibly derived from the Portuguese tuff, was found at several localities near the small landslide northwest of the extensive landslide just described. Some of the inadequately exposed rocks along the anticline in the deep canyon west of this small landslide probably represent the lower part of the Altamira.

MIRALESTE AREA

The lower part of the strata underlying the basalt sill on the Miraleste anticline is assigned to the lower part of the Altamira shale. A poorly exposed bentonitic tuff on the south limb of the anticline, about 100 feet stratigraphically below the base of the sill, is 25 or 30 feet thick and may represent the Portuguese tuff. The strata underlying the tuff, as exposed in isolated areas, consist of silty shale, thin-bedded sandstone, and relatively soft porcelaneous shale. Foraminifera from silty shale (locality 2) are assigned to the same faunal zone as that in the lower part of the Altamira in the Portuguese Canyon area.

BLUFF COVE AREA

Strata exposed in the sea cliff at Bluff Cove, at the west end of the eastward-plunging Bluff Cove anticline, appear to represent the lower part of the Altamira shale but are lithologically different from those already described. The Portuguese tuff was not recognized in this region.

A sketch of the sea cliff at Bluff Cove is shown in figure 5. The statigraphic relations of some of the lithologic units are uncertain, owing to extensive slides and talus and to incomplete knowledge of the structural features. The schist-debris breccia forming the high greenish cliff appears to represent the oldest strata. Bedding is not clearly discernible in the breccia, but there is a vague suggestion of anticlinal arching toward the top of the cliff. The breccia consists of a rude mass of schist slabs embedded in an unsorted greenish muddy matrix (pl. 6, *B*). The schist slabs have a maximum observed length of 3 feet, but most of them are less than half a foot long. Greenish schist is the most abundant rock, pieces of vein quartz are numerous, and blue schist is a minor but conspicuous constituent. Breccia of this type was not found elsewhere in the Palos Verdes Hills. It resembles the San Onofre breccia described by Woodford,[36] in the San Joaquin Hills, 30 miles southeast of the Palos Verdes Hills, and farther south along the coast. Like the San Onofre breccia the breccia at Bluff Cove may represent alluvial fan material deposited at the foot of a schist highland, or landslides and avalanches derived from such a highland. At all events it is composed of rocks similar to those in the Franciscan (?) area in the Palos Verdes Hills.

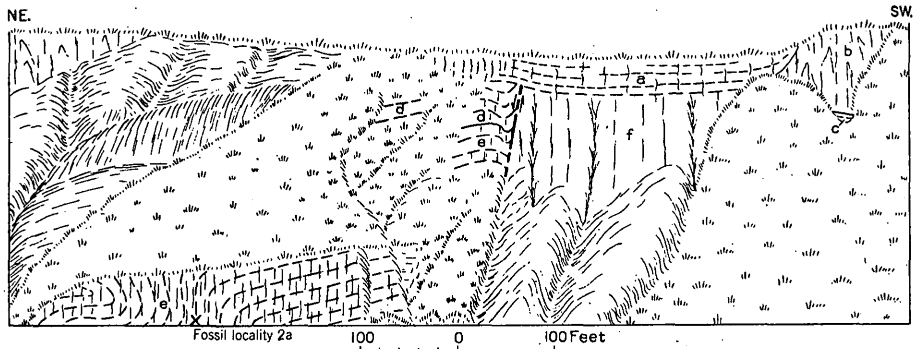
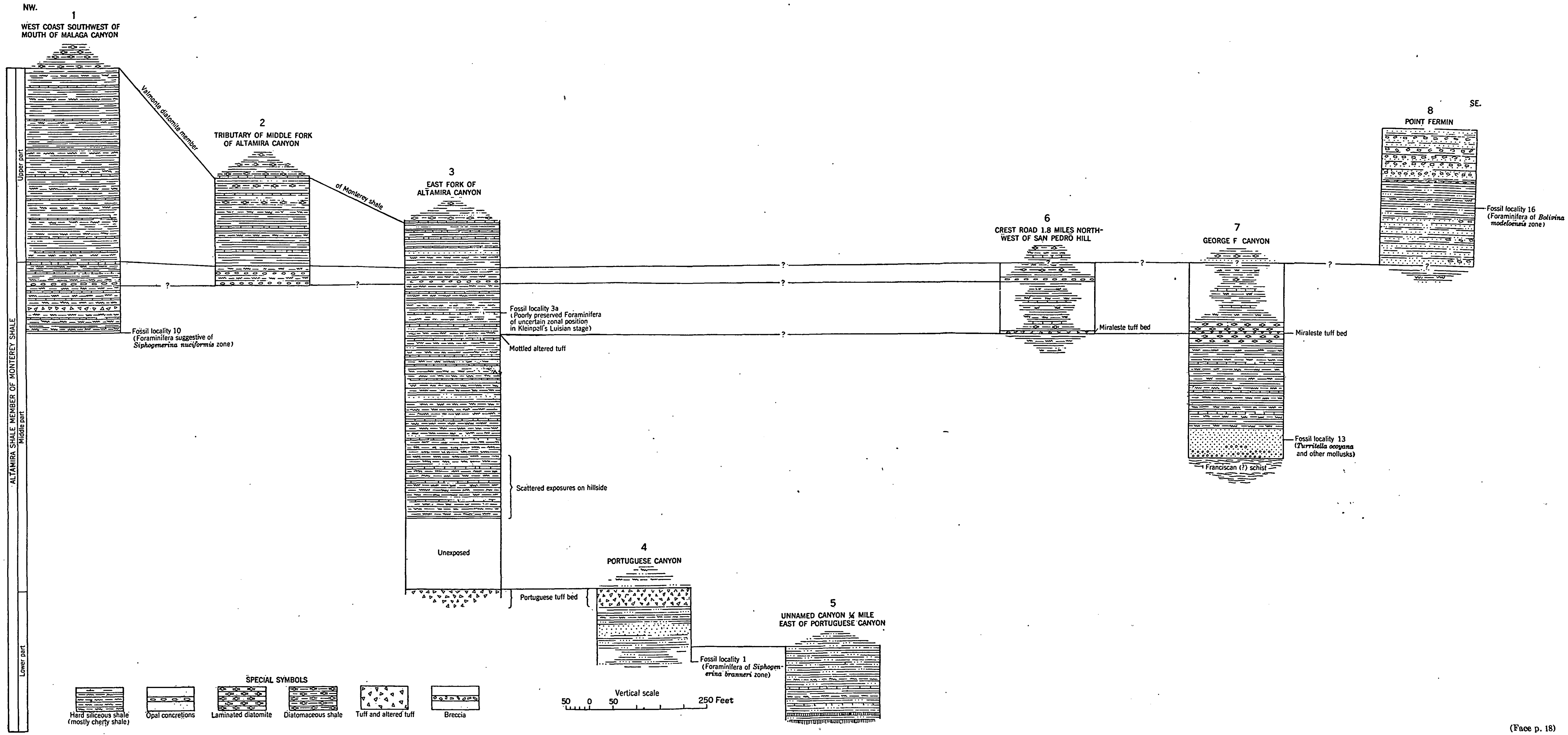


FIGURE 5.—Sea cliff at Bluff Cove. *a*, Pleistocene terrace deposits; *b*, basalt in middle part of Altamira member of Monterey shale; *c*, silty shale and cherty shale in middle part of Altamira shale; *d*, sandstone and conglomerate assigned to middle part of Altamira shale; *e*, silty sandstone and sandy siltstone in lower part of Altamira shale; *f*, schist-debris breccia assigned to lower part of Altamira shale.

Thin-bedded, generally fine-grained silty sandstone and sandy siltstone form the lower part of the cliff north of the breccia. These strata are presumably younger than the breccia and evidently are faulted against the breccia. A coarse-grained sandstone in these thin-bedded rocks contains much angular schist debris. Some layers of silty sandstone contain logs of carbonized and silicified wood as much as 1½ feet in diameter. Foraminifera from sandy siltstone (locality 2a), found by Dr. Hampton Smith, are interpreted as representing the same faunal zone as that in the lower

[36] Woodford, A. O., The San Onofre breccia: California Univ., Dept. Geol. Sci. Bull., vol. 15, pp. 182–205, 1925.

RELIEF MAP OF CALIFORNIA SHOWING LOCATION OF PALOS VERDES HILLS.



(Face p. 18)

SECTIONS OF ALTAMIRA MEMBER OF MONTEREY SHALE IN PALOS VERDES HILLS.

Thickness of upper part of Altamira in column 1 possibly exaggerated, owing to duplication by faulting. Column 6 based on isolated exposures in road cuts. Column 7 based on incomplete exposures.

VIEW ON SOUTH SLOPE OF PALOS VERDES HILLS LOOKING NORTHWARD UP ALTAMIRA CANYON AND TRIBUTARIES.

Gently dipping strata in background consist of Altamira member of Monterey shale overlain by thin cover of Valmonte diatomite member. Skyline shows rolling upland. Foreground and middle distance are part of landslide. Photograph by Palos Verdes Estates.

VIEW ON SOUTH COAST OF PALOS VERDES HILLS LOOKING WESTWARD ACROSS INSPIRATION POINT AND PORTUGUESE POINT TO LONG POINT.

Portuguese tuff bed at landward end of Inspiration Point shows in middle distance. Irregular topography at right is part of landslide. Photograph by Palos Verdes Estates.

part of the Altamira shale in the Portuguese Canyon area.

The south boundary of the breccia is obscured by talus. Inasmuch as the basalt sill and underlying silty and porcelaneous shale exposed at the south edge of the talus are part of a section assigned on faunal and lithologic grounds to the middle part of the Altamira shale, it is inferred that the talus conceals a fault.

FOSSILS

FORAMINIFERA

Foraminifera were collected from the lower part of the Altamira shale in Portuguese Canyon at a horizon 110 feet below the base of the Portuguese tuff. Through an error the horizon of this collection was cited in the preliminary paper [37] as 95 feet below the base of the Portuguese tuff. According to Kleinpell, these fossils suggest strongly the *Siphogenerina branneri* zone (zone A of preliminary paper), the upper zone in his Relizian stage. Foraminifera from locality 2 in the Miraleste area and from locality 2a in the Bluff Cove area are interpreted as representing the same zone. The species from these localities are given in the following table.

Foraminifera from lower part of Altamira shale member of Monterey shale

[Identifications by R. M. Kleinpell. R, Rare; F, few; C, common]

Species	Localities			
	Siphogenerina branneri zone			
	1	2	2a	Bluff Cove [1]
Hemicristellaria beali (Cushman)?	R	----	----	----
Nonionella miocenica Cushman?	R	----	----	----
Buliminella curta Cushman	----	----	R	C
Virgulina californiensis Cushman?	R	----	----	----
Bolivina advena var. striatella Cushman?	----	----	F	C
Bolivina imbricata Cushman	----	----	F	F
Bolivina floridana Cushman	----	----	F	----
Bolivina marginata Cushman	----	----	R	----
Bolivina aff. B. tumida Cushman	R	----	----	----
Valvulineria californica var. appressa Cushman	C	----	----	----
Valvulineria californica var. obesa Cushman	F	R	F	C
Valvulineria depressa Cushman	C	C	R	----
Valvulineria ornata Cushman	R	----	F	C
Pulvinulinella subperuviana Cushman	----	----	F	R
Globigerina bulloides d'Orbigny	----	----	----	R

[1] Same locality as 2a (see p. 18). Hampton Smith, collector. This collection was available through the kindness of D. D. Hughes.

Kleinpell's comments are summarized as follows:

The fauna from the lower part of the Altamira shale suggests that this part of the Monterey in the Palos Verdes Hills is a local correlative of the *Siphogenerina branneri* zone. The fauna from the Palos Verdes Hills is closely related to that from the Gould shale member of the Monterey shale, the lowest member of the Monterey in the type region of the Gould shale, on the west side of the San Joaquin Valley.[38] *Valvulineria ornata* is not known from older horizons. The two varieties of *Valvulineria californica*, *Hemicristellaria beali*, and perhaps *Bolivina imbricata* range downward into the *Siphogenerina hughesi* zone, which underlies the zone represented by the Gould shale (*Siphogenerina branneri* zone), but are not known from older horizons. All the Foraminifera found in the lower part of the Altamira shale range upward into the *Siphogenerina reedi* zone, overlying the *Siphogenerina branneri* zone, and all except *Valvulineria depressa* range still higher. Therefore, the fauna from the Palos Verdes Hills may represent the *Siphogenerina reedi* zone rather than the *Siphogenerina branneri* zone. The abundance of *Valvulineria californica* var. *appressa* and also of typical *Valvulineria depressa* suggests strongly, however, a correlation of the lower part of the Altamira with the Gould shale, as neither form is well developed at higher horizons.

MIDDLE PART, INCLUDING MIRALESTE TUFF BED

The middle part of the Altamira shale member is thicker than the other parts, is the most widely distributed division of the Monterey shale, and includes most of the cherty shale of the Monterey. In the Portuguese Canyon-Altamira Canyon area it is 675 feet thick. On the north slope of the hills it overlaps the schist basement and has a thickness of about 400 feet. Beds of sandstone and conglomerate ranging in thickness from a few feet to 75 feet are found at or near the base of the section in that region.

Bentonitic tuffs are common in the middle part of the Altamira. A distinctive tuff characterized by the abundance of pumice lapillae was mapped on the north slope of the hills at a horizon 125 to 175 feet below the top of the middle part of the Altamira. Despite its thinness, this tuff is named, because it is one of the few distinctive lithologic units in the Monterey. It is designated the Miraleste tuff bed,[39] a name derived from the Miraleste residential district. The type region is along the west side of upper Agua Negra Canyon. The dark-brown pumice lapillae, commonly an inch or less in diameter, are embedded in a matrix of light-colored impure fine-grained volcanic ash. The pumice (index about 1.54) is more basic than the fine-grained ash of the matrix (index about 1.50). The Miraleste tuff is generally 2 to 4 feet thick, but at places is only a few inches thick and has a maximum thickness of 8 feet. Locally, dikelike extensions penetrate overlying and underlying strata. At several localities on the north slope of the hills there appear to be two beds of pumice tuff, but the apparent occurrence of two beds may be due to minor structural complications.

A zone of ellipsoidal opal concretions, similar to those in the Monterey of central California,[40] was found at scattered localities in the western half of the hills. The Miraleste tuff was recognized in the same section with the concretions at only one locality (column 6, pl. 3), where the concretions are about 100 feet above the tuff. At several other localities, however, there is some evidence that the zone of concretions is at a uniform horizon (columns 1, 2, 3, pl. 3). Should this suggestion be confirmed, the zone of concretions may be useful in working out details of the stratigraphy and structure in areas where they are now obscure. The localities where the concretions were recognized are shown on the geologic map (pl. 1).

Characterized in general by the prevalence of cherty shale, the middle part of the Altamira includes, nevertheless, in some areas a varying thickness of softer diatomaceous rocks. In the western half of the hills and on the south slope diatomaceous rocks were not found in this division of the Altamira. In the area on the north slope of the hills, extending approximately from Agua Negra Canyon to Miraleste Canyon, the

[37] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit., p. 132.

[38] Barbat, W. F., Age of producing horizon at Kettleman Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 16, pp. 611-612, 1932. Kleinpell, R. M., Miocene stratigraphy of California, p. 121, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938. Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, Calif.; stratigraphy, paleontology, and structure: U. S. Geol. Survey Prof. Paper 195, pp. 125, 137, 1940 [1941].

[39] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit., p. 134.

[40] Taliaferro, N. L., Contraction phenomena in cherts: Geol. Soc. America Bull., vol. 45, pp. 194-207, pls. 13-24, 1934.

Miraleste tuff is in a tongue of diatomaceous strata 50 to 100 feet thick. Farther east, in and northwest of San Pedro, the middle division of the Altamira above the Miraleste tuff and also apparently as much as 200 feet below the tuff consists principally of diatomaceous rocks. That is, there is an eastward and northward change from cherty rocks to softer diatomaceous rocks. That the change is due to interfingering of the two rock types is inferred from the relations near the crest of the hills south of Agua Negra Canyon, where the Miraleste tuff was traced southward across the crest. Westward on the south slope the tuff is progressively bentonitized, the pumice being the last consituent to be altered. In the area where the change in character of the tuff takes place the tongue of diatomaceous rocks that includes the tuff in the Agua Negra Canyon district interfingers evidently with cherty shale.

STRATIGRAPHY AND LITHOLOGY

BLUFF COVE-MALAGA COVE AREA

The conglomerate and sandstone exposed near the top of the cliff at Bluff Cove (see fig. 5) are assigned arbitrarily to the middle part of the Altamira. The

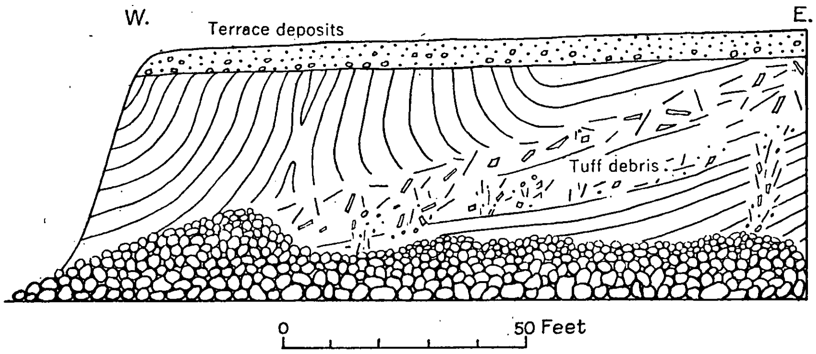


FIGURE 6.—Minor isoclinal anticline exposed in sea cliff a quarter of a mile southwest of mouth of Malaga Canyon.

coarse-grained strata on the north limb of the Bluff Cove anticline, overlying the siltstone and silty sandstone assigned to the lower part of the Altamira, continue upward in the section to the thick basalt sill. The conglomerate consists principally of schist pebbles, and some beds contain angular pieces of schist in addition to pebbles. Molds of *Anadara?* and *Aequipecten* were found in massive buff sandstone about 150 feet stratigraphically below the basalt sill (locality 2b). Irregularly oriented borings are abundant in this sandstone.

The strata in the cliff on the north limb of the syncline near Flatrock Point, overlying the basalt forming Flatrock Point, consist chiefly of cherty shale and limestone. They appear to be higher in the section than the conglomerate and sandstone just described, for it is improbable that the entire thickness of conglomerate and sandstone grades laterally so abruptly into cherty shale and limestone. The north boundary of the basalt forming Flatrock Point is probably marked by a fault, which, however, was not recognized inland.

An essentially continuous section extending from the upper part of the middle division of the Altamira upward into the Valmonte diatomite member is exposed in the sea cliff, from the crest of the minor anticline northeast of Flatrock Point northeastward to the mouth of Malaga Canyon. Soft calcareous shale, some of which contains phosphatic layers and nodules, is interbedded with cherty shale and limestone in the middle division of the Altamira. Foraminifera suggestive of the *Siphogenerina nuciformis* zone were found in granular limestone at locality 10. The following section shows the lithology of the middle part of the Altamira above the limestone at locality 10 (column 1, pl. 3).

Section of middle part of Altamira shale member of Monterey shale in sea cliff between Malaga Canyon and Flatrock Point

	Ft.	*in.*
31. Limestone. Overlain by phosphatic shale assigned to upper part of Altamira shale. For upward continuation of section see p. 29	3	6
30. Chert, cherty shale, calcareous shale, and soft phosphatic shale	8	0
29. Limestone	3	0
28. Cherty and calcareous shale	1	2
27. Limestone	2	3
26. Chert and cherty limestone	6	0
25. Soft shale containing a few phosphatic nodules and harder calcareous shale	2	0
24. Cherty and calcareous shale	5	5
23. Limestone	4	6
22. Chert, cherty shale, and thin zones of soft shale containing a few phosphatic nodules; layer of opal concretions 3 feet above base and scattered concretions at other horizons	13	0
21. Limestone	2	0
20. Chert, cherty calcareous shale, and thin-bedded limestone	23	0
19. Brecciated limestone	9	0
18. Thin-bedded limestone, phosphatic shale, and cherty shale	4	0
17. Crushed rock and debris of bentonitic tuff. Thickness uncertain	15(?)	0
16. Shale containing light-colored phosphatic stringers, cherty shale and tuff	3	0
15. Thin-bedded limestone, calcareous shale, and cherty shale	2	6
14. Shale containing light-colored phosphatic stringers, and cherty shale	1	3
13. Limestone	1	9
12. Calcareous and cherty shale	2	0
11. Brecciated limestone	3	6
10. Calcareous shale containing light-colored phosphatic stringers, and cherty shale	3	0
9. Thin-bedded limestone		10
8. Calcareous and cherty shale	4	8
7. Brecciated limestone	1	8
6. Shale containing few phosphatic nodules	1	0
5. Limestone	2	9
4. Calcareous and cherty shale	2	8
3. Brecciated limestone	6	0
2. Brown bituminous (?) shale	2	0
1. Limestone. A granular layer at top contains Foraminifera suggestive of *Siphogenerina nuciformis* zone (locality 10)	5	8
Thickness of section	146±	0

The total thickness given for the preceding section is of doubtful value, because unit 17 is represented by slide debris that may conceal a fault. A thickness of 15 feet is assigned to unit 17, and it is assumed that there is no gap or duplication in the stratigraphic succession. Immediately north of the slide the strata are folded in a narrow isoclinal anticline (fig. 6). The strong deformation appears to have been localized by bentonitic tuff, which may have acted as a lubricant. If the opal concretions in unit 22 of the preceding section are at the same horizon as similar concretions elsewhere in undisturbed sections, this tuff, the presence of which is indicated by slide debris, is younger than the Miraleste tuff.

In the Malaga Cove residential district inland from the coast the middle part of the Altamira shale, consisting chiefly of cherty shale, porcelaneous shale, and limestone, can be seen in highway cuts and natural exposures. A tuff about 60 feet thick exposed on Del Monte road near La Venta Inn consists of soft bentonitic material in the upper part and hard silicified tuff in the lower part. Opal concretions were observed in a highway cut southeast of the Malaga Cove business district and on the north limb of a steeply folded anticline in the upper part of Valmonte Canyon.

BLUFF COVE-LUNADA BAY AREA

A virtually continuous section complicated by minor folds extends from a horizon apparently low in the middle part of the Altamira shale upward to the Valmonte diatomite in the sea cliff between Bluff Cove and Lunada Bay. Foraminifera from limestone immediately overlying the basalt sill, at locality 3, on Palos Verdes Drive West, near Bluff Cove, are assigned to the *Siphogenerina reedi* zone. Foraminifera were observed also in hard baked limestone underlying the basalt sill on the sea cliff. The limestone at locality 3 contains broken large bones, presumably whale remains. Beds of limestone at the same horizon form low-tide reefs at the foot of the sea cliff, 2,100 feet west-southwest of locality 3. (See pl. 26.) Huge concretionary hard masses weathered out of the reefs contain large bones like those at locality 3. A field sketch of a skull exposed in longitudinal section suggests, according to Dr. Remington Kellogg, a whalebone whale.

Silty shale and porcelaneous shale overlie the bone-bearing reefs. Still higher in the section is the main cherty shale zone of the Monterey, with which many beds of limestone are interbedded. Toward the top of the section calcareous mudstone and soft shale, both containing phosphatic nodules, are interbedded with the cherty shale, forming a transition zone to the bituminous and phosphatic shale assigned to the upper part of the Altamira, the base of which is about 2,000 feet northeast of Palos Verdes Point.

LUNADA BAY-POINT VICENTE AREA

The middle part of the Altamira reappears underlying the upper part of the member on the south limb of the main syncline at Lunada Bay. Loose limestone concretions along the beach, on the north side of Resort Point, contain cetacean remains. These concretions probably weather out of the limestone interbedded with calcareous phosphatic siltstone that forms reefs along the shore. The area southward to Point Vicente and beyond toward the east is characterized by the abundance of basalt. At many places the present sea cliff and also the cliff at the seaward edge of the second terrace inland are capped by hard limestone and cherty shale overlying basalt.

A tuff about 40 feet thick is exposed in the second cove south of Resort Point. It consists of light-colored bentonitic material containing glass shards toward the top. This tuff is evidently in the lower part of the middle division of the Altamira and may correspond to the 60-foot tuff in the Bluff Cove-Malaga Cove area. Tuff of comparable thickness was not recognized in areas where the stratigraphic succession is more definite, unless the tuff at these two localities corresponds to the Portuguese tuff.

ALTAMIRA CANYON-PORTUGUESE CANYON AREA

The best section of the middle part of the Altamira shale is found along Altamira Canyon and its tributaries, where the structure is simple and the rocks are generally well exposed. A section measured in the east fork of Altamira Canyon follows. (See column 3, pl. 3, measured in canyon at right edge of view on pl. 4.)

Section of middle part of Altamira shale member of Monterey shale in east fork of Altamira Canyon

	Ft.	*in.*
102. Laminated siliceous limestone, overlain by soft silty shale and nodular phosphatic shale assigned to upper part of Altamira shale. For upward continuation of section see p. 31	1	6
101. Porcelaneous shale	4	5
100. Soft, somewhat silty, porcelaneous shale	4	0
99. Limestone	2	9
98. Rusty altered tuff (?)		8
97. Silty shale	1	0
96. Laminated limestone	2	6
95. Porcelaneous shale		6
94. Altered tuff		6
93. Soft, somewhat silty, porcelaneous shale	2	0
92. Cherty shale	3	0
91. Limestone	1	0
90. Soft, somewhat silty, porcelaneous shale	2	5
89. Cherty shale; 3 layers of opal concretions	9	0
88. Shale, softer and more silty than unit 86	2	6
87. Siliceous limestone	1	8
86. Porcelaneous shale	3	8
85. Siliceous limestone		8
84. Cherty shale	9	8
83. Soft, somewhat silty, porcelaneous shale	2	6
82. Lenticular limestone	2	0
81. Rhythmically bedded porcelaneous shale, units several inches thick	7	0
80. Reddish altered tuff	4	0
79. Brown phosphatic shale	7	0
78. Granular limestone	2	0
77. Soft, somewhat silty, porcelaneous shale	4	0
76. Granular limestone	1	6
75. Soft, somewhat silty, porcelaneous shale	1	0
74. Cherty shale	1	0
73. Soft, somewhat silty, porcelaneous shale	2	0
72. Cherty shale	2	0
71. Altered tuff (?)	3	8
70. Porcelaneous shale	5	0
69. Limestone containing poorly preserved Foraminifera of uncertain zonal position in Kleinpell's Luisian stage (locality 3a)	3	0
68. Soft, somewhat silty, porcelaneous shale	4	0
67. Rhythmically bedded porcelaneous shale	7	0
66. Soft, somewhat silty, porcelaneous shale	2	0
65. Dense limestone containing *Valvulineria*	1	6
64. Alternating soft silty shale and harder porcelaneous shale	8	0
63. Limestone	3	6
62. Alternating soft silty shale and harder porcelaneous shale; 2½ feet above base a 2-inch altered tuff. Fifty feet down canyon 1 foot + of altered mottled tuff at base; probable equivalent of Miraleste tuff bed	19	0
61. Cherty shale	3	0
60. Silty shale	3	0
59. Limestone	4	0
58. Porcelaneous and silty shale	1	6

Section of middle part of Altamira shale member of Monterey shale in east fork of Altamira Canyon—Continued

	Ft.	in.
57. Tuffaceous (?) clay		1
56. Porcelaneous and silty shale	4	0
55. Unexposed; probably mostly tuff	10	0
54. Altered white tuff	2+	0
53. Porcelaneous shale	5	0
52. Limestone	1	10
51. Silty shale	1	5
50. Soft porcelaneous shale	4	0
49. Bentonitic clay		2
48. Silty and soft porcelaneous shale	5	6
47. Porcelaneous shale and limestone	1	6
46. Poorly exposed; mostly silty shale	5	0
45. Limestone	3	0
44. Poorly exposed silty and porcelaneous shale	6	6
43. Cherty shale		6
42. Silty shale	2	0
41. Porcelaneous shale	5	4
40. Siliceous limestone and cherty shale	2	0
39. Cherty shale	1	0
38. Silty shale	4	0
37. Rhythmically bedded porcelaneous shale	4	0
36. Laminated siliceous limestone	3	0
35. Silty shale	5	0
34. Porcelaneous shale	1	2
33. Fissile silty shale and soft porcelaneous shale	5	3
32. Fine-grained dolomite (?)		5
31. Porcelaneous shale	3	0
30. Bentonitic clay	1	4
29. Silty shale	1	0
28. Fine-grained dolomite (?)	3	0
27. Fissile silty shale	1	2
26. Porcelaneous shale	3	10
25. Poorly exposed silty shale	9	0
24. Dense limestone		3
23. Porcelaneous shale 2 feet thick grading upward into silty and calcareous shale	4	4
22. Fine-grained sandstone		2
21. Siltstone	1	1
20. Limestone	1	7
19. Porcelaneous shale		8
18. Limestone		4
17. Reddish tuffaceous (?) clay		5
16. Silty porcelaneous shale	2	2
15. Hard cherty shale	6	0
14. Reddish tuffaceous (?) clay		2
13. Siltstone	6	3
12. Laminated porcelaneous shale, dark brown or black when fresh	5	0
11. Reddish tuffaceous (?) clay		6
10. Siltstone	4	0
9. Dense limestone		6
8. Principally porcelaneous shale	5	0
7. Siltstone	1	4
6. Dense siliceous limestone containing diatoms		2
5. Siltstone	2	0
4. Porcelaneous shale	1	6
3. Scattered exposures, more numerous upward, of porcelaneous shale rhythmically bedded with fine-grained dolomite (?) and a few beds of limestone. Thickness computed	80	0
2. Unexposed. On hillside scattered exposures of porcelaneous shale, thin-bedded fine-grained dolomite (?), and limestone. Thickness computed	133	0
1. Unexposed. Thickness computed. Underlain by Portuguese tuff bed, which is not clearly exposed. Water seep at estimated top of bed	150	0
Thickness of section	670	0

The preceding section includes many thin beds of bentonitic tuff. The mottled tuff in unit 62 was selected as the probable equivalent of the Miraleste tuff bed by tracing limestone ledges between the canyon and the westernmost exposure of the Miraleste tuff 1,000 feet east of the canyon. Opal concretions were found in a 9-foot cherty shale (unit 89) 35 feet below the top of the middle part of the Altamira and 110 feet above the probable equivalent of the Miraleste tuff. Basalt, which is abundant to the east and to the west, was not found along the east fork of Altamira Canyon. Sandstone is rare but farther east occurs in thick beds.

AGUA NEGRA CANYON AREA

The Agua Negra Canyon area includes the area drained by Agua Negra Canyon and its tributaries and adjoining parts of the north slope of the hills. In this region the Miraleste tuff bed is in a tongue of soft diatomaceous rocks about 50 feet thick. The following section was measured on the west slope of upper Agua Negra Canyon in the type region of the Miraleste tuff (see pl. 7, *A*).

Section of middle part of Altamira shale member of Monterey shale, including Miraleste tuff bed, on west side of upper Agua Negra Canyon

	Ft.	in.
29. Laminated diatomite penetrated by several tuff dikes. Top not exposed	10+	0
28. Miraleste tuff bed:		
c. Fine-grained massive tuff containing many fragments of dark-colored pumice having an average length of half an inch and a maximum length of about an inch; includes slabs of diatomite and limestone (maximum length about a foot) lying in various attitudes; basal contact slightly irregular	3	8
b. Laminated diatomite		6
a. Tuff like unit *c*; basal contact slightly irregular		7
27. Laminated diatomite	6	0
26. Limestone	1	2
25. Laminated diatomite penetrated by a 1-foot pumice tuff dike inclined at an angle of about 30° to bedding	11	0
24. Siliceous limestone	0	5
23. Thin-bedded diatomaceous limestone	0	11
22. Laminated diatomite; grades upward into overlying limestone	4	4
21. Poorly exposed soft laminated shale; a few diatoms in some layers, many in others	3	6
20. Porcelaneous shale; soft layers in upper part	8	0
19. Unexposed	8	0
18. Porcelaneous shale; upper part silty	1	10
17. Poorly exposed thin-bedded silty shale	5	6
16. Siliceous limestone; upper part silty limestone	1	6
15. Porcelaneous shale	12	0
14. Breccia bed. Fine-grained sandy calcareous siltstone containing slabs of porcelaneous shale lying in various attitudes; maximum length of slabs about 6 inches	3	4
13. Rhythmically bedded porcelaneous and silty shale	5	2
12. Hard very siliceous laminated limestone grading upward into chert; forms base of cliff (see pl. 7, *A*, at right)	1	7
11. Poorly exposed rhythmically bedded porcelaneous and silty shale	20	0
10. Siliceous limestone	2	0
9. Poorly exposed rhythmically bedded porcelaneous and silty shale; units 5 to 10 feet thick. Zones of porcelaneous shale, where well exposed, themselves show rhythmic bedding of more siliceous and less siliceous shale on a smaller scale; units a few inches thick	45	0
8. Porcelaneous shale	6	0
7. Thin-bedded silty shale, sandy shale, and fine-grained sandstone	10	0
6. Porcelaneous shale; few layers 1 to 2 inches thick of denser cherty shale	16	0
5. Hard laminated cherty shale	2	6
4. Thin-bedded shale, lower half more siliceous than upper half	9	0
3. Dense laminated chert		10
2. Imperfectly exposed hard porcelaneous shale containing many fish scales	23	0

Section of middle part of Altamira shale member of Monterey shale, including Miraleste tuff bed, on west side of upper Agua Negra Canyon—Continued

	Ft.	in.
1. Thin-bedded silty and porcelaneous shale; exposed in cut bank at canyon floor.		
e. Rhythmically bedded shale; units of sandy shale grading upward into porcelaneous shale	2	10
d. Silty shale	1	0
c. Porcelaneous shale	1	7
b. Medium-grained sandstone	1	6
a. Porcelaneous shale		7
Thickness of section	230	10

As shown in the preceding section, the strata in this area underlying the tongue of diatomaceous shale and diatomite associated with the Miraleste tuff, comprising an exposed thickness of about 200 feet, consist chiefly of porcelaneous shale. Sandstone is rare and is generally absent.

The Miraleste tuff varies in thickness from a few inches to several feet within short distances. The maximum thickness is generally 3 to 4 feet, exceptionally 6 to 8 feet. The dark-colored pumice lapillae embedded in the light-colored matrix vary in length from a fraction of an inch to 2 inches. At many localities the tuff has been squeezed into cracks and along bedding planes in the underlying and overlying soft rocks, dike-like and sill-like bodies of tuff extending through a thickness of as much as 15 to 30 feet. As may be seen on plate 7, *A*, the soft diatomite interbedded with the Miraleste tuff is irregularly deformed toward the south end of the cliff where the preceding section was measured, whereas the underlying harder strata have a uniform gentle dip. Locally the matrix of the tuff is calcified, forming a hard limy bed speckled with pumice.

The strata in the middle part of the Altamira shale overlying the diatomaceous rocks interbedded with the Miraleste tuff are about 125 feet thick. They include porcelaneous shale and cherty shale as well as softer shale that is generally poorly exposed, but the proportion of hard siliceous shale decreases eastward. Opal concretions were found in cherty shale about 100 feet above the Miraleste tuff on the Crest Road at the head of Sepulveda Canyon (column 6, pl. 3) and at scattered localities west of Agua Negra Canyon. They were not observed farther to the north or east, but at many places a conspicuous zone of chert and cherty shale is in the same part of the section approximately 100 feet above the Miraleste tuff. Fragmentary large bones, presumably cetacean remains, occur in limestone 25 feet above the Miraleste tuff at a locality 0.4 mile west of Agua Negra Canyon.

GEORGE F CANYON-MIRALESTE CANYON AREA

Along George F Canyon and its tributaries strata assigned to the middle part of the Altimira shale rest on the schist basement (column 7, pl. 3), conglomerate and sandstone of varying thickness lying on the schist surface. The conglomerate contains slightly rounded or angular pieces of schist that have a maximum length of 6 to 12 inches. The sandstone is buff on fresh surfaces and reddish brown on weathered surfaces. On the 862-foot hill on the west side of George F Canyon a thickness of about 10 feet of conglomerate is exposed. At places in the main schist area the conglomerate and sandstone are evidently thin, as cherty shale is exposed within a few feet of the schist. Sandstone about 75 feet thick overlies the small area of schist exposed along the crest of an anticline in the first canyon east of Palos Verdes Drive East. Other outcrops of sandstone were found along this anticline in the next canyon to the south, a tributary of Miraleste Canyon. The schist is not far below the surface in this region, for it was penetrated in the Whites Point sea-level tunnel on the crest of the same anticline 470 to 500 feet below the surface (section *E—E'*, pl. 1). In the tunnel conglomerate having a thickness of 50 to 60 feet and consisting of imperfectly rounded green schist pebbles 1 to 6 inches long overlies the schist on the north limb of the anticline. On the south limb similar conglomerate is about 50 feet thick and is overlain by about 25 feet of massive greenish sandstone containing a few angular pieces of schist.

The schist is probably close to the surface also west of George F Canyon. Conglomerate containing schist cobbles and slabs as much as a foot long is exposed along Crenshaw Boulevard in the Rolling Hills district, 800 feet south of the syncline containing the Miraleste tuff.

Turritella ocoyana and other mollusks were collected from sandstone overlying schist at locality 13, on the west slope of George F Canyon, 20 feet above the canyon floor. The fossiliferous strata are estimated to be 40 feet above the top of the schist and 225 feet below the Miraleste tuff. A few mollusks were found also near the top of the sandstone along the first canyon east of Palos Verdes Drive East (locality 13a).

The exposed strata between the coarse-grained detrital rocks at the base of the section and the soft diatomaceous rocks interbedded with the Miraleste tuff consist generally of cherty shale and limestone. Light-colored bentonitic tuff is exposed about 150 feet below the Miraleste tuff on the west slope of George F Canyon. Similar material is found on the 918-foot hill west of the canyon. The rocks penetrated in the Whites Point tunnel show that soft shale and siltstone are more abundant in this part of the section than is apparent from surface exposures. Some of the siltstone contains phosphatic nodules, and a few thin layers of blue-schist sandstone are interbedded with the siltstone Along Miraleste Canyon outcrop relations between cherty shale and overlying diatomaceous rocks were interpreted as indicating a fault with downthrow to the north.[41] According to observations in the tunnel the strata are in normal sequence. The outcrop relations are probably to be attributed to sharp folds and minor displacement.

Owing to inadequate exposures and minor structural complications, the Miraleste tuff was not mapped continuously east of George F Canyon. On the north limb of the minor anticline extending across George F Canyon and at localities farther southeast there appear to be two beds of pumice tuff, possibly due to dike-like and sill-like extensions of the tuff or to duplication by minor folds or faults.

As in the Agua Negra Canyon area, the Miraleste tuff is interbedded with diatomaceous rocks. Lenses of limestone in the diatomaceous rocks contain molds of *Siphogenerina* and *Valvulineria*. In the district between Palos Verdes Drive East and Miraleste Canyon diatomaceous strata, with which some cherty shale is interbedded, extend evidently both higher and lower in the section than in the area farther west. Though the Miraleste tuff was not observed in the Whites Point tunnel, the stratigraphic relations of the diatomaceous shale penetrated in the tunnel indicate that the division between hard cherty shale and softer diamaceous rocks is about 200 feet below the projected horizon of the

[41] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), pp. 128–129, fig. 1.

Miraleste tuff. On the preliminary geologic map[42] part of the diatomaceous rocks overlying the Miraleste tuff was assigned to the Valmonte diatomite. That member is now thought to be overlapped by the Pleistocene San Pedro sand and Lomita marl.

MIRALESTE-SAN PEDRO HILL AREA

In the deep canyons on the south slope of San Pedro Hill and in Averill Canyon beds of sandstone, some of which contain lenses of conglomerate made up chiefly of schist pebbles, are conspicuous constituents of the middle part of the Altamira. Altered diatoms occur in a thin zone included in moderately soft laminated shale exposed on Palos Verdes Drive East, about 40 feet stratigraphically above the thick basalt sill on the south limb of the Miraleste anticline. Foraminifera from silty shale at locality 4, on Crest Road, are assigned doubtfully to the *Siphogenerina reedi* zone. A collection from buff siltstone at locality 11, southeast of San Pedro Hill, is assigned to the *Siphogenerina nuciformis* zone.

East of the Cabrillo fault the Miraleste tuff is exposed on the road leading from Ninth Street to Miraleste and at two nearby localities in a tributary of San Pedro Canyon, where there are many minor folds. Diatomaceous silt at locality 5 contains Foraminifera of the *Siphogenerina reedi* zone. In San Pedro Canyon and its tributaries isolated outcrops show cherty shale and limestone dipping in various directions. The structure and stratigraphy are obscure, but presumably these strata underlie the Miraleste tuff.

The rocks penetrated in the Whites Point tunnel in the Miraleste area north of the Cabrillo fault consist of shale containing many thin beds of greenish sand and siltstone containing scattered phosphatic nodules. Two thin sills of altered basic igneous rock, one of which is too thin to be shown on the structure section (section *E—E′*, pl. 1), were encountered. South of the Cabrillo fault, beds of greenish sandstone and conglomerate several feet thick, containing schist pebbles as much as 6 inches long, are interbedded with siltstone. Higher in the section phosphatic siltstone, thin beds of sandstone, cherty shale, and limestone were encountered.

SAN PEDRO AREA

The Miraleste tuff was recognized in a ravine adjoining the west edge of Peck Park in the northwestern part of San Pedro and also in the next canyon to the north. At both localities there appear to be two beds of tuff. Foraminifera of the *Siphogenerina reedi* zone were found in steeply dipping calcareous sandstone at locality 7, on the north side of the main ravine in Peck Park, opposite a great mass of chert on the south side. The steeply dipping strata are probably faulted against flat-lying diatomaceous shale cropping out upstream. Downstream diatomaceous shale and limestone are presumably in the same part of the section as the diatomaceous shale upstream.

Along San Pedro Canyon and its main tributary, just north of Seventh Street, the complexly folded cherty shale and limestone mentioned under the heading "Miraleste-San Pedro Hill area" are overlain by diatomaceous silt and limestone, with which some cherty shale is interbedded. The lower part of the diatomaceous silt contains pebbles and slabs of schist. The largest pebble observed has a length of 10 inches, but an occasional slab of schist is as much as 2 feet long. Even as far east as a locality in San Pedro Canyon 300 feet upstream from the projection of Leland Avenue diatomaceous silt contains pieces of schist a foot long. Foraminifera from the lower part of the diatomaceous silt at locality 6 represent a fauna of small, possibly immature forms assigned doubtfully to the *Siphogenerina reedi* zone. The diatomaceous silt at locality 6 is estimated to be at about the horizon of the Miraleste tuff, which, however, was not found in this area nor farther south.

Diatomaceous silt, limestone, and thin beds of blue-schist sandstone exposed along Averill Canyon and nearby in western San Pedro represent presumably the same part of the section as that just described.

The relative abundance in the San Pedro area of diatomaceous silt in strata now assigned to the middle part of the Altamira led to the assignment of part of this section to the Valmonte diatomite member on the preliminary geologic map.[43]

POINT FERMIN AREA

In the Point Fermin area the upper part of the Altamira shale includes a coarse-grained detrital facies, less phosphatic shale, and more cherty shale than elsewhere. Consequently lithologic differentiation between the middle and upper parts of the member is indefinite. One lithologic type, however, may serve in distinguishing the two parts of the Altamira. Wherever massive siltstone was found it is referable to the middle part on both stratigraphic and faunal grounds. In the sea-cliff section on the east side of Point Fermin the base of the upper part of the Altamira is drawn arbitrarily at the base of the lower of the two thick units of blue-schist sandstone.

The strata along the Point Fermin anticline inland from the coast consist of thin-bedded blue-schist sandstone, silty shale, siltstone, cherty shale, and thin beds of phosphatic shale. The sandstone is generally medium-grained. Locally, however, it is coarse-grained and conglomeratic, as at Thirty-fifth Street and Patton Avenue, where a 1-foot bed contains pebbles and angular pieces of schist half an inch long. Foraminifera assigned to the *Siphogenerina collomi* zone were collected from massive buff siltstone at locality 12, on Alma Street.

Porcelaneous shale, silty shale, calcareous phosphatic shale, and minor beds of blue-schist sandstone form the 100-foot cliff along the crest of the Point Fermin anticline where it emerges on the coast. A thin layer of silty shale about 4 feet above the foot of the cliff (locality 8) yielded a collection of small, possibly immature, Foraminifera assigned doubtfully to the *Siphogenerina reedi* zone. The stratigraphic relations of these strata to those in western San Pedro north of the Cabrillo fault are doubtful, but they are presumably the equivalent of part of the section in western San Pedro that includes much diatomaceous silt. A local discontinuity or a bedding-plane fault was visible formerly at the foot of the cliff, about 100 feet east of the abandoned oil well (pl. 7, *B*).

The Cabrillo fault is well exposed in the sea cliff (pl. 6, *D*). South of the fault are massive buff siltstone and lenticular limestone in the middle part of the Altamira; to the north are porcelaneous shale, phos-

[42] Idem.

[43] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), pp. 128–129), fig. 1.

phatic shale, and limestone in the upper part of the Altamira. The buff siltstone contains Foraminifera typical of the *Siphogenerina reedi* zone (locality 9). The relations between the buff siltstone and the strata on the crest of the Point Fermin anticline at locality 8 are obscured by talus in the intervening area, but the siltstone is presumably younger.

In San Pedro, north of the Fort McArthur Upper Reservation and north of the Cabrillo fault, blueschist sandstone, porcelaneous shale, and silty shale are exposed in street cuts. These strata appear to grade northwestward into those including diatomaceous silt, described on page 24.

WHITES POINT AREA

No satisfactory lithologic basis for separating the middle and upper parts of the Altamira was discovered in the Whites Point area. In the preliminary paper [44] porcelaneous shale and silty shale containing Foraminifera of the *Bolivina modeloensis* zone at localities 14 and 15 were referred on lithologic grounds to a position near the top of the middle part of the Altamira. According to the classification now adopted, however, the strata are assigned to the upper part on the basis of the faunal data.

Stratigraphic relations in the strongly deformed rocks at Whites Point and nearby are obscure. The schist conglomerate, sandstone, and silty shale in the core of the fan-shaped anticline near Whites Point, shown in figure 14, and in the anticlinal reefs at the point probably represent the middle part of the Altamira. An incomplete mold of *Aequipecten* was collected from sandstone overlying schist conglomerate on the north limb of the anticline (locality 12a). In the reefs 2,000 feet northwest of Whites Point rounded masses of basalt are embedded in a limy matrix containing basaltic debris and fragments of pectens. This material represents intrusion under a thin cover of unconsolidated sediments or a submarine flow.

The oldest rocks exposed on the anticline emerging on the coast half a mile northwest of Whites Point consist of siltstone, mudstone, limestone, and a little porcelaneous shale. These strata, about 100 feet thick, and an overlying unit about 25 feet thick, mostly porcelaneous shale, are thought to represent the middle part of the Altamira. Foraminifera suggestive of the *Siphogenerina nuciformis* zone were found in calcareous mudstone exposed at low tide 1.2 miles northwest of Whites Point (locality 12b). Loose limestone masses among the reefs at that locality contain cetacean remains. Well-preserved Foraminifera, including *Siphogenerina* and *Valvulineria*, were found recently on the extension of Twenty-fifth Street, 0.45 mile southeast of the junction with Palos Verdes Drive South.

In the Whites Point area the Whites Point tunnel penetrated strata consisting of siltstone, some of which contains hard phosphatic nodules, cherty shale, limestone, and thin beds of clay. The rocks are strongly deformed in the part of the tunnel between the coast and a locality 0.3 mile inland. Poorly preserved Foraminifera of uncertain zonal position in Kleinpell's Luisian stage were collected 250 and 355 feet north of the south portal (localities 12c and 12d, respectively). At the outermost edge of the offshore reefs the open cut exposed buff sandstone underlying basaltic rocks. A diver brought up schist conglomerate about 100 feet beyond the edge of the reefs.

[44] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit., pp. 135, 142.

FOSSILS

FORAMINIFERA

Foraminifera were collected from the middle part of the Altamira shale at the localities given in the following table. At many other localities molds of *Siphogenerina* and large *Valvulineria* were observed, particularly in limestone interbedded with soft rocks near the horizon of the Miraleste tuff. These forms may be recognized in the field and are not known to occur in the upper part of the Altamira shale or at higher horizons.

The collections from the middle part of the Altamira are assigned by Kleinpell to his Luisian stage. The preservation of much of the material is poor, and the zonal position at many localities is uncertain. According to Kleinpell's identifications, however, the three zones in his Luisian stage—in ascending order the *Siphogenerina reedi*, *S. nuciformis*, and *S. collomi*—are represented. No evidence is apparent for the relative stratigraphic position of the three zones in the Palos Verdes Hills. The *S. reedi* zone appears to extend up to about the Miraleste tuff. Foraminifera characteristic of that zone were found at locality 5 in diatomaceous silt, evidently near the horizon of the Miraleste tuff. It may be expected that the *S. nuciformis* and *S. collomi* zones are in the uppermost part of the middle division of the Altamira. Stratigraphic control at the localities where these two zones are identified is lacking. Locality 10, where a few species suggestive of the *S. nuciformis* zone were found, appears to be rather low in the section for that zone. (See pl. 3.) The stratigraphic data at that locality are, however, uncertain.

The species identified by Kleinpell are given in the table on the following page.

Kleinpell's comments on these fossils are summarized as follows:

The Foraminifera from the middle part of the Altamira shale are generally poorly preserved. The preservation of the Siphogenerinas, which might give a clue to zonal position, is particularly poor in most of the collections including that genus. The best preserved material may be referred to the Luisian stage (group 2 of preliminary paper),[45] which corresponds to the undefined *Valvulineria californica* zone in its most restricted sense.

The collections from localities 3a, 12c, and 12d consist of a few poorly preserved species. Their zonal position in the Luisian stage is uncertain. Foraminifera from localities 4, 6, and 8 are assigned doubtfully to the *Siphogenerina reedi* zone (zone B of preliminary paper). Localities 6 and 8 are referable to the *S. reedi* zone or the underlying *S. branneri* zone, or possibly to even somewhat older zones. Locality 4 may be referred to either zone just mentioned but hardly to any older horizon. All three localities appear to be referable to the *S. reedi* zone rather than to older zones on the basis of rather indefinite field relations. A peculiar faunal facies, in which all the species are represented by very small possibly immature specimens, occurs at localities 6 and 8. Assemblages from localities 5 and 9 are typical of the *S. reedi* zone, and the assemblage from locality 3 appears to represent that zone. A sample that seems to be a duplicate of that from locality 3 contains *Valvulineria californica*. The assemblages from localities 3, 5, and 9 may be correlated with the typical fauna of the *S. reedi* zone of the Monterey

[45] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit., pp. 125-149.

Foraminifera from middle part of Altamira shale member of Monterey shale

[Identifications by R. M. Kleinpell. R, rare; F, few; C, common; A, abundant; cf., not certainly identified but resembles the species listed]

Species	Localities															
	Siphogenerina reedi zone (?)			*Siphogenerina reedi* zone				*Siphogenerina nuciformis* zone (?)				*Siphogenerina nuciformis* zone	*Siphogenerina collomi* zone	Zonal position uncertain		
	4	6	8	3	SPH9[1]	5	9	7	SPH12[2]	10	12b	11	12	3a	12c	12d
Robulus? cf. R. smileyi Kleinpell														R		
Hemicristellaria beali (Cushman)?						R										
Dentalina obliqua (Linné)								R		R		F				(?)
Glandulina laevigata d'Orbigny?	F															
Nonion costiferum (Cushman)?				R												
Nodogenerina advena Cushman and Laiming?						R										
Buliminella brevior Cushman	R															
Buliminella curta Cushman		R	F		R	F										
Buliminella subfusiformis Cushman		C													R	
Bulimina ovata d'Orbigny?	F															
Virgulina californiensis Cushman		F	R	(?)	(?)											
Bolivina advena Cushman			R	(?)		R										
Bolivina advena var. ornata Cushman (including Bolivina cf. B. conica Cushman) [3]			(?)			C	C								(?)	
Bolivina advena var. striatella Cushman							F									
Bolivina brevior Cushman		F			F	R										
Bolivina californica Cushman					(?)	C										
Bolivina floridana Cushman		F	R					R								
Bolivina imbricata Cushman?					R		R									
Uvigerinella californica Cushman			F			F		R				A				
Uvigerinella californica var. ornata Cushman			R													
Uvigerinella californica var. parva Kleinpell (Uvigerinella cf. U. californica Cushman)						A										
Siphogenerina cf. S. branneri (Bagg)				R												
Siphogenerina collomi Cushman													F			
Siphogenerina nuciformis Kleinpell (Siphogenerina aff. S. collomi Cushman)									cf.	F	(?)	C	C			
Siphogenerina reedi Cushman								(?)		R	F	C	R			
Valvulineria californica Cushman					R	F	A	C	C	A	R		C	F	(?)	
Valvulineria californica var. appressa Cushman					C							(?)	R			
Valvulineria californica var. obesa Cushman	R				R	A		R	F		R	A	A	R	F	F
Valvulineria miocenica Cushman?										R						
Valvulineria depressa Cushman		C	A	(?)												
Valvulineria ornata Cushman (including Valvulineria? sp.)					cf.	F	F					R				
Baggina californica Cushman						R		R	(?)	F		F			F	F
Pulvinulinella subperuviana Cushman? (Pulvinulinella? sp.)				R							R					
Cassidulina panzana Kleinpell (Cassidulina aff. C. crassa d'Orbigny)						C				R						
Cassidulina williami Kleinpell (Cassidulina cf. C. subglobosa H. B. Brady)						F										
Pullenia miocenica Kleinpell (Pullenia aff. P. sphaeroides d'Orbigny)	(?)					A	F	R	F		F		F		R	
Pullenia miocenica var. globula Kleinpell (Pullenia aff. P. sphaeroides d'Orbigny var.)											R		R			
Globigerina bulloides d'Orbigny	R		F													
Planulina cf. P. ariminensis d'Orbigny						R										
Planulina depressa d'Orbigny						R										

[1] Apparently same as locality 3.
[2] Apparently same as locality 7.
[3] Names in parentheses were used in preliminary paper (Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 2, pp. 125-149, 1936).

shale in Reliz Canyon in Monterey County,[46] with the fauna from Santa Clara County described by Chapman,[47] and with the fauna of the Claremont shale in the Monterey group of Contra Costa County.[48]

Locality 11 represents the *S. nuciformis* zone (zone C of preliminary paper), which overlies the *S. reedi* zone. The *S. nuciformis* zone is particularly well developed in the Monterey on Chico Martinez Creek, on the west side of San Joaquin Valley, where it is known locally as "the *Valvulineria* flood zone."[49] The assemblages from localities 7, 10, and 12b are suggestive of the *S. nuciformis* zone rather than the *S. reedi* zone. A sample that appears to be a duplicate of that from locality 7 contains a *Siphogenerina* that may be *S. nuciformis*.

Locality 12 represents a still higher zone, the *S. collomi* zone (zone D of preliminary paper). The assemblage from locality 12 may be correlated with that from the frequently cited locality in the lower part of the Monterey shale in the type region near Monterey, on Seventeen-mile Drive, three-quarters of a mile toward Pebble Beach from the tollhouse (Leland Stanford Junior University locality 333).[50]

MOLLUSKS

Mollusks are rare in the middle part of the Altamira shale but are more abundant than in other divisions of the Monterey in the Palos Verdes Hills. Those that were found occur in sandstone and are of shallow-water facies. A mold of a small right valve of *Aequipecten andersoni*[51] (pl. 28, fig. 11) and an incomplete mold of *Anadara*? were collected from sandstone at locality 2b, on the north limb of the Bluff Cove anticline. An incomplete mold from sandstone on the north limb of the fan-shaped anticline near Whites Point (locality 12a) is identified as *Aequipecten* cf. *A. andersoni*. A lens of hard concretionary sandstone at locality 13, on the west side of George F Canyon, yielded the only large collection. The fossiliferous lens

[46] Kleinpell, R. M., Miocene Stratigraphy of California, p. 125, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938.
[47] Chapman, Frederick, Foraminifera from the Tertiary of California: California Acad. Sci. Proc., 3d ser., vol. 1, pp. 241-260, pls. 29, 30, 1900.
[48] Kleinpell, R. M., op. cit., p. 56.
[49] Kleinpell, R. M., op. cit., p. 125.
[50] Kleinpell, R. M., op. cit., p. 127.
[51] The type material of this species, which has recently been recorded as "lost (?)" (Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, p. 203, 1931), is in the National Museum (catalog No. 164932).

is in the upper part of the sandstone overlying the schist basement. Most of the specimens are in the form of molds and impressions, some of which yield satisfactory guttapercha squeezes. A few similarly preserved species were found at a nearby locality (locality 13a), also near the top of sandstone resting on schist.

The species collected from the middle part of the Altamira shale are given in the following table:

Mollusks from middle part of Altamira shale member of Monterey shale

[Identifications by W. P. Woodring. R, rare; F, few; C, common; A, abundant; cf., not certainly identified but resembles the species listed]

Species	Localities			
	13	13a	2b	12a
Gastropods:				
Acmaea cf. A. scabra (Gould)	R			
Diodora aff. D. aspera ("Eschscholtz" Rathke)	F			
Calliostoma cf. C. supragranosum Carpenter	R			
Homalopoma? sp	R			
Lacuna? sp. (or Tricolia? sp.)	A			
Turritella ocoyana Conrad (small specimens) (pl. 28, figs. 1, 2)	C	R[1]		
Strombus cf. S. gatunensis Toula (pl. 28, figs. 3, 4)	F			
Hipponix cf. H. "barbatus Sowerby"	R	(?)		
Crepidula praerupta Conrad?	F			
Crucibulum sp	R	R		
Crucibulum? cf. C. imbricatum (Sowerby)	F			
Neverita? cf. N. reclusiana (Deshayes) (small specimens) (Neverita cf. N. reclusiana (Deshayes)) [2]	A	R		
"Nassa" aff. "N." arnoldi Anderson	C			
"Nassa" aff. "N" cooperi Forbes	F			
"Phos" dumbleanus Anderson (Tritiaria (Antillophos) dumblei (Anderson)) (pl. 28, figs. 5, 6)	R			
"Murex" cf. "M." wilkesanus (Anderson) ("Murithais" wilkesanus (Anderson)?)	F			
"Purpura"? cf. "P. foliata Martyn" (Purpura? cf. P. foliata Martyn)	R			
Tritonalia? sp	R			
Cancellaria cf. C. condoni Anderson (pl. 28, fig. 8)	R			
Mitrella cf. M. tuberosa (Carpenter)	C			
Anachis (Costoanachis) sp. (pl. 28, fig. 7)	C			
Olivella pedroana (Conrad)?	C			
Knefastia cf. K. funiculata (Valenciennes) (pl. 28, fig. 13)	R			
Crassispira sp. (cf. undescribed species from Gulf of California in U. S. Nat. Mus.)	R			
Agladrillia? sp	R			
"Clavatula" cf. "C." labiata Gabb (pl. 28, fig.9)	F			
Terebra (Paraterebra) cf. T. (P.) lepta Woodring		R		
Terebra (Strioterebrum) cf. T. wolfgangi Toula (small specimens)	F			
Conus owenianus Anderson (pl. 28, figs. 14, 15)	A			
Conus cf. C. fergusoni Sowerby (small specimen)	R			
Scaphander? sp	R			
Bulla cf. B. cantuaensis Anderson (Bulla cantuaensis Anderson?)	A			
Scaphopod:				
Dentalium sp	C			
Pelecypods:				
Anadara aff. A. osmonti (Dall)		R	(?) sp.	
Mytilus? sp	R			
Aequipecten andersoni (Arnold) (pl. 28, fig. 11)		(?)	R	cf.
Aequipecten cf. A. sancti-ludovici (Anderson and Martin) (pl. 28, fig. 10)	R			
Lima cf. L. dehiscens Conrad	R			
Crassinella cf. C. mexicana Pilsbry and Lowe (Gouldia? sp.) (pl. 28, fig. 12)	R			
Miltha sanctaecrucis (Arnold) (pl. 28, fig. 16)	A			
Divaricella cf. D. eburnea (Reeve) (pl. 28, figs. 17, 20, 21)	A			
Tellina cf. T. nevadensis Anderson and Martin	F			
Tellina cf. T. idae Dall	R			
Tellina cf. T. reclusa Dall	F			
Dosinia aff. D. ponderosa (Gray) (pl. 28, figs. 18, 22)	A	F		
Macrocallista cf. M. maculata (Linné) (pl. 28, fig. 19)	A			
Amiantis? sp	R			
Chione cf. C. succincta (Valenciennes)	C			
Chione (Lirophora) aff. C. mariae (d'Orbigny) (Chione (Lirophora) aff. C. latilaminosa Anderson and Martin, (pl. 28, fig. 23)	C			
Callithaca? cf. C. staminea (Conrad)	R			
Transennella cf. T. tantilla (Gould)	R			
Trachycardium aff. T. quadragenarium (Conrad)	C			
Trachycardium aff. T. consors (Sowerby)	A			
Trigoniocardia aff. T. antillarum (d'Orbigny) (Trigoniocardia cf. T. haitensis (Sowerby)) (pl. 28, figs. 24, 25)	A			
Panope cf. P. estrellana (Conrad)	C			

[1] Impression of large carinate specimen. Not collected.
[2] Names in parentheses were used in preliminary paper (Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 2, pp. 125-149, 1936).

Though the material from localities 13 and 13a is poorly preserved, it represents an essentially new fauna for the Coast Ranges. *Strombus* (pl. 28, figs. 3, 4), *Costoanachis* (pl. 28, fig. 7), *Knefastia* (pl. 28, fig. 13), "*Clavatula*," (pl. 28, fig. 9), *Paratereba* in the restricted sense, *Crassinella* (pl. 28, fig. 12), *Divaricella* (pl. 28, figs. 17, 20, 21), and *Trigoniocardia* (pl. 28, figs. 24, 25) have not been recorded from the Miocene of coastal California and the San Joaquin Valley; "*Phos*" (pl. 28, figs. 5, 6) and *Lirophora* (pl. 28, fig. 23) have not been found heretofore in the Coast Ranges. The three following factors may have a bearing on the composition of this fauna—location, horizon, and preservation of small species. (1) The genera and subgenera constituting new records are tropical migrants that may not have ranged much farther northward during Miocene time. (2) According to the stratigraphic position of the fossiliferous sandstone with reference to the Miraleste tuff, the fauna is evidently approximately in the *Siphogenerina reedi* zone; that is, near the base of the *Valvulineria californica* zone in the restricted sense. The fossiliferous sandstone may be older than the *S. reedi* zone, as it may represent long-continued deposition on a schist ridge. The field relations suggest, however, that the sandstone is as young as the *S. reedi* zone. Mollusk faunas of comparable size have not been found elsewhere in California in the approximate position of the *S. reedi* zone. In the Coast Ranges strata in that part of the Miocene section consist generally of fine-grained rocks in which mollusks are absent. (3) Small species of mollusks are generally rare in the California Miocene. "*Phos*" and *Lirophora* are recorded from the Bakersfield region on the east side of the San Joaquin Valley but not from other localities.

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Turritella ocoyana (pl. 28, figs. 1, 2), "*Nassa*" aff. "*N.*" *arnoldi*, "*Phos*" *dumbleanus* (pl. 28, figs. 5, 6), *Cancellaria* cf. *C. condoni* (pl. 28, fig. 8), *Conus oweni-anus* (pl. 28, figs. 14, 15), and *Aequipecten andersoni*? suggest the Temblor fauna as that term is generally used. According to Kleinpell's interpretation of the succession of foraminiferal zones, the fauna from the Palos Verdes Hills is younger than the Barker's Ranch fauna [52] in the Bakersfield region—a fauna that has a comparable proportion of small species and is considered characteristic of the Temblor. Mollusks from the Topanga formation in the Santa Monica Mountains [53] and from strata assigned to the Temblor along the coast southeast of the Palos Verdes Hills [54] consist principally of large species. Foraminifera from the lower part of the Topanga formation are assigned by Kleinpell to the *Siphogenerina branneri* zone, which is identified in the lower part of the Altamira shale. The upper part of the Topanga formation may, however, include deposits of the same age as the middle part of the Altamira. The fauna of the Oursan sandstone and Hambre sandstone of the Monterey group in the San Francisco Bay region also consists principally of large species.[55] These sandstone formations in the Monterey group are referred by Kleinpell to horizons higher than the middle part of the Altamira shale.

Strombus and *Divaricella* are found in the Imperial formation of the Colorado Desert.[56] The Imperial fauna includes species that are more similar to Caribbean Miocene fossils than to fossil or living species from the Pacific coast. The following species from the Palos Verdes Hills appear also to show that relation: *Strombus* cf. *S. gatunensis* (pl. 28, figs. 3, 4), "*Clavatula*" cf. "*C.*" *labiata* (pl. 28, fig. 9), *Terebra* cf. *T. lepta*, *Terebra* cf. *T. wolfgangi*, *Macrocallista* cf. *M. maculata* (pl. 28, fig. 19), and *Trigoniocardia* aff. *T. antillarum* (pl. 28, figs. 24, 25).[57] The preservation of some of these species is so poor, however, that their affinities are not certain. The similarity between the Imperial fauna and the fauna from the Palos Verdes Hills may have no age significance, as it may be the result of derivation from the same source. The Imperial formation is considered of Miocene age by some paleontologists and of Pliocene age by others.[58]

UPPER PART

The upper part of the Altamira shale is characterized generally by abundance of phosphatic shale, the phosphatic material forming thin light-colored or brownish layers or nodules. In many areas, particularly in the western part of the hills, brown bituminous shale is interbedded with the phosphatic shale. Phosphatic shale is a minor constituent of the middle part of the Altamira, and the Valmonte diatomite member includes locally thin layers of phosphatic material.

In the western half of the hills the top of the upper division of the Altamira corresponds approximately to the transition from hard cherty to soft diatomaceous rocks. On the northeast and east slopes the upper division includes, however, diatomaceous strata that contain blue-schist debris and that are interbedded with fine-grained blue-schist sandstone and phosphatic shale. In the Whites Point area cherty shale is more abundant than elsewhere.

A peculiar lithologic facies, consisting of thick blue-schist conglomeratic sandstone and brecciated shale, is represented in the Point Fermin area. In that area the thickness and grain size of the sandstone decrease northward. The thin layers of fine-grained blue-schist sandstone and the diatomaceous silt containing schist debris farther north are thought to be the equivalent of the coarse-grained sandstone of the Point Fermin area. The schist debris was derived evidently from a schist area farther south, now covered by the ocean, as was inferred for the San Onofre breccia, a Miocene formation in the coastal district southeast of the Palos Verdes Hills.[59]

Natural exposures of the soft shale constituting a large part of the upper division of the Altamira in most areas are found only along the sea cliff and in some of the deep canyons. The best exposures are in the Lunada Bay and Malaga Cove areas, in the cliffs near the head of Altamira Canyon and its tributaries, and at Point Fermin. The thickness appears to be as much as 300 feet, possibly even as much as 400 feet, in the Malaga Cove area and 250 feet in the Lunada Bay area. In a tributary of the middle fork of Altamira Canyon the thickness is 185 feet, and in the east fork of Altamira Canyon, 1,500 feet to the southeast, it diminishes to 95 feet. In the Point Fermin area the thickness is at least 300 feet, and the top is not exposed. In that area, however, sandstone forms two thick units.

Foraminifera assigned to the *Bolivina modeloensis* zone and the overlying *Bulimina uvigerinaformis* zone were found in strata referred to the upper part of the Altamira.

STRATIGRAPHY AND LITHOLOGY

MALAGA COVE AREA

Strata assigned to the upper part of the Altamira shale are exposed in the sea cliff southwest of the Malaga Cove beach clubhouse, near the mouth of Malaga Canyon. They consist of phosphatic shale with which cherty shale and limestone are interbedded. The proportion of cherty shale and limestone decreases upward in the section. The lithology in this area is shown in the following sections (column 1, pl. 3). The exceptionally great thickness suggests some duplication in the two sections; however, the thickness is at least 270 feet and may be as much as 400 feet, the combined thickness of the two sections. If the opal concretions in the underlying middle part of the Altamira are at the same horizon as in the Altamira Canyon area (columns 2, 3, pl. 3), the base of the upper part of the Altamira is drawn at essentially the same horizon in the two areas.

[52] The Barker's Ranch species have been described or recorded in the following publications: Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., vol. 2, pp. 187–188, 195–206, pls. 14–16, 1905; The Neocene deposits of Kern River, Calif., and the Temblor Basin: Idem, 4th ser., vol. 3, pp. 99–100, 1911. Anderson, F. M., and Martin, Bruce, Neocene record in the Temblor Basin, Calif., and Neocene deposits of the San Juan district, San Luis Obispo County: Idem, 4th ser., vol. 4, pp. 41–44, 52–96, pls. 1–8, 1914.

[53] Arnold, Ralph, New and characteristic species of fossil mollusks from the oil-bearing Tertiary formations of southern California: U. S. Nat. Mus. Proc., vol. 32, pp. 525–526, 528–534, pls. 40–46, 1907. Arnold, Ralph, in Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: U. S. Geol. Survey Bull. 309, pp. 147–148, pls. 27–33, 1907. Kew, W. S. W., Geology and oil resources of a part of Los Angeles and Ventura Counties, Calif.: U. S. Geol. Survey Bull. 753, pp. 50–51, 1924. Woodring, W. P., in Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.; U. S. Geol. Survey Prof. Paper 165, pp. 100–101, 1931.

[54] Woodford, A. O., The San Onofre breccia: California Univ., Dept. Geol. Sci., Bull., vol. 15, p. 208, 1925.

[55] Merriam, J. C., in Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (No. 193), p. 11, 1914.

[56] Hanna, G. D., Paleontology of Coyote Mountain, Imperial County, Calif.: California Acad. Sci. Proc., 4th ser., vol. 14, pp. 454–455, 464–465, pls. 20, 26, 1926.

[57] *Macrocallista maculata* has a range from Miocene to Recent in the Caribbean region. *Trigoniocardia antillarum* is a Recent Caribbean species, the Caribbean Miocene allies of which have been overnamed.

[58] Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif., and their inferred environment: U. S. Geol. Survey Prof. Paper 190, pp. 46–47, 1938.

[59] Woodford, A. O., The San Onofre breccia: California Univ., Dept. Geol. Sci. Bull., vol. 15, p. 140, 1925.

Section of upper part of Altamira shale member of Monterey shale in sea cliff southwest of mouth of Malaga Canyon

	Ft.	in.
30. Phosphatic shale and thin zones of cherty shale. Overlain 60 feet southwest of beach clubhouse by laminated diatomaceous and phosphatic shale mapped as base of Valmonte diatomite member of Monterey shale	9	0
29. Limestone	2	6
28. Unexposed, except occasional beds of limestone and cherty shale. Evidently mostly soft shale	46	0
27. Phosphatic shale and a few thin zones of cherty shale	22	0
26. Limestone	1	4
25. Phosphatic shale and a few thin zones of cherty shale, especially in lower part	35	0
24. Brecciated limestone	2	6
23. Phosphatic shale and cherty shale	15	0
22. Limestone	1	5
21. Phosphatic shale	4	6
20. Limestone	1	9
19. Unexposed, except few beds of phosphatic shale and limestone	30	0
18. Phosphatic shale	15	0
17. Limestone	1	7
16. Phosphatic shale	15	0
15. Limestone	3	0
14. Phosphatic shale	18	0
13. Limestone	1	0
12. Phosphatic and cherty shale	1	3
11. Limestone	2	0
10. Phosphatic shale	1	4
9. Limestone	1	0
8. Poorly exposed phosphatic shale	4	6
7. Limestone	1	6
6. Phosphatic shale containing crushed and leached Foraminifera. Thin zones of cherty shale near top	7	0
5. Limestone	1	0
4. Phosphatic and calcareous shale, including thin zones of cherty shale	4	6
3. Limestone	2	0
2. Unexposed	18	0
1. Limestone	3	6
Thickness of section	272	2

The following section is a continuation of the preceding section southwestward along the sea cliff. There is some evidence of faulting, however, at the locality where the sections join.

Section of upper part of Altamira shale member of Monterey shale in sea cliff immediately southwest of preceding section

	Ft.	in.
28. Phosphatic shale	3	6
27. Limestone	1	4
26. Phosphatic shale	2	6
25. Limestone	1	6
24. Phosphatic shale and thin zones of cherty shale	3	6
23. Limestone	3	0
22. Cherty shale, calcareous phosphatic shale, and limestone. A 5-inch layer of sandy bentonitic tuff 10 inches from top	10	0
21. Limestone	1	6
20. Cherty and calcareous shale	5	5
19. Limestone	3	0
18. Cherty and calcareous shale	5	0
17. Limestone	2	9
16. Cherty shale, calcareous shale, phosphatic shale, and limestone	11	6
15. Limestone	1	4
14. Limestone, calcareous shale, phosphatic shale, and cherty shale	8	0
13. Limestone	1	0
12. Laminated chert		10
11. Thin-bedded limestone		10
10. Phosphatic and cherty shale	4	6
9. Concealed by retaining wall at pier	33	0
8. Phosphatic and cherty shale	9	0
7. Limestone	1	10
6. Phosphatic and cherty shale	5	0
5. Limestone	5	10
4. Phosphatic shale	3	6

Section of upper part of Altamira shale member of Monterey shale in sea cliff immediately southwest of preceding section—Continued

	Ft.	in.
3. Calcareous, phosphatic, and cherty shale	2	6
2. Limestone	2	0
1. Phosphatic shale. Underlain by strata assigned to middle part of Altamira shale. For downward continuation of section see p. 20	5	6
Thickness of section	139	2

Phosphatic shale is exposed in road cuts on the flanks of the syncline on the upper slope of the hills in the southeastern part of the Malaga Cove residential district inland from Bluff Cove.

LUNADA BAY AREA

Bituminous and phosphatic shale crop out along Lunada Bay on the south limb of the syncline emerging on the coast on the south side of Palos Verdes Point (pl. 8). The fresh bituminous shale is dark brown; weathered surfaces are light buff-gray. The phosphatic layers are grayish-brown on unweathered surfaces and greenish yellow on weathered surfaces. The shale in the sea cliff at Lunada Bay, north of the mouth of Agua Amarga Canyon, is reddish and black, owing to combustion of organic matter in the bituminous shale. A section that includes strata in the middle and upper parts of the Altamira, as exposed in Agua Amarga Canyon at the head of Lunada Bay, is as follows:

Section of upper and middle parts of Altamira shale member of Monterey shale in Agua Amarga Canyon at head of Lunada Bay

	Ft.	in.
Upper part:		
41. Limestone	1	5
40. Bituminous phosphatic shale, weathering like unit 35. A few thin beds of harder shale	7	9
39. Concretionary limestone containing pieces of large bones, presumably cetacean remains	1	6
38. Bituminous phosphatic shale, weathering like unit 35, and zones 2 to 3 inches thick of harder somewhat porcelaneous shale	9	6
37. Platy limestone and calcareous siltstone	1	6
36. Porcelaneous shale		5
35. Bituminous phosphatic shale. Main part of shale weathers light buff gray; phosphatic layers weather greenish yellow	11	0
34. Blocky-weathering limestone	3	10
33. Tuffaceous (?) sandstone stained greenish	1	2
32. Mostly porcelaneous shale	2	0
31. Poorly exposed siltstone, bituminous shale, and harder porcelaneous shale	10	0
30. Fresh brown bituminous phosphatic shale, somewhat porcelaneous	1	10
29. Chert lens		2–4
28. Fine-grained calcareous (?) sandstone; includes 3-inch chert lens		10
27. Fissile brown bituminous phosphatic shale	2	3
26. Siltstone and fine-grained calcareous (?) sandstone	1	8
25. Platy somewhat porcelaneous brown shale	1	3
24. Brown bituminous shale containing a few phosphatic nodules	4	7
23. Limestone	1	2
22. Brown bituminous shale. Lower foot somewhat harder than remainder	2	9
21. Limestone	1	7
20. Brown bituminous phophatic shale	16	0
19. Limy siltstone and limestone. Includes a half-inch bentonitic (?) clay	2	7
18. Brown bituminous phosphatic shale containing leached Foraminifera	12	0
Middle part:		
17. Laminated silty limestone	2	2
16. Fissile, somewhat porcelaneous shale containing phosphatic nodules	3	0
15. Alternating porcelaneous and softer shale	6	0
14. Porcelaneous shale	1	4

Section of upper and middle parts of Altamira shale member of Monterey shale in Agua Amarga Canyon at head of Lunada Bay—Continued

	Ft.	in.
Middle part—Continued.		
13. Fissile, somewhat porcelaneous shale		5
12. Porcelaneous shale	2	2
11. Fissile, somewhat porcelaneous shale	1	3
10. Hard cherty shale		9
9. Calcareous siltstone	1	2
8. Hard cherty shale	1	11
7. Brown somewhat porcelaneous shale		11
6. Hard cherty shale in layers 1 to 3 inches thick alternating with softer shale in layers ½ to 1 inch thick	5	8
5. Soft, somewhat porcelaneous shale	3	1
4. Brown phosphatic shale		7
3. Tuffaceous (?) sandstone		3
2. Dark brown shale containing phosphatic stringers	2	11
1. Calcareous siltstone. Base not exposed	2	8
Thickness of section	135	2

A thickness of approximately 100 feet in the foregoing section is assigned to the upper part of the Altamira shale. The uppermost part of this division is exposed in the trough of the syncline on the south side of Palos Verdes Point under a thin cover of the overlying Valmonte diatomite member, where the section given below was measured. This section and that measured on Agua Amarga Canyon could not be certainly tied together, owing to a possible fault in the area of burnt shale immediately to the left of the relatively steeply dipping strata shown on plate 8. If there is no significant break in that area, the base of the Palos Verdes Point section is estimated to be about 150 feet above unit 34 of the Agua Amarga Canyon section, making a total estimated thickness of about 250 feet for the upper part of the Altamira.

Section of upper part of Altamira shale member and Valmonte diatomite member of Monterey shale in sea cliff on south side of Palos Verdes Point

	Ft.	in.
Valmonte diatomite member:		
16. Diatomaceous and phosphatic shale. Thickness estimated	10	0
15. Phosphatic shale. Thickness estimated	10	0
14. Lens of diatomaceous shale		6
13. Silty phosphatic shale	6	6
12. Diatomaceous and phosphatic shale	3	2
Upper part of Altamira shale member:		
11. Phosphatic shale stained greenish yellow and thin zones of harder shale	6	7
10. Porcelaneous shale		6
9. Limestone	1	0
8. Phosphatic shale		11
7. Porcelaneous shale and thin zones of softer bituminous shale	3	5
6. Phosphatic shale		10
5. Limestone	1	3
4. Porcelaneous shale and thin zones of softer bituminous shale	4	9
3. Bituminous shale, including a 2-inch layer of harder shale	2	8
2. Porcelaneous shale	1	11
1. Limestone	3	6
Thickness of section	57	6

Bituminous shale and phosphatic shale, locally burnt, are exposed in highway cuts in the synclinal area in the eastern part of the Margate residential area inland from Lunada Bay.

CREST OF HILLS

Phosphatic shale, including toward the top thin laminae of diatomaceous shale, underlies the flanks of the broad, shallow syncline along the crest of the hills, but is well exposed only in the cliffs near the head of Altamira Canyon and its tributaries and in highway cuts. In the following section, measured in a tributary of the middle fork of Altamira Canyon (third canyon from right in background, pl. 4), strata assigned to the upper part of the Altamira have a thickness of about 185 feet (column 2, pl. 3).

Section of Monterey shale, including upper part of Altamira shale member, in tributary of middle fork of Altamira Canyon

	Ft.	in.
Valmonte diatomite member:		
58. Limestone	1	0
57. White silty shale		3
56. Bentonitic clay		2
55. Diatomaceous shale		6
54. Laminated cherty and porcelaneous shale	5	6
53. Diatomite	10	0
52. Laminated chert		1–6
51. White silty shale		10
50. Limestone	1	6
49. Diatomaceous shale and diatomite	3	0
48. Laminated cherty and diatomaceous shale		11
47. Diatomaceous shale and diatomite	4	6
46. Laminated chert		3
45. Diatomaceous shale	3	0
44. Laminated chert		5
43. White silty shale, thin laminae diatomaceous	3	0
42. Porcelaneous shale		3
41. White silty shale	4	0
40. Limestone mapped as base of Valmonte diatomite	8	0
Altamira shale member:		
Upper part:		
39. Phosphatic shale and diatomaceous shale in thin laminae		11
38. Poorly exposed brown phosphatic shale; a few diatoms in some layers	7	6
37. Limestone		7
36. Poorly exposed brown phosphatic shale	12	6
35. Limestone	1	0
34. Brown phosphatic shale, lower part poorly exposed	10	8
33. Limestone		6
32. Poorly exposed brown phosphatic shale and thin laminae of white diatomaceous shale. Laminae of diatomaceous shale more abundant than in unit 30, gradually less abundant upward	12	0
31. Limestone	1	0
30. Poorly exposed brown phosphatic shale and thin white laminae of diatomaceous shale, some layers of which consist mostly of *Thalassiothrix*	5	0
29. Brown phosphatic shale and thin zones of porcelaneous shale	15	0
28. Limestone	2	7
27. Brown phosphatic shale including 7 zones of porcelaneous shale 1 to 3 inches thick	20	7
26. Limestone	2	2
25. Unexposed	4	0
24. Brown phosphatic shale; a few thin zones of porcelaneous shale in lower half	20	6
23. Limestone	1	9
22. Unexposed	4	0
21. Brown bituminous shale and thin zones of porcelaneous shale	11	2
20. Brown bituminous shale, a few phosphatic nodules	5	3
19. Dense limestone	3	0
18. Unexposed	3	0
17. Brown phosphatic shale	4	0
16. Limestone	1	0
15. Brown phosphatic shale	3	10
14. Limestone containing phosphatic nodules		11
13. Brown bituminous shale containing phosphatic nodules	6	11
12. Poorly exposed soft shale and thin zones of porcelaneous shale	11	6
11. Limestone	1	3
10. Brown bituminous shale, lower part containing scattered phosphatic nodules and upper part including many thin phosphatic layers	3	0

Section of Monterey shale, including upper part of Altamira shale member, in tributary of middle fork of Altamira Canyon—Con.

	Ft.	in.
Altamira shale member—Continued.		
Middle part:		
9. Rhythmically bedded porcelaneous shale	3	5
8. Limestone	1	8
7. Poorly exposed hard cherty shale	3	0
6. Rhythmically bedded cherty and porcelaneous shale including 3 layers of opal concretions 1½, 6, and 9 feet, respectively, above base	10	7
5. Soft porcelaneous shale	1	6
4. Limestone	1	8
3. Porcelaneous shale		8
2. Unexposed	6	0
1. Rhythmically bedded cherty and porcelaneous shale including 3 layers of opal concretions 4, 6⅔, and 8 feet, respectively, above base	12	0
Thickness of section	265	2

A section measured in the east fork of Altamira Canyon (first canyon from right in background, pl. 4), 1,500 feet southeast of the preceding section, is as follows (column 3, pl. 3):

Section of upper part of Altamira shale member of Monterey shale in east fork of Altamira Canyon

	Ft.	in.
15. Unexposed. Overlain by limestone, apparently the bed mapped farther west as base of Valmonte diatomite member, which, however, is not exposed here	16	6
14. Limestone	3	9
13. Unexposed	14	0
12. Limestone	2	6
11. Poorly exposed phosphatic shale	18	0
10. Limestone	2	10
9. Unexposed	4	0
8. Brown nodular phosphatic shale	6	0
7. Sandstone containing blue schist shreds		3
6. Soft porcelaneous shale	1	11
5. Poorly exposed soft shale	5	0
4. Limestone	3	6
3. Poorly exposed phosphatic shale	10	0
2. Limestone	1	0
1. Soft silty shale and nodular phosphatic shale. Underlain by strata assigned to middle part of Altamira shale member. For downward continuation of section see p. 21	6	6
Thickness of section	95	9

Whether the apparent eastward thinning shown by the preceding two sections represents actual thinning or lateral gradation is uncertain. It is reasonably certain, however, that the top of the upper part of the Altamira is placed at the same horizon in the two sections, and the opal concretions suggest that the base is also. The less definite sections in the Malaga Cove and Lunada Bay areas suggest a southward thinning.

NORTH SLOPE OF HILLS

The upper part of the Altamira shale is poorly exposed on the north slope of the hills. Scattered highway cuts suggest that phosphatic shale is less abundant than in the areas already described and that diatomaceous silt and diatomaceous shale are more abundant. A cut on Palos Verdes Drive North, 700 feet southeast of locality 88, exposes soft shale, including phosphatic shale and diatomaceous shale, overlying cherty shale. The soft shale is thought to represent the base of the upper part of the Altamira. On the abandoned road from the Valmonte residential district to the plant of the Dicalite Co., on the north side of Valmonte Canyon, a bed of vitric volcanic ash 4¼ feet thick is interbedded with limestone, diatomaceous shale, and cherty shale apparently near the top of the Altamira. This is the greatest thickness of unaltered volcanic ash observed in any part of the Monterey. Phosphatic shale was not found on the north side of Valmonte Canyon, but soft white shale in that area may represent leached phosphatic shale. Cuts on Palos Verdes Drive East south of George F Canyon show diatomaceous silt, a little phosphatic shale, and beds a fraction of an inch to 2 inches thick of fine-grained silty sand containing much blue-schist debris.

SAN PEDRO AREA

The upper part of the Altamira, as now identified, crops out in western San Pedro. In that area two poorly defined units are recognized, a lower unit consisting of diatomaceous shale and fine-grained blue-schist sandstone and an upper unit consisting of diatomaceous shale and phosphatic shale. The lower unit is thought to correspond to the thick blue-schist sandstone of the Point Fermin area, including shale containing Foraminifera of the *Bolivina modeloensis* zone. The upper unit is correlated with cherty and phosphatic shale at Cabrillo Beach containing Foraminifera of the *Bulimina uvigerinaformis* zone. Owing to the prevalence of diatomaceous rocks, part of the strata in western San Pedro was grouped formerly with the overlying Valmonte diatomite member.[60]

In Peck Park the upper part of the Altamira is made up of diatomaceous silt and fine-grained blue-schist sandstone overlain by diatomaceous shale and phosphatic shale. Limestone occurs throughout but is less abundant upward. Toward the top of the section a few beds of vitric volcanic ash an inch or two thick are interbedded with the shale. In one bed the glass shards are stained black with a film of organic matter. Phosphatic shale is well exposed on Twenty-first and Twenty second Streets between Meyler and Cabrillo Avenues. On Twentieth Street, 120 feet east of Meyler Avenue, phosphatic shale appears to be faulted against diatomaceous shale mapped as the Valmonte member.

On the north side of the Cabrillo fault at Cabrillo Beach (pl. 6, *D*), limestone, porcelaneous shale, and phosphatic shale underlie the Valmonte diatomite member. Though these strata are near the top of the upper part of the Altamira shale, they include porcelaneous shale, which was not observed in the area just described. Foraminifera of the *Bulimina uvigerinaformis* zone were collected 200 feet north of the fault (locality 17).

POINT FERMIN-WHITES POINT AREA

A facies quite different from any so far described is represented at Point Fermin. In that area the upper part of the Altamira includes thick beds of blue-schist sandstone and breccia (column 8, pl. 3). The total thickness is difficult to estimate but is at least 300 feet.

On the east side of Point Fermin these strata consist of two sandstone units and an intervening shale unit. The base of the lower sandstone is selected arbitrarily as the base of the upper part of the Altamira. This unit (right foreground, pl. 9, *B*) is about 100 feet thick but thins northeastward. It is composed of blue-schist sandstone, minor beds of breccia, and interbedded silty and phosphatic shale. The overlying shale, made up

[60] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), pp. 128-129, fig. 1.

chiefly of rather soft porcelaneous shale and silty shale, is almost 100 feet thick at the top of the cliff but thins southwestward down the cliff, evidently through gradation into the sandstone forming the overlying unit.

The upper sandstone forms the 100-foot sheer cliff at the Point (pl. 9) and has approximately that thickness. It consists of blue-schist sandstone, bituminous and phosphatic shale, and breccia. The sandstone is of coarser grain than that in the lower unit and contains pieces of schist generally a few inches long but exceptionally as much as 7 feet long. The beds of sandstone are as much as 5 to 10 feet thick. Some contain bone fragments, one of which was observed to have a brilliant blue coat, presumably vivianite. The bituminous and phosphatic shale is thin-bedded, and some layers contain diatoms. The thickness of the beds of breccia ranges from a fraction of a foot to several feet. Most of the beds consist of shale fragments ranging in length from a few inches to several feet (pl. 10, *B*). Layers of shale can be traced into breccia composed of shale fragments of identical composition and embedded in a sandstone matrix like that interbedded with the shale. Breccia composed of sandstone or of mixtures of shale and sandstone is relatively rare. The breccias were formed evidently while the sediments were being deposited; that is, they are evidently penecontemporaneous, and the shale and sandstone were consolidated enough to form fragments when they were ruptured. The rupturing may have been due to earthquake jars and submarine sliding. The entire upper sandstone has other curious depositional features. At the base of many of the beds of sandstone is a scour discontinuity, as may be seen on plate 10, *B*. Discordant contacts, including truncation of minor folds, are common. Isolated fragments of shale occur in sandstone, and sandstone grades laterally into shale.

On the west side of Point Fermin (pl. 9, *A*) the shale underlying the upper sandstone appears to be thicker than on the east side, but much of it is obscured by talus. As exposed on the cliff it consists of porcelaneous and silty shale underlain by silty shale, phosphatic shale, and thin beds of fine-grained blue-schist sandstone. A 3-foot bentonitic tuff is included in the shale 15 feet below the irregular contact at the base of the upper sandstone. Foraminifera of the *Bolivina modeloensis* zone were found in silty shale at the foot of the cliff about 65 feet stratigraphically below the base of the upper sandstone (locality 16).

Half a mile to a mile northwest of Point Fermin blue-schist sandstone including a few beds of brecciated shale is exposed along the sea cliff. This sandstone corresponds apparently to the lower sandstone on the east side of Point Fermin. The mineralogy of a sample of sandstone from this area was described by Woodford.[61] Silty shale at the top of the cliff, along the road leading to Whites Point, contains Foraminifera of the *Bolivina modeloensis* zone (locality 14). This shale appears to overlie the sandstone just mentioned.

The upper and middle parts of the Altamira are not satisfactorily differentiated in the area inland from Whites Point. Silty shale interbedded with cherty shale at locality 15 contains Foraminifera assigned doubtfully to the *Bolivina modeloensis* zone. Phosphatic shale was not observed in this region.

FOSSILS

FORAMINIFERA

Identifiable Foraminifera were found in the upper part of the Altamira shale only at localities near Point Fermin and Whites Point. Leached and crushed Foraminifera were observed in the more typical phosphatic and bituminous shale of other areas. The material collected is assigned by Kleinpell to his Mohnian stage, the base of which corresponds to the base of the upper Miocene according to current Coast Range usage. The faunas from localities 14 and 16, and doubtfully from locality 15, are referred to the *Bolivina modeloensis* zone (zone E of preliminary paper)[62] and that from locality 17 to the overlying *Bulimina uvigerinaformis* zone (zone F of preliminary paper). Locality 17 is close to the top of the Altamira shale according to the stratigraphic classification adopted.

The following species were identified by Kleinpell:

[61] Woodford, A. O., The San Onofre breccia: California Univ., Dept. Geol. Sci., Bull., vol. 15, p. 210, 1925.

[62] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), pp. 125-149.

Foraminifera from upper part of Altamira shale member of Monterey shale

[Identifications by R. M. Kleinpell. R, rare; F, few; C, common; A, abundant]

Species	Localities			
	Bolivina modeloensis zone			*Bulimina uvigerinaformis* zone
	[1] 15	14	16	17
Bathysiphon? sp	F			
Robulus mohnensis Kleinpell? (Robulus cf. R. nikobarensis (Schwager)) [2]				R
Dentalina barnesi Rankin		(?)		F
Dentalina cf. D. filiformis (d'Orbigny) (Dentalina sp.)				R
Nodosaria longiscata d'Orbigny?		R	R	
Nodosaria tympaniplectriformis Schwager (cf.)				R
Elphidium granti Kleinpell (Elphidium aff. E. crispum (Linné))(Kleinpell, pl. 19, figs 1, 11) [3]			F	
Nodogenerina advena Cushman and Laiming		F	R	
Nodogenerina irregularis Kleinpell (Nodogenerina aff. N. lepidula (Schwager))		R		
Buliminella brevior Cushman				R
Buliminella curta Cushman	R	C	R	R
Buliminella dubia Barbat and Johnson?			R	
Buliminella subfusiformis Cushman	R	C		(?)
Bulimina monteryana var. delmonteensis Kleinpell? (Bulimina cf. B. affinis d'Orbigny of Brady)			R	
Bulimina uvigerinaformis Cushman and Kleinpell				C
Virgulina californiensis Cushman	R	R	C	
Virgulina californiensis var. ticensis Cushman and Kleinpell			R	
Virgulina (Virgulinella) miocenica Cushman and Ponton	F			
Bolivina advena Cushman			F	
Bolivina brevior Cushman	C	A	R	
Bolivina californica Cushman		R	F	R
Bolivina floridana Cushman		R	R	

See footnotes at end of table.

Foraminifera from upper part of Altamira shale member of Monterey shale—Continued

Species	Localities			
	Bolivina modeloensis zone			*Bulimina uvigerinaformis* zone
	[1] 15	14	16	17
Bolivina marginata Cushman			R	
Bolivina modeloensis Cushman and Kleinpell		F	R	
Bolivina parva Cushman and Galliher		R		
Bolivina pseudospissa Kleinpell ("Bolivina aff. B. spissa Cushman" Rankin)				C
Bolivina sinuata var. alisoensis Cushman and Adams				F
Bolivina subhughesi Kleinpell (Bolivina sp.)	C			
Bolivina tumida Cushman	F	C		
Bolivina woodringi Kleinpell? (Bolivina cf. B. argentea Cushman?)				R
Uvigerina angelina Kleinpell (Uvigerina sp.) (Kleinpell, pl. 18, fig. 12) [3]				R
Uvigerina hootsi Rankin		A	F	
Uvigerina modeloensis Cushman and Kleinpell				R
Uvigerina segundoensis Cushman and Galliher		C		R
Uvigerina subperegrina Cushman and Kleinpell			R	F
Valvulineria araucana (d'Orbigny)		R		C
Eponides exigua (H. B. Brady) (Eponides? sp.) (Kleinpell, pl. 20, figs. 6, 10, 12) [3]		R		
Eponides keenani Cushman and Kleinpell		R	R	
Eponides multicameratus Kleinpell ("Eponides aff. E. broeckiana (Karrer)" (Rankin) (Kleinpell, pl. 19, figs. 2, 3, 7) [3]		R		
Baggina californica Cushman		A	F	
Baggina subinaequalis Kleinpell (Valvulinera aff. V. inequalis (d'Orbigny) (Kleinpell, pl. 19, figs. 6, 9, 12) [3]		F	R	
Pulvinulinella gyroidinaformis Cushman and Goudkoff ("Pulvinulinella sp." Rankin)		R		
Pulvinulinella pacifica Cushman		R		
Cassidulina crassa d'Orbigny				R
Cassidulina monicana Cushman and Kleinpell		R	R	
Chilostomella cf. C. ovoidea Reuss (Chilostomella? cf. C. oolina Schwager)		R	R	
Pullena moorei Kleinpell (Pullenia aff. P. quinqueloba (Reuss))		R	R	
Sphaeroidina bulloides d'Orbigny		R	F	
Globigerina bulloides d'Orbigny		R	R	
Planulina ornata (d'Orbigny)		R		R
Cibicides altamiraensis Kleinpell (Cibicides sp.) (Kleinpell, pl. 19, figs. 4, 5, 8) [3]		R	R	
Cibicides illingi (Nuttall) (cf.)				R

[1] Zonal position uncertain.
[2] Names in parentheses were used in preliminary paper (Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 2, pp. 125-149, 1936).
[3] Kleinpell, R. M., Miocene stratigraphy of California, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938. The citations in the table refer to illustrations of specimens from the Palos Verdes Hills.

Kleinpell's comments on the foraminiferal faunas are summarized as follows:

Assemblages from localities 14 and 16 are characteristic of the *Bolivina modeloensis* zone, which immediately overlies the *Siphogenerina collomi* zone at several widely separated localities in California. *Bolivina modeloensis*, *Cassidulina monicana*, and *Virgulina californiensis* var. *ticensis* are restricted to this zone. It is further characterized by the earliest appearance of *Uvigerina hootsi*, *Uvigerina segundoensis*, *Uvigerina subperegrina*, and *Valvulineria araucana*. Though a number of species, particularly those belonging to the Buliminidae, are held over from the preceding Luisian stage, stocks like those of *Valvulineria californica*, *Valvulineria miocenica*, and *Siphogenerina*, which dominate the Luisian faunas and are tropical in their affinities, are lacking in the *Bolivina modeloensis* zone. Faunas very close to those from localities 14 and 16 occur in the typical *Bolivina modeloensis* zone at the base of the Modelo formation (Monterey shale of some geologists) near Mohn Spring in the Santa Monica Mountains [63] and in the Tice shale of the Monterey group in Contra Costa County.[64]

The relatively meager collection from locality 15 lacks stratigraphically diagnostic elements other than *Virgulina miocenica* and *Bolivina subhughesi*, both of which are known to range from the *Bolivina modeloensis* zone up into the lower part of the *Bolivina hughesi* zone. Field relations indicate that the strata at locality 15 are not younger than those at localities 14 and 16.

Locality 17 represents a distinct zone, the *Bulimina uvigerinaformis* zone. *Bolivina sinuata* var. *alisoensis* and *Bulimina uvigerinaformis* appear to be characteristic of that zone. The faunas from the *Bulimina uvigerinaformis* and *Bolivina modeloensis* zones are closely related, and some paleontologists group them in one zonal unit designated the *Baggina californica* zone. Assemblages with which that from locality 17 may be correlated are found near the base of the McLure member of the Monterey shale along Reef Ridge in the Coalinga district,[65] 250 feet above the base of the Modelo formation near Mohn Spring in the Santa Monica Mountains,[66] and at the type locality of the *Bulimina uvigerinaformis* zone east of the mouth of Dos Pueblos Canyon, Santa Barbara County.[67]

[63] Kleinpell, R. M., Miocene stratigraphy of California, p. 129, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938.
[64] Idem.

MOLLUSKS

Kew found poorly preserved remains of an *Aequipecten*, suggestive of *A. andersoni*, and an oyster in sandstone in the Point Fermin area. Fragmentary remains from sandstone in the same area were recorded by Woodford [68] as *Lyropecten crassicardo?* ["*Pecten*"], and *Ostrea titan?*. An incomplete mold of a large *Lyropecten* from conglomeratic sandstone in the Fort McArthur Upper Reservation is identified as *L.* cf. *crassicardo*.

VALMONTE DIATOMITE MEMBER

The Valmonte diatomite member [69] overlies the Altamira shale member. The type region is along the lower course of Agua Negra Canyon, southeast of the Valmonte residential district, where diatomite is quarried and processed. The Valmonte includes the relatively pure diatomaceous strata of the Monterey.

[65] Kleinpell, R. M., in Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil fields, Calif.; stratigraphy, paleontology, and structure; U. S. Geol. Survey Prof. Paper 195, pp. 127-128, 1940 [1941].
[66] Kleinpell, R. M., Miocene stratigraphy of California, p. 129, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938.
[67] Idem.
[68] Woodford, A. O., op. cit., p. 211.
[69] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), p. 143.

Owing to the change from cherty shale and phosphatic shale to diatomaceous rocks, the Altamira and Valmonte members are well defined in the western part of the hills. On the northeast and east slopes differentiation of the two members is difficult, as the middle and upper parts of the Altamira include diatomaceous rocks. In those areas only relatively pure diatomaceous strata overlying diatomaceous rocks interbedded with cherty shale, blue-schist sandstone, and phosphatic shale are now assigned to the Valmonte.

Diatomite occurs in the Valmonte as layers or laminae of varying thickness. In some areas thinly laminated diatomite forms units several feet thick alternating with massive diatomaceous mudstone. In other areas the entire exposed thickness of the Valmonte consists of laminated diatomite and diatomaceous shale containing varying proportions of diatoms. Some of the thick units and also some of the thin laminae in areas where thick units are absent consist of a feltlike mass of the pelagic hairlike diatom *Thalassiothrix*. In most of the layers and laminae, however, relatively large discoidal diatoms are the most abundant constituents noted in field examination.

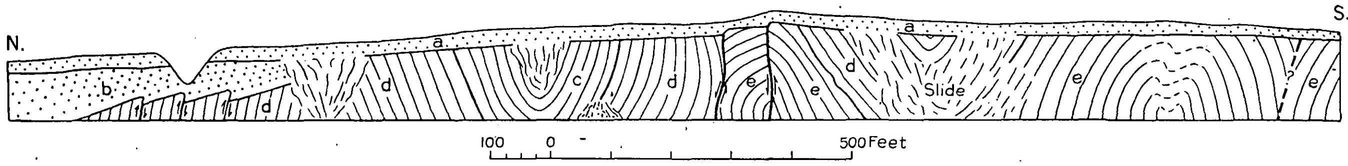


FIGURE 7.—Sea cliff at Malaga Cove. *a*, Nonmarine terrace cover and dune sand (Pleistocene to Recent); *b*, San Pedro (?) sand (Pleistocene); *c*, Repetto siltstone (lower Pliocene); *d*, Malaga mudstone member of Monterey shale (upper Miocene); *e*, Valmonte diatomite member of Monterey shale (upper Miocene).

At least locally, thin layers of phosphatic material are interbedded with laminated diatomite and diatomaceous shale. Perhaps phosphatic material is more prevalent than is apparent, for the thin layers may be difficult to recognize in weathered outcrops. Limestone is less abundant than in the Altamira shale. In the lower part of the Valmonte of most areas limestone occurs in lenticular beds, as in the Altamira. In the upper part and in some places throughout the member it occurs as concretions. In laminated rock laminae pass generally without interruption into the concretions. Locally zones of cherty shale are included in the Valmonte, but they are rare. Black chert in the form of discontinuous thin layers and stringers parallel to the bedding and as veins cutting across the bedding is found as a minor constituent in the Valmonte. Vitric volcanic ash in layers a few inches thick, appropriately called silver sand by the diatomite quarrymen, is another minor constituent.

The soft rocks of the Valmonte member are exposed for the most part only in cliffs and artificial excavations. No exposed section of the entire member was found, and the thickness is difficult to estimate. The estimate of 750 feet for the north slope of the hills cited in the preliminary paper [70] may be excessive, owing to inclusion of soft shale in the upper part of the Altamira; 500 feet is perhaps a better estimate. In San Pedro the thickness is only about 250 to 300 feet according to the classification now adopted.

Foraminifera of the *Bolivina hughesi* zone were found in the Valmonte at localities in the San Pedro area.

[70] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit.

STRATIGRAPHY AND LITHOLOGY

MALAGA COVE AREA

The strongly deformed formations in the sea cliff at Malaga Cove include the Valmonte diatomite (pl. 10, *A*; fig. 7). The strata at that locality assigned to the Valmonte consist of laminated diatomite and diatomaceous shale containing exceptionally abundant layers, stringers, and elongate nodules of soft phosphatic material. A thickness of about 100 feet is exposed on the north limb of the syncline containing the overlying Malaga mudstone member and apparently about 200 feet on the south limb. In the faulted areas beyond the limb of the syncline stratigraphic relations are uncertain.

The dry diatomite and diatomaceous shale, including the phosphatic layers, are white (pl. 11, *B*). At the base of the cliff, where the rocks are kept wet by waves and spray, the diatomite and diatomaceous shale are almost black and the phosphatic layers are light gray, the two types of rock being strongly contrasted. As shown on plate 10, *C*, many phosphatic layers pinch and swell, and others are broken into minute displaced blocks. The generally consistent relation of offsets suggests that the blocks are the result of shearing produced by differential movement during deformation rather than the result of penecontemporaneous brecciation. Limestone occurs in the form of concretions,

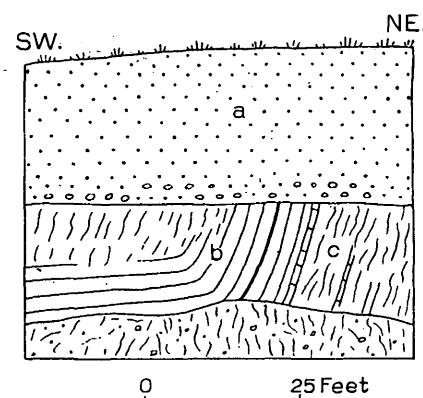
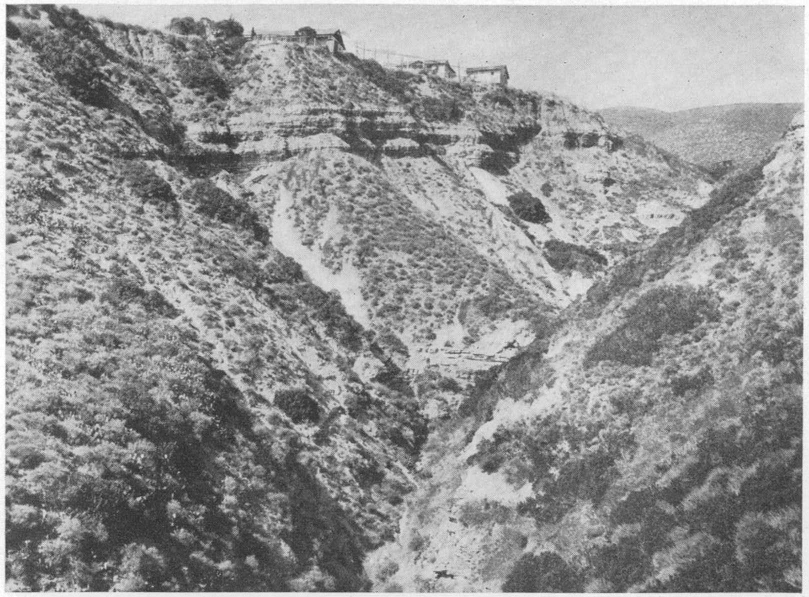


FIGURE 8.—Valmonte diatomite and Altamira shale members of Monterey shale in sea cliff near mouth of Malaga Canyon. a, Pleistocene terrace deposits; b, Valmonte diatomite member of Monterey shale (laminated diatomaceous and phosphatic shale); c, Altamira shale member of Monterey shale (phosphatic shale, limestone, and cherty shale).

generally laminated, of varying dimensions. The only hard siliceous rock observed consists of thin lenticular layers, stringers, and veins of black chert. On the south limb of the syncline a 4-inch layer of vitric volcanic ash is interbedded with diatomaceous shale.

The base of the Valmonte is exposed in the sea cliff 200 feet southwest of the mouth of Malaga Canyon. The strata are abruptly upturned at that locality, but

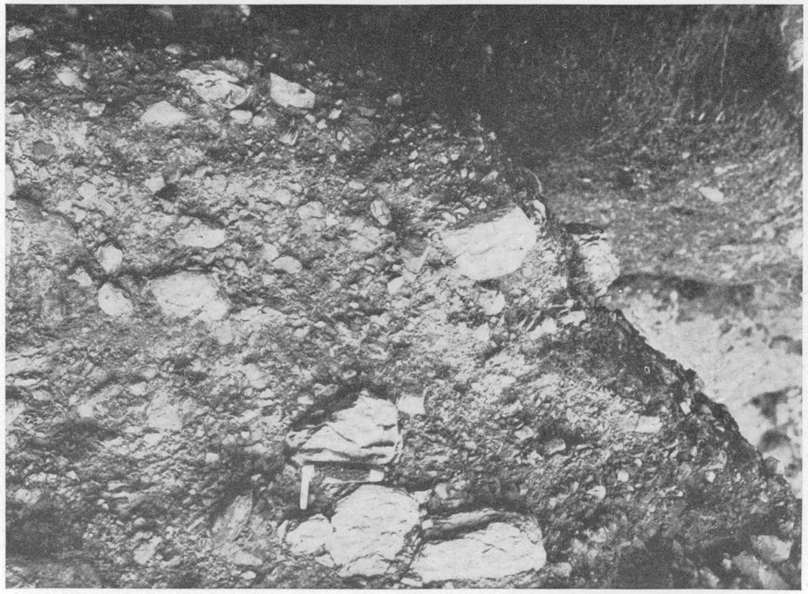


A. PORTUGUESE TUFF BED AT TYPE LOCALITY IN KLONDIKE CANYON.

Light-colored slope in middle of picture is formed by the tuff. Photograph by R. D. Reed.

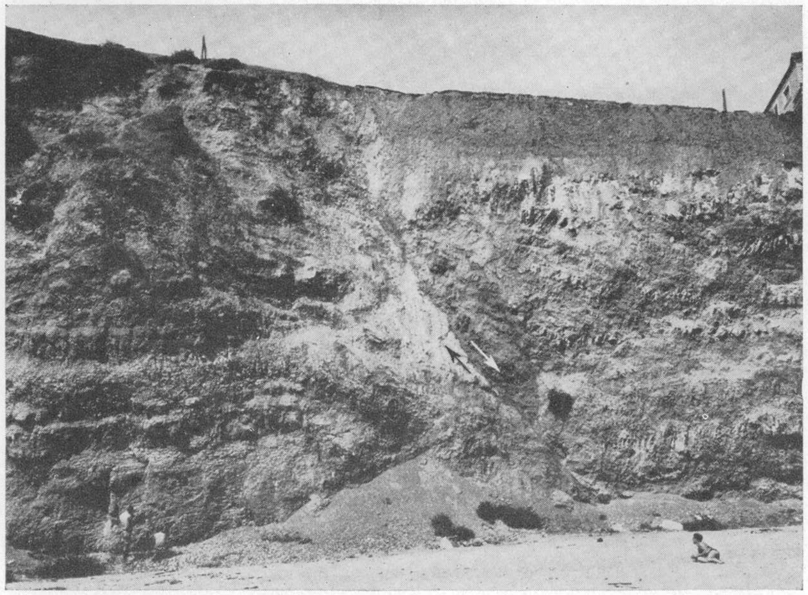
C. INTRUSIVE BASALT A QUARTER OF A MILE EAST OF POINT VICENTE.

The basalt shows as dark rock high on cliff.



B. SCHIST-DEBRIS BRECCIA AT BLUFF COVE.

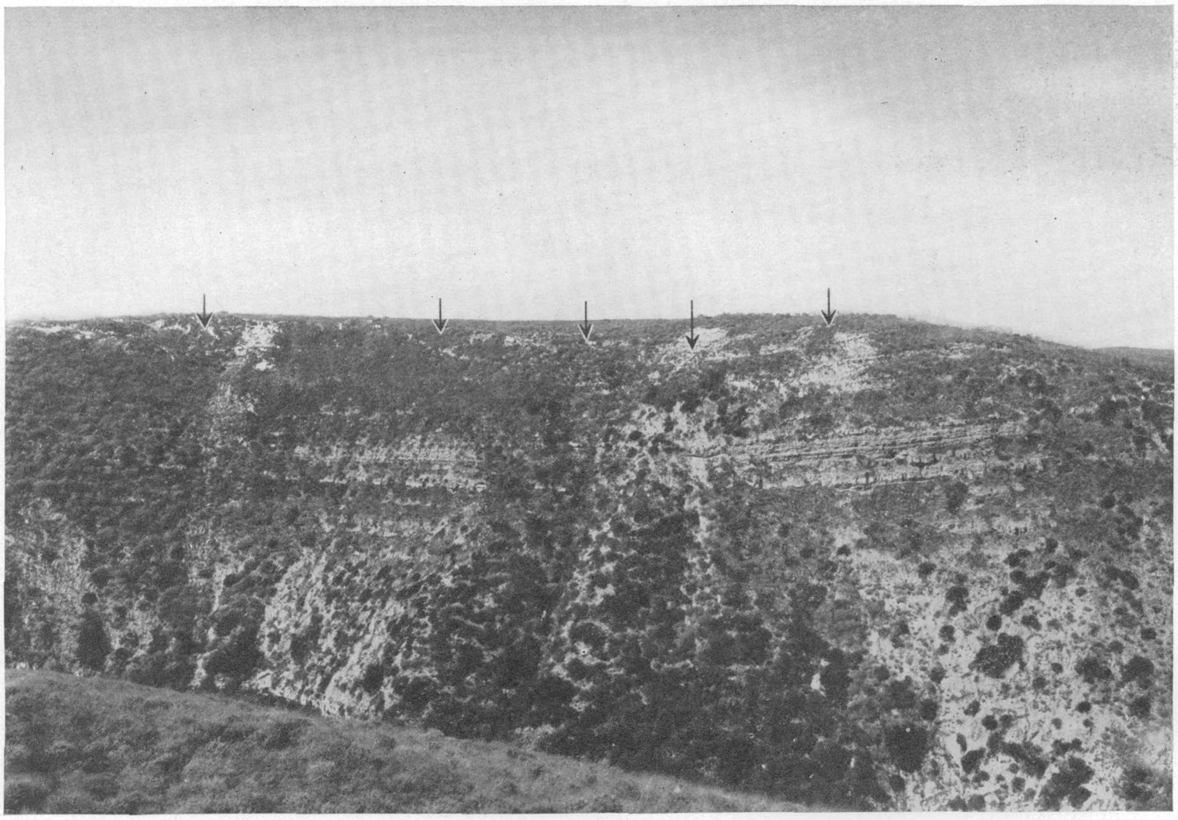
Photograph by R. D. Reed.



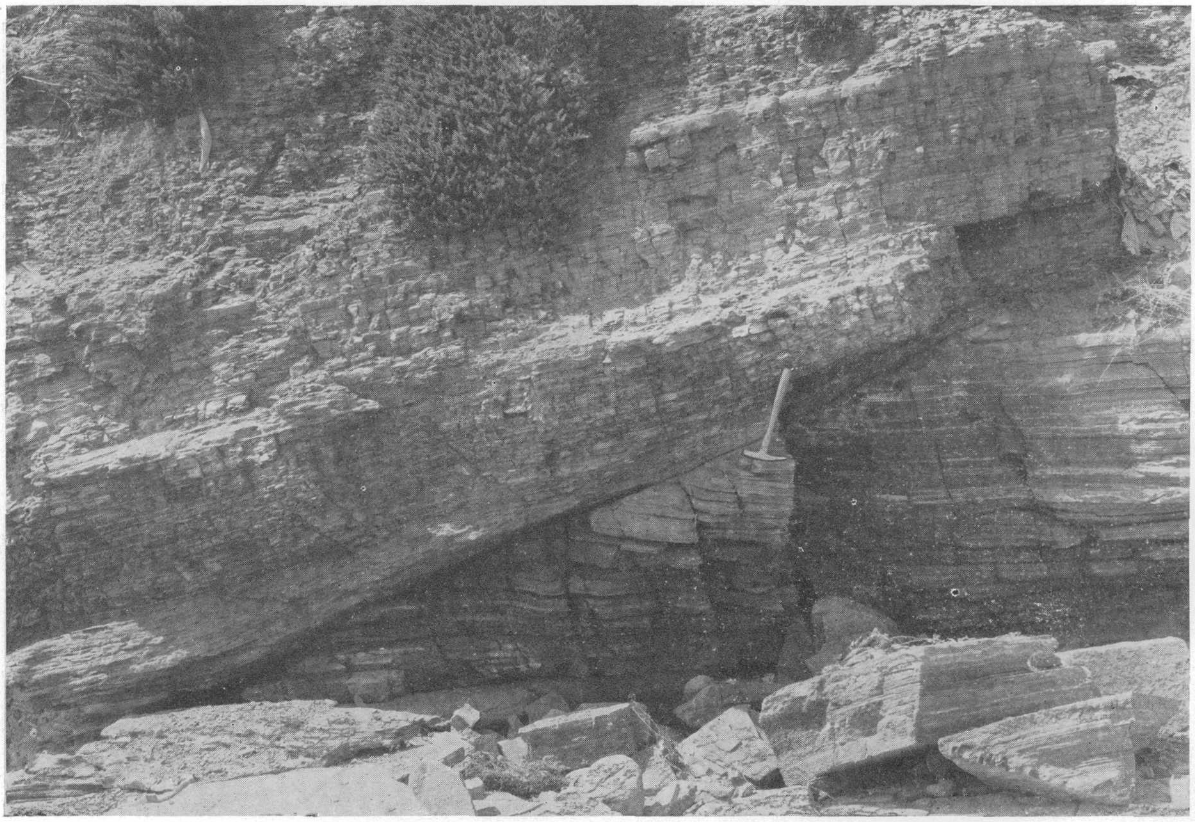
D. CABRILLO FAULT AT CABRILLO BEACH.

Light-colored cherty and phosphatic shale of upper part of Altamira member on hanging wall, buff siltstone of middle part of Altamira on footwall.

ALTAMIRA MEMBER OF MONTEREY SHALE AND BASALT.



A. TYPE LOCALITY OF MIRALESTE TUFF BED ON WEST SIDE OF UPPER AGUA NEGRA CANYON.
Arrows point to base of tuff.



B. LOCAL DISCONTINUITY OR BEDDING-PLANE FAULT.
Foot of sea cliff east of Point Fermin.

ALTAMIRA MEMBER OF MONTEREY SHALE.

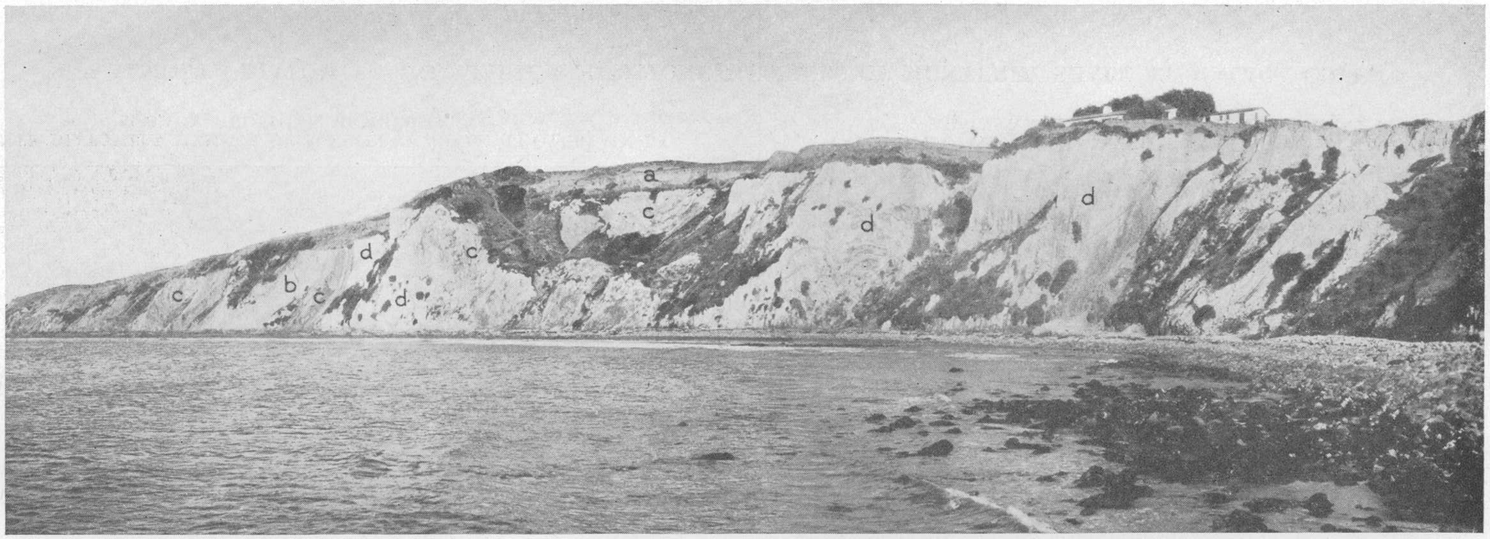
PHOSPHATIC AND BITUMINOUS SHALE IN UPPER PART OF ALTAMIRA MEMBER OF MONTEREY SHALE AT LUNADA BAY.

Note the extensive marine terrace. Photograph by Palos Verdes Estates.

A. WEST SIDE OF POINT FERMIN.

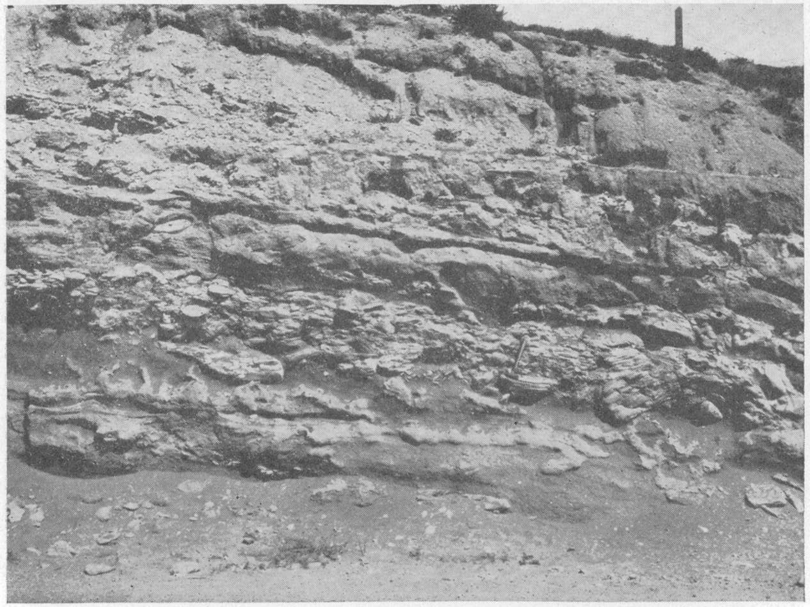
B. EAST SIDE OF POINT FERMIN.

BLUE-SCHIST SANDSTONE IN UPPER PART OF ALTAMIRA MEMBER OF MONTEREY SHALE AT POINT FERMIN.



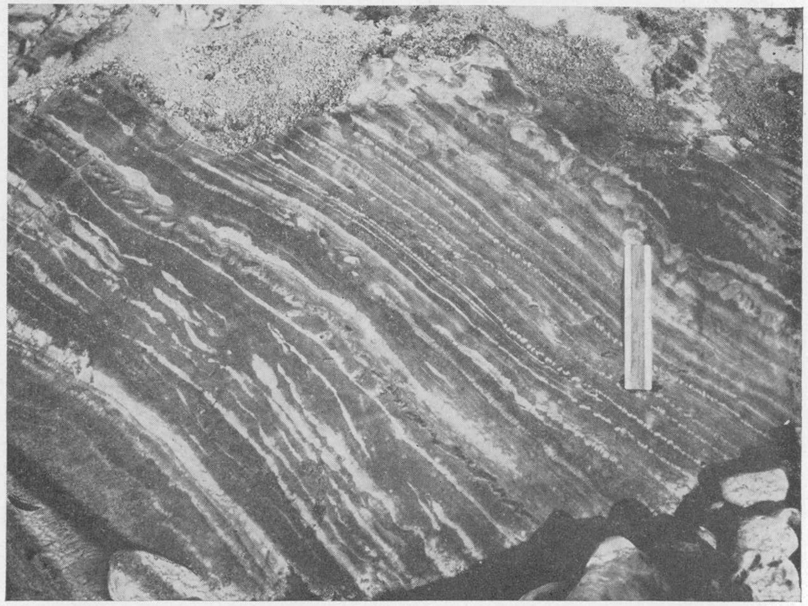
A. SEA CLIFF SECTION AT MALAGA COVE.

a, Nonmarine terrace cover and dune sand (Pleistocene to Recent); b, Repetto siltstone (lower Pliocene); c, Malaga mudstone member of Monterey shale (upper Miocene); d, Valmonte diatomite member of Monterey shale (upper Miocene).



B. BLUE-SCHIST SANDSTONE AND BRECCIATED SHALE IN UPPER PART OF ALTAMIRA MEMBER OF MONTEREY SHALE.

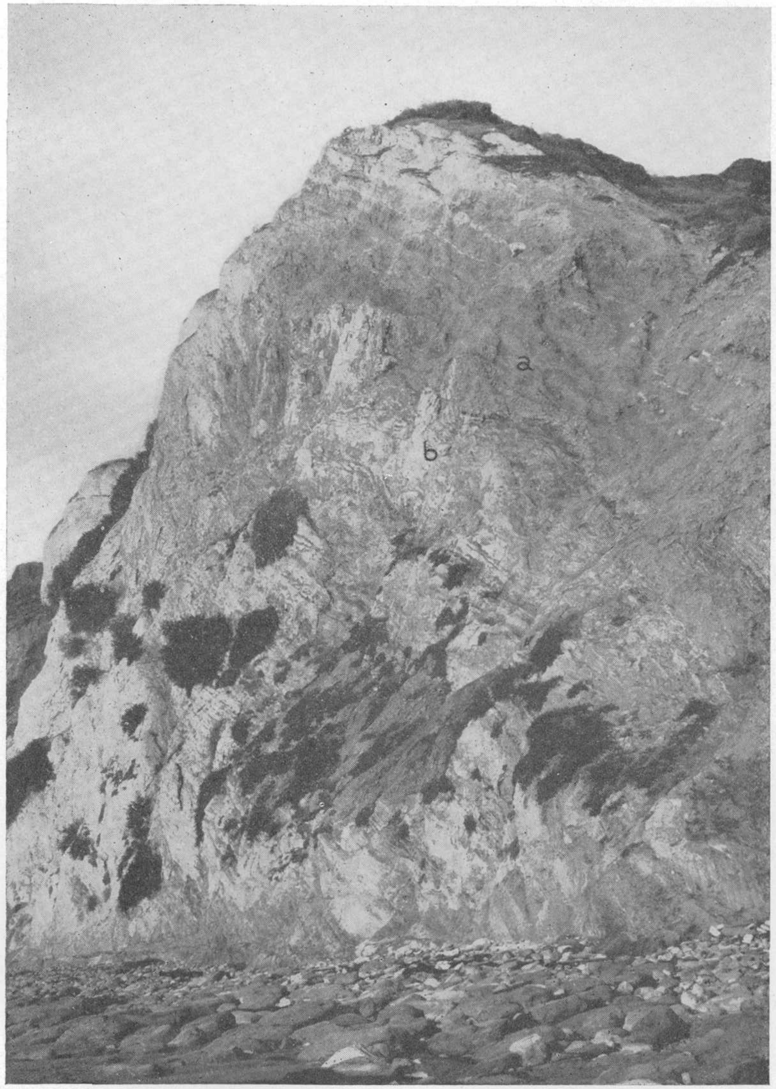
Highway cut on west side of Point Fermin.



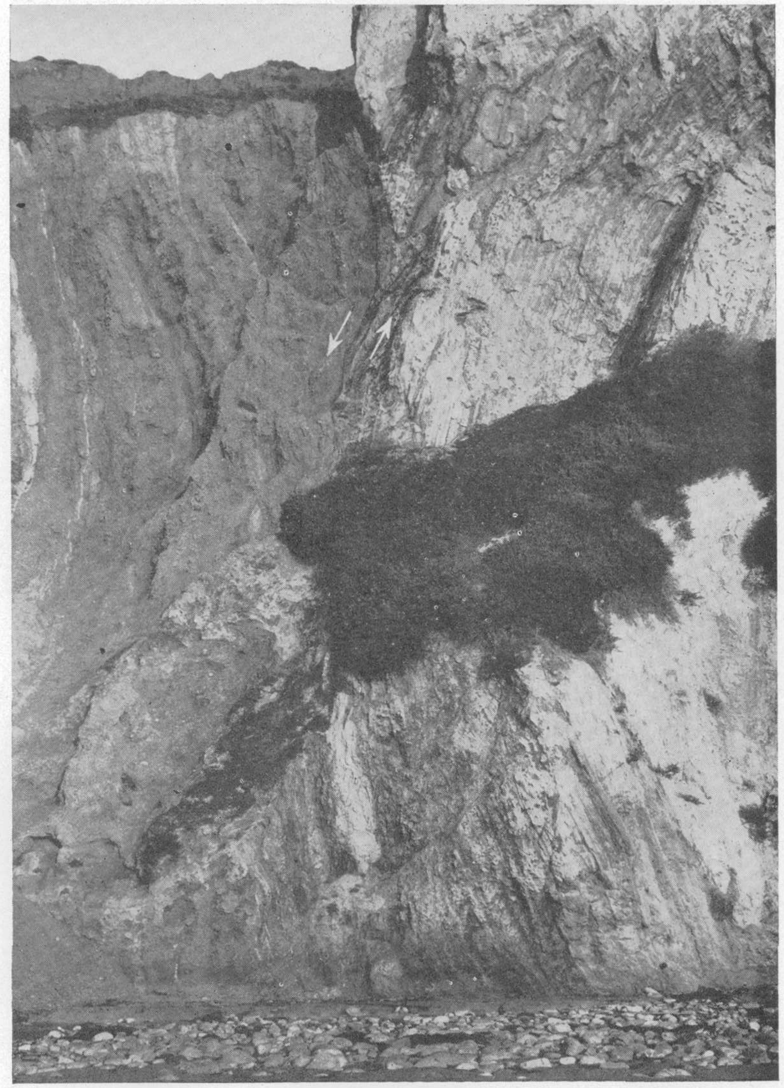
C. BROKEN AND STRETCHED PHOSPHATIC LAYERS (LIGHT-COLORED) IN LAMINATED DIATOMITE AND DIATOMACEOUS SHALE (DARK-COLORED).

Valmonte diatomite member of Monterey shale on north limb of southern syncline at Malaga Cove.

MIOCENE AND PLIOCENE FORMATIONS.



A. VALMONTE DIATOMITE MEMBER OF MONTEREY SHALE (b) OVERLAIN BY MALAGA MUDSTONE MEMBER (a).



B. VALMONTE DIATOMITE MEMBER OF MONTEREY SHALE (AT RIGHT) FAULTED AGAINST MALAGA MUDSTONE MEMBER (AT LEFT).

VALMONTE DIATOMITE AND MALAGA MUDSTONE MEMBERS OF MONTEREY SHALE AT MALAGA COVE.

there appears to be no displacement (fig. 8). Diatomaceous laminae were not obeserved in the phosphatic shale at the top of the Altamira, whereas diatoms are abundant in the laminated shale assigned to the Valmonte. As at the top of the Valmonte in the Malaga Cove section just described, phosphatic layers are interbedded with the diatomite and diatomaceous shale.

SYNCLINAL AREAS IN WESTERN PART OF HILLS

The lowermost part of the Valmonte, representing a thickness of 30 to perhaps 75 feet, was identified in several synclinal areas in the western part of the hills, as shown on the geologic map (pl. 1). It is doubtful, however, whether the base of the Valmonte represents the same horizon in the different areas. In most of these areas thin layers of diatomaceous shale are interbedded with the phosphatic shale near the top of the Altamira. (See sec., p. 30.)

Sections of the Valmonte as exposed in the sea cliff on the south side of Palos Verdes Point and in the cliff at the head of a tributary of the middle fork of Altamira Canyon, on the south limb of the syncline along the crest of the hills, are included in the sections given on page 30. Very little diatomite proper is found in those areas. In the area along the crest of the hills a few thin zones of laminated chert and laminated cherty shale are included in the exposed part of the Valmonte.

NORTH SLOPE OF HILLS

The open cuts and drifts of the Dicalite Co., along Agua Negra Canyon and farther east, are located in the upper half of the Valmonte. The section exposed in the open cuts consists of alternating laminated diatomite and massive diatomaceous mudstone, both in units 2 to 6 feet thick. In one diatomite unit laminae containing the hairlike *Thalassothrix* were observed throughout the entire thickness of 5 to 6 feet. In other units discoidal diatoms are abundant, though some laminae contain *Thalassothrix*. Vitric volcanic ash occurs in layers a few inches thick. A 4-inch pebble of decomposed schist was found at the base of a bed of diatomaceous mudstone. The prevailing dip in this area is northeast; however, the strike and the rate of dip change within short distances. The relatively great width of outcrop is due apparently to these structural irregularities.

Elsewhere on the north slope of the hills the Valmonte is poorly exposed, with the exception of scattered outcrops along ravines and highway exposures.

SAN PEDRO AREA

In the San Pedro area the Valmonte appears to be considerably thinner than in the type region. The underlying Altamira shale includes much diatomaceous silt and diatomaceous shale, some layers of which contain so many diatoms that they may be classified as diatomite. Only the part of the section that includes thick units of relatively pure diatomaceous rocks is assigned to the Valmonte. The change from the underlying Altamira member takes place, however, in a transition zone.

In Peck Park the diatomite, diatomaceous shale, and diatomaceous mudstone forming the cliff at the north boundary of the park are assigned to the Valmonte member. Differentiation from the underlying Altamira member, which includes much diatomaceous material, is, however, not sharp. Thin limestone lenses and concretions are included in the Valmonte. Foraminifera of the *Bolivina decurtata* subzone were found at the foot of the cliff (locality 20). A collection from a horizon 20 feet higher stratigraphically is assigned to the overlying *Bolivina goudkoffi* subzone (locality 20a). At locality 20 a thin layer contains impressions and molds of the thin-shelled scallop *Delectopecten*.

In the first deep ravine east of Peck Park, immediately west of Bandini Avenue, a thickness of 225 feet of diatomite and diatomaceous mudstone, including thin limestone lenses and concretions, is exposed. An additional unexposed thickness of 60 feet is estimated to underlie the Malaga mudstone member. As the lowest exposed strata are near the base of the Valmonte, the total thickness of that member is not much more than 300 feet. Foraminifera of the *Bolivina goudkoffi* subzone were collected at horizons 45, 125, and 127 feet above the base of the exposed section (localities 21, 21a, 21b, respectively).

The same lithologic types, representing the upper part of the Valmonte, are exposed on the north side of San Pedro Canyon, between Meyler and Cabrillo Avenues, where Foraminifera of the *Bolivina goudkoffi* subzone were collected (locality 22). Farther south the Valmonte is found in street cuts along Alma Avenue between Eighth and Eleventh Streets, on Meyler Avenue between Seventh and Nineteenth Streets, and on Cabrillo Avenue at Twentieth and Twenty-first Streets. On Twentieth Street, 120 feet east of Meyler Avenue, diatomite appears to be faulted against phosphatic shale in the upper part of the Altamira. On the geologic map in the preliminary paper [71] a fault was continued southeastward between the Altamira and Valmonte members. Even if they are in fault contact on Twentieth Street, the displacement is probably too small to justify that interpretation.

The transition zone between the Altamira and Valmonte members was formerly visible at Cabrillo Beach but is now concealed by fill. The Valmonte is exposed more or less continuously in the sea cliff from a locality immediately south of the drive to Cabrillo Beach northward to the Fort McArthur Lower Reservation. Owing to many minor folds the thickness is uncertain. The strata consist chiefly of diatomite, diatomaceous shale, diatomaceous mudstone, and thin lenses of limestone. Occasional thin layers of volcanic ash are impregnated with asphalt. At a point about 1,000 feet north of the Cabrillo Beach drive a zone 25 feet thick includes cherty shale. Foraminifera were found in the lower part of the section at locality 18a, immediately south of the Cabrillo Beach drive, and at localities 18, 19, and 19a, north of the drive. All these collections are assigned to the *Bolivina decurtata* subzone. Locality 18 is now concealed by fill.

FOSSILS

FORAMINIFERA

At various localities in the San Pedro area the Valmonte diatomite contains well-preserved Foraminifera. These collections are assigned by Kleinpell to the *Bolivina hughesi* zone, both the *Bolivina decurtata* subzone (zone G of preliminary paper)[72] and the overlying *Bolivina goudkoffi* subzone (zone H of preliminary paper) being represented. In the San Pedro area the *Bolivina hughesi* zone corresponds approximately to

[71] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), pp. 128–129, fig. 1.
[72] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit., pp. 125–149.

the Valmonte diatomite, for Foraminifera from immediately underlying and overlying strata are assigned to other zones. If the section in the deep ravine immediately west of Bandini Avenue may be taken as a guide, the *Bolivina decurtata* subzone is thinner than the *Bolivina goudkoffi* subzone. At that locality Foraminifera referred to the *Bolivina goudkoffi* subzone occur 100 feet or less above the base of the Valmonte.

The species identified by Kleinpell are given in the following table:

Foraminifera from Valmonte diatomite member of Monterey shale

[Identifications by R. M. Kleinpell. R, rare; F, few; C, common; A, abundant]

Species	Localities									
	Bolivina hughesi zone									
	Bolivina decurtata subzone					*Bolivina goudkoffi* subzone				
	18	18a	19	19a	20	20a	21	21a	21b	22
Planularia cushmani Kleinpell (Planularia sp.? Cushman and Kleinpell) [1]						R				
Dentalina barnesi Rankin					R					
Dentalina cf. D. filiformis (d'Orbigny) (Dentalina sp.) (Kleinpell pl. 22, fig. 1) [2]	R					R			R	
Nodosaria longiscata d'Orbigny?	R									
Nodosaria tympaniplectriformis Schwager (cf.)				R		R		F	R	R
Frondicularia advena Cushman		F		R		F				
Lagena globosa (Montagu)?					R					
Nonion goudkoffi Kleinpell (Nonion sp.) (Kleinpell, pl. 20, figs. 2, 5) [2]			R							R
Nonionella miocenica Cushman	R	F								
Nodogenerina advena Cushman and Laiming	R									
Buliminella dubia Barbat and Johnson?					R					
Buliminella subfusiformis Cushman	R	F	F	R		R				
Bulimina inflata Seguenza	R									
Bulimina montereyana var. delmonteensis Kleinpell? (Bulimina cf. B. affinis d'Orbigny of Brady)	R									
Bulimina ovula d'Orbigny	R		R							
Bulimina ovula var. pedroana Kleinpell (Bulimina aff. B. ovula d'Orbigny)	A	R			F	F				R
Virgulina californiensis Cushman					R					
Virgulina californiensis var. grandis Cushman and Kleinpell	R		F	F		R	R			
Virgulina delmonteensis Cushman and Galliher	F		R	R	C		F			
Bolivina advena Cushman	F									
Bolivina bramlettei Kleinpell ("Bolivina beyrichi alata (Seguenza)" Rankin) (Kleinpell, pl., 21, figs. 9–11) [2]	F	R		R	F			C	F	F
Bolivina brevior Cushman	R		F							
Bolivina decurtata Cushman (cf.) (Kleinpell, pl. 21, figs. 3, 8) [2]		R	C	R						
Bolivina girardensis Rankin		R	F							R
Bolivina goudkoffi Rankin								C		A
Bolivina hootsi Rankin				R						
Bolivina granti Rankin						F				
Bolivina hughesi Cushman	A	A	A	A	A			R		R
Bolivina cf. B. interjuncta Cushman			R	R						
Bolivina malagaensis Kleinpell (Bolivina aff. B. advena Cushman)			R			R				
Bolivina parva Cushman and Galliher		C								
Bolivina pseudospissa Kleinpell ("Bolivina aff. B. spissa Cushman" Rankin)	F	F	C	F	C	R	R	F	F	R
Bolivina seminuda Cushman	R		F	R	F	R	A	F		R
Bolivina sinuata Galloway and Wissler	R				C	A		C	C	
Bolivina subhughesi Kleinpell (Bolivina sp.) (Kleinpell, pl. 21, figs. 7, 12) [2]			R							
Bolivina subadvena var. spissa Cushman (Bolivina aff. B. subadvena Cushman) (Kleinpell, pl. 21, figs. 1, 2, 13) [2]	F	R		R						R
Bolivina tumida Cushman			R							
Bolivina woodringi Kleinpell (Bolivina cf. B. argentea Cushman) (Kleinpell, pl. 21, figs. 4, 5) [2]	C		F	F	R	R	F	F	F	R
Uvigerina hannai Kleinpell (Uvigerina aff. U. hootsi Rankin)								C	F	F
Uvigerina hootsi Rankin	R				C		F	A	A	A
Uvigerina modeloensis Cushman and Kleinpell	C	F	A	F	A					
Uvigerina segundoensis Cushman and Galliher	F			F				F	C	
Uvigerina cf. U. senticosa Cushman (Kleinpell, pl. 20, fig. 9) [2]					R					
Uvigerina sp.? (Kleinpell, pl. 20, figs. 1, 17) [2]	R									
Uvigerina subperegrina Cushman and Kleinpell		R	F		A	A				
Valvulineria araucana (d'Orbigny)	C		(?)	F	F	R		F	F	R
Gyroidina soldanii var. rotundimargo R. E. and K. C. Stewart	C	C	R	F	R					
Eponides multicameratus Kleinpell ("Eponides aff. E. broeckiana (Karrer)" Rankin)					R				R	
Eponides healdi R. E. and K. C. Stewart						F				F
Eponides keenani Cushman and Kleinpell				R	F	F				
Baggina californica Cushman			R							
Pulvinulinella capitanensis Cushman and Kleinpell?	R		R							
Pulvinulinella sp. (Kleinpell, pl. 20, figs. 3, 4, 7) [2]	R	R								
Cassidulina delicata Cushman				R						
Cassidulina barbarana Cushman and Kleinpell			R		F			R	R	
Cassidulina crassa d'Orbigny	R		R		F					R
Cassidulina modeloensis Rankin	R		R	R	R	C		A	C	A
Chilostomella cf. C. ovoidea Reuss		R								
Sphaeroidina bulloides d'Orbigny	R	R	R	R	R					R
Globigerina bulloides d'Orbigny	F	R						R		
Anomalina hughesi Rankin						F				
Planulina cf. P. ariminensis d'Orbigny	R									
Planulina depressa d'Orbigny	F	R		R						
Planulina ornata (d'Orbigny)				R	F	R				R
Discorbinella valmonteensis Kleinpell (Cibicides cf. C. cicatricosa (Schwager) (Kleinpell, pl. 21, figs. 14–16) [2]			A		F		F			
Cibicides illingi (Nuttall) (cf.) (Kleinpell, pl. 20, figs. 18–20) [2]			R							

[1] Names in parentheses were used in preliminary paper (Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 2, pp. 125–149, 1936).
[2] Kleinpell, R. M., Miocene stratigraphy of California, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938. The citations in the table refer to illustrations of specimens from the Palos Verdes Hills.

Kleinpell's comments are summarized as follows:

The Foraminifera from the Valmonte diatomite represent the fauna of the typical *Bolivina hughesi* zone listed by Rankin from Hoots' lithologic units 7 to 16, inclusive, in the lower member of the Modelo formation (Monterey shale of some geologists) exposed along the road from Girard to Mohn Spring in the Santa Monica Mountains.[73] Rankin, Hughes, and Goudkoff[74] have cited the same fauna from the upper shale member of the Puente formation as exposed in La Habra Canyon, on the south flank of the Puente Hills. The fauna is represented by rich assemblages of well-preserved and characteristic forms in the Palos Verdes Hills. Of the species listed by Rankin, Hughes, and Goudkoff as characteristic of the zone, only the two species of *Buliminella* are missing in the Palos Verdes Hills collections. The fauna from the Valmonte can also be correlated with Galliher's middle *Nonion* fauna,[75] which represents the *Bolivina hughesi* zone in the Monterey shale of the type region.

Two faunal divisions treated tentatively as subzones[76] are recognized in the Valmonte. The differentiation is not as clearly defined as the differentiation between the zones and is based on quantitative more than on qualitative differences. Nevertheless the distinctive features of the two subzones persist at a number of localities in southern California, including the Girard-Mohn Spring section in the Santa Monica Mountains. So far as now known, *Baggina californica*, *Pulvinulinella capitanensis*, and *Uvigerina modeloensis* are not found above the *Bolivina decurtata* subzone, and *Uvigerina hannai* is not found below the *Bolivina goudkoffi* subzone. *Bolivina goudkoffi* is restricted apparently to the subzone named for it. A marked increase in the number of specimens of *Bolivina seminuda*, *Bolivina sinuata*, *Cassidulina modeloensis*, and *Planularia cushmani* and a falling off of *Bolivina hughesi* seem also to characterize that subzone.

MOLLUSKS

Impressions and molds of the small thin-shelled deep-water scallop *Delectopecten* were collected at locality 20. They were cited in the preliminary paper [77] as *Delecopecten pedroanus*. They are now identified, however, as *Hyalopecten* (*Delectopecten*) aff. *H. peckhami*.[78] Similar material in the collections of the California Academy of Sciences (California Acad. Sci. No. 1894) from a locality about 220 yards northwest of the end of the breakwater at Cabrillo Beach, close to locality 19a of the present report, appears to represent the same form.[79] In 1856 Trask [80] described three forms of scallops from the east coast of the Palos Verdes Hills and believed the strata to be of Cretaceous age. The three forms are regarded as one species, which is cited as *Hyalopecten* (*Delectopecten*) *pedroanus*. Trask's specimens evidently came from the lower part of the Valmonte diatomite or the upper part of the Altamira shale at Cabrillo Beach, for that is the only locality on the east coast where the dip is as steep as recorded by Trask (about 50°). According to his description and figures, *H. pedroanus* is a relatively large species that has strong concentric undulations and evidently has radial ribs. Specimens that show these characters have not been found in the Palos Verdes Hills since Trask's time. A similar form occurs, however, near the top of the Miocene in the Los Angeles Basin subsurface section.[81]

VERTEBRATES

Miller [82] has described three sea birds found in diatomite assigned in the present report to the Valmonte member. A shearwater (*Puffinus diatomicus*) collected at Cabrillo Beach was described originally from material in the diatomite of the Monterey shale at Lompoc, Santa Barbara County. A gannet (*Sula stocktoni*) and the oldest recorded albatross from America (*Diomedea?* sp.) were collected in the quarry of the Dicalite Co. Miller also recorded the finding in the quarry of several specimens of a small cetacean similar to *Lagenorhynchus*. Sea lion remains from the quarry of the Dicalite Co. have been referred by Lyon [83] to *Pontolis magnus*.

MALAGA MUDSTONE MEMBER

The Malaga mudstone member [84] overlies the Valmonte diatomite member and is the uppermost division of the Monterey shale in the Palos Verdes Hills. The type region is at Malaga Cove, at the northwest end of the hills, where the lower and upper parts of the member, but possibly not the entire thickness, are exposed. Unlike the other members of the Monterey, the Malaga is found only near the north and east margins of the hills. That it formerly extended over a much larger area, probably the entire area of the hills, is indicated by the absence of a shallow-water facies. Schist pebbles suggest, however, that a schist land area was close by.

The Malaga mudstone consists chiefly, and in some areas virtually entirely, of massive radiolarian mudstone or fine-grained siltstone. Relatively large globular Radiolaria and scattered diatoms are visible in field examination. Though the term "radiolarian mudstone" is used to differentiate the mudstone from ordinary mudstone, Radiolaria actually are a minor constituent. The mudstone is light chocolate brown or olive gray when dry and almost black when wet. The dry rock is greatly jointed and hackly. At Malaga Cove the Malaga member includes laminated diatomite and diatomaceous shale in thin streaks or in well-defined units several feet thick. Such material was observed elsewhere on the north slope of the hills but not in San Pedro. Limestone occurs as concretions and lenses in both massive mudstone and laminated diatomite. In the laminated rock laminae pass generally without interruption into the limestone. Vitric volcanic ash in thin layers is a minor constituent. Hard siliceous rocks were not observed at outcrop localities.

The lithologic change from the Valmonte to the Malaga is fairly abrupt at Malaga Cove. Limy phosphatic nodules and schist and quartz pebbles occur at and just above the base of the Malaga. This material indicates slow deposition or nondeposition during the early period of the subsidence suggested by the deep-water aspect of the Malaga Foraminifera. Assignment of formation rank to the Malaga may be preferable to member rank in the Monterey. The prevailing litho-

[73] Rankin, W. D., in Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, pp. 103–104, 113, pl. 27, 1931. Kleinpell, R. M., Miocene stratigraphy of California, p. 130, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938.

[74] Rankin, W. D., Hughes, D. D., and Goudkoff, P. P., in Hoots, H. W., idem, p. 114.

[75] Galliher, E. W., Stratigraphic position of the Monterey formation: Micropaleontology Bull., vol. 2, No. 4, pp. 71–74, 1931.

[76] Kleinpell, R. M., op. cit., p. 130.

[77] Woodring, W. P., in Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20)p. 146.

[78] Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif., and their inferred environment; U. S. Geol. Survey Prof. Paper 190, p. 39, 1938.

[79] Idem.

[80] Trask, J. B., Description of three new species of the genus *Plagiostoma* from the Cretaceous rocks of Los Angeles: California Acad. Sci. Proc., vol. 1, p. 86, 4 figs., 1856.

[81] Woodring, W. P., op. cit. (U. S. Geol. Survey Prof. paper 190), p. 41, pl. 6, figs. 1, 2, 1938.

[82] Miller, Loye, New bird horizons in California: California Univ. at Los Angeles Pub. Biol. Sci., vol. 1, No. 5, pp. 73–80, 2 figs., 1935.

[83] Lyon, G. M., A Miocene sea lion from Lomita, Calif.: California Univ., Pub. Zoology, vol. 47, pp. 23–42, pls. 2–6, 2 figs., 1941.

[84] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit., (Am. Assoc. Petroleum Geologists Bull., vol. 20), p. 146.

logic type in the Malaga is included, however, as a minor constituent in the underlying Valmonte, and some beds of laminated diatomite and diatomaceous shale, like that in the Valmonte, are included in the Malaga.

The thickness of the Malaga mudstone is difficult to estimate. A thickness of about 150 feet above the base is represented in the southern syncline at Malaga Cove and about the same thickness at the top of the member on the south limb of the northern syncline. It is not known, however, whether these sections overlap. An apparently unbroken section of 325 feet, presumably near the top of the member, is exposed at the north end of Malaga Cove. Along most of the north slope of the hills the thickness is probably not more than 300 feet, but in part of that area the mudstone is overlapped by Pleistocene strata. In San Pedro, where the Malaga is overlapped, the thickness is as much as 600 feet if the average dip is 15° and minor folds and faults are absent. The structure in that area is obscure, however, and the thickness may be considerably less.

The Malaga is rich in organic matter. Samples from Malaga Cove have a nitrogen content of 0.325 per cent,[85] indicating an estimated percentage of organic matter of 7.8 [86]—the highest nitrogen content for California outcrop samples analyzed by Trask and Patnode in their study of source beds of petroleum.

STRATIGRAPHY AND LITHOLOGY

MALAGA COVE AREA

The base of the Malaga mudstone is well exposed on the north limb of the southern syncline at Malaga Cove (pls. 10, *A*; 11, *A*; fig. 7). As may be seen on plate 11, *A*, there is some minor crumpling along the contact between the Valmonte and Malaga. About 20 feet above the beach a lens of flat limy phosphatic nodules 1½ feet thick is 7½ feet above the base of the Malaga. Similar nodules are scattered between the base of the lens and the base of the member. The nodules are 2 to 4 inches long and many contain leached Foraminifera. A few pebbles of quartz and rotten schist are included among the nodules. A thicker lens of apparently similar material higher on the cliff was not examined, owing to inaccessibility. A 3-inch layer of vitric volcanic ash is 15 feet above the base of the Malaga. A few Foraminifera were found in a limestone concretion 18 feet above the base of the member (locality 23). Laminated diatomite in thin layers is a minor constituent at this locality and also on the south limb of the northern syncline (pl. 11, *B*), where the uppermost part of the member is exposed.

The anticlinal crest in the Malaga mudstone farther north along the cliff, shown in an earlier sketch,[87] is now concealed by talus. The structure in that area is evidently not so simple as shown on the 1932 sketch. If it were, the overlying Repetto siltstone should appear on the north limb of the anticline. Toward the north end of Malaga Cove the Malaga mudstone consists of alternating units of massive radiolarian mudstone and laminated diatomite and diatomaceous shale (pl. 12, *A*, *B*). The massive units are almost invariably thicker than the laminated units. These strata are presumably near the top of the Malaga. A section measured at that locality is as follows:

Section of Malaga mudstone member of Monterey shale at north end of Malaga Cove

	Feet
Massive radiolarian mudstone, overlapped by Pleistocene San Pedro (?) sand	90
Laminated diatomite and diatomaceous shale, including a limestone concretion 1½ feet thick 10 feet below top	19
Massive radiolarian mudstone	7
Laminated diatomite and diatomaceous shale	8½
Massive radiolarian mudstone	22
Laminated diatomite and diatomaceous shale	1
Massive radiolarian mudstone	23
Laminated diatomite and diatomaceous shale, including a limestone concretion 8 inches thick at middle	4
Massive radiolarian mudstone	3
Unexposed	17
Massive radiolarian mudstone, including a limestone concretion 1¼ feet thick 6 feet above base	16
Laminated diatomite and diatomaceous shale	6
Massive radiolarian mudstone	10
Laminated diatomite and diatomaceous shale, including a limestone concretion 1½ feet thick at base	7½
Massive radiolarian mudstone	6
Laminated diatomite and diatomaceous shale	1
Massive radiolarian mudstone	8
Laminated diatomite and diatomaceous shale	1½
Massive radiolarian mudstone	6
Laminated diatomite and diatomaceous shale	2½
Massive radiolarian mudstone	6
Laminated diatomite and diatomaceous shale, including a limestone concretion 1½ feet thick 3 feet above base	10
Massive radiolarian mudstone	8
Laminated diatomite and diatomaceous silt	2
Massive radiolarian mudstone	6
Laminated diatomite and diatomaceous shale, including a limestone concretion 2½ feet thick at top	4
Massive radiolarian mudstone	7
Laminated diatomite and diatomaceous shale	4½
Massive radiolarian mudstone	7½
Laminated diatomite and diatomaceous shale	1½
Massive radiolarian mudstone	6
Laminated diatomite and diatomaceous shale	12
	333½

The "non-foraminiferal siliceous shale" at Malaga Cove described by Reed [88] includes both the Malaga mudstone and the Valmonte diatomite. Reed found that in some samples, presumably from the Malaga mudstone, Radiolaria, silicoflagellates, and sponge spicules are more abundant than diatoms, particularly in the very fine debris. He found volcanic glass in small fragments to be abundant. He interpreted the small percentage of detrital minerals to indicate ultimate, perhaps direct, derivation from a Franciscan (?) area.

NORTH SLOPE OF HILLS

On the north slope of the hills the Malaga mudstone is exposed in some of the deep, narrow ravines west of Walteria, in Sepulveda Canyon, and at various localities along the Gaffey anticline. At places thin layers of diatomite and diatomaceous shale are interbedded with the massive mudstone. Mudstone in a small outcrop in the trough of a steeply folded syncline, on the east side of Agua Negra Canyon, 85 feet north of the Palos Verdes fence, may represent the Malaga or may be a mudstone unit near the top of the Valmonte.

At a locality half a mile east of Palos Verdes Drive East an apparently steeply dipping limestone ledge that contains a few schist pebbles is thought to represent the base of the Malaga mudstone on the south limb of the Gaffey syncline. The locality is on the

[85] Trask, P. D., and Patnode, H. W., Source beds of petroleum, pp. 176, 177, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1942.
[86] Nitrogen content X 24 (Idem, p. 33).
[87] Woodring, W. P., San Pedro Hills: 16th Internat. Geol. Cong. Guidebook 15, fig. 6, 1932.
[88] Reed, R. D., A siliceous shale formation from southern California: Jour. Geology ol. 36, pp. 345-353, figs. 1-3, 1928.

nose of a spur on the north side of George F Canyon. The Malaga is exposed at nearby localities farther north, and diatomite, possibly representing the Valmonte, was found on the spur 30 feet south of the limestone ledge.

The Whites Point tunnel penetrated the Malaga mudstone along the Gaffey anticline. The wet rock in the tunnel consists of black massive mudstone including scattered diatomaceous streaks. A zone of limestone concretions was observed on the south limb of the anticline. A thin band of black chert on the north limb is a minor constituent not seen at outcrop localities.

SAN PEDRO AREA

In San Pedro the Malaga mudstone crops out in ravines and on the sea cliff at the Fort McArthur Lower Reservation. It was formerly visible in the sea cliff at Timms Point, where it is overlapped by Pleistocene strata, but it is now concealed by fill. The best exposures in San Pedro, however, are in street cuts, such as those on Second Street between Gaffey and Cabrillo Avenues and nearby, where the dip is only a few degrees northeast. In the natural and artificial exposures the Malaga consists of massive mudstone containing limestone lenses and concretions. Bedded mudstone and siltstone are minor constituents. Well-preserved Foraminifera were collected from mudstone near the base of the member, on the north side of Cabrillo Avenue 75 feet north of Fourth Street (locality 24), a locality found by Dr. Hampton Smith. A few Foraminifera were found near the exposed top of the member, in a limestone concretion on the south face of Timms Point at locality 25, now inaccessible.

FOSSILS

FORAMINIFERA

Foraminifera appear to be rare in the Malaga mudstone. Well-preserved material from locality 24 and a small collection from locality 25, both in San Pedro, are assigned by Kleinpell to the *Bolivina obliqua* zone [89] (zone I of preliminary paper).[90] A fauna similar to that at locality 24 was found recently on the Gaffey anticline near the Los Angeles city boundary. A few poorly preserved species from locality 23 are grouped with the others on the basis of stratigraphic occurrence. Locality 24 is estimated to be 35 feet above the base of the Malaga, and locality 25 is 25 feet below the base of the overlapping Pleistocene formation at Timms Point. The *Bolivina obliqua* zone, therefore, includes approximately the entire thickness of the Malaga mudstone in the San Pedro area, where that member appears to be thicker than in other parts of the hills.

The following table gives the list of species identified by Kleinpell:

[89] Bramlette prefers to assign Foraminifera from the Malaga mudstone to the lower part of Kleinpell's Delmontian stage and the *Bolivina obliqua* zone to the upper part. (See discussion in Woodring, W. P., Bramlette, M. N., and Lohman, K. E., Stratigraphy and paleontology of Santa Maria district, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 27, No. 10, pp. 1346, 1349-1350, 1943.)

[90] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., Miocene stratigraphy and paleontology of Palos Verdes Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 2, pp. 125-149, 1936.

Foraminifera from Malaga mudstone member of Monterey shale

[Identifications by R. M. Kleinpell. R, Rare; F, few; C, common; A, abundant]

Species	Localities		
	Bolivina obliqua zone		
	23 [1]	24	25
Bathysiphon? sp	------	C	------
Dentalina cf. D. filiformis (d'Orbigny) (Dentalina sp.[2])	------	R	------
Nodosaria tympaniplectriformis Schwager (cf.) (Kleinpell, pl. 22 fig. 2)[3]	------	F	------
Frondicularia advena Cushman	------	F	------
Buliminella dubia Barbat and Johnson	R	(?)	------
Buliminella subfusiformis Cushman? ("Buliminella sp." Rankin	------	F	------
Bulimina inflata Seguenza	------	C	------
Bulimina montereyana var. delmonteensis Kleinpell? (Bulimina cf. B. affinis d'Orbigny of Brady)	R	R	R
Bulimina ovula d'Orbigny	------	R	------
Bulimina ovula var. pedroana Kleinpell (Bulimina aff. B. ovula d'Orbigny) (Kleinpell, pl. 22, fig. 13)[3]	------	C	------
Virgulina californiensis Cushman	------	R	------
Virgulina delmonteensis Cushman and Galliher	F	------	------
Bolivina malagaensis Kleinpell (Bolivina aff. B. advena Cushman) (Kleinpell, pl. 22, figs. 3, 7)[3]	------	F	------
Bolivina seminuda Cushman	------	R	------
Bolivina sinuata Galloway and Wissler	------	F	------
Uvigerina hannai Kleinpell (Uvigerina aff. U. hootsi Rankin)	?	F	------
Uvigerina hootsi Rankin	------	A	F
Uvigerina segundoensis Cushman and Galliher	------	------	R
Valvulineria araucana var. malagaensis Kleinpell (Valvulineria aff. V. araucana (d'Orbigny)) (Kleinpell, pl. 22, figs. 10-12)[3]	------	F	R
Gyroidina soldanii var. rotundimargo R. E. and K. C. Stewart	------	C	------
Eponides multicameratus Kleinpell ("Eponides aff. E. broeckiana (Karrer)" Rankin)	------	R	------
Eponides healdi R. E. and K. C. Stewart	------	F	------
Eponides keenani Cushman and Kleinpell	------	F	------
Cassidulina delicata Cushman	------	F	------
Cassidulina modeloensis Rankin	------	C	------
Chilostomella cf. C. ovoidea Reuss (Chilostomella? cf. C. oolina Schwager) (Kleinpell, pl. 22, fig. 8)[3]	------	R	------
Pullenia pedroana Kleinpell (Pullenia cf. P. salisburyi R. E. and K. C. Stewart) (Kleinpell, pl. 22, figs. 14, 15)[3]	------	R	------
Globigerina bulloides d'Orbigny	------	F	------
Planulina ornata (d'Orbigny)	------	R	------

[1] Zonal position uncertain.

[2] Names in parentheses were used in preliminary paper (Am. Assoc. Petroleum Geologists, Bull., vol. 20, No. 2, pp. 125-149, 1936).

[3] Kleinpell, R. M., Miocene stratigraphy of California, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938. The citations in the table refer to illustrations of specimens from the Palos Verdes Hills.

Kleinpell's comments are summarized as follows:

The assemblages from localities 24 and 25 may be correlated with the fauna of the typical *Bolivina obliqua* zone in Hoots' lithologic unit 18 of the upper member of the Modelo formation (Monterey shale of some geologists) at the north edge of the Santa Monica Mountains, as listed by Rankin.[91] They may also be correlated with the fauna in the upper shale member of the Modelo formation in the type region in Modelo Canyon, Ventura County,[92] and with that in the lower part of the Reef Ridge shale of the Coalinga district in the San Joaquin Valley.[93]

ENVIRONMENT SUGGESTED BY FOSSILS

Suggestions concerning the environment of the Monterey Foraminifera in the following discussion are based on comments prepared by Kleinpell.

Sandstones in the middle and upper parts of the Altamira shale member contain shallow-water mollusks. That the shale in the upper part of the Altamira between

[91] Rankin, W. D., in Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, pp. 113-114, 1931. Kleinpell, R. M., Miocene stratigraphy of California, p. 134, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938.

[92] Rankin, W. D., op. cit.

[93] Kleinpell, R. M., in Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, Calif.: stratigraphy, paleontology, and structure: U. S. Geol. Survey Prof. Paper 195, p. 121, 1940 [1941].

the two thick sandstone units at Point Fermin was deposited in comparatively shallow-water is indicated by the presence of *Elphidium* and other Foraminifera. The peculiar faunal facies characterized by very small specimens of Foraminifera at localities 6 and 8 in the middle part of the Altamira shale is comparable to the facies shown by species that inhabit seaweed forests in the modern oceans and may indicate a similar habitat. The Foraminifera at other localities in silty shale and siltstone of the three parts of the Altamira shale indicate moderate depth, possibly near the 100-fathom line. The fauna at locality 5, however, suggests somewhat greater depth, perhaps between 300 and 500 fathoms. That locality represents diatomaceous silt in the middle part of the Altamira, evidently near the horizon of the Miraleste tuff.

The Foraminifera of the Valmonte diatomite member point to deposition at depths of 300 to 500 fathoms. Modern forms related to the thin-shelled scallop *Hyalopecten* aff. *H. peckhami* have been dredged along the coast of Oregon and California at depths of 100 to almost 1,100 fathoms.

The mudstone of the Malaga member was deposited evidently in deeper water than the sediments of the other two members. The abundance of *Bathysiphon*, *Bulimina inflata*, *Cassidulina delicata*, *Eponides healdi*, and *Gyroidina soldanii rotundimargo* at locality 24 suggests depths of 500 fathoms or more. It is assumed that lithologically similar mudstone at other localities represents deposition at considerable depths. The abundance of shallow-water bottom-dwelling diatoms in diatomite from Malaga Cove has been cited as evidence for deposition in shallow water.[94] It is not known whether the diatomite examined was collected from the Valmonte member or the Malaga member. The abundance of shallow-water attached diatoms is not incompatible, however, with ultimate deposition in deep water. Seaweeds to which such diatoms are attached may be torn loose and float a considerable distance from shore. It is suggested that a comparitive study of diatoms in the mudstone and laminated diatomite of the Malaga member and in different laminae in the diatomite of both Malaga and Valmonte members might be useful in attempting to reconstruct environmental conditions. It appears improbable that the many alternating units of mudstone and diatomite in the Malaga member at the north end of Malaga Cove indicate alternating deep and shallow water.

The foraminiferal faunas of the lower and middle parts of the Altamira shale are characterized by forms whose modern analogs are found in subtropical and tropical American waters. These forms are not known to occur in the upper part of the Altamira nor in the younger members. That the difference is not due to difference in depth facies is indicated by the absence of the warm-water forms in both shallow-water and deep-water facies in the upper part of the Altamira. Sandstone in the middle part of the Altamira contains a mollusk fauna including a notable number of tropical genera. Faunas of comparable size have not been found, however, in other parts of the Monterey in the Palos Verdes Hills.

AGE AND CORRELATION

Age assignments and correlation of the Monterey shale of the Palos Verdes Hills are based on Kleinpell's identifications of the foraminiferal zones. His views are included in the comments on preceding pages and are summarized in the correlation chart in his publication.[95] According to Kleinpell's identifications and according to usual Coast Range usage, the Monterey shale of the Palos Verdes Hills is of late middle to late upper Miocene age, the division between middle and upper Miocene being between the middle and upper parts of the Altamira shale member. Strata in the upper part of the Altamira are correlated with the lower part of the Modelo formation of the Santa Monica Mountains, selected by Kleinpell as the type region of his *Bolivina modeloensis* zone, the lowest zone recognized in the upper Miocene.

The mollusks found in sandstone of the middle part of the Altamira shale are of no assistance in correlation, as a similar fauna is unknown elsewhere in the Coast Ranges.

Though phosphatic shale is most abundant in the upper part of the Altamira shale, similar material and phosphatic mudstone occur also in the middle part. It is doubtful whether the abundance of phosphatic shale alone is a safe basis for correlation. Foraminifera from the upper part of the Altimira indicate, however, that the phosphate-rich strata in the Palos Verdes Hills are of the same age as phosphatic shale overlying schist in the Torrance, El Segundo, and Playa del Rey oil fields,[96] and at the base of the Modelo formation in the Santa Monica Mountains.

PLIOCENE SERIES

REPETTO SILTSTONE

GENERAL FEATURES

The Pliocene series has a meager representation in the Palos Verdes Hills. A maximum exposed thickness of about 150 feet of siltstone assigned to that series represents a greatly condensed and incomplete section of the lower Pliocene Repetto formation. In the Los Angeles Basin the Repetto formation has a thickness of as much as 4,000 or 5,000 feet but thins southward toward the Palos Verdes Hills. In the basin the upper Pliocene is represented by the Pico formation, ranging in thickness from several hundred to 3,000 feet. The Pico formation is missing in the Palos Verdes Hills.

The type region of the Repetto formation is in the Repetto Hills, on the north border of the Los Angeles Basin.[97] In that region the formation consists of 2,000 to 3,000 feet of siltstone and rests conformably on diatomaceous shale referred to the upper Miocene. Farther east in the Puente Hills the Repetto includes thick beds of conglomerate and sandstone. In the subsurface section in the basin it includes the sandstones that yield the oil produced in most of the major fields. Owing to its economic importance the subsurface Repetto has been studied exhaustively. Numerous faunal subdivisions, based on abundant well-preserved Foraminifera, are recognized and used in oilfield correlations.

In the Palos Verdes Hills the Repetto consists entirely of siltstone, and the term "Repetto siltstone"

[94] Hanna, G. D., The age of the diatom-bearing shales at Malaga Cove, Los Angeles County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 1111, 1928.

[95] Kleinpell, R. M., Miocene stratigraphy of California, fig. 14, (in pocket, column under heading "Los Angeles Basin") Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1938.

[96] Wissler, S. G., Stratigraphic formations [relations] of the producing zones of the Los Angeles Basin oil fields: California Div. Mines Bull. 118, pt. 2, p. 222, 1941.

[97] For a brief description of the Repetto formation in the Los Angeles Basin and on its borders and for citations to literature see Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif., and their inferred environment: U. S. Geol. Survey Prof. Paper 190, pp. 3-6, 1938.

is used for the formation in that area. The Repetto siltstone disconformably overlies the Malaga mudstone member of the Monterey shale and is unconformably overlain by Pleistocene strata. Though the contact between the Malaga and Repetto appears to be gradational, faunal data indicate a discontinuity of considerable magnitude. The Repetto is found at Malaga Cove and at other localities near the north border of the hills, extending eastward to an area straddling Palos Verdes Drive East. At many places between Malaga Cove and Palos Verdes Drive East and in the entire area east and southeast of Palos Verdes Drive East Pleistocene formations rest directly on the Miocene, the Repetto being overlapped. How far south the Repetto originally extended is not known, but it covered probably the entire area of the hills. The fossils indicate that the sediments in the Palos Verdes Hills were laid down in deep water. Scattered schist pebbles were apparently derived from a schist area perhaps to the south or west of the present Palos Verdes Hills. It is doubtful whether the original thickness of the Repetto prior to the erosion that preceded the deposition of Pleistocene strata was much greater than the present thickness at Malaga Cove.

The Repetto consists of soft, massive, glauconitic foraminiferal siltstone. The dry rock is bluish gray on fresh surfaces and buff on weathered surfaces. The coarser grain of the sediments, the abundance of glauconite grains and Foraminifera, and the scarcity or absence of Radiolaria and diatoms distinguish the Repetto siltstone from the Malaga mudstone. The differences are in general readily apparent, but outcrops of small extent may consist of rocks that are not typical, and in such outcrops the two units may be difficult to distinguish.

STRATIGRAPHY AND LITHOLOGY

MALAGA COVE

The best and most readily accessible exposures of the Repetto siltstone are at Malaga Cove, where the Repetto disconformably overlies the Malaga mudstone

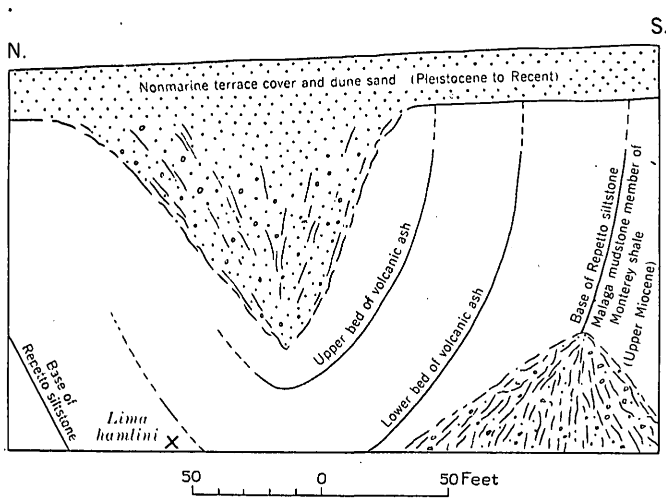


FIGURE 9.—Repetto siltstone in northern syncline at Malaga Cove.

member of the Monterey in the northern syncline (pls. 10, *A*; 12, *C*; figs. 7, 9). The Repetto consists of soft massive bluish-gray siltstone. Glauconite grains and well-preserved Foraminifera may be found in virtually any hand specimen. A thickness of 100 feet is exposed, and it is estimated that an additional thickness of about 50 feet in the trough of the syncline is concealed by slump at the top of the cliff. At accessible places on the cliff the contact with the underlying Malaga mudstone appears to be gradational through a thickness of a few inches. About half way up the cliff, on the south limb of the syncline, a lens of sand a foot thick, streaked with siltstone, is at or near the base of the Repetto. Another 1-foot sandy zone is 17 feet above the base. Two thin beds of vitric volcanic ash varying in thickness from 2 to 6 inches are in the Repetto, the lower bed 39 feet above the base of the formation and the upper bed 33 feet higher. Both beds are at places in the form of discontinuous short stringers. The ash is discernible only at times when the cliff face is clean and fresh. The siltstone contains a few pebbles of schist, quartz, and black basaltic rock 1 to 4 inches long. Limestone occurs as concretions, which are much less abundant than in the Malaga mudstone. The concretions contain glauconite grains and Foraminifera filled with calcite.

The "foraminiferal rock" at Malaga Cove described by Reed [98] is the Repetto siltstone. He estimated that Foraminifera make up 20 percent of the samples examined and echinoid spines and siliceous organisms—diatoms, Radiolaria, silicoflagellates, and sponge spicules—5 percent. Glauconite was found to be abundant both as grains and in the fine-grained matrix. The detrital mineral grains, including blue soda amphibole, were interpreted as indicating ultimate or perhaps direct derivation from a Franciscan (?) area.

Foraminifera were collected from the lower 85 feet of the formation on the south limb and in the trough of the syncline (locality 26). A few specimens of a large thin-shelled clam, *Lima hamlini*, were collected 5 to 10 feet below the lower bed of volcanic ash on the north limb of the syncline, just north of the trough (locality 27). A vertebra found by Dr. H. W. Hoots about 10 feet above the base of the formation is identified by Dr. Remington Kellogg as a caudal vertebra of a whale.

RAVINE WEST OF HAWTHORNE AVENUE NEAR WALTERIA

The Repetto siltstone crops out in a small area at the head of a ravine on the north slope of the hills, the fourth ravine northwest of Hawthorne Avenue. Fragmentary remains of *Lima hamlini* as well as Foraminifera were found at this locality. The siltstone is overlain by Pleistocene sandy marl. In other ravines in this area the Pleistocene strata rest on Miocene rocks.

LOMITA QUARRY-PALOS VERDES DRIVE EAST AREA

In the Lomita quarry-Palos Verdes Drive East area the Repetto siltstone is found on the flanks of the Gaffey syncline and locally on the north flank of the Gaffey anticline. Only two exposures were observed near the Lomita quarry, one in the ravine north of the quarry and the other in a cut along the road leading to the quarry. At both localities the siltstone is overlain by Pleistocene calcareous beds. Several outcrops were found along Palos Verdes Drive East and in nearby ravines, but contacts with overlying and underlying formations are not exposed. Foraminifera are particularly abundant at locality 28, near Palos Verdes Drive East.

[98] Reed, R. D., A siliceous shale formation from southern California: Jour. Geology vol. 36, pp. 353–357, fig. 4, 1928.

FOSSILS

FORAMINIFERA

Foraminifera are abundant in the Repetto siltstone. The faunas are the same as those in the Repetto of Los Angeles Basin oil fields, where the general succession of foraminiferal zones was known before Foraminifera were found in the outcrop section along the borders of the basin.

MOLLUSKS

Specimens of *Lima hamlini* were collected at Malaga Cove (locality 28), and remains of that species too fragmentary to collect were recognized in a ravine west of Hawthorne Avenue. *Lima hamlini* [99] is closely related to *L. agassizii*, dredged in the Gulf of Panama at a depth of 322 fathoms.

ENVIRONMENT SUGGESTED BY FOSSILS

The Repetto siltstone of the Palos Verdes Hills contains the characteristic Foraminifera of the Repetto formation of the Los Angeles and Ventura Basins. According to Natland's analysis [1] of the Repetto Foraminifera, they are similar to forms living at depths of about 6,500 to 8,340 feet off the California coast. *Lima hamlini* is the most widespread of a group of Los Angeles Repetto mollusks that suggest depths of 300 to 600 fathoms (roughly 2,000 to 4,000 feet).[2]

AGE AND CORRELATION

On the basis of a twofold subdivision of the Pliocene of the Los Angeles Basin, the Repetto is lower Pliocene.

The lowermost 85 feet of an estimated thickness of 150 feet of Repetto siltstone at Malaga Cove was sampled for Foraminifera with the assistance of H. L. Driver, G. C. Ferguson, H. W. Hoots, and S. G. Wissler. According to Wissler,[3] the entire lower Repetto and the basal part of the middle Repetto are missing, and the missing divisions are represented by 150 feet of strata in the nearby Torrance field and by 500 feet in the Dominguez field.

PLEISTOCENE SERIES

PRINCIPAL SUBDIVISIONS

The Pleistocene deposits of the Palos Verdes Hills are exceptionally fossiliferous, and in part of the area they were studied exhaustively by Arnold, whose great monograph [4] on the stratigraphy and paleontology of these deposits has played an important part in the development of geologic investigations in the Coast Ranges. Arnold studied the section exposed along the San Pedro water front and on Deadman Island and described the fossils collected during a period of many years by him and his father, Delos Arnold. Arnold's stratigraphic units are still recognized, but the nomenclature adopted in the present report is different from that used by him, as shown in the following table:

Stratigraphic nomenclature used by Arnold for formations assigned to Pliocene and Pleistocene and nomenclature used in present report for corresponding units.

Arnold, 1903			This report	
Pleistocene	San Pedro series	Upper San Pedro series	Palos Verdes sand	Upper Pleistocene
		Lower San Pedro series	San Pedro sand	Lower Pleistocene
Pliocene	Sandstone at Deadman Island and Timms Point		Timms Point silt	

The marine strata assigned to the Pleistocene in this report include two principal subdivisions designated lower Pleistocene and upper Pleistocene. These subdivisions and their stratigraphic units are shown in the following table:

Marine Pleistocene deposits in Palos Verdes Hills

Principal subdivisions	Stratigraphic units	
Upper Pleistocene.	Marine deposits on marine terraces, including those on youngest terrace—the Palos Verdes sand.	
	Unconformity	
Lower Pleistocene.	San Pedro sand.	San Pedro sand.
		Lomita marl. / Timms Point silt.

As explained under the heading "Age and correlation" (p. 96), these deposits are considered Pleistocene in terms of the succession of marine formations on the Pacific coast. The subdivisions of the Pleistocene have, however, only a relative age significance.

Arnold's lower San Pedro series is now designated the San Pedro sand, and the Timms Point silt is his Pliocene. The Lomita marl is a calcareous facies that is not present along the San Pedro water front and, therefore, was not observed by Arnold. The upper Pleistocene terrace deposits older than the Palos Verdes sand also were not included in his studies.

Arnold recognized the unconformity between his lower San Pedro series and his upper San Pedro series, that is, between the San Pedro sand and the Palos Verdes sand. As his work was limited to the water front, he did not recognize evidently the relative magnitude of the unconformity in terms of the events that took place during the time interval represented by the unconformity. If the geologic history of the Palos Verdes Hills is correctly interpreted, these events included deformation; almost complete submergence or probably complete submergence of the area now constituting the Palos Verdes Hills; and intermittent emergence during which the series of marine terraces were formed and the marine deposits now found on most of them were laid down, the Palos Verdes sand constituting the marine deposits on the lowest and most extensive terrace on the landward side of the hills.

The exposures of the Pleistocene formations are described as they were found during the course of field work in 1930, supplemented by observations in 1933 and 1935 and by scattered observations during the

[99] Woodring, W. P., op. cit. (U S. Geol. Survey Prof. Paper 190), pp. 47–49.

[1] Natland, M. L., The temperature and depth distribution of some Recent and fossil Foraminifera in the southern California region: California Univ., Scripps Inst. Oceanography Bull., Tech. sér., vol. 3, pp. 225–230, 1 table, 1933; in Cushman, J. A., Report of the Committee on Micropaleontology: Nat. Research Council Div. Geology and Geography Rept. 1936–1937, app. E., p. 6, 1937.

[2] Woodring, W. P., op. cit., pp. 13–16.

[3] Wissler, S. G., Stratigraphic formations [relations] of the producing zones of the Los Angeles Basin oil fields: California Div. Mines Bull. 118, pt. 2, pp. 217–218, 1941.

[4] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, 420 pp., 37 pls. 1903. (Reprint Leland Stanford Jr. Univ. Contr. Biol. Hopkins Seaside Lab., No. 31, 1903.)

spring of 1938. Owing to urban and other developments exposures change rapidly or are completely obliterated, particularly in San Pedro. Even under natural conditions exposures are rapidly obscured by slump and talus or by growth of vegetation. On the other hand, new and important exposures are continually being uncovered. At least along the water front, however, the net result is a distinct loss geologically. Many of Arnold's famous fossil localities are not accessible, Deadman Island being, for example, no longer in existence. Small areas of fossiliferous San Pedro sand at Second and Beacon Streets, bounded by streets excavated to grade, are a few hundred feet inland from Arnold's lower San Pedro locality (now destroyed) at the San Pedro bluff. By 1943 this entire area was excavated to grade and exposures of the San Pedro sand, comparable to Arnold's San Pedro Bluff locality, can no longer be seen. Arnold's upper San Pedro locality at the north end of San Pedro bluff, near the lumber yard (locality 113, on the east side of Harbor Boulevard), has been destroyed recently. His upper San Pedro locality at Crawfish George's (locality 108, at the north boundary of the Fort McArthur Lower Reservation) and his Pliocene locality at Timms Point were still accessible in 1938, but the point at Timms Point is concealed by fill.

LOMITA MARL, TIMMS POINT SILT, AND SAN PEDRO SAND

GENERAL FEATURES

STRATIGRAPHIC RELATIONS

Strata assigned to the lower Pleistocene are found along and near the northeast and north borders of the hills from San Pedro northwestward to Malaga Cove. They lie unconformably on the Repetto siltstone or lap up on different members of the Monterey shale. At many places they are concealed by overlapping terrace deposits. Sections of the lower Pleistocene strata are shown on plate 13.

At most localities the lower Pleistocene deposits consist chiefly or entirely of the San Pedro sand. At places calcareous beds or silt, or both, of varying thickness are found at the base of the section. The calcareous beds are designated the Lomita marl, and the silt is designated the Timms Point silt. In central San Pedro, where the three units—Lomita marl, Timms Point silt, and San Pedro sand—are superimposed, they are found in upward sequence in the order named. If each unit represents a distinct time interval, discontinuities might be expected to account for the varying thickness of the Lomita marl and Timms Point silt and for their local absence. With the following exceptions, however, no marked discontinuities are apparent. On Deadman Island, which has been destroyed, the San Pedro sand overlay the Timms Point silt along an abrupt and irregular contact. At Lomita quarry sand doubtfully identified as the San Pedro appears to overlie the Lomita unconformably. At other localities where contacts between the three units were observed the change in lithology is generally gradational. Though continuous exposures along the strike are not extensive, the observed relations appear to be most satisfactorily explained by the inference that the lower part of the San Pedro sand grades laterally into the Lomita marl and Timms Point silt and by the further inference that minor discontinuities are found locally between the three units and also within them, as shown in figure 10. Inasmuch as the Lomita marl and Timms Point silt are considered facies of a major stratigraphic unit, the San Pedro sand, the view that they are to be assigned member rank under the San Pedro sand may be justified. To avoid violation of current usage and also to avoid cumbersome stratigraphic names, the three units are assigned formation rank.

GENERAL CHARACTER AND DISTRIBUTION

The maximum outcrop thickness of the lower Pleistocene strata is not more than 350 feet; the maximum subsurface thickness is estimated to be about 600 feet. The thickness varies, however, from place to place owing to the unconformity at the top.

Wherever the Lomita marl was found it is at the base of the lower Pleistocene deposits. It has an extensive but discontinuous distribution from San Pedro to the region west of Walteria. It is thickest in the Gaffey syncline and in San Pedro. On the north flank of the Gaffey anticline it is absent generally or if present is thin. The maximum exposed thickness is 60 to 70 feet. The computed thickness in San Pedro is about 100 feet. Subsurface sections in the Gaffey syncline show a thickness as great as 275 feet.

The Timms Point silt is the least extensive of the three units. The only area of considerable size is in San Pedro, where the silt rests on the Miocene or overlies the Lomita marl. Isolated exposures of strata assignable to the Timms Point silt were found on the north flank of the Gaffey anticline and along the north border of the hills near Agua Magna Canyon. The exposed thickness in San Pedro is 30 to 80 feet, but the maximum computed thickness is about 120 feet.

The San Pedro sand is found throughout the area where the lower Pleistocene strata are exposed. It rests directly on the Pliocene or Miocene or overlies the Lomita marl or Timms Point silt. The maximum exposed thickness is about 175 feet. In subsurface sections the thickness is as much as 300 feet.

The Lomita marl consists of a variety of calcareous rocks, principally marl and calcareous sand. The term "calcareous sand" is used for unconsolidated calcareous material of sand or granule size composed chiefly of calcareous organic remains—calcareous algae, Foraminifera, Bryozoa, small shells, and shell fragments. There appears to be no simple term for such calcareous sediments. The calcareous sand of the Lomita marl is representative of a particular type in that the calcareous material which is its principal constituent is derived from contemporaneous or penecontemporaneous organisms. The term "calcarenite" [5] has been proposed for clastic limestone or dolomite composed of coral sand, shell sand, or of lime sand derived from the erosion of older limestones. That term is, however, hardly suitable for the unconsolidated sediments under discussion, and a special term such as "biocalcigranulyte" [6] is cumbersone and meaningless to most geologists.

The proportions of different organic constituents in the calcareous sediments change from place to place and from layer to layer. Foraminifera or mollusks are the usual most abundant constituents; locally Bryozoa or calcareous algae are most abundant. Echinoids, represented generally by spines, are less frequent. Corals, brachiopods, ostracodes, barnacles, and decapod crustaceans are relatively rare. At some places the calcareous sediments contain little detrital material, about 10 percent or less; at other places they

[5] Grabau, A. W., Paleozoic coral reefs: Geol. Soc. America Bull., vol. 14, p. 349, 1903.
[6] Grabau, A. W., Principles of stratigraphy, 2d ed., p. 283, New York, 1924.

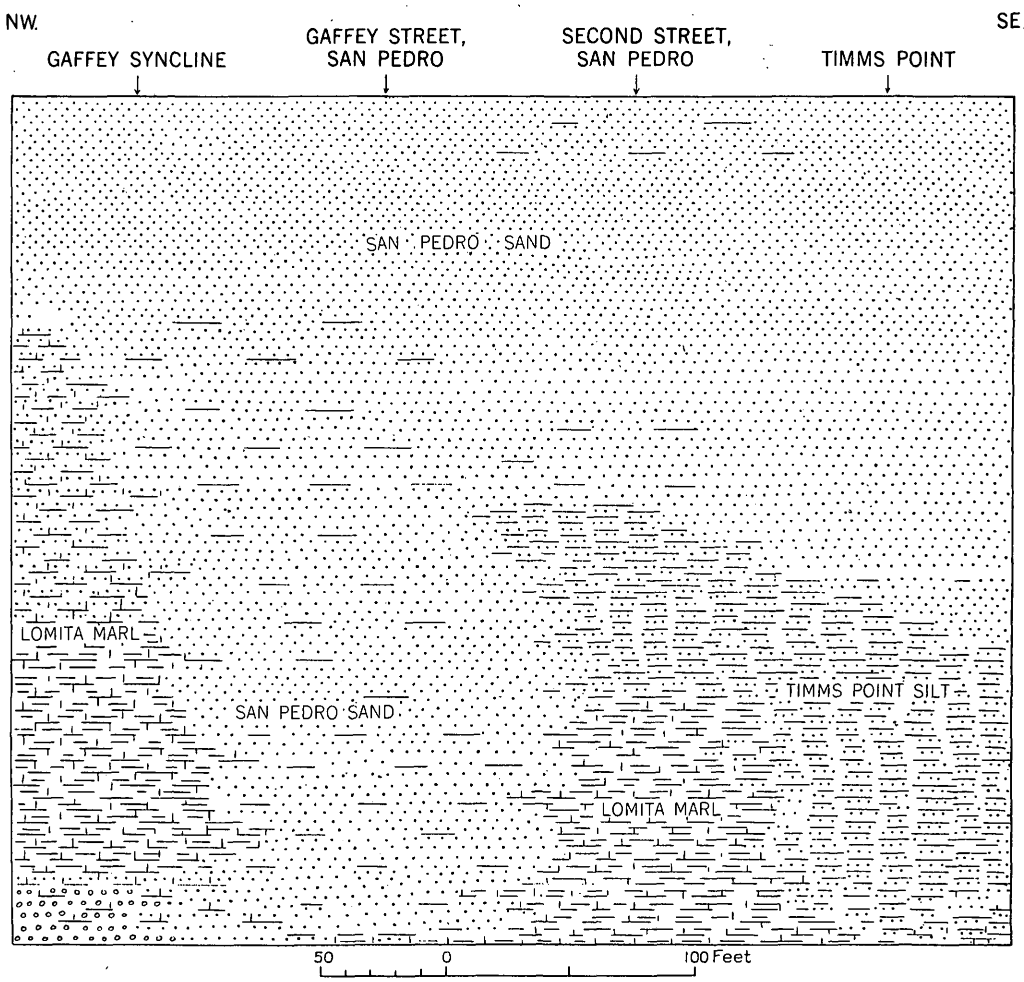


FIGURE 10.—Chart showing inferred relations of Lomita marl, Timms Point silt, and San Pedro sand.

are sandy or silty. In excavations or fresh outcrops the calcareous sediments are uncemented or poorly cemented. In most natural outcrops, however, they consist of hard rocks cemented by secondarily deposited calcareous material. At many localities glauconite and limy phosphatic nodules are abundant in some layers. The Lomita marl includes also beds of gravel consisting chiefly or entirely of limestone pebbles and cobbles derived from the Monterey shale. Locally huge boulders of soft Miocene mudstone and Pliocene siltstone are embedded in calcareous strata. The petrology of the calcareous sediments has been studied by Reed,[7] but only summaries of the results of his studies have been published.

The Timms Point silt consists of brownish generally massive sandy silt and silty sand. At Timms Point the silt is marly near the base of the member. At that locality the silt and sand contain pebbles of limestone like that in the underlying Miocene strata.

The San Pedro sand is made up chiefly of regularly bedded and cross-bedded sand, but includes gravel, silty sand, and silt. In San Pedro, where the San Pedro sand overlies the Timms Point silt, a transition zone between the two units consists of thin-bedded sand and thin-bedded silt and silty sand. At many localities where the San Pedro overlies the Lomita a transition zone is marked by the gradual addition of detrital material. The petrology of the sand and gravel in the San Pedro has not been studied. For the most part these sediments consist apparently of granitic debris, derived presumably from granitic areas north of the Los Angeles Basin. Some of the beds of gravel, however, contain pebbles of limestone, cherty shale, and schist, which are assumed to represent local debris derived from the Palos Verdes Hills.

TYPE REGION OF STRATIGRAPHIC UNITS

The name "San Pedro beds" was used by Dall [8] in 1898. It is not certain but is now immaterial whether the strata briefly described represent the San Pedro sand of this report, the Palos Verdes sand, or both. The term "lower San Pedro series" was used by the Arnolds,[9] for the San Pedro sand of this report. When the lower San Pedro series was named particular attention was devoted to exposures on Deadman Island. Localities along the San Pedro water front were mentioned, however, and that general region is regarded as the type region of the San Pedro sand.

The strata assigned to the Timms Point silt were designated Pliocene by the Arnolds [10] and were assigned

[7] Reed, R. D., Petrology of the calcareous beds of San Pedro Hills, Calif. (abstract): Geol. Soc. America Bull., vol. 42, pp. 310–311, 1931; Geology of California, pp. 259–260, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1933.

[8] Dall, W. H., A table of the North American Tertiary horizons, correlated with one another and with those of western Europe, with annotations: U. S. Geol. Survey 18th Ann. Rept., pt. 2, 335, 1898.

[9] Arnold, Delos and Ralph, The marine Pliocene and Pleistocene stratigraphy of the coast of California: Jour. Geology, vol. 10, pp. 120, 124–126, 1902. Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, pp. 12, 18–23, 1903.

[10] Arnold, Ralph and Delos, op. cit., pp. 120, 121–123. Arnold, Ralph, op cit. (California Acad. Sci. Mem., vol. 3), pp. 12, 14–17, 1903.

by Crickmay [11] to the Santa Barbara formation. The name "Timms Point" as a stratigraphic term of formation or lower rank was proposed by Clark,[12] who designated Timms Point as the type region.

The name "Lomita formation" has come into local usage and has been mentioned casually in other printed reports. In this report the term "Lomita marl" is used and refers to the calcareous strata of the Palos Verdes Hills assigned to the lower Pleistocene. The type region is near Lomita quarry, in the western part of the Gaffey syncline.

STRATIGRAPHY AND LITHOLOGY

DEADMAN ISLAND

Deadman Island, which is Reservation Point on the current edition of the Wilmington topographic map, was destroyed in 1928 to widen the channel to the inner harbor. The strata formerly exposed there are briefly described, as they played an important part in early investigations. (See pl. 13, column 16.)

The Timms Point silt (Arnold's Pliocene) dipping northeastward rested without marked discordance on the Malaga mudstone member of the Monterey shale, which was exposed at the south end of the island. The Timms point silt consisted of massive brownish sandy silt and silty sand locally cemented. At the base were pebbles of limestone and hard mudstone. According to Arnold's description,[13] the thickness was 20 to 45 feet, and the dip changed from about 25° at the base to 8° or 10° at the top. Crickmay [14] recognized six zones in the Timms Point silt (his Santa Barbara formation) representing a total thickness of 54½ feet. He found that northern fossils, including *Patinopecten caurinus* and *Thyasira disjuncta*, were most abundant in zone 5, which was 25 feet thick, the base being 14½ feet above the base of the member. Crickmay's zone 5 included Arnold's *Cryptodon* [*Thyasira*] bed.

The San Pedro sand [15] overlaid the Timms Point silt along a sharp and irregular contact, as may be seen on Arnold's photographs.[16] It consisted of massive coarse-grained gray sand locally cemented. The sand dipped northeastward at about the same rate as the top of the Timms Point silt, 8° to 10°. Owing to the dip and unconformity along an almost horizontal plane at the top of the formation, the thickness increased from a maximum of 10 feet on the west side of the island to 20 feet on the east side. The basal 2 to 3 feet contained limestone pebbles and cobbles as much as a foot long. Most of the cobbles were riddled with borings, and some had masses of the wormlike gastropod *Aletes squamigerus* attached to them. During the destruction of the island exceptionally well-preserved fossils were found on its east side at locality 30 in loose sand in the basal 6 feet of the formation. The fauna resembles that in the San Pedro sand in San Pedro but includes some species of moderate-depth facies not found in San Pedro. At locality 30 fossils were scarce or absent more than 8 feet above the base of the formation.

TIMMS POINT

The geology of the Timms area is shown on plate 14. Timms Point (pl. 15, *B*) is the type locality of the Timms Point silt. At that locality the Timms Point silt rests on the Malaga mudstone member of the Monterey shale (see pl. 13, column 15). The contact was formerly well exposed at the point but is now concealed by fill. It is exposed or is close to the surface also at several localities on the east face of the bluff near the point. Bedding is not clearly discernible in the Miocene mudstone nor in the silt at the contact. At and near the point, the contact, which may conform to the attitude of the Miocene mudstone, dips 30° northeastward, whereas on Harbor Boulevard, 700 feet northwest of the point, the silt dips 14° northeastward near the contact.

The Timms Point silt at Timms Point has been described by Clark,[17] who recognized three units. The following section, in which the units are the same as Clark's, was measured on the east face of the bluff:

Section of Timms Point silt in type region at Timms Point

	Ft.	*in.*
3. Yellowish brown silty sand. Includes a layer containing a few fossils, mostly *Lucinoma annulata*, 2 feet 8 inches above base	16	0
2. Yellowish brown silt and silty sand containing pebbles a few inches long of limestone and hard mudstone and many shells		2–6
1. Yellowish brown silt, marly toward base. Contains scattered small pebbles of limestone and hard mudstone and generally a layer of pebbles at base. Pockets of silty calcareous sand at and near base contain many Foraminifera and small shells. Shells throughout, but scarce in upper 2½ feet. Bryozoa locally abundant in lower part	14	0
Maximum exposed thickness	30	6

The estimated total thickness of the formation in this region is 70 feet.

The sediments in the basal foot or two of unit 1 are somewhat calcareous, consisting of marly silt and pockets of silty calcareous sand. Foraminifera and small shells are particularly abundant in the more calcareous material (localities 32, 32b). About 150 feet north of the point an almost pure concentrate of Foraminifera ½ to 2 inches thick rests on the Miocene. Foraminifera are rare above the basal 2 feet of the formation. Small shells and large shells, the latter including *Patinopecten caurinus* and fragments of *Trachycardium quadragenarium*, are abundant in unit 1 (localities 32a, 32c). Bryozoa, particularly *Idmonea californica*, are locally abundant in the lower few feet near the point.

Unit 2, not more than 6 inches thick, is characterized by the abundance of pebbles. Fossils are less abundant than in unit 1 (localities 32d, 32e, 33). On the east side of Harbor Boulevard,[18] 30 feet south of locality 33, unit 2 rests directly on Miocene mudstone, the surface of which is probably irregular. Fossiliferous strata at locality 34, on the west side of Harbor Boulevard, represent probably unit 2. The fossils include an almost complete *Trachycardium quadragenarium* and *Pandora grandis*. Poorly preserved fossils, including paired *Thyasira disjuncta*, a northern species, were found on the west side of Harbor Boulevard at locality 35, in strata higher than any exposed along the bluff.

A retaining wall at the north end of the bluff conceals the strata for a distance of several hundred feet. North

[11] Crickman, C. H., The anomalous stratigraphy of Deadman's Island, Calif.: Jour. Geology, vol. 37, p. 618, 1929.
[12] Clark, Alex, The cool-water Timms Point Pleistocene horizon at San Pedro, Calif.: San Diego Soc. Nat. History Trans., vol. 7, No. 4, p. 40, 1931.
[13] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 14, 1903.
[14] Crickmay, C. H., op. cit., pp. 622–627, table (p. 634).
[15] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 18, 1903. Crickmay, C. H., op. cit., pp. 628–630 (zone 6).
[16] Arnold, Ralph, idem, pl. 25.

[17] Clark, Alex, the cool-water Timms Point Pleistocene horizon at San Pedro, Calif.: San Diego Soc. Nat. History Trans., vol. 7, No. 4, pp. 25–42, 2 figs., 1931.
[18] Since the current edition of the Wilmington topographic map was issued Harbor Boulevard has been extended from the business district of San Pedro to Timms Point.

of the retaining wall sand and silty sand assigned to the Sand Pedro sand form a low arch. Small specimens of *Lucinoma annulata* and *Cerastoderma?* were observed in a layer of silty sand. Even before the retaining wall was built Arnold[19] found the stratigraphic relations north of the bluff uncertain owing to inadequate exposures, but his diagram,[20] which may have been drawn with the well-exposed Deadman Island section as a guide shows a discontinuity at the base of the sand.

CENTRAL SAN PEDRO

The most complete exposures of the lower Pleistocene strata in San Pedro are found in the central part of the town, between Pacific Avenue and Harbor Boulevard. In that area, and in no other so far as known, the three lithologic units are in superposition. The total estimated thickness is about 350 feet. (See pl. 14.)

At the base of the section are calcareous strata assigned to the Lomita marl, the computed thickness of which is about 100 feet. On Eighth Street, between Pacific and Mesa, the calcareous strata consist of fossiliferous marl (locality 36). More extensive exposures of the marl were found at locality 37, in the alley north of Eighth Street. Fossils, including *Bittium rugatum, Turritella cooperi,* and *Thracia trapezoides*, are abundant at locality 37. Bedding was not recognized in the marl, but eastward toward Mesa Street, presumably upward in the section, the marl becomes silty.

The most extensive exposures of the Lomita marl are on Second Street, between Pacific and Mesa (pl. 15, *A*; pl. 13, column 14), where the strata dip northeastward at an angle of 22°. The following section was measured at that locality:

Section of Lomita marl on south side of Second Street, between Pacific Avenue and Mesa Street

	Ft.	*in.*
4. Calcareous sand containing nodular masses of hard limestone of irregular shape. Overlain by Timms Point silt. For upward continuation of section see opposite column.		
b. Calcareous sand containing fewer and smaller limestone nodules than unit a (locality 42h, composite; locality 42i, 3 feet below top)	6	10
a. Calcareous sand containing many limestone nodules (locality 42f, 1 foot above base; locality 42g, 7½ feet above base)	18	6
3. Calcareous sand, marly calcareous sand, and marl containing coarse-grained calcareous material.		
c. Coarse-grained and fine-grained calcareous sand. A coarse-grained layer 10 inches thick at base and moderately coarse-grained layers throughout (locality 42d, coarse-grained layer at base; locality 42e, 2 feet 10 inches above base)	6	0
b. Marl containing coarse-grained calcareous material	3	3
a. Marly calcareous sand, basal 10 to 12 inches cemented, forming nodular layer (locality 42c)	1	2
2. Gray marl and calcareous sand.		
b. Gray marl (locality 42b)	7	9
a. Gray calcareous sand (locality 42a)		5–11
1. Gray marl containing pockets of marly calcareous sand (locality 42). Base not exposed	5	2
Maximum exposed thickness	49	7

Marl like that in unit 1, presumably part of that unit, is exposed in an excavation along the alley south of Second Street. By tracing the nodular layer at the base of unit 3 on the intervening hillside it is estimated that marl in the excavation extends 17 feet lower stratigraphically than the lowest exposures on the street, making a total exposed thickness of about 66½ feet. Unit 1 in both the excavation and on the street contains small and moderately large shells. *Bittium rugatum* and *Turritella cooperi* are abundant, and the fossils include fragments of the northern *Thracia trapezoides*. The fauna is the same as that in similar marl on Eighth Street and along the adjoining alley. The calcareous sand and the marl that includes coarse-grained calcareous material contain small and young shells only or small shells, a few moderately large shells, and fragments of large shells, the last group consisting of *Lucinoma annulata, Epilucina californica,* and *Macoma nasuta*. The coarse-grained calcareous sand at the base of unit 3c (locality 42d), for example, contains only small and young shells. *Turritella cooperi* is abundant in that layer, but the specimens collected are minute tips.

Exposures of the Timms Point silt were found on Eighth Street at and near Center (locality 38), where an almost complete large valve of the northern *Patinopecten caurinus* was collected near the top of the formation; on Mesa, near Seventh (locality 39); and on Third, near Mesa (locality 40). The computed thickness in this region, based on an assumption of an average dip of 12°, is 120 feet. The best exposures and the only locality where the contact with the underlying Lomita marl was observed are on Second Street (see pl. 15, *A*), where the formation is considerably thinner and dips northeastward 17° to 22°. A section measured on Second Street (pl. 13, column 14) is as follows:

Section of Timms Point silt on Second Street, between Pacific Avenue and Mesa Street

	Ft.	*in.*
8. Massive yellowish-brown silty sand. Overlain by thin-bedded sand and silty sand assigned to San Pedro sand	4	0
7. Fossiliferous massive yellowish-brown silty sand (locality 45)	2	0
6. Massive yellowish-brown sandy silt and silty sand, more sandy upward. Contains scattered fossils	30	0
5. Fossiliferous massive yellowish-brown sandy silt	1	2–5
4. Massive yellowish-brown sandy silt	2	9–10
3. Fossiliferous massive yellowish-brown sandy silt (locality 44a)		6–9
2. Massive yellowish-brown sandy silt	36	6
1. Fossiliferous massive yellowish-brown sandy silt (locality 44). Rests on Lomita marl. Contact apparently slightly irregular but not sharp, lower few inches containing much calcareous material. For downward continuation of section see opposite column		7–8
Maximum thickness	78	2

The subdivisions of the preceding section are based on fossiliferous zones, not on lithologic units. The entire formation consists of massive sandy silt and silty sand, sand increasing in abundance upward. The calcareous material at the base of the member is regarded as a transition zone to the underlying Lomita marl. It might be regarded, however, with equal plausibility as reworked material from the marl. The Timms Point fossils include northern species, notably *Mitrella carinata gausapata, Patinopecten caurinus, Mya truncata,* and a small variety of *Panomya beringianus*. None of these species were found in the underlying Lomita marl in San Pedro, and with the exception of *Patinopecten caurinus* they were not found in the overlying San Pedro sand.

[19] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 21, 1903.
[20] Idem, pl. 22, diagram D.

The base of the San Pedro sand is drawn arbitrarily at the base of the lowest bed of sand in a transition zone about 30 feet thick consisting of thin-bedded sandy silt and silty sand. These strata dip northeastward 12° to 19°. The transition zone is exposed at the southeast corner of Eighth and Center Streets, on Fourth between Mesa and Center, at the southeast corner of Third and Mesa, and at the northwest corner of Second and Mesa (see pl. 13, column 14). At the last locality a few fossils were found in a bed of sand a few inches thick 7½ feet above the lowest bed of sand, which was selected as the base of the San Pedro sand (locality 46). These fossils represent an association like that at higher horizons in the San Pedro.

The transition zone is overlain by apparently unfossiliferous cross-bedded sand. The thickness of the cross-bedded sand is difficult to estimate but is probably about 50 feet. It is exposed on Third Street near Palos Verdes, on First between Mesa and Center, on Center between First and Santa Cruz, and in the lower part of the bluff at Second and Beacon and nearby. It was described by Thompson,[21] who interpreted it as lower foreshore deposits superimposed on upper foreshore deposits.

Bedded fossiliferous and unfossiliferous sand about 20 feet thick overlies the cross-bedded sand. These strata, which dip gently northeastward, are well exposed at and near Second and Beacon Streets (pl. 15, *C*), but the exposures are being rapidly destroyed by removal of the sand. A section measured on the west side of Harbor Boulevard, immediately south of Second Street (see pl. 13, column 14), is as follows:

Section of Pleistocene strata, including San Pedro sand, on west side of Harbor Boulevard, immediately south of Second Street (locality 47)

	Ft.	in.
Nonmarine terrace cover:		
5. Reddish-brown sand. Palos Verdes sand represented at base locally by lenses of gravel containing shell fragments	10–12	0
San Pedro sand:		
4. Moderately coarse-grained fossiliferous gray sand (locality 47a):		
e. Shells decreasing in abundance upward	7	3
d. Shells abundant, particularly at top. *Pupillaria optabilis knechti* and *Bittium armillatum* notably abundant	1	10
c. Shells scattered		11
b. Shells abundant, notably flat-lying *Macoma nasuta* and *Macoma secta*		2
a. Shells scattered	1	3
3. Moderately coarse-grained fossiliferous gray sand containing clay pellets (locality 47). Fossils less abundant than in unit 4. Contact at base sharp	1	3
2. Coarse-grained unfossiliferous gray sand	4	4
1. Coarse-grained cross-bedded gray and limonite-stained sand containing limonitic concretions. Thickness estimated; base not exposed	20	0
Exposed thickness of San Pedro sand	37	0

The fossils in unit 3 of the preceding section (locality 47) are similar to those in unit 4 (locality 47a) but are less abundant and do not include oysters. Unit 4 is characterized by the abundance of *Pupillaria optabilis knechti* and *Bittium armillatum* and by the presence of oysters.

Nearby, on the west side of Beacon Street between Second and First (pl. 15, *C*), where the following section was measured, unfossiliferous sand increasing in thickness northward to 10 feet overlies the fossiliferous sand.

Section of San Pedro sand on west side of Beacon Street, between Second and First Streets

	Ft.	in.
7. Unfossiliferous gray sand increasing in thickness northward. Overlain by reddish-brown dirty sand of nonmarine terrace cover	0–10	0
6. Gray sand containing scattered fossils, which are more abundant toward top	4	0
5. Gray sand. At top a 2-inch layer of flat-lying *Macoma nasuta* and *Macoma secta;* paired or single valves, convex side down		3
4. Hard silt		4–5
3. Fossiliferous gray sand containing silt pellets. Most of the pelecypods are single valves, convex side down		9
2. Unfossiliferous gray sand	6	6
1. Cross-bedded limonite-stained gray sand. Thickness estimated; base not exposed	15	0
Maximum exposed thickness of San Pedro sand	36	11

The fossiliferous San Pedro sand at and near Second and Beacon Streets is all that is left to represent Arnold's San Pedro Bluff locality,[22] which was located to the southeast along the edge of the bluff before it was cut back. Since this report was originally prepared even those exposures were destroyed. The Nob Hill section described by Oldroyd [23] was located between Third and Fourth Streets, where the sand has been completely removed. Oldroyd found in upward succession a gravel 2 feet thick containing off-shore shells, an *Ostrea-Aletes* layer 4 inches thick, and a *Macoma* layer 4 inches thick, the last corresponding evidently to unit 4 of the Harbor Boulevard section on this page.

Virtually flat-lying strata at localities farther northeast overlie presumably the fossiliferous sand at Second and Beacon Streets and appear to represent the uppermost exposed part of the San Pedro sand in this area. On Ancon Street, between First and Second, these strata consist of about 15 feet of massive and thin-bedded silt and lenses of sand. At the intersection of Beacon and O'Farrell Streets they include cross-bedded sand as well as silt and silty sand. The following section was measured at that locality:

Section of Pleistocene strata, including San Pedro sand, on west side of Beacon Street at intersection with O'Farrell Street

	Ft.	in.
Nonmarine terrace cover:		
7. Reddish-brown sand. Grades upward into soil	4–5	0
Palos Verdes sand:		
6. Fossiliferous gray sand containing scattered pebbles	3	0
5. Brownish-gray silty sand grading upward into gray sand	3	4
San Pedro sand:		
4. Gray cross-bedded sand grading upward into brownish-gray silty sand containing molds of small pelecypods	7	0
3. Brownish-gray silty sand and gray sand	1	1
2. Cross-bedded gray sand	4	0
1. Massive silt and laminated limonite-stained silty sand	16	6
Exposed thickness of San Pedro sand	28	7

[21] Thompson, W. O., Original structures of beaches, bars, and dunes: Geol. Soc. America Bull., vol. 48, pp. 742–744, pl. 7. fig. 1, 1937.

[22] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), pp. 21–22, 1903.

[23] Oldroyd, T. S., The fossils of the lower San Pedro fauna of the Nob Hill cut, San Pedro, Calif.: U. S. Nat. Mus. Proc., vol. 65, art. 22, pp. 1–2, 1924.

At the Ancon and Beacon Street localities beds of silt are minutely crumpled, probably the result of submarine gliding down relatively steep slopes at the end of underlying lenses of sand.

NORTHWESTERN SAN PEDRO

In the northwestern part of San Pedro the lower Pleistocene strata consist almost entirely of sand and silty sand assigned to the San Pedro sand. The Lomita marl and Timms Point silt are absent or are so thin that they do not appear in natural exposures. The surface of the Miocene strata, on which the Pleistocene deposits rest, is evidently irregular. In a narrow ravine on the bluff opposite the end of Meyler Street Miocene mudstone and limestone are overlain by Pleistocene sandy silt in an exposure 15 feet long and a few feet wide. The limestone is riddled with bore holes, but no fossils were found in the overlying sandy silt.

Cuts along the extension of Gaffey Street into San Pedro (not shown on current edition of Wilmington topographic map) furnish the best exposures in the northwestern part of San Pedro. (See pl. 13, column 13.) The contact with the underlying Malaga mudstone member of the Monterey shale is exposed 125 feet north of the Elberon Street overpass. The basal 4 to 6 feet of the Pleistocene strata, dipping 20° northeastward, consists of marly silt containing Foraminifera, notably *Cassidulina* and *Pyrgo*. The marly sediments resemble those at the base of the Timms Point silt at Timms Point and may be assigned to that formation or to the Lomita marl. They are overlain by silty gray sand containing a few bored limestone pebbles. The next overlying strata consist of bluff silty sand and cleaner gray sand about 125 feet thick. A cross-bedded unit, shown on plate 15, *D*, consists of silty sand and is about 50 feet thick. Fossils were not observed in any of the sand or silty sand.

Strata consisting chiefly of silty sand are exposed at intervals along the bluff at the north edge of San Pedro, east of Gaffey Street. At locality 48, opposite the end of Grand Street, fossils are abundant in a lens of clean gray sand overlying 3½ feet of barren silty sand. The fossiliferous sand increases in thickness eastward to a maximum of 3 feet and where it is thickest includes stringers of barren sand. According to the regional strike, the fossiliferous sand at locality 48 is the equivalent of the cross-bedded sand in the central part of San Pedro and, therefore, underlies the fossiliferous sand at Second and Harbor.

EASTERN PART OF GAFFEY ANTICLINE

Strata in the upper part of the San Pedro sand are exposed at intervals along Harbor Boulevard, north of San Pedro. In that area the formation is made up of sand, silty sand, and silt. The strata are gently folded on the flanks of the Gaffey anticline and the adjoining Gaffey syncline. A dip of 30° on the south flank of the anticline, in a ravine near Harbor Boulevard, represents presumably cross-bedding or slumping. The San Pedro sand is overlain normally by fossiliferous sand and gravel at the base of the Palos Verdes sand. At some localities, however, the fossiliferous sand and gravel are absent, and the contact between the Palos Verdes and San Pedro is obscure, though it represents an unconformity.

Fossiliferous cross-bedded sand at locality 49, opposite the San Pedro Lumber Co. (not to be confused with Arnold's lumber yard locality in San Pedro), and interbedded sand and silty sand are assigned to the San Pedro sand. These beds are estimated to be as high stratigraphically as those at Second and Beacon Streets and may be higher. A section measured at locality 49 is as follows:

Section of San Pedro sand and Palos Verdes sand on Harbor Boulevard, opposite San Pedro Lumber Co. (locality 49)

	Ft.	*in.*
Palos Verdes sand:		
6. Gray silty sand containing few fossils	8	6
5. Fossiliferous gravel and coarse-grained sand (locality 120). Contact at base irregular	2	7
San Pedro sand:		
4. Gray silty sand, channeled by overlying gravel, which at places rests on unit 3	2	6
3. Cross-bedded fossiliferous gray sand (locality 49a)	1	2
2. Gray silty laminated sand	5	0
1. Cross-bedded fossiliferous gray sand (locality 49)	1	0
Exposed thickness of San Pedro sand	9	8

The entire preceding section may represent the Palos Verdes sand instead of both the Palos Verdes and San Pedro. The collections from the sand assigned to the San Pedro include *Cerithidea californica*, *Macron aethiops kellettii*, and *Cancellaria tritonidea*. These species were not found in the San Pedro sand in the areas already described, whereas they are found in the Palos Verdes sand. Typical Palos Verdes species—"*Nassa*" *cerritensis*, *Crassinella branneri*, *Crassinella nuculiformis*, *Diplodonta sericata*, and *Trachycardium procerum*—were collected from the sand and gravel identified as the basal part of the Palos Verdes sand but not in the underlying cross-bedded sand identified as the San Pedro sand. The faunal evidence is not conclusive, however, for typical Palos Verdes species are absent farther west on the Gaffey anticline in a faunal facies interpreted as representing that formation.

Fossils in a poor state of preservation, including *Cancellaria tritonidea* and large sand dollars (*Dendraster*), occur in sand interbedded with silty sand 10½ feet below a fossiliferous sand identified as the base of the Palos Verdes along the siding of the Western Oil and Refining Co. (locality 50). A lenticular *Ostrea-Anomia-Chione* layer is in the San Pedro sand 5 feet above the sand containing the sand dollars.

Along the valley followed by Gaffey Street and the Pacific Electric tracks the San Pedro sand consists of sand, some of which is cross-bedded, silty sand, and gravel (pl. 13, column 12). Locally sand and gravel are cemented, forming hard sandstone and conglomerate, probably along joints adjoining faults. A scour discontinuity is generally apparent at the base of gravel layers, as shown in the section on page 58. The gravel consists chiefly of granitic debris but includes also limestone, siliceous shale, and rarely schist pebbles. The contact with the Miocene mudstone is exposed on the south side of a canyon, near the garbage disposal plant west of Gaffey Street. Fossils are not abundant in this region. A few species were collected from blocks of cemented sand and gravel discarded during excavation of sand at an abandoned sand pit on the west side of Gaffey Street (locality 51). Discontinuous *Aequipecten-Anomia* and *Ostrea-Chione* layers were observed in gravel and sand on the east side of Gaffey Street, west of the tanks at the Union Oil Refinery. At locality 52, west of Gaffey Street, which was found by Dr. Hampton Smith, Bryozoa and mollusks, including a fragment of the northern *Neptunea tabulata*, were found in silty sand. The faunal and lithologic facies suggests the Timms Point silt. Pieces of large bones were observed at several places on the east side of Gaffey Street, and in that area Dr. Smith found a fragmentary mastodon tusk.

HILLTOP QUARRY AND NEARBY LOCALITIES

An abandoned quarry between Peck Park and the Standard Oil Co. tank farm is designated "Hilltop quarry" by geologists and local collectors. The quarry was recently filled during construction of a housing project. Calcareous strata in the Lomita marl were formerly excavated in this quarry. Figure 11 is a sketch of the southwest face of the quarry. The sand-filled fissures on the quarry face appear to mark the location of faults along which solution took place followed by filling of the fissures with the reddish-brown sand of the overlying nonmarine terrace cover.

(pl. 13, column 11). In the canyon the lower Pleistocene strata rest on Miocene diatomite, but the contact is not well exposed. The section given below was measured with the collaboration of J. M. Hamill, B. G. Laiming, and R. D. Reed. The lowest Lomita strata, exposed in a pit on the canyon floor about 200 feet downstream from the site of the loading hopper, are probably close to the base of the formation. By enlarging prospect pits on the east side of the canyon a continuous section was measured.

Section of Lomita marl in canyon west of Hilltop quarry (locality 54)

	Ft.	in.
9. Gravel composed of loosely cemented limestone cobbles and pebbles in matrix of calcareous sand. Exposed on northeast face of Hilltop quarry. Thickness approximate	10	0
8. Light-gray marl. Thickness approximate	10	0

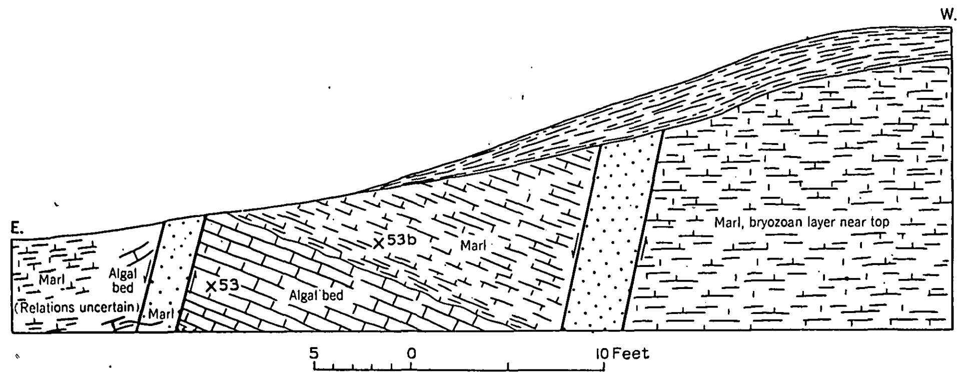


FIGURE 11.—Lomita marl on southwest face of Hilltop quarry.

A bed 6 feet thick, composed chiefly of a loose mass of calcareous algae, is in the fault block on the quarry face and also at or near the level of the floor in the southern part of the quarry. An occasional mass of algae is cemented, particularly around pieces of Miocene(?) mudstone. The pieces of mudstone are as much as a foot long, and some are bored. A phosphatized limestone boulder a foot long was dug out of the algal bed in the floor of the quarry. Large shells, including *Bursa californica, Kelletia kelletii, Glycymeris profunda, Eucrassetella fluctuata, Cyclocardia* aff. *C. occidentalis*, and *Ventricola fordii*, are scattered through the mass of algae. Many of the shells are encrusted with Bryozoa, and some have corals attached to them. Many pieces of algae are also encrusted with Bryozoa. Locality 53 represents the algal bed on the quarry face and locality 53a the algal bed on the floor near the west end of the quarry.

The algal bed is overlain by gray marl. In the fault block on the southwest face of the quarry the contact between the two beds is irregular; elsewhere it is not exposed. Small shells are abundant in a 2-inch fossiliferous lens 18 inches above the base of the marl on the southwest face (locality 53b). Toward the west a thickness of 14 feet of marl, including a bryozoan layer near the top, is exposed on the quarry face. On the northeast face of the quarry a gravel about 10 feet thick composed of limestone cobbles overlies marl, evidently the same bed as that on the south face.

A more complete section of the Lomita marl is accessible in the canyon immediately west of the quarry

Section of Lomita marl in canyon west of Hilltop quarry (locality 54)—Continued

	Ft.	in.
7. Coarse-grained calcareous sand and gravel. Large and small shells abundant, particularly in some gravel layers. Shells include *Cyclocardia* aff. *C. occidentalis, Eucrassatella fluctuata*, and *Ventricola fordii*. Corals, generally attached to pebbles or shells, more abundant in gravel layers than in any other part of section. (Locality 54g.)		
d. Alternating layers of gravel and coarse-grained calcareous sand containing scattered pebbles. Contact at base of some gravel layers irregular. Shells abundant	3	5
c. Gray calcareous sand containing few pebbles		9
b. Gravel consisting of pebbles in matrix of sandy marl. Contains abundant shells	4	0
a. Coarse-grained calcareous sand containing scattered shells	2	4
6. Calcareous sand:		
d. Marly gray calcareous sand	7	6
c. Marly gray and greenish calcareous sand containing small shells, including *Cyclocardia barberensis*, and broken larger shells in upper greenish part (locality 54f)	1	6
b. Calcareous sand. Fine grained in upper part, coarse grained toward base; a few pebbles 2 to 3 inches above base	1	4
a. Gray calcareous sand. Upper part fine-grained, lower part coarse-grained glauconitic, and foraminiferal. Echinoid spines abundant near base. Contains small shells and fragments of larger shells. *Cyclocardia barbarensis* abundant (locality 54e). Contact at base irregular	1	2–4

Section of Lomita marl in canyon west of Hilltop quarry (locality 54)—Continued

	Ft.	in
5. Foraminiferal calcareous sand:		
d. Coarse-grained well-bedded yellowish calcareous sand containing scattered pebbles and a few small shells (locality 54d)	3	7
c. Gray calcareous sand. Fine grained in upper part, coarse-grained layer at base. Small shells and a few larger shells mostly in lenticular pockets (locality 54c)	2	8
b. Yellowish calcareous sand, basal 2 inches of coarser grain than remainder. Contains abundant Foraminifera and a few small shells (locality 54b)	1	
a. Gray foraminiferal calcareous sand	2	5
4. Gravel and coarse-grained calcareous sand:		
b. Coarse-grained calcareous sand containing pebbles of soft mudstone		4
a. Gravel made up of pebbles of varying size in matrix of coarse-grained calcareous sand. Some pebbles are phosphatic. Contains small shells and fragments of larger shells (locality 54a)	2	0
3. Glauconitic foraminiferal sand containing scattered pebbles and limy phosphatic nodules. Contains abundant Foraminifera and a few small shells, including *Cyclocardia barbarensis* (locality 54)		8–12
2. Gravel consisting of pebbles and cobbles in matrix of glauconitic foraminiferal sand. Pebbles and cobbles of varying size, one limestone cobble 16 inches long, and small limy phosphatic nodules. Contains a few small shells, mostly *Cyclocardia*	1	9–11
1. Glauconitic sand, foraminiferal and lighter in color toward top. Base not exposed	3	6–10
Thickness of section	60	11

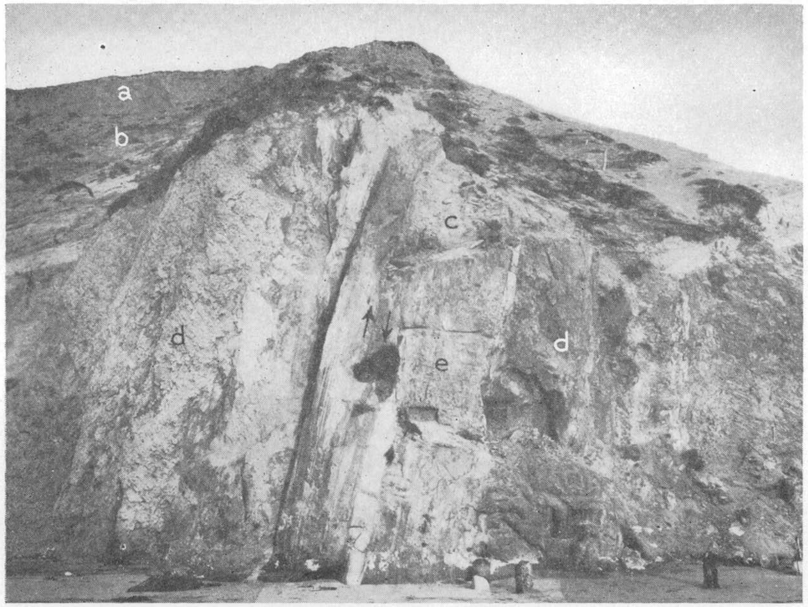
The gravel at the top of the preceding section is exposed on the northeast face of the quarry. It overlies marl that rests evidently on the algal bed. The coarse grained calcareous sand and gravel forming unit 7 of the canyon section appears to correspond, therefore, in stratigraphic position to the algal bed and grades southward presumably into the algal bed. Faunally unit 7 is more similar to the algal bed than any other unit in the canyon section. It, is, however, thicker than the algal bed, contains far less calcareous algae, and includes more coarse detrital material. The algal bed is evidently a local feature of small extent, at least across the strike and possibly also along the strike. Foraminifera occur throughout the canyon section, except in the gravel at the top. They are particularly abundant in some layers of calcareous sand, notably in units 6a (pl. 16) and 5b, and in the glauconitic sand forming units 3, 2, and 1. *Turritella pedroensis* is more abundant in calcareous sand exposed in a pit on the west side of the canyon (locality 55) than in any bed on the east side of the canyon or in the quarry.

Northwest of Hilltop quarry the Lomita marl is exposed at localities on the flanks of the Gaffey syncline. In natural exposures and in long-abandoned prospect pits it consists generally of hard limestone or calcareous sandstone containing calcareous algae, encrusting Bryozoa, and other calcareous organisms. Locally fossils are not discernible, owing to leaching and deposition of secondary calcareous material. Limestone cobbles at or near the base of the formation are generally riddled with the burrows of boring clams, some of which are preserved in their burrows.

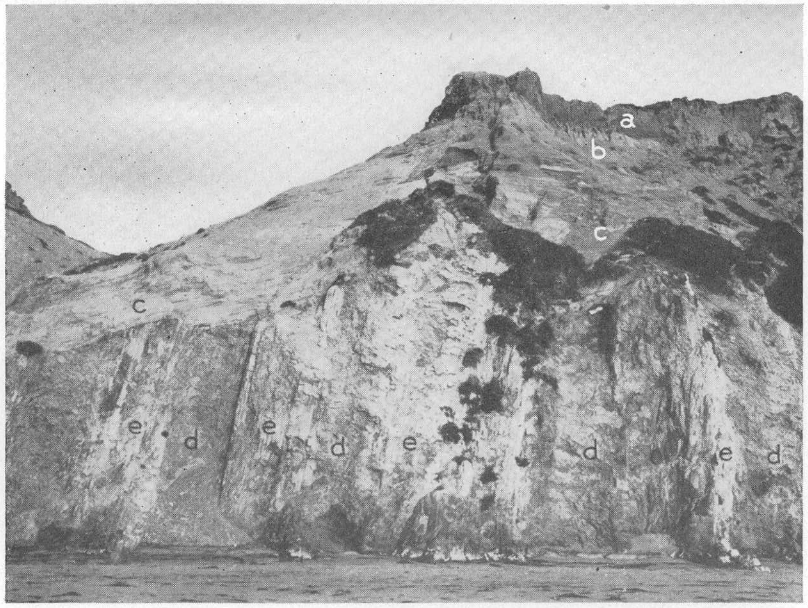
The basal part of the lower Pleistocene strata on the north flank of the Gaffey syncline is well shown in a cut on Western Avenue. The lowermost 5 feet, assigned to the Lomita marl, consists of a mixture of sand and calcareous sand containing calcareous algae, shell fragments, and bored angular and rounded limestone pebbles. These calcareous sediments dip 30° southward and rest on Miocene mudstone of the Malaga member of the Monterey shale that appears to dip southward at a low angle. They grade upward into the San Pedro sand, at the base of which is about 10 feet of silty sand containing small shells and shell fragments. The silty sand in turn grades upward into partly cemented gray sand overlain by cross-bedded limonite-stained gray sand. As shown on plate 17, *B*, the lower Pleistocene deposits and the overlying terrace cover are displaced by a minor bedding-plane thrust fault along the contact between the Miocene and Pleistocene strata.

At Hilltop quarry and in the area to the northwest the San Pedro sand overlies the Lomita marl. Locally sand appears to extend down to the base of the Pleistocene section; at least locally no outcrops of the Lomita marl were found. The sand is generally poorly exposed. In an excavation on the Standard Oil Co. tank farm, gray sand, assigned to the San Pedro, contains fragile shells (locality 56). On the south flank of the Gaffey syncline a cut on Western Avenue exposes about 15 feet of sand and gravel considered of San Pedro age. A collection of fossils from gray sand at the base of the cut on the east side of the highway includes fragments of *Neptunea tabulata* (locality 58). This sand is overlain along an irregular contact by cross-bedded sand, at the base of which is gravel consisting of limestone and schist pebbles. The cross-bedded sand is as much as 10 feet thick and contains numerous specimens of *Anomia* and *Ostrea* (locality 58a). An *Anomia-Ostrea* layer in a natural outcrop of cemented sand nearby, locality 59, is doubtless the same layer. A fossiliferous gravel overlying the *Anomia-Ostrea* layer in the highway cut is selected as the base of the Palos Verdes sand. The contact between the two formations might, however, be placed at the base of the *Anomia-Ostrea* layer, which represents an association like that in strata assigned to the Palos Verdes sand on the north limb of the Gaffey syncline.

The Whites Point tunnel penetrated the lower Pleistocene deposits on the flanks of the Gaffey anticline and Gaffey syncline (pl. 1, section *E—E'*; pl. 13, columns 8, 9, 10). On the north flank of the anticline the San Pedro sand, about 275 feet thick, rests directly on the Malaga mudstone member of the Monterey shale, as at the outcrop nearby. It consists of regularly bedded sand, crossbedded sand, and thin layers of silt and clay. Throughout a considerable thickness layers of sand contain glauconite, a constituent not observed at outcrop localities. On the south flank of the anticline 15 feet of silty marl represents the Lomita marl. The marl grades upward into the San Pedro sand, which includes glauconitic sand. On the south limb of the Gaffey syncline the Lomita marl is about 275 feet thick and rests with marked unconformity on Miocene diatomaceous shale and diatomite. At the base is gravel 25 feet thick composed of limestone cobbles and angular pieces of shale. The conglomerate is overlain by fossiliferous marl and silty marl grading upward into sandy marl. The overlying San Pedro sand consists of gravel overlain by sand and silt. A total thickness of about 175 feet of strata assigned to the San Pedro sand was penetrated, and an estimated additional thickness of 125 feet is represented in the trough of the syncline. The tunnel shaft on the south limb of the syncline penetrated the Lomita marl. Well-preserved fossils,

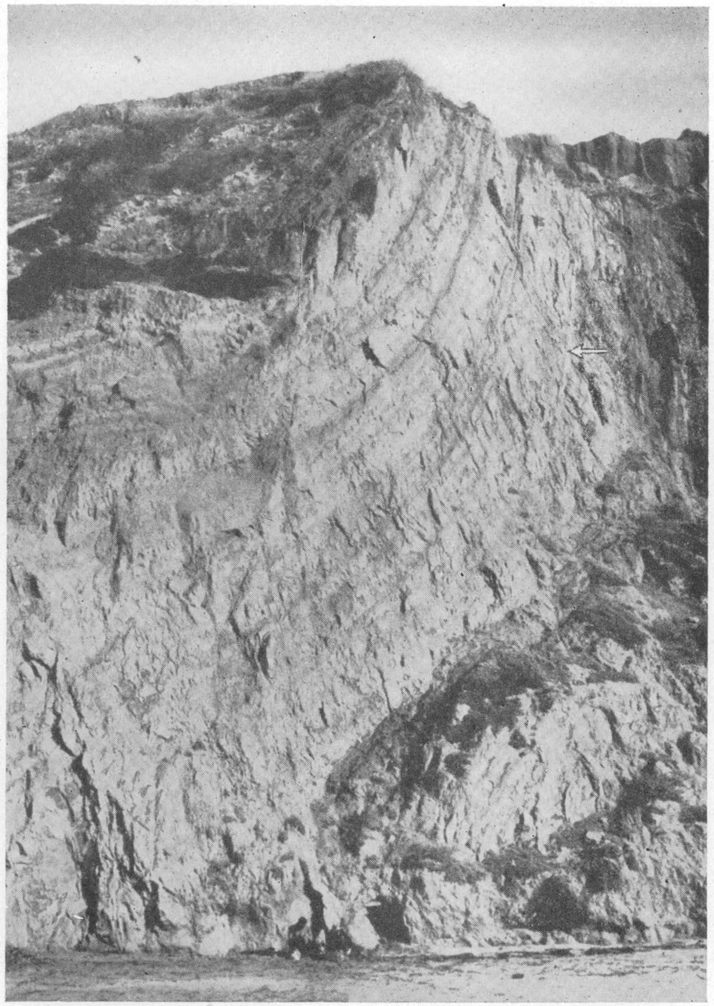


A. VIEW NEAR NORTH END OF MALAGA COVE.
For explanation see *B.*



B. VIEW 200 FEET SOUTH OF *A.*

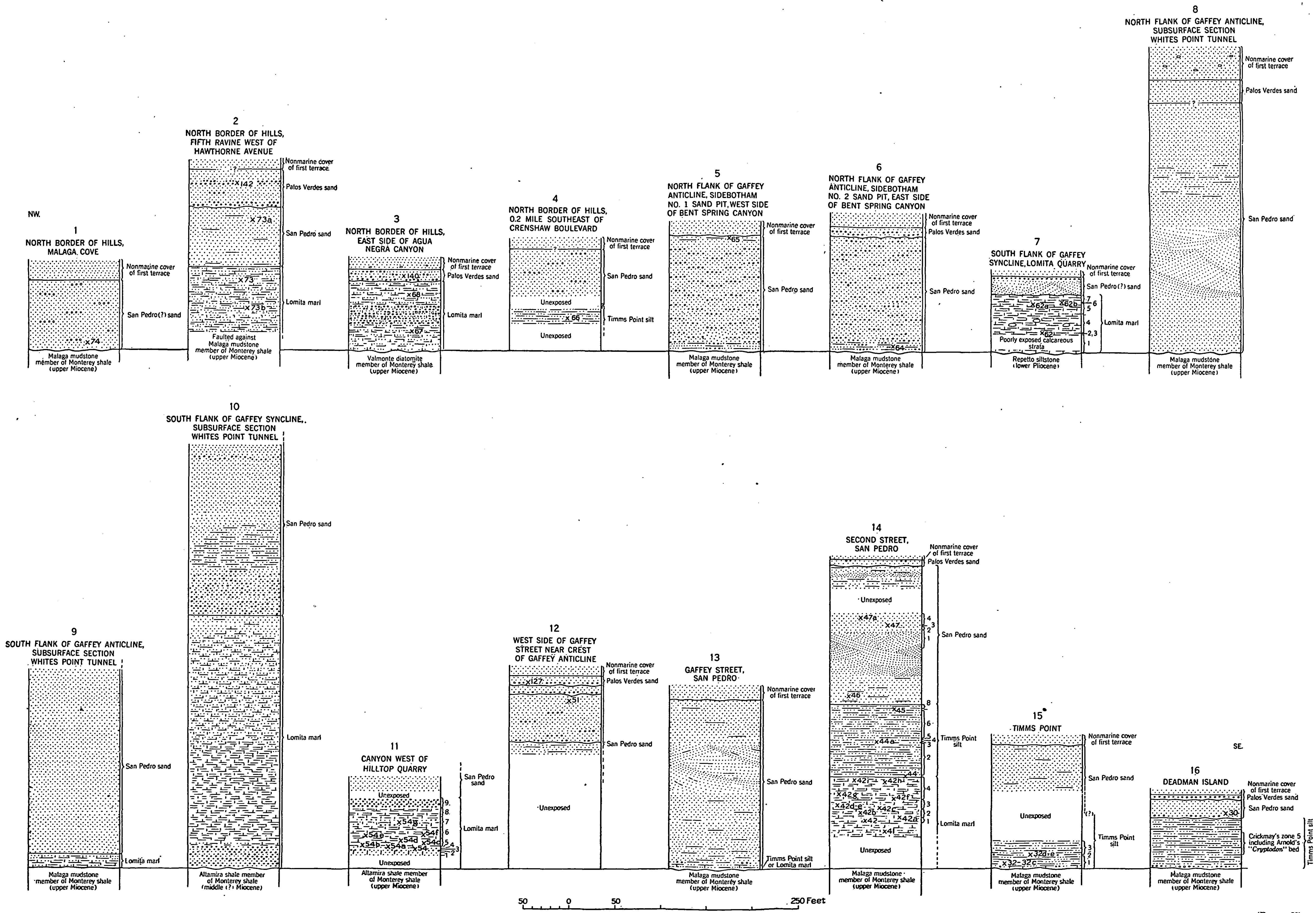
a, Dune sand (Recent); b, nonmarine cover of lowest terrace (upper Pleistocene to Recent); c, San Pedro (?) sand (lower (?) Pleistocene); d, massive radiolarian mudstone, Malaga mudstone member of Monterey shale (upper Miocene); e, laminated diatomite, Malaga mudstone member of Monterey shale (upper Miocene).



C. REPETTO SILTSTONE (LOWER PLIOCENE) ON SOUTH LIMB OF NORTHERN SYNCLINE.

Arrow points to lower bed of volcanic ash. Note seated men at foot of cliff, which is 150 feet high.

MIOCENE, PLIOCENE, AND PLEISTOCENE FORMATIONS AT MALAGA COVE.

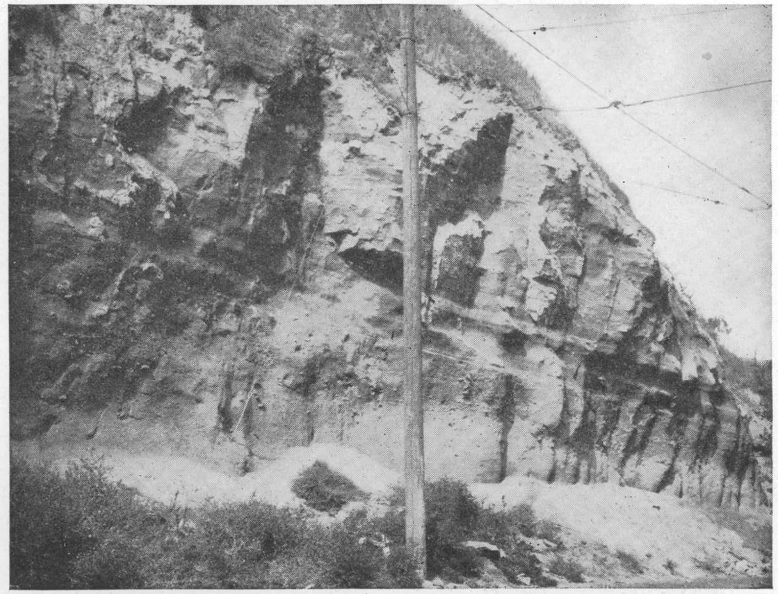


(Face p. 50)

SECTIONS OF PLEISTOCENE STRATA IN PALOS VERDES HILLS.

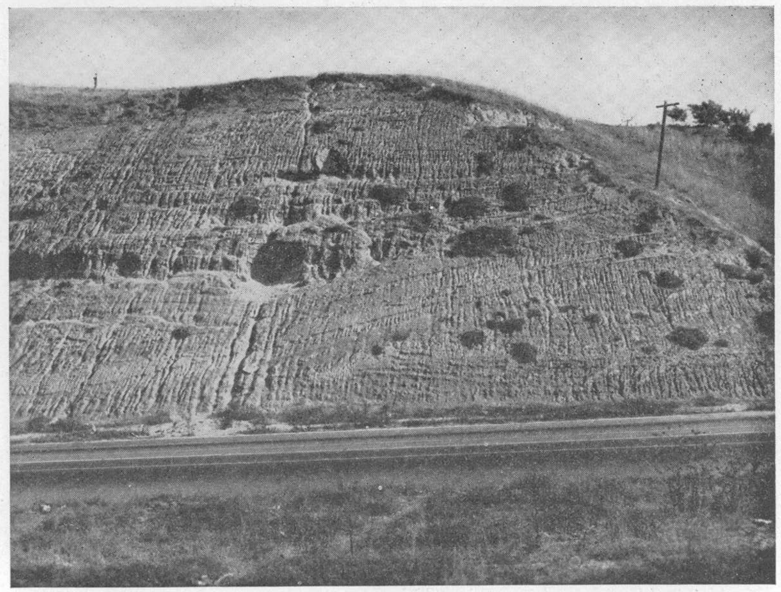
A. NORTH SIDE OF SECOND STREET IN BLOCK BETWEEN PACIFIC AVENUE AND MESA STREET.

Lomita marl (c) conformably overlain by Timms Point silt (b). Both formations unconformably overlain by Palos Verdes sand and nonmarine terrace cover (a).



B. TIMMS POINT SILT IN TYPE REGION AT TIMMS POINT.

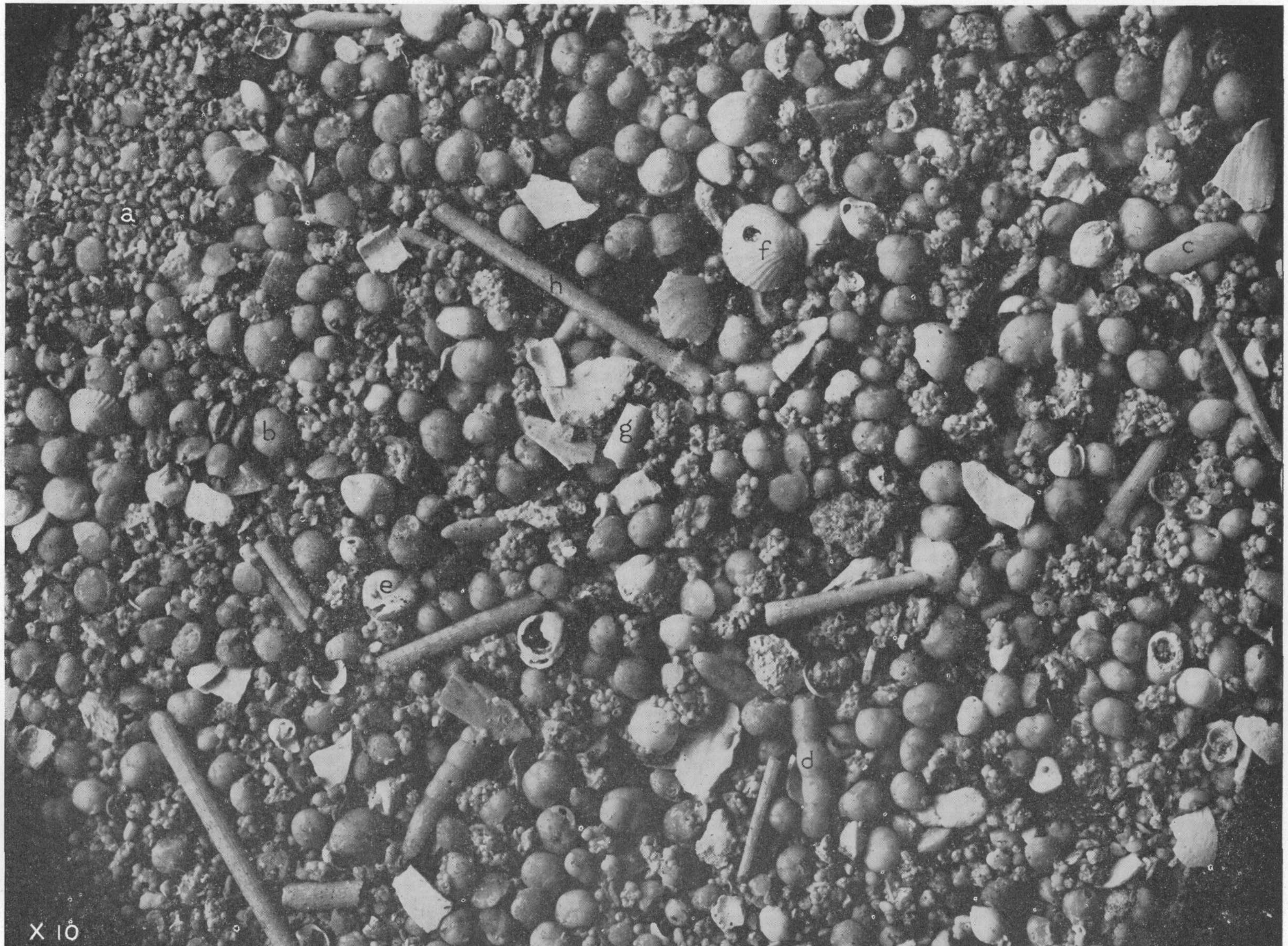
C. SAN PEDRO SAND (b) UNCONFORMABLY OVERLAIN BY PALOS VERDES SAND AND NONMARINE TERRACE COVER (a) AT SOUTHWEST CORNER OF SECOND AND BEACON STREETS.



D. CROSS-BEDDED SAND IN SAN PEDRO SAND ON EAST SIDE OF GAFFEY STREET.

Photograph by U. S. Grant.

PLEISTOCENE FORMATIONS IN SAN PEDRO.



MICROSCOPIC ORGANIC CONSTITUENTS IN UNIT 6a OF LOMITA MARL IN CANYON WEST OF HILLTOP QUARRY.

Unsorted washed residue. a, *Globigerina*; b, *Cassidulina*; c, *Polymorphina*; d, *Dentalina*; e, *Pyrgo*; f, *Cyclocardia*; g, *Cadulus?*; h, echinoid spine.

including numerous specimens of *Bittium rugatum*, *Turritella pedroensis*, *Olivella biplicata*, *Conus californicus*, and *Cyclocardia* aff. *C. occidentalis*, were collected from the dump at the shaft (locality 57).

LOMITA QUARRY AND NEARBY LOCALITIES

The type region of the Lomita marl is in the area near Lomita quarry in the western part of the Gaffey syncline. In that area the Lomita overlies the Repetto siltstone or overlaps the Repetto and rests on the Malaga mudstone member of the Monterey shale. At the localities where the base of the Lomita is well exposed—in the ravine northeast of Lomita quarry and along the road leading to the quarry—the underlying formation is the Repetto. Toward the north, that is, toward the crest of the Gaffey anticline, the calcareous strata appear to finger into sand, but there are no excavations to show that relationship. The greatest exposed thickness of the Lomita is about 65 feet, but core holes in the syncline are reported to have penetrated a thickness of 300 feet. A section measured at Lomita quarry (pl. 17, *A*; pl. 13, column 7), on the north limb of the syncline, is as follows:

Section of Lomita marl in type region at Lomita quarry (locality 62)

	Ft.	in.
Soil	4	0
Nonmarine terrace cover(?): Coarse-grained brownish sand, grading upward into dirty brownish sand	6	0
San Pedro(?) sand:		
Gravel, consisting principally of small granitic pebbles	2	4
Cross-bedded gray limonite-stained sand including lenses of gravel consisting principally of small granitic pebbles	18	0
Lomita marl:		
7. Fine-grained calcareous sand and foraminiferal calcareous sand including partings of glauconitic foraminiferal sand	8	3
6. Glauconitic formainiferal sand:		
b. Glauconitic foraminiferal sand lighter in color than unit a		8
a. Dark-colored glauconitic foraminiferal sand containing scattered shells, principally *Cyclocardia barbarensis* (locality 62b)		10
5. Foraminiferal calcareous sand and glauconitic foraminiferal sand in layers 2 to 6 inches thick (locality 62a)	10	7
4. Fine-grained calcareous sand and foraminiferal calcareous sand. Contains boulders of Miocene Malaga mudstone and of Pliocene Repetto siltstone in lower 9 feet, one boulder measuring 12 by 5 feet, and scattered limy phosphatic nodules	21	10
3. Glauconitic sand		11
2. Foraminiferal calcareous sand containing scattered glauconite grains (locality 62). Base not exposed		9
1. Poorly exposed calcareous strata. In the ravine northwest of the quarry they rest on the lower Pliocene Repetto siltstone and contain limy phosphatic nodules. Thickness computed	20	0
Thickness of Lomita marl	63	10

The glauconitic foraminiferal sand forming unit 6 of the preceding section can be traced as a dark-colored band across the quarry face. (See pl. 17, *A*.) It shows many minor faults, along which the displacement is down toward the west. The huge boulders in unit 4 consist of both Miocene mudstone and Pliocene siltstone. As both kinds of rock readily disintegrate in water, the boulders were preserved probably by sinking into soft calcareous sand. Foraminifera from the Lomita marl at Lomita quarry were described by Galloway and Wissler.[24] Mollusks are not abundant. A collection from unit 6 (locality 62b) includes fragments of *Patinopecten caurinus?*, but *Cyclocardia barbarensis* is the most common species, as it is in other mollusk-bearing layers.

Parts of the Lomita marl are exposed in prospect excavations southeast of the quarry. At locality 61 a bed of gravel and coarse-grained calcareous sand, evidently higher in the section than the strata in the quarry, contains large shells of shallower facies than those in the quarry, including *Turritella pedroensis*, *Ostrea megodon cerrosensis*, and *Ventricola fordii*. Most of the shells are worn and broken. The following section was measured in a prospect excavation at locality 60, near the trough of the Gaffey syncline, 500 feet west of Palos Verdes Drive East:

Section of Lomita marl in prospect excavation 500 feet west of Palos Verdes Drive East (locality 60)

	Ft.	in.
18. Foraminiferal calcareous sand, grading upward into soil. Thickness approximate	4	0
17. Coarse-grained calcareous sand		3–4
16. Foraminiferal calcareous sand	1	3
15. Coarse-grained calcareous sand	1	7
14. Foraminiferal calcareous sand	1	
13. Glauconitic foraminiferal calcareous sand. Cross-bedded at base, 3-inch dark layer at top. Base extremely irregular (locality 60b)		11–19
12. Foraminiferal calcareous sand and glauconitic sand:		
c. Foraminiferal calcareous sand. One angular pebble observed		16–22
b. Glauconitic sand		1
a. Foraminiferal calcareous sand		8–10
11. Fine-grained calcareous sand		2–3
10. Glauconitic sand and foraminiferal calcareous sand:		
b. Glauconitic foraminiferal calcareous sand containing scattered pebbles		7
a. Foraminiferal sand	1	1
9. Coarse-grained calcareous sand containing many pebbles, including a 5-inch pebble standing on end and projecting above top of bed		4–5
8. Foraminiferal calcareous sand, including a half inch parting of glauconitic foraminiferal sand at middle	1	0
7. Coarse-grained calcareous sand containing many rounded and angular pebbles, broken large shells, and small shells (locality 60a)		5
6. Foraminiferal calcareous sand		4–6
5. Coarse-grained calcareous sand		7
4. Foraminiferal calcareous sand (locality 60)		5
3. Coarse-grained calcareous sand containing many calcareous algae and Bryozoa and scattered limy phosphatic nodules. One 8-inch pebble extends above top of bed	1	2
2. Fine-grained glauconitic, foraminiferal sand		5
1. Coarse-grained calcareous sand containing many calcareous algae and Bryozoa. Base not exposed		10+
Exposed thickness	20	2

The contact at the base of most of the main units in the preceding section is sharply defined and slightly irregular. The base of unit 13 is very irregular, forming angular gutters 5 to 7 inches deep. The glauconitic sand filling the gutters and extending above them is cross-laminated. Foraminifera are more abundant at this locality in foraminiferal calcareous sand and in glauconitic sand than at Lomita quarry. The coarse-grained pebbly calcareous sand forming unit 7 contains broken large shells and small shells (locality 60a).

[24] Galloway, J. J., and Wissler, S. G., Pleistocene Foraminifera from Lomita quarry Palos Verdes Hills, Calif.: Jour. Paleontology, vol. 1, pp. 35–87, pls. 7–12, 1927.

The sand and gravel overlying the Lomita marl at Lomita quarry are assigned doubtfully to the San Pedro sand. (See section above.) At the time when the Lomita quarry section was measured the sand and gravel were excavated back from the quarry face, and the relations were not clear. From the view on plate 17, *A*, which was taken soon after the quarry was opened many years ago, it appears that the sand and gravel unconformably overlie the Lomita. They are similar lithologically to deposits in the San Pedro sand as identified nearby on the north limb of the Gaffey anticline. It is improbable that they represent either the Palos Verdes sand or the nonmarine terrace cover. Strata identified as the Palos Verdes sand at locality 136 are thinner and contain limestone cobbles. The nonmarine cover in this region is not known to be so thick or to include clean sand and granitic gravel. Sand and gravel similar to those at Lomita quarry are exposed in the upper part of the ravine northwest of the quarry. At locality 63 silty sand contains Bryozoa, worn opercula of *Homalopoma*, and pelecypod fragments including *Cyclocardia*. Mudstone at the level of the ravine floor may represent a boulder or outcrop of the Miocene.

According to the interpretation suggested, the San Pedro sand appears to overlie unconformably the Lomita marl in the western part of the Gaffey syncline.

WESTERN PART OF GAFFEY ANTICLINE

Outcrops of calcareous strata referable to the Lomita marl were found on the north flank of the Gaffey anticline, along the ravine followed by Palos Verdes Drive East and in the next two ravines to the east. The calcareous strata, consisting of calcareous sand generally cemented, are only a few feet thick. They rest on the Repetto siltstone or Malaga mudstone. In the easternmost ravine, where the calcareous sediments are 6 feet thick, the contact with the Malaga mudstone is well exposed.

At the localities just mentioned the San Pedro sand, which is not well exposed, overlies the Lomita marl. Along Bent Spring Canyon, northeast of Lomita quarry, the sand rests directly on the Malaga mudstone. The contact is plainly exposed at the loading hopper of Sidebotham No. 2 sand pit on the east side of the canyon (pl. 18, *A*) and along the road leading to Lomita quarry on the west side. At the loading hopper the lowermost 11 feet consist of silty sand including lenses of gravel. The silty sand is overlain by coarse-grained sand and gravel. Between the loading hopper and the water tank the basal silty sand contains a Lomita-like fauna of moderate-depth facies (locality 64). Coarse-grained sand and gravel overlie the silty sand with a sharp contact, but the silty sand itself includes lenses of coarse-grained sand and gravel. Fossils similar to those at locality 64 were observed in the basal part of the sand on the west side of the canyon.

Sidebotham No. 1 pit (pl. 13, column 5; pl. 19), on the west side of the canyon, shows about 100 feet of sand and interbedded layers and lenses of gravel dipping gently northward. The sand is gray or limonite-stained and includes thin cross-bedded units. No. 2 pit (pl. 13, column 6; pl. 18, *B*) shows steeply dipping sand and gravel overlain by gently dipping sand and gravel. The gravel in both pits consists chiefly of granitic debris but includes limestone and cherty shale pebbles. At the top of the west face of No. 1 pit, immediately underlying the nonmarine terrace cover shown on plate 18, Bryozoa and Lomita-like mollusks of moderate-depth facies were found in a 21-inch lens of marly, silty sand (locality 65). Unidentifiable broken organic calcareous particles were observed in a 2-inch layer of sand and gravel in the steeply dipping strata at the south edge of No. 2 pit.

The stratigraphic and chronologic relations of the sand and gravel in this area may be interpreted in different ways. These deposits are assigned to the San Pedro sand. Most or perhaps all of the section is doubtless the detrital equivalent of the Lomita marl. On the west side of the canyon fossils resembling in facies those found at places in the Lomita occur at the bottom and top of the section. Inasmuch, however, as fossils of similar facies occur at places in the San Pedro, the faunal data are inconclusive. The section in No. 2 pit may represent two stratigraphic units or the steeply dipping strata may represent a thick cross-bedded unit. It may be argued that the deposits of steeply dipping sand and gravel in No. 2 pit are the equivalent of the Lomita, whereas the gently dipping sand and gravel are the equivalent of similar deposits that appear to be unconformable on the Lomita at Lomita quarry.

NORTH BORDER OF HILLS BETWEEN BENT SPRING CANYON AND HAWTHORNE AVENUE

The sand and gravel in ravines along the north border of the hills between Bent Spring Canyon and Agua Magna Canyon, except a thin cover of nonmarine terrace material, are assigned to the San Pedro sand. These San Pedro strata consist of brownish sand and gray limonite-stained sand, both containing stringers of granitic gravel. Toward the top small limestone and cherty shale pebbles are abundant in the gravel stringers. The Palos Verdes sand is not identified in this area. The uppermost few feet, consisting of reddish-brown sand, is assigned to the nonmarine terrace cover, but no sharp contact with the underlying deposits was recognized. Fossils, including *Mitrella carinata gausapata*, a large broken *Patinopecten caurinus*, *Mya truncata*, a small variety of *Panomya beringianus*, Foraminifera, and Bryozoa, were collected from silty sand in a ravine at locality 66 (pl. 13, column 4). On lithologic and faunal grounds the strata at locality 66 are referred to the Timms Point silt, the only locality in the western part of the hills where that formation was found. Exposures are inadequate at locality 66, but the silty beds are evidently at or near the base of the section and are overlain by sand. Sand, containing stringers of gravel consisting chiefly of small limestone and cherty shale pebbles, and silty sand in the two sand pits east of Agua Negra Canyon are assigned to the San Pedro sand. Layers of sand in the eastern pit contain Foraminifera and pieces of Bryozoa and shells.

On the east side of Agua Negra Canyon the Lomita marl is represented by marl and gravel. (See pl. 13, column 3.) At the level of the canyon floor rubble and boulders of limestone and cherty shale abut against an ancient cliff face of Miocene mudstone (fig. 12). On the north face of the northernmost cut in the workings of the Dicalite Co. near Agua Negra Canyon the marl rests on Miocene diatomite. A few limestone cobbles are at the base of the marl, and a thick gravel composed of limestone cobbles is 30 to 35 feet above the base, underlying fossiliferous gravel and sand of the Palos Verdes sand. Farther north the Lomita marl is estimated to be about 75 feet thick. It includes beds of gravel as much as 20 feet thick made up of limestone cobbles. Fossils are abundant in the marl, particularly *Bittium rugatum* and *Turritella pedroensis* (localities 67, 68).

Miocene diatomite is exposed at the southeast edge of Richard Ball sand pit, immediately east of Hawthorne Avenue. Steeply dipping marl of the Lomita 10 to 15 feet thick rests on the diatomite, a fossiliferous gravel 2 or 3 feet thick being at the base. The marl gradually becomes more and more sandy toward the top and is

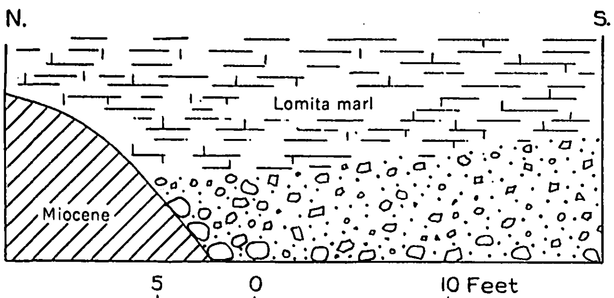


FIGURE 12.—Contact between Lomita marl and Miocene mudstone on east bank of Agua Negra Canyon.

overlain by about 60 feet of sand and gravel assigned to the San Pedro sand. (See pl. 20, *A*.) Though the dip changes from 55° in the marl to 25° in the upper part of the sand, the change is gradual, and there appears to be no unconformity.

On the 461-foot hill south of the sand pit the thin cover of nonmarine terrace deposits has been stripped off, revealing the Lomita marl and at places the underlying Miocene diatomite. Fossils collected from the marl include broken specimens of *Eucrassatella fluctuata* and *Mercenaria perlaminosa* (locality 69).

NORTH BORDER OF HILLS BETWEEN HAWTHORNE AVENUE AND MALAGA COVE

Steeply dipping lower Pleistocene strata similar to those just described are exposed in ravines northwest of Hawthorne Avenue. The geology of the area adjoining Hawthorne Avenue is shown on plate 21. The lower Pleistocene deposits overlie Miocene mudstone or diatomite, except at the head of the fourth ravine west of Hawthorne Avenue where the underlying formation is the Repetto siltstone. Fossiliferous sandy marl of variable thickness at the base of the lower Pleistocene deposits represents the Lomita marl. At the base of the marl are scattered limestone cobbles or gravel composed of limestone cobbles. The marl grades upward into the San Pedro sand, which includes layers of gravel. The dip of the sand is gradually less upward in the section. Plate 20, *B*, shows the succession in a sand pit on the west side of the fourth ravine west of Hawthorne Avenue. At that locality there is a minor fault between the sandy marl and the sand. The strata exposed in the fifth ravine west of Hawthorne Avenue are shown in figure 13 and on plate 13, column 2. Fossils occur in the Lomita marl, *Turritella pedroensis* being generally abundant (localities 70, 71, 72, 72a, 73, 73b). They are rare in the San Pedro sand (locality 73a).

MALAGA COVE

At the north end of Malaga Cove, sand and gravel about 75 feet thick unconformably overlie the Malaga mudstone member of the Monterey shale (pl. 12, *A*, *B*; pl. 13, column 1; fig. 7). The dip of the sand and gravel changes gradually from 13° at the base to about 8° near the top. The sand is clean and gray or limonite-stained. The gravel is made up chiefly of granitic debris, but the largest pebbles, 2 to 4 inches long, consist of cherty shale. A few Foraminifera were found in a 3-inch layer of sand 7 feet above the base of the sand on the upthrown side of the bedding-plane fault shown on plate 12, *A* (locality 74). The sand and gravel at Malaga Cove are assigned doubtfully to the San Pedro. Assignment to the San Pedro sand rather than to the Palos Verdes sand is based on the lithology, which agrees with that of deposits identified as the San Pedro to the east. If the Foraminifera at locality 74 are not detrital constituents, they also favor assignment to the San Pedro. Reddish-brown sand 15 to 25 feet thick near the top of the cliff is identified as the nonmarine terrace cover. The contact with the underlying San Pedro (?) sand, however, is generally not well defined.

MARINE TERRACE DEPOSITS

GENERAL FEATURES

The marine terraces are described under the heading "Physiography" (p. 113), and their distribution and designation are shown on plate 22. They are designated in numerical sequence in reverse age order, the first terrace being the youngest and lowest, the last to be formed.

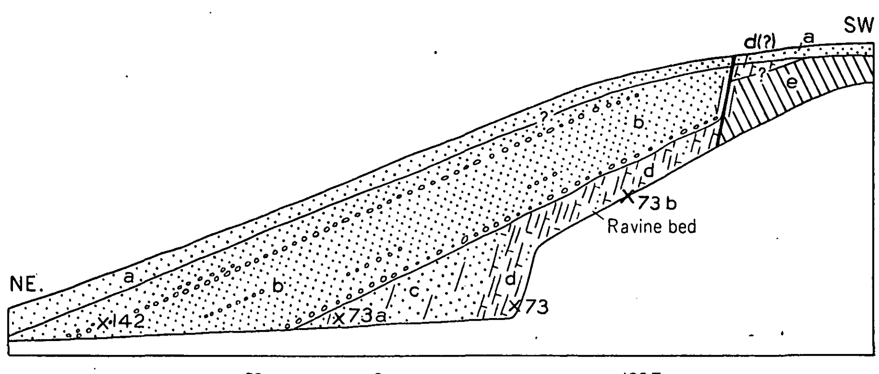


FIGURE 13.—Pleistocene strata in fifth ravine west of Hawthorne Avenue. a, Nonmarine terrace cover (upper Pleistocene to Recent); b, Palos Verdes sand (upper Pleistocene); c, San Pedro sand (lower Pleistocene); d, Lomita marl (lower Pleistocene); e, Malaga mudstone member of Monterey shale (upper Miocene).

Deposits lying on the terraces embrace material of two classes—marine sand and gravel and nonmarine debris designated the nonmarine cover. The marine deposits consist generally of cleanly washed, poorly sorted stratified coarse-grained sand and gravel but include silty sand and rubble. They form a thin veneer on the terrace platform. They are generally only a few feet thick but toward the seaward edge of a terrace they may be as much as 10 to 15 feet thick. At places they are represented by only a single layer of pebbles and interstitial sand. Owing to inequalities on the platform, to submarine scouring, or to subaerial erosion prior to deposition of the nonmarine cover, marine deposits are at places absent.

The present sea cliff and excavations afford the best exposures of marine terrace deposits. With few exceptions they were not found on terraces above the first in natural exposures inland from the coast. Inasmuch as marine strata wese recognized at numerous localities in artificial exposures on terraces older than the first, their usual absence in natural exposures is due presumably to concealment by surficial debris and soil. Additional localities will be found doubtless as residential development continues. Marine terrace deposits that are exposed only in highway cuts and other excavations are not shown on the geologic map (pl. 1), except in San Pedro. Their outcrop width on steep declivities is necessarily exaggerated on a map of the scale of plate 1. Owing to their thinness and unconsolidation marine terrace deposits are geologically ephemeral unless protected from erosion. In the Palos Verdes Hills they are saved from destruction by the overlying thick nonmarine cover.

Marine deposits have been found on 9 of the 13 main terraces recognized. Those on the first or lowest terrace are the only deposits that have received a formal stratigraphic designation. They constitute Arnold's upper San Pedro series, now known as the Palos Verdes sand.

MARINE TERRACE DEPOSITS OLDER THAN PALOS VERDES SAND

Aside from a preliminary generalized account,[25] marine terrace deposits older than the Palos Verdes sand have not been recorded, with one exception. As these deposits and their fossils are of exceptional interest, the localities where they were found are described or mentioned under the following heading.

STRATIGRAPHY AND LITHOLOGY

TWELFTH TERRACE

The oldest and highest marine terrace deposits found are on a remnant of the twelfth terrace at an altitude of 1,215 feet above sea level. They are exposed in a cut on Crest Road, on the southeast slope of San Pedro Hill (locality 75), where the following section was measured:

Section of deposits on twelfth terrace in cut on Crest Road on southeast slope of San Pedro Hill (locality 75)

	Feet
Nonmarine cover:	
5. Reddish-brown sand and soil	1–7
4. Cliff rubble	4–5
3. Cliff rubble containing many abalones (*Haliotis cracherodii*) and a few turban shells (*Tegula gallina*) [26] wedged between stones	2

[25] Woodring, W. P., Fossils from the marine Pleistocene terraces of the San Pedro Hills, Calif.: Am Jour. Sci., 5th ser., vol. 29, pp. 292–305, 1 fig., 1935.
[26] Erroneously reported as *Tegula funebralis* (Woodring, W. P., op. cit., p. 297).

Section of deposits on twelfth terrace in cut on Crest Road on southeast slope of San Pedro Hill (locality 75)—Continued

	Feet
Marine deposits:	
2. Coarse-grained sand and gravel composed principally of rock-cliff and tide-pool shells and fragments; includes pebbles	1–2
1. Mixture of cliff rubble, pebbles, and cobbles, many of which are bored. Rests on platform of cherty shale, the surface of which is bored at many places	1½–2

Most of the marine deposits of the preceding section may be storm-swept material, for even the lowest unit includes cliff rubble. The marine shells wedged between the stones of unit 3, assigned to the nonmarine cover but representing talus rubble of the same age as at least the upper part of the marine strata, quite certainly are storm-driven.

NINTH TERRACE

At locality 76, on Palos Verdes Drive East, marine fossils were found in deposits near the rear of the ninth terrace at an altitude of 925 feet. The terrace deposits, evidently a mixture of marine material and cliff rubble, are 13 feet thick. The highway cut exposes the cliff, which is apparently slightly overhanging, at the rear of the terrace. Fossils, including large and small specimens of *Epilucina californica*, many paired, are in buff calcareous silty sand containing angular bored stones at a place 135 feet southwest of the exposed ancient cliff face. The terrace platform is not exposed. A few small shells and shell fragments are at a higher level in buff calcareous silty sand containing small angular stones 50 feet farther to the southwest, along the highway (locality 76a).

EIGHTH TERRACE

The platform of the eighth terrace (altitude 765 feet) is exposed in a cut on Palos Verdes Drive East in the Miraleste district (locality 77). Gravel 3 to 5 feet thick lying on the platform contains marine fossils.

SIXTH TERRACE

At locality 78, also in the Miraleste district, the platform (altitude 560 feet) and the vertical cliff face at the rear of the sixth terrace are exposed. Marine fossiliferous gravel ½ to 2½ feet thick lies on the platform. The gravel is overlain by 7 to 8 inches of sand, and above the sand is buff calcareous silty sand 1 to 1½ feet thick containing numerous echinoid spines, small shells, shell fragments, scattered pebbles, and angular rubble.

At locality 79, in the Malaga Cove district near La Venta Inn, gravel and rubble on the platform of the sixth terrace (altitude 550 feet) yielded marine fossils, including numerous specimens of *Tegula gallina*.

FIFTH TERRACE

Fossiliferous marine deposits were found on the fifth terrace at two localities. At locality 81, southwest of Flatrock Point, the fossils are in gravel and rubble lying on the platform, which has an altitude of 360 feet. At locality 80 (altitude 370 feet), on Crest Road, fossils are in coarse rubble 1 to 2 feet thick containing a few bored cobbles and boulders.

FOURTH TERRACE

At localities 82 to 89 fossiliferous marine deposits were observed on the fourth terrace. At locality 83 (altitude 200 feet), on Gaffey Street near Point Fermin, fossils were found near the seaward edge of the terrace in sand containing angular stones and some cobbles. At locality 82 nearby, on Peck Street, where the section given below was measured, fossils are wedged between boulders and rock slabs near the rear of the terrace. At that locality the platform has an altitude of 240 feet.

Section of deposits on fourth terrace on west side of Peck Street 375 feet north of Thirty-sixth Street (locality 82)

	Ft.	in.
Black soil	3	0
Nonmarine cover: Rubble consisting of flat slabs of blue-schist sandstone and cherty shale in matrix of sand	5	0
Marine deposits: Gravel consisting of cobbles and boulders mixed with angular rock slabs. Rock-cliff and tide-pool shells and a little sand in interstices. Rests on platform of blue-schist sandstone	1	5–14

A highway cut near Point Vicente (locality 84) exposes the platform of the fourth and third terraces and the intervening cliff face, as shown on plate 23. Marine deposits were not recognized on the third terrace, but on the fourth terrace marine fossils occur in sand filling spaces between boulders and blocks of rock, some of which are 3 to 4 feet long. The platform of the fourth terrace is at an altitude of about 250 feet. Farther northwest on Palos Verdes Drive West, at locality 85, at an altitude of 250 feet, fossiliferous gravel and coarse rubble are 1 to 1½ feet thick.

At the localities so far described the marine deposits consist of clean gray sand, calcareous silty buff sand, gravel, and a mixture of gravel and cliff rubble, and the fossils are rock-cliff and tide-pool species. At Bluff Cove, however, where the present sea cliff has retreated to the fourth terrace, a large fauna including offshore shells in addition to rock-cliff and tide-pool shells was collected from reddish-brown sand and relatively fine-grained rubble (locality 86; altitude 260 feet). The terrace deposits are evidently a mixture of marine and nonmarine constituents, the latter predominating. The offshore shells presumably were swept in over the platform, which was probably narrow, by storm waves and were mixed with sand and rubble lying at the foot of the cliff backing the platform.

On the north slope of the hills terrace remnants, thought to represent the fourth terrace, are at a higher altitude than the fourth terrace on the west and south coasts. Fossiliferous gravel and calcareous, silty sand are poorly exposed on Campesina Road in the Malaga Cove district (locality 87; altitude 375 feet). On Campesina Road, half a mile southeast of locality 87, gravel at an altitude of 475 feet contains small clusters of the wormlike gastropod *Aletes squamigerus*. At locality 88, on Palos Verdes Drive North, where no bench is discernible, a foot of fossiliferous gravel (altitude 510 feet) is overlain by black soil, no nonmarine cover intervening. Farther southeast on Palos Verdes Drive North, at locality 89 (altitude 460 feet), *Tegula gallina* and *Hinnites giganteus* were found in sand and gravel containing finely broken shell fragments and stones. The deposits at that locality are probably close to the unexposed platform and grade upward into the nonmarine cover, which includes much schist debris.

THIRD TERRACE

Marine deposits were found at altitudes of 160 to 180 feet on the third terrace, on the slope between the fourth and first terraces, west and southwest of Fort McArthur Lower Reservation in southern San Pedro. In that area the third terrace forms locally a narrow, steeply sloping bench, but a bench is generally not apparent. At locality 90 the terrace deposits, 2 to 3 feet thick, consist principally of rubble and interstitial fossiliferous sand. A mineralized femur of an immature gopher, possibly *Thomomys*, and marine fossils were collected from rubble and sand a foot thick at locality 91. Rubble, gravel, and sand a foot thick at locality 92 contain marine fossils.

On the southwest face of Hilltop quarry (locality 93), northwest of San Pedro, a thin veneer of gravel rests on an uneven platform of soft Pleistocene marl at an altitude of 220 feet. The gravel ranges in thickness from a layer of pebbles to several layers half a foot thick. Worn and broken shells, representing a protected-bay facies like that on the first terrace in this region, were found in a pocket of sand in the gravel.

SECOND TERRACE

The second terrace is the lowest terrace along almost the entire length of the windward side of the hills—west and south. In extensive areas the present sea cliff truncates this terrace and exposes the platform and overlying marine gravel and sand, which is 1 to 12 feet thick. Here and there angular stones are mixed with the gravel or predominate over gravel. Fossils were collected along the sea cliff at localities extending from the Point Fermin district to Lunada Bay (localities 94, 96, 98 to 103; altitude 100 to 140 feet). Locality 94, near Point Fermin, where chitons are exceptionally abundant, was described many years ago by the Chaces,[27] but it is now virtually destroyed, owing to park development. At that locality the fossils are in 2 to 5 feet of angular rubble, sand, and a few cobbles resting on the platform of blue-schist sandstone. At locality 102, on the south side of Agua Amarga Canyon at Lunada Bay, the fossiliferous sediments consist of calcareous silty sand containing minute shells and broken echinoid spines.

Fossiliferous gravel at the top of the cliff at Flatrock Point lies apparently on a small remnant of the second terrace (locality 104; altitude 150 feet).

A cut on Corta Road, at locality 105, in the Malaga Cove district, exposes the platform of the second terrace at an altitude of 190 feet. At that locality a large fauna, consisting of rock-cliff, tide-pool, and protected-bay shells, was found in granule-gravel that was trapped by storm waves in a niche and sealed by boulders.

In San Pedro the second terrace forms locally a distinct bench and at other places merges into the first terrace. Mr. E. P. Chace, of San Pedro, reports that gravel and sand containing a fauna like that in deposits on the first terrace in northern San Pedro were penetrated in an excavation for the high school on the south side of Fifteenth Street, between Leland and Alma, at an altitude of about 170 feet. Pockets of fossiliferous gravel are exposed on the north side of Second Street, between Gaffey and Cabrillo. A path in Peck Park exposes fossiliferous gravel on a terrace remnant that represents probably the second terrace but may be the third (locality 106; altitude 200 feet).

[27] Chace, E. P., and E. M., An unreported exposure of the San Pedro Pleistocene: Lorquinia, vol. 2, No. 6, pp. 41–43, 1919.

PALOS VERDES SAND

GENERAL FEATURES

Marine deposits on the youngest or first terrace, which is well developed on the leeward side of the hills in San Pedro, are designated the Palos Verdes sand. They were described by Delos and Ralph Arnold [28] and at greater length by Ralph Arnold [29] under the designation "upper San Pedro series." In a manuscript report on the geology of the Palos Verdes Hills Kew restricted the name "San Pedro" to the Arnolds' lower San Pedro series and proposed the name "Palos Verdes formation" for their upper San Pedro series. The designation "Palos Verdes formation" first appeared in print in 1926.[30] Inasmuch as sand is the prevailing lithologic type, the term "Palos Verdes sand" is used in this report. Arnold [31] recognized that his upper San Pedro series corresponds in areal extent to the "lower or 50-foot terrace." He did not, however, differentiate the marine deposits from the nonmarine cover. Inasmuch as the marine deposits and their fossils were emphasized, the name "Palos Verdes sand" is restricted herewith to the marine deposits in Arnold's upper San Pedro series, that is, to the marine deposits on the lowest terrace.

In the original description of the upper San Pedro series exposures along the water front in the present northern part of San Pedro were described as representing the best development of that unit.[32] Later Arnold [33] expressly stated that the type locality is "at the north end of the San Pedro Bluff near the lumber yard." Though that locality is shown on a geologic map in this report (pl. 14, locality 113), it is no longer in existence. The water front and adjoining region in San Pedro are regarded as the type region.

The Palos Verdes sand, like the older marine terrace deposits, consists of a thin veneer on the terrace platform, which bevels formations ranging in age from lower Pleistocene to Miocene. Also like the older marine terrace deposits, the strata consist generally of coarse-grained sand and gravel but include silty sand and silt. Limestone cobbles are the prevailing constituent of the gravel, but granitic and schist pebbles are locally abundant. The Palos Verdes generally ranges in thickness from a few inches to 15 feet and is usually less than 10 feet. At places it consists of thin lenses, and at other places it is absent. In San Pedro the terrace and the deposits lying on it have the expectable gentle seaward slope. Along the north border of the hills they are deformed, mildly in the eastern part of the area, more strongly in the western part. In the area where they are deformed the deposits were originally terrace deposits, but the platform on which they rest has no longer the usual form of a terrace. In the eastern part of the area where deformation has taken place the marine deposits are the equivalent of the undeformed deposits, at least so far as can be determined by ordinary stratigraphic methods. Farther west where the deformation is stronger the marine deposits are as much as 30 to 35 feet thick and possibly may be the equivalent of more than one set of terrace deposits in the area where no deformation took place. Nevertheless the term "Palos Verdes sand" is used, even in the area of strong deformation, because equivalents of two or more sets of terrace deposits, if represented, were not differentiated.

The Palos Verdes sand is shown on the geologic maps (pls. 1, 14, 21) only at localities where it was observed and identified by marine constituents. It is doubtless represented at many other places but is covered with a mantle of surficial debris and soil. At other places it may be represented by unfossiliferous sand mapped as part of overlying or underlying units.

In thickness, and presumably also in time duration the Palos Verdes sand represents a small fraction of ordinary formations in the Coast Range. Assignment of formation rank and naming of the marine deposits would be justified as fully for any other terrace as for the marine deposits on the youngest terrace. A formal name is used for the marine deposits on the youngest terrace, because they are extensive and because they have played an important part in descriptions of Coast Range geologic history.

[28] Arnold, Delos and Ralph, The Marine Pliocene and Pleistocene stratigraphy of the coast of California: Jour. Geology, vol. 10, pp. 120, 126–128, 1902.
[29] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), pp. 12, 23–30, 1903.
[30] Tieje, A. J., The Pliocene and Pleistocene history of the Baldwin Hills, Los Angeles County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 502–503, 1926.
[31] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 27, 1903.
[32] Arnold, Delos and Ralph, op. cit., p. 126.
[33] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 27, 1903.

STRATIGRAPHY AND LITHOLOGY

DEADMAN ISLAND

On Deadman Island the Palos Verdes sand consisted of 2 to 5 feet of gravel and coarse-grained sand containing marine fossils, generally broken and worn. These virtually horizontal strata truncated the gently dipping San Pedro sand. They were locally consolidated by the addition of calcareous cement. Arnold [34] identified cobbles of fossiliferous cemented San Pedro sand in the gravel.

SOUTHERN SAN PEDRO

The Palos Verdes sand was found at only a few localities along the coast south of Timms Point. In much of that area, however, the strata at and near the top of the sea cliff are poorly exposed or unexposed. The following section was measured along the north side of the ravine at the north boundary of Fort McArthur Lower Reservation (locality 108)—Arnold's Crawfish George's locality.[35]

Section of Palos Verdes sand at north boundary of Fort McArthur Lower Reservation (locality 108, Arnold's Crawfish George's locality)

	Ft.	*in.*
Black soil	3	0
Nonmarine terrace cover:		
3. Brownish sand, lighter in color toward base	4	0
Palos Verdes sand:		
2. Grayish-brown silty, calcareous sand containing many shells and shell fragments and scattered small pebbles. Gastropods abundant, especially "*Nassa*"		11–13
1. Grayish-brown silty, calcareous sand, including a 2-inch to 4-inch *Macoma* layer at base. Contains few pebbles and cobbles. Gastropods not abundant. Rests on platform of Miocene mudstone	1	1–2
Maximum thickness of Palos Verdes sand	2	3

Fossils from the preceding locality include *Fusitriton oregonensis*, *Exiloidea rectirostris*, and other northern species. They represent an unusual faunal facies of the Palos Verdes. The lithologic facies also is unusual. A similar lithologic and faunal facies is represented farther south, at locality 107, near Cabrillo Beach.

[34] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 23, 1903.
[35] Idem, p. 24.

NORTHERN SAN PEDRO

In the northern part of San Pedro the Palos Verdes sand is exposed in numerous street cuts and in some natural exposures along the seaward edge of the terrace. Wherever a street is cut below the level of the first terrace, the terrace platform and Palos Verdes sand, if present, are exposed. Changes have been so numerous since the current edition of the Wilmington topographic map was issued that it is impractical to make the alterations that would be necessary to show the present areal geology; furthermore, the areal pattern is continually changing. Alterations have been made at only a few important localities. (See pl. 14.)

At places, even near the seaward edge of the terrace, the Palos Verdes sand is lenticular and is locally absent, as on the east side of Palos Verdes Street near Third and on Ancon Street between First and Santa Cruz. At many places west of Pacific Avenue the nonmarine cover rests directly on the terrace platform. New cuts farther west along First Street, between Grand and Gaffey near the landward edge of the terrace, show, however, pockets of fossiliferous sand and gravel. Those cuts are not shown on the geologic map (pl. 1); neither are outcrops of fossiliferous sand and gravel in cuts along the extension of Gaffey Street into San Pedro at the Elberon Street overpass.

Coarse-grained sand and gravel ranging in thickness from a few inches to 8 feet are the prevailing lithologic types in northern San Pedro. If only part of the formation is fossiliferous, that part is generally at the base. On the west side of Beacon Street, northward from O'Farrell, however, 1 to 3 feet of fossiliferous sand and gravel composed of limestone cobbles overlie 3 to 8 feet of barren brownish-gray sand at the base of the formation, as shown in the section on page 47. The following section, measured on the west side of Pacific Avenue, between Oliver and Bonita Streets (locality 112), is representative of the sand-gravel facies:

Section of Palos Verdes sand on west side of Pacific Avenue, midway between Oliver and Bonita Streets (locality 112)

	Ft.	in.
Palos Verdes sand:		
3. Fine-grained gray sand including stringers of gray silty sand 1 to 10 inches thick. Grades upward into overlying reddish-brown sand of nonmarine terrace cover	5	6
2. Fossiliferous moderately coarse-grained sand, coarse-grained sand, and gravel (locality 112). Pebbles consist of limestone and cherty shale and have maximum length of 7 inches; many limestone pebbles bored	--	12–19
Maximum thickness of Palos Verdes sand	7	1
San Pedro sand:		
1. Moderately coarse-grained gray cross-bedded unfossiliferous sand. Base not exposed	9	6

Large shells of the gaper clam (*Schizothaerus nuttallii*), oriented in life position, siphon end upward, may be seen in their burrows on the south side of Second Street between Pacific and Mesa and on the west side of Center Street between Santa Cruz and First. At the southeast corner of Third and Mesa Streets transverse sections of burrows filled with Palos Verdes sand and shells are visible in the San Pedro sand 6 to 8 feet below the base of the Palos Verdes. On the west side of Beacon Street, 150 feet south of Dreifus, a channel-filling lens of gravel at the base of the Palos Verdes is 50 feet wide at the top, 15 feet wide at the base, and 6 feet thick at the middle.

A beach facies, consisting of cross-bedded sand containing worn and relatively small shells and shell fragments, was formerly represented near the northwest corner of Palos Verdes and Eighth Streets (locality 109), where the section given below was measured. The strata at that locality have been removed recently, and new outcrops nearby to the west represent the usual sand-gravel facies.

Section of Palos Verdes sand in lot at northwest corner of Palos Verdes and Eighth Streets (locality 109)

	Ft.	in.
Nonmarine terrace cover:		
4. Reddish-brown sand	6	6
Palos Verdes sand:		
3. Shell fragments in matrix of cross-bedded fine-grained sand	1	11–19
Cross-bedded fine-grained gray sand including two, or locally three, 1-inch to 2-inch layers of small worn gastropods (locality 109). Thickness variable	1	1
Maximum thickness of Palos Verdes sand	3	8
San Pedro (?) sand:		
1. Gray sand.		

In northeastern San Pedro, silty sand containing a *Macoma* layer or layers overlies the usual fossiliferous coarse-grained sand and gravel. The silty sand indicates evidently more protected water than does the underlying sand and gravel. *Macoma*-bearing silty sand was represented at Arnold's lumber yard locality (locality 113),[36] now destroyed. At that locality a basal fossiliferous gravel that varied in thickness but was as much as 6 feet rested on an uneven surface of cross-bedded San Pedro sand having a relief of 1 to 2 feet. Silty sand overlying the gravel included a *Macoma* layer a foot above the top of the gravel. The following section, measured on the west side of this remnant of the lowest terrace, now destroyed, shows four *Macoma* layers in a thickness of about 5 feet:

Section of Palos Verdes sand on east side of Harbor Boulevard opposite Dreifus Street

	Ft.	in.
Nonmarine terrace cover:		
6. Reddish-brown sand. Thickness estimated	20	0
Palos Verdes sand:		
5. Brownish-gray silty sand including a 3-inch *Macoma* layer at base	1	7
4. Brownish-gray silty sand including a 4-inch to 5-inch *Macoma* layer at base	1	0
3. Brownish-gray silty sand including a 4-inch to 6-inch *Macoma*-"*Paphia*" layer at base	1	5–8
2. Brownish-gray silty sand containing scattered shells, mostly *Macoma*		2–6
1. Fossiliferous gravel	2	2–7
Maximum thickness of Palos Verdes sand	7	4

The following section measured nearby, on the west side of Harbor Boulevard at locality 114, also shows a *Macoma* layer in silty sand.

Section of Palos Verdes sand on west side of Harbor Boulevard near crossing of Pacific Electric tracks (locality 114)

	Ft.	in.
Nonmarine terrace cover:		
4. Brownish-sand grading upward into reddish-brown sand	12	0

[36] Arnold, Ralph, op. cit., p. 27.

Section of Palos Verdes sand on west side of Harbor Boulevard near crossing of Pacific Electric tracks (locality 114)—Con.

	Ft.	*in.*
Palos Verdes sand:		
3. Silty sand and silt containing scattered pelecypods	2	8
2. Coarse-grained gray sand containing scattered shells, mostly broken, and shell fragments, grading upward into silty sand of finer grain including a 9-inch to 12-inch *Macoma* layer, the top of which is 11 inches below top of unit (locality 114)	3	5
1. Brownish silty sand grading laterally into clean gray sand. Base not exposed	1	7+
Exposed thickness of Palos Verdes sand	7	8

Fossils were collected in the northern part of San Pedro at localities 109 to 114. At localities where they are found in gravel or cross-bedded sand, fragments are more abundant than unbroken shells, but in large collections many specimens are unbroken, and many pelecypods are paired. Pockets have concentrates of coarse-grained sand and small or young shells. The proportion of unbroken shells in silty sand is larger than in gravel and cross-bedded sand. Southern species, including *Crassinella branneri* and *Trachycardium procerum*, were not found south of localities 112 and 113.

GAFFEY ANTICLINE AND SYNCLINE EAST OF PALOS VERDES DRIVE NORTH

Northwest and north of San Pedro the first terrace and its deposits dip gently northeastward toward the trough of the Gaffey syncline and are gently arched over the Gaffey anticline. The terrace platform and overlying terrace deposits, including here and there the Palos Verdes sand, may be traced, except for gaps due to stream erosion, into the area where they are mildly deformed. In perfect exposures the Palos Verdes sand is seen to be at some places lenticular and locally absent, but its apparent absence in extensive areas is probably due to lack of exposures. In the eastern part of the Gaffey anticline and syncline, as farther south, fossiliferous coarse-grained sand and gravel are the prevailing types in the Palos Verdes. They are a few inches to 11 feet thick, generally about 5 feet.

At locality 117, along a cattle trail outside the fence at the south boundary of the Standard Oil Co. tank farm, fossiliferous gravel is made up of limestone pebbles and cobbles, which are not as riddled with holes of boring marine animals as limestone cobbles in the Lomita marl forming part of the terrace platform. The gravel is identified as the Palos Verdes but may correspond to marine deposits on the second terrace farther southeast.

On Harbor Boulevard, opposite the San Pedro Lumber Co. (locality 120), strata assigned to the Palos Verdes sand are 11 feet thick. (See section, p. 48.) The base of the Palos Verdes is drawn at the base of the fossiliferous gravel and sand that contains southern species and that rests on an uneven surface of sand assigned to the San Pedro. As explained under the description of the San Pedro, however, the sand assigned to that formation may represent also the Palos Verdes.

A formerly accessible locality for the Palos Verdes is on the north side of Anaheim Boulevard, on the bluff overlooking the east edge of Bixby Slough (locality 124). At that locality a lenticular cross-bedded abundantly fossiliferous layer in brownish sand has a maximum thickness of 4½ feet and rests on San Pedro silt and silty sand forming the terrace platform.

On the west side of Gaffey Street, 350 feet south of Anaheim Boulevard, an isolated transverse section of fossiliferous Palos Verdes sand, 16 inches long and 7 inches high, is sharply limited by cross-bedded San Pedro sand at a level 3 feet below the terrace platform (locality 129). The Palos Verdes sand is absent on the platform. Another transverse section nearby, 5 feet below the platform, is at least 6 feet long and 2 feet high. The material in these sections fills openings that are apparently too large for burrows of marine animals. They represent holes of unknown origin filled with debris from the cleanly swept platform.

A section measured farther south on the west side of Gaffey Street at locality 127, where granite pebbles are exceptionally abundant in the Palos Verdes, is as follows:

Section of Pleistocene strata, including Palos Verdes sand, in abandoned sand pit on west side of Gaffey Street (locality 127)

	Ft.	*in.*
Palos Verdes sand:		
5. Coarse-grained gray sand grading upward into reddish-brown sand (nonmarine terrace cover) and soil	8	0
4. Fossiliferous gravel and coarse-grained gray sand (locality 127). Limestone pebbles relatively scarce; granitic pebbles abundant. Contact at base irregular	2	2
Thickness of Palos Verdes sand	10	2
San Pedro sand:		
3. Massive gray limonite-stained sand	4	8
2. Gravel, consisting of granitic pebbles and coarse-grained gray sand. Contact at base irregular	1	8
1. Coarse-grained cross-bedded gray sand. Base not exposed	10+	

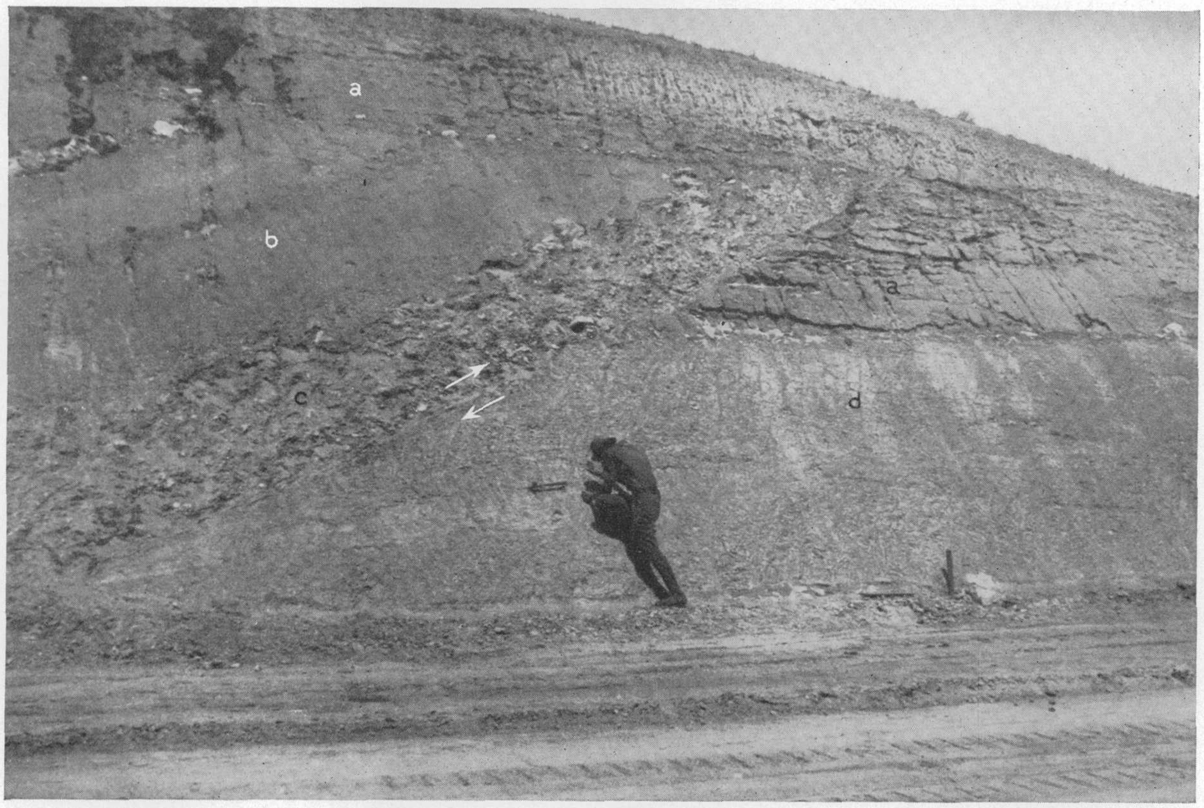
Along the greater part of the slope on the east side of Gaffey Street identification of the Palos Verdes is uncertain, as fossiliferous layers were not found in the formation except at localities 122 and 123. Strata thought to represent the Palos Verdes between these localities include gray silt and olive-gray silty sand. *Aequipecten-Anomia* and *Chione-Ostrea* layers in underlying sand and gravel are assigned to the San Pedro sand.

At localities 125, 131, and 132, on the south limb of the Gaffey anticline west of Gaffey Street, the Palos Verdes is represented by an *Anomia-Ostrea* facies. The strata consist of brownish-gray cross-bedded sand, ½ to 2 feet thick, resting on Miocene mudstone or on cross-bedded gray sand referred to the San Pedro. No characteristic Palos Verdes fossils were found at localities 125 and 132, but the collection from locality 131 includes a worn fragment of the southern *Trachycardium procerum*. On the south flank of the Gaffey syncline, at locality 58 on Western Avenue, an *Anomia-Ostrea* facies is included in strata identified as the San Pedro sand. At that locality the base of the Palos Verdes is drawn at the base of overlying fossiliferous gravel, 3 feet thick, consisting principally of schist pebbles. Fossils from the schist gravel include a small specimen of *Trachycardium procerum*. The *Anomia-Ostrea* facies on opposite flanks of the Gaffey syncline may be of the same age. It appears probable, however, that a similar facies was developed under similar environmental conditions in an arm of the sea behind the actively growing Gaffey anticline during both San Pedro time and Palos Verdes time.

A cut on Palos Verdes Drive East, at locality 133, on the east side of George F Canyon, exposes gravel composed of limestone cobbles and sand resting on the platform at the rear of a terrace (pl. 24, *A*). A few fossils were found in gravel and sand 100 feet farther north where the platform is not exposed. The platform

A. LOMITA MARL IN TYPE REGION AT LOMITA QUARRY.

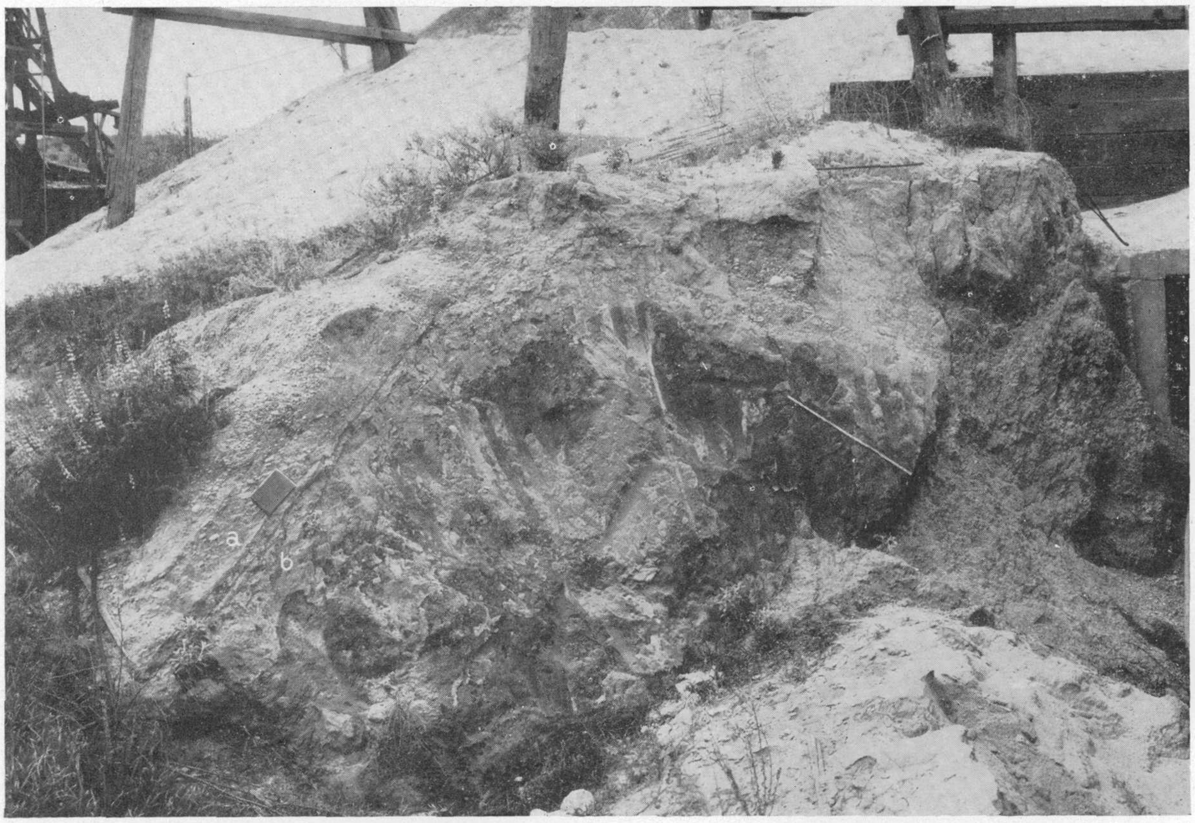
Note minor faults shown by displacement of dark-colored layer of glauconitic sand. The dark-colored strata at top of quarry face consist of sand and gravel assigned to San Pedro (?) sand.



B. LOMITA MARL RESTING UNCONFORMABLY ON MALAGA MUDSTONE MEMBER OF MONTEREY SHALE, AS EXPOSED IN HIGHWAY CUT ON SOUTH LIMB OF GAFFEY ANTICLINE.

Note minor thrust fault along contact, shown by displacement of base of terrace cover. a, Nonmarine cover of lowest terrace; b, San Pedro sand; c, Lomita marl; d, Malaga mudstone member of Monterey shale.

LOMITA MARL.



A. SAN PEDRO SAND (a) LYING UNCONFORMABLY ON MALAGA MUDSTONE MEMBER OF MONTEREY SHALE (b) AT LOADING HOPPER OF SIDEBOTHAM NO. 2 SAND PIT.

Photograph by U. S. Grant.

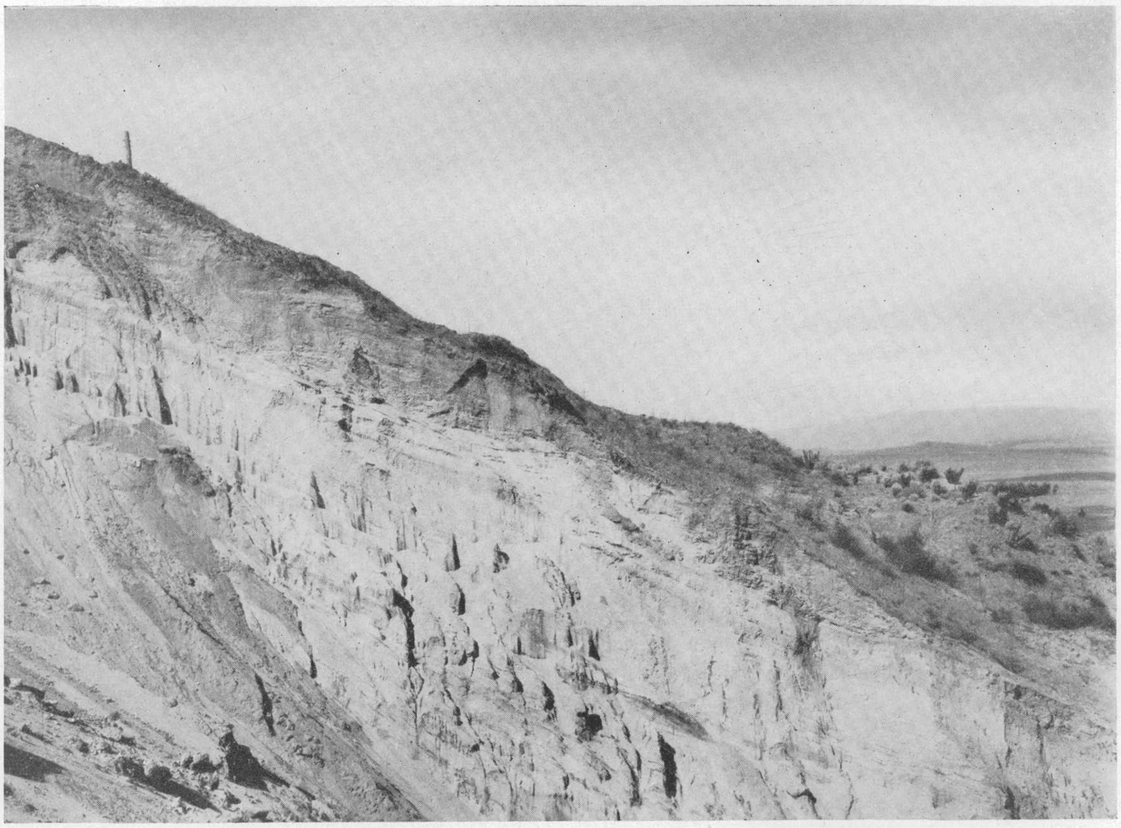
B. CROSS-BEDDED SAN PEDRO SAND (b) OVERLAIN UNCONFORMABLY BY PALOS VERDES SAND AND NONMARINE TERRACE COVER (a) IN *SIDEBOTHAM NO. 2 SAND PIT.*

Photograph by U. S. Grant.

PLEISTOCENE FORMATIONS ON NORTH BORDER OF PALOS VERDES HILLS.

SAN PEDRO SAND IN SIDEBOTHAM NO. 1 SAND PIT.

The pit is about 100 feet deep. The little hill has a cap of nonmarine terrace cover.



A. SAN PEDRO SAND IN RICHARD BALL SAND PIT.

B. SAND PIT ON WEST SIDE OF FOURTH RAVINE WEST OF HAWTHORNE AVENUE.

Lomita marl (c), San Pedro sand (b), and unconformably overlying Palos Verdes (?) sand and nonmarine terrace cover (a).

PLEISTOCENE FORMATIONS ON NORTH BORDER OF PALOS VERDES HILLS.

is at an altitude of 365 feet, much higher than the rear of the first terrace in San Pedro. It may represent the second or third terrace, but is identified provisionally as the first. The marine deposits are, therefore, identified provisionally as the Palos Verdes.

Fossils were collected in the eastern part of the Gaffey anticline and syncline at localities 115 to 133. These collections include southern species, notably *Crassinella branneri*, *Dosinia ponderosa*, *Chione gnidia*, and *Trachycardium procerum*, except those from localities 125, 132, and 133. *Dosinia ponderosa* was not found south of localities 118 and 119, and *Chione gnidia* was found only at locality 123.

GAFFEY ANTICLINE WEST OF PALOS VERDES DRIVE NORTH

The Palos Verdes sand was identified at localities on the north flank of the Gaffey anticline west of Palos Verdes Drive North but was not recognized in the adjoining syncline.

On the west side of Palos Verdes Drive North, 300 feet south of Anaheim Boulevard (locality 134), where the base of the formation is not exposed, lenses of fossiliferous coarse-grained sand, 8 inches to 1½ feet thick, are separated by a foot of silty sand. Float *Anomia*, *Ostrea*, and broken sand dollars occur on the slope of overlying silty sand, also considered of Palos Verdes age. One of the best localities for Palos Verdes fossils is in a ravine west of Palos Verdes Drive North, near the head of Senator Street in Harbor City (locality 135). Fossils are scattered through 5½ to 6 feet of brownish-gray coarse-grained sand resting on an uneven surface of limonite-stained gray San Pedro sand. Farther up the ravine lenses of fossiliferous sand are overlain by 8 to 15 feet of barren olive-gray silt and sandy silt.

In addition to the localities mentioned, fossils were collected from sand and gravel at localities 136 to 138. Characteristic southern species, including *Crassinella branneri*, *Dosinia ponderosa*, *Chione gnidia*, and *Trachycardium procerum*, were not found in the western part of the Gaffey anticline west of locality 135.

NORTH BORDER OF HILLS BETWEEN BENT SPRING CANYON AND HAWTHORNE AVENUE

The Palos Verdes sand is not recognized on the north border of the hills between Bent Spring Canyon and Agua Magna Canyon. In that area strata identified as the nonmarine terrace cover rest on sand and gravel assigned to the San Pedro sand. In the absence of fossils it is difficult, however, to differentiate the Palos Verdes from the San Pedro and the nonmarine cover.

On the west side of Agua Magna Canyon float *Anomia* fragments were observed on the surface of a gravel composed of limestone cobbles that represents probably the Palos Verdes. In the first sand pit (Graham Bros.) west of Agua Magna Canyon 15 feet of coarse-grained sand and limestone cobbles are assigned to the Palos Verdes. The strata dip 15° to 20° northeastward at approximately the same rate as the underlying San Pedro sand. On the east face of the pit fossils were found at the top of a basal gravel 3 to 7 feet thick (locality 139) and also 5 feet higher at the top of a gravel 1 foot thick (locality 139a). In the adjoining sand pit to the west sand that includes lenses of limestone cobble gravel may represent the Palos Verdes, but no fossils were observed. Pockets of fossiliferous sand and gravel are exposed in a cut at the workings of the Dicalite Co. (locality 140).

Strata assignable to the Palos Verdes were not identified in the Richard Ball sand pit between Agua Negra Canyon and Hawthorne Avenue. Coarse-grained sand and limestone cobble gravel exposed on Hawthorne Avenue and the adjoining ravine are assigned to the Palos Verdes. Fossils collected from sand at locality 141 include numerous specimens of *Donax gouldii*.

The small collections of fossils from the area between Bent Spring Canyon and Hawthorne Avenue do not include characteristic Palos Verdes species.

NORTH BORDER OF HILLS BETWEEN HAWTHORNE AVENUE AND MALAGA COVE

Along the north border of the hills, between Hawthorne Avenue and Malaga Cove, deformed strata mapped as the Palos Verdes sand are as much as 30 to 35 feet thick—twice as thick as the maximum thickness farther southeast. The upper part of this thick section is considered the equivalent of the Palos Verdes, and perhaps the entire section is. For the geology of the area immediately northwest of Hawthorne Avenue see plate 21.

In the fourth ravine west of Hawthorne Avenue gravel composed of limestone cobbles and sand unconformably overlap the San Pedro sand (pl. 20, *B*). Though no fossils were found in these strata, they represent probably the Palos Verdes, in view of relations in the fifth ravine. As shown in figure 13, the fifth ravine west of Hawthorne Avenue exposes 30 to 35 feet of sand and gravel dipping 22° to 26° northeastward and resting with marked unconformity on the San Pedro sand and the underlying Lomita marl. The basal gravel, apparently barren of fossils, consists of relatively small granitic and limestone pebbles. The upper gravel is made up of limestone pebbles, cobbles, and boulders, some as much as 2 feet long. The intervening sand, gray in the lower part and brownish-gray in the upper part, includes stringers of gravel composed of pebbles of cherty shale and limestone. The upper gravel at locality 142 is sparingly fossiliferous. It contains *Trachycardium procerum*, this locality being the only one west of locality 135 where this southern species was found, *Nucella biserialis*, and other species. Perhaps only the upper gravel represents the Palos Verdes, the underlying strata corresponding to marine deposits of the second or third terrace, or both.

In ravines farther west along the north border of the hills the Palos Verdes sand was not identified. Some of the gray limonite-stained sand assigned to the nonmarine terrace cover may, however, be unfossiliferous Palos Verdes. In the upper part of the ninth and last ravine west of Hawthorne Avenue the platform of Miocene mudstone is bored at many places. Below the falls a pocket of gravel composed of limestone cobbles possibly represents the Palos Verdes.

MALAGA COVE

At the north end of Malaga Cove, as at many other places along the north border of the hills, the Palos Verdes sand is apparently absent, the nonmarine terrace cover resting on sand doubtfully assigned to the San Pedro (see fig. 7). Farther south the nonmarine cover overlaps Pliocene and Miocene formations and is arched over those strongly deformed formations. South of the mouth of Malaga Canyon deposits on the first terrace are as much as 25 to 30 feet thick. The lower few feet include bored cobbles and are probably marine, but no fossils were found.

FOSSILS

FORAMINIFERA

Foraminifera are abundant in the Lomita marl, particularly in foraminiferal calcareous sand and glauconitic foraminiferal sand, and in parts of the Timms Point silt. They are rare and generally are absent in the San Pedro sand and in the Palos Verdes sand and have not been found in terrace deposits older than the Palos Verdes sand. Locality 64, where a Lomita-like fauna occurs in silty sand at the base of the San Pedro sand, is an exception, for at that locality Foraminifera are abundant. Bagg [37] described 105 species and varieties from the Timms Point silt at Timms Point. Galloway and Wissler [38] described 79 species and varieties from the Lomita marl at Lomita quarry. Their upper bed [39] is unit 6 of the section on page 51; their middle and lower beds have not been identified.

The numerous collections obtained during the field work for this report have not been identified. The collections represent evidently several different faunal associations.

CORALS

Small solitary corals representing presumably the genus *Caryophyllia*, three species of which were described in Arnold's memoir,[40] occur in the Lomita marl and are recorded by Arnold from the Timms Point silt. They are relatively common in the algal bed at Hilltop quarry (localities 53, 53a) and in the calcareous sand and gravel nearby (locality 54g), thought to be the equivalent of the algal bed.

ECHINOIDS

Echinoids are rare in the collections at hand. Poorly preserved specimens of a large *Dendraster* were found in the San Pedro sand at locality 50. The collection from the fourth terrace at locality 84 includes fragments of a small *Strongylocentrotus*, that from the second terrace at locality 105 includes *Dendraster* fragments. Echinoid spines are abundant in some layers of the Lomita marl, and collections from some of these layers include also minute fragments of plates. Arnold [41] recorded *Dendraster excentricus* from the San Pedro sand and Palos Verdes sand, and spines from the San Pedro sand were assigned to *Strongylocentrotus franciscanus* and *S. purpuratus*.

BRYOZOA

Bryozoa are very abundant in the Lomita marl and in the lower part of the Timms Point silt at Timms Point but are rare in the other Pleistocene units. *Idmonea californica* is the most abundant species. Encrusting Bryozoa occur at numerous localities, being most abundant in the algal bed at Hilltop quarry. Canu and Bassler [42] described 19 species from Deadman Island, presumably from the Timms Point silt.

BRACHIOPODS

Unidentified forms of *Terebratalia* occur in the Lomita marl. *Terebratalia smithi* was based on material from the Timms Point silt, and *Terebratalia* cf. *T. hemphilli* and *Laqueus jeffreysi* also are recorded from that unit.[43]

MOLLUSKS

Pleistocene mollusks from the San Pedro district have been described or recorded in numerous publications, beginning with Conrad's 1855 account [44] of material collected by Blake during the transcontinental railroad surveys. Since the publication in 1903 of Arnold's monumental memoir [45] the San Pedro district has become a classic area for California Pleistocene mollusks. Arnold described 395 species and varieties of mollusks collected from strata now assigned to the Timms Point silt, the San Pedro sand, and the Palos Verdes sand at localities on Deadman Island, which has been destroyed, and along the San Pedro water front. The most important publications since then are those on deposits lying on the second terrace near Point Fermin, by the Chaces; [46] on the chitons, by Berry; [47] on the San Pedro sand at a locality now destroyed, near Third and Beacon Streets, by Oldroyd;[48] on the Timms Point silt, San Pedro sand, and Palos Verdes sand at Deadman Island, by Crickmay;[49] and on the Timms Point silt at Timms Point, by Clark; [50] and by Willett.[51] Records up to the early part of 1931 are summarized by Grant and Gale [52] in their indispensable catalog, and some of the species are illustrated.

Mollusks are generally the most abundant fossils in the marine Pleistocene strata and are represented in all but 4 of the 152 collections of Pleistocene fossils obtained during the field work on which this report is based. Almost 100 collections were selected to represent age, facies, and geographic differentiation. About half the gastropods, almost 150 species, were identified in those collections. The plan to complete the identifications was abandoned when it became apparent that an attempt to do so would delay unduly completion of the report. Attention therefore was devoted to the stratigraphically and ecologically important forms. It is estimated that about 450 species and varieties of mollusks are represented in the collections and that additional forms not in the collections but recorded from the San Pedro district would bring the total to about 500. Of the species and varieties identified, about 50 were unrecorded heretofore as fossils from the San Pedro district. The collections at hand do not add much to the recorded fauna of the Timms Point silt, San Pedro sand, and Palos Verdes sand, aside from a few notable exceptions. With few exceptions fossils from terrace deposits older than the Palos Verdes sand represent an association like that recorded by the Chaces [53] from the second terrace. The molluscan fauna of the Lomita marl, not represented along the water front but repre-

[37] Bagg, R. M., Jr., Pliocene and Pleistocene Foraminifera from southern California: U. S. Geol. Survey Bull. 513, 1912.

[38] Galloway, J. J., and Wissler, S. G., Pleistocene Foraminifera from the Lomita quarry, Palos Verdes Hills, Calif.: Jour. Paleontology, vol. 1, pp. 35–87, pls. 7–12, 1927.

[39] Idem, p. 36.

[40] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), pp. 86–88, 1903.

[41] Arnold, Ralph, op. cit., pp. 90–91.

[42] Canu, Ferdinand, and Bassler, R. S., North American later Tertiary and Quaternary Bryozoa: U. S. Nat. Mus. Bull. 125, p. 14, 1923.

[43] Arnold, Ralph, op. cit., pp. 93–94. Clark, Alex, The coolwater Timms Point Pleistocene horizon at San Pedro, Calif.: San Diego Soc. Nat. History Trans., vol. 7, No. 4, table op. p. 30, 1931.

[44] Conrad, T. A., Report on the fossil shells collected in California by W. P. Blake, geologist of the expedition under the command of Lt. R. S. Williamson, United States Topographical Engineers: U. S. Pacific R. R. Expl., 33d Cong. 1st sess., H. Ex. Doc. 129, app., pp. 11–18, 1855. (Reprinted in U. S. Geol. Survey Prof. Paper 59, pp. 165–169, 1909.)

[45] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, 420 pp., 37 pls., 1903.

[46] Chace, E. P. and E. M., An unreported exposure of the San Pedro Pleistocene Lorquinia, vol. 2, No. 6, pp. 41–43, 1919.

[47] Berry, S. S., Fossil chitons of western North America: California Acad. Sci. Proc., 4th ser., vol. 11, pp. 399–526, 16 pls., 11 figs., 1922.

[48] Oldroyd, T. S., The fossils of the lower San Pedro fauna of the Nob Hill cut, San Pedro, Calif.: U. S. Nat. Mus. Proc., vol. 65, art. 22, 39 pp., 2 pls., 1924.

[49] Crickmay, C. H., The anomalous stratigraphy of Deadman's Island, Calif.: Jour. Geology, vol. 37, pp. 617–638, 1929.

[50] Clark, Alex, The cool-water Timms Point Pleistocene horizon at San Pedro Calif.: San Diego Soc. Nat. History Trans., vol. 7, No. 4, pp. 25–42, 2 figs., 1931.

[51] Willett, George, Additions to knowledge of the fossil invertebrate fauna of California: Southern California Acad. Sci. Bull., vol. 36, pp. 61–64, pls. 24–25, 1937.

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

[53] Chace, E. P. and E. M., op. cit.

sented by 43 collections in the material at hand, is unrecorded. It is hoped that at a future date this deficiency may be remedied and that the facies and geographic differentiation of the fauna of the Lomita marl and of the other Pleistocene units may be studied adequately.

The following discussion consists of comments on the stratigraphically and ecologically important species, 80 of which are illustrated on plates 29–37. Inasmuch as, with few exceptions, the different faunas consist of living species grouped in different associations, most of the stratigraphically important species are also evidently ecologically important. Unless otherwise specified the species mentioned are still living. Dimensions of the figured specimens, including the types of new forms, and National Museum catalog numbers may be found on the explanation of the plates. References that may be found in Grant and Gale's well-indexed catalog [54] are omitted. References for recent species not included in that catalog are also generally omitted, as they may be found in Dall's well-known publication.[55]

The following new names are proposed for Pleistocene mollusks:

Gastropods:
- Elassum Woodring, n. gen., Cerithiidae. Type *Bittium (Elachista) californicum* Dall and Bartsch (p. 68).
- "Nassa" fossata coilotera Woodring, n. var. (p. 73).
- "Nassa" delosi Woodring, n. sp. (p. 74).
- Tritonalia coryphaena Woodring, n. sp. (p. 76).

Pelecypods: Chlamys anapleus Woodring, n. sp. (p. 81).

CHITONS

The chitons, 21 species and varieties of which are recorded by Berry [56] from the Pleistocene strata of the San Pedro district, have not been identified. Represented in collections at hand from all the units except the Timms Point silt, they are abundant only in terrace deposits. Mr. and Mrs. Chace [57] found them to be extraordinarily abundant in deposits on the second terrace near Point Fermin (locality 94), where they collected 350 specimens representing 15 species and varieties.

GASTROPODS

ACMAEIDAE

Six of the 13 species of limpets of the genus *Acmaea* represented in the collections examined were not recorded by Arnold, but all except the last have been recorded at later dates—*A. limatula* (Lomita marl (?), San Pedro sand, terrace deposits,[58] and Palos Verdes sand (?)), *A. persona* (terrace deposits), *A. funiculata* (pl. 34, figs. 1, 2; the three lower Pleistocene units), *A. asmi* (terrace deposits and Palos Verdes sand), *A. lepisma* [59] (Lomita marl), and *A.* cf. *A. ochracea* (Lomita marl). Limpets are most abundant in the terrace deposits, *A. scrabra* and *A. limatula* being the most common species. *A. insessa* is the only species found in all the Pleistocene units.

[54] Grant, U. S., IV, and Gale, H. R., op. cit.
[55] Dall, W. H., Summary of the marine shell-bearing mollusks of the northwest coast of America: U. S. Nat. Mus. Bull. 112, 1921.
[56] Berry, S. S., op. cit.
[57] Chace, E. P. and E. M., op. cit., pp. 42–43. Berry, S. S., op. cit., p. 409.
[58] For brevity marine terrace deposits older than the Palos Verdes sand, the only marine terrace deposits named, are designated simply terrace deposits. For the purpose of this account they are treated as a unit, though, of course the deposits on each terrace are as distinct chronologically as the Palos Verdes sand.
[59] Berry, S.S., New Mollusca from the Pleistocene of San Pedro, Calif., I: Bull. Am. Paleontology, vol. 25, No. 94a, p. 9, pl. 1, figs. 3, 4, 1940.

HALIOTIDAE

Abalones, which are rare as fossils, were collected at 13 localities in terrace deposits. The identifiable material represents *Haliotis cracherodii*, and fragmentary remains are probably that species. Complete specimens were found at localities 75 and 84. *H. rufescens* and *H. fulgens*, as well as *H. cracherodii*, are recorded as Pleistocene fossils from the San Pedro district.

FISSURELLIDAE

Fissurella volcano is one of the most abundant gastropods in the terrace deposits. Virtually all the shells retain fresh coloration, a feature noticed by Arnold, indicating a thick outer calcite layer.

The Pleistocene species of *Puncturella* on the Pacific coast represent two groups.[60] One group, *Puncturella* proper, has a prop on the sides of the internal septum and includes only the northern *P. galeata*. That species is not in the collections at hand but is recorded from the Timms Point silt and San Pedro sand. The other group, which lacks the props and is apparently unnamed, includes *P. cucullata*, *P. cooperi*, and *P. delosi*. *P. cucullata* is in collections from the Lomita marl and Timms Point silt and is recorded from the San Pedro sand and Palos Verdes sand. *P. cooperi* (pl. 29, fig. 1) is abundant in the three lower Pleistocene units but was not recorded from the San Pedro district until recently.[61] *P. delosi* (pl. 29, fig. 2), the most distinctive of the three species, occurs in the Lomita marl and San Pedro sand and is recorded from the Timms Point silt.[62] It was based on Pleistocene material from Santa Barbara and was formerly thought to be extinct. As Willett [63] suspected, the unfigured Recent *P. caryophylla* [64] is closely related to *P. delosi*, and represents probably that species. The Recent material in the National Museum consists of three lots dredged off Point Loma, California, by the *Albatross* at depths of 67 to 81 fathoms. The concentric threads between the ribs are stronger on fossils than on most Recent specimens, owing probably to slight abrasion.

TROCHIDAE

Halistylus pupoideus, heretofore recorded only from the San Pedro sand, was found in the Lomita marl at Hilltop quarry (locality 53) and in deposits on the second terrace at Malaga Cove (locality 105). The specimens from the Lomita marl are exceptionally large.

Tegula funebralis, which at the present time is rare as far south as San Pedro, occurs in the San Pedro sand, the Palos Verdes sand, and in terrace deposits up to the fifth terrace, inclusive. It is differentiated from *T. gallina* principally by the presence of puckered sutural lamellae and by the absence of diagonally reticulate sculpture and color banding. As identified it is found in association with *T. gallina* in terrace deposits at localities 83 and 104. *T. gallina* is abundant at the present time along the coast of the Palos Verdes Hills. It is likewise abundant in terrace deposits, especially at localities 75, 79, 84, and 88, is found in the Palos Verdes sand, and is represented by doubtfully identified fragments from the Lomita marl (localities 53, 53a, 61). *T. brunnea* (Timms Point silt (?), terrace deposits, Palos Verdes sand), *T. montereyi* (Lomita marl, re-

[60] Dall, W. H., Notes on West American Emarginulinae: Nautilus, vol. 28, pp. 62–64, 1914.
[61] Willett, George, op. cit., p. 64, 1937.
[62] Idem.
[63] Idem.
[64] Dall, W. H., op. cit., p. 63.

corded from Timms Point silt, San Pedro sand, terrace deposits, Palos Verdes sand), and probably *T. marcida*[65] ("*pulligo*")[66] (Palos Verdes sand) appear to be extinct locally, as they are not known to be living along the mainland in the latitude of San Pedro. *T. ligulata* (San Pedro sand, terrace deposits, Palos Verdes sand) is more abundant than *T. aureotincta* (terrace deposits, Palos Verdes sand).

In addition to the five species of *Calliostoma* described by Arnold, *C. supragranosum* (recorded from deposits on the second terrace) was found in terrace deposits and may be represented by a worn and broken specimen from the Lomita marl at locality 37, and *C. eximium* (pl. 35, fig. 7) occurs in the Palos Verdes sand at locality 121. *C. eximium* is a southern species said to range from Catalina Island to Mazatlan, Mexico, and has not been reported heretofore as a fossil from California. *C. decarinatum*[67] ("*canaliculatum*") is the most abundant *Calliostoma*, being represented in all the Pleistocene units. The only specimen from terrace deposits is, however, a worn and broken shell. *C. ligatum* ("*costatum*") is likewise found in all the units. *C. virgineum*[68] (Lomita marl (?), San Pedro sand, Palos Verdes sand) appears to be the name for the species generally known as *C.* "*annulatum.*" The recently described *C. grantianum*,[69] based on material from the Lomita marl at Hilltop quarry, is not recognized in the collections at hand.

Cidarina cidaris is represented by imperfect specimens in the Timms Point silt and by a doubtfully identified fragment in the Lomita marl at locality 41.

Turcica caffea (pl. 32, figs. 1, 2) was found only in the Timms Point silt but is recorded from the San Pedro sand at Deadman Island. The type locality of this species is presumably Monterey, where, as recorded by Gabb, it was dredged at a depth of 20 fathoms. Gabb also mentioned, however, fossils from San Pedro and Santa Barbara. No specimens from Monterey are in the National Museum. On the fossils from the Timms Point silt the sculpture and peripheral spiral are of variable strength on the later whorls. None of the few available Recent shells from the California coast (La Jolla, San Diego) are as large as the fossil shown on plate 32, figure 1, and none are as weakly sculptured as the fossil shown on plate 32, figure 2. *T. caffea brevis*,[70] from the *Acila* and *Pecten* zones of the San Joaquin formation (upper Pliocene) of the Kettleman Hills, is more strongly sculptured than the Timms Point fossils and Recent California shells, and has a stronger peripheral spiral. In general sculpture it resembles more closely a large specimen (length 30 millimeters), larger than any California fossil or Recent shell available, dredged off Cape San Lucas, Lower California, at a depth of 66 fathoms. *T. caffea brevis* has more tightly coiled later whorls than the Lower California form. The strong peripheral spiral suggests that *brevis* is more closely related to the Recent Japanese *T. imperialis* than to *T. caffea*. The comparison between *brevis* and *caffea* in the Kettleman Hills report was based on the large Lower California form, which is doubtless not *T. caffea* but closely resembles *T. imperialis*.

Solariella peramabilis occurs in the Timms Point silt (pl. 32, fig. 3) and Lomita marl. Owing to the strong axial threads between the spirals, fragments are identified with reasonable certainty. The much smaller unfigured *S. rhyssa*[71] is represented by broken specimens from the Lomita marl. It was based on a shell dredged in Catalina Channel and has not been reported heretofore as a fossil.

Pupillaria is generally assigned subgeneric rank under *Margarites*, which, however, is smooth and has a rather narrow umbilicus. *Lirularia* is considered a subgenus under *Pupillaria*. The common *Pupillaria* of the San Pedro district, found in all the Pleistocene units but rare in terrace deposits, is identified as *P. optabilis*. It has brownish crudely axial blotches visible on fossils, except bleached specimens. The type is a Recent shell from San Pedro. This species has probably been reported as *P. parcipicta*. The type of *P. parcipicta* from Santa Cruz [Island?] has a higher spire and stronger axial threads on the body whorl. Some of the fossils, especially some from the Lomita marl, have narrow sharp-crested spirals. They are probably *P. optabilis acuticostata* but are not readily differentiable. The type of "*Margarita*" *parcipicta* var. *pedroana*, based on a worn specimen from the San Pedro sand, is considered *P. optabilis*. Likewise "*Margarita*" *optabilis* var. *nodosa*, also from the San Pedro sand, is considered *P. optabilis*, the nodes on the type being principally color markings. A large form, *P. optabilis knechti* (pl. 34, figs. 3, 4), is abundant in the San Pedro sand, especially at localities 47 and 47a, and is identified in the Palos Verdes sand at localities 112 and 113. The dark blotches cover more of the shell than in *P. optabilis* proper, and as the whorls enlarge they tend to flatten. Differentiation on a basis other than size is, however, doubtful. Perhaps this large form does not deserve nomenclatorial recognition, but it is not know to be living.[72] "*Lirularia*" *magna*, which like *P. optabilis knechti* is based on fossil material from the San Pedro sand, is a synonym of *knechti*.

Pupillaria succincta is of the same size as *P. optabilis* and has the same color markings, but the base is flatter, and the spirals, which are especially noticeable on the base, are more crowded. Found at five localities in terrace deposits, this species was not reported previously as a fossil. The type material, from an undesignated California locality, was collected from an abalone. A Timms Point *Pupillaria*, *P.* cf. *P. salmonea*, is represented by fragmentary and immature specimens. It is probably most similar to a form dredged off Point Loma at a depth of 71 to 75 fathoms, possibly a form of *P. salmonea*. Another *Pupillaria* from the Lomita marl and San Pedro sand has relatively fine spirals on the base, like *P. salmonea*, but the spirals above the base are wider. *P. salmonea* (type locality, Monterey) or forms similar to it are unrecorded as fossils.

The genus *Macheroplax* is represented by a small, imperfect specimen from the Timms Point silt identi-

[65] Gould, A. A., Descriptions of shells from the Gulf of California and the Pacific coasts of Mexico and California: Boston Jour. Nat. History, vol. 6, p. 381, pl. 14, fig. 11, 1853 ("*Trochus*," Monterey).

[66] The names in Martyn's "Universal Conchologist" are not accepted in this report. Ralph Arnold recorded this species from his upper San Pedro (The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, p. 328, 1903. ("*Phorcus pulligo.*")

[67] Perry, George, Conchology, pl. 47, No. 2, 1811 ("*Trochus*, New Zealand") Rehder, H. A., Notes on the nomenclature of the Trochidae: Biol. Soc. Washington Proc., vol. 50, p. 116, 1937.

[68] Dillwyn, L. W., A descriptive catalogue of Recent shells, vol. 2, pp. 800–801, 1817 ("*Trochus*").

[69] Berry, S. S., op. cit., p. 12, pl. 2, figs. 4, 5.

[70] Stewart, Ralph, in Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field: U. S. Geol. Survey Prof. Paper 195, p. 84, pl. 11, figs. 1, 6, 1940 [1941].

[71] Dall, W. H., Descriptions of new species of Mollusca from the north Pacific Ocean in the collection of the United States National Museum: U. S. Nat. Mus. Proc., vol. 56, p. 360, 1919.

[72] According to a recent communication from George Willett, of the Los Angeles Museum, his collection from Forrester Island, Alaska, includes four Recent specimens of this form.

fied as *M.* cf. *M. varitosa*. *M. varicosa* has been recorded recently at Timms Point.[73]

LIOTIIDAE

Two species of *Liotia*, neither of which has been recorded heretofore as a fossil, are rare in the Pleistocene collections. They are *L. fenestrata* (Lomita marl and terrace deposits) and *L. acuticostata* (terrace deposits and Palos Verdes sand). The type of *L. fenestrata*, occupied by a hermit crab, is from the "Santa Barbara Islands," and most of the other specimens in the National Museum are also hermit crab shelters. The shells from the Lomita marl are unbroken, whereas those from terrace deposits, possibly hermit crab shelters, are broken. The type of *L. acuticostata* is from Catalina Island. The 1 shell from locality 105 has a few faint axials, approaching the variety *L. acuticostata radiata*. According to local collectors, both *L. fenestrata* and *L. acuticostata* appear to be more abundant on the islands than on the mainland.

VITRINELLIDAE

Vitrinella thomasi, based on material from the San Pedro sand at Oldroyd's Nob Hill locality, is represented by two specimens from that formation at locality 48. They are considerably larger than the type (width 2.7 millimeters). The species is not known to be living. *V. williamsoni*, represented in the National Museum only by the type, a Recent shell from San Pedro, is much larger (width 5.5 millimeters) and flatter. Arnold recorded *V. williamsoni* from the San Pedro sand and Palos Verdes sand without mentioning the size or other characters. *V. oldroydi* has been recorded from the San Pedro sand [74] and was found in terrace deposits at five localities. The umbilicus is much narrower than in *V. thomasi* and *V. williamsoni*. *V. eshnauri*, reported from the San Pedro sand [75] but not in the collections at hand, has a higher spire than the species already mentioned. Discovery of the heretofore unfigured *V. salvania* [76] (pl. 29, figs. 3–5) in the Lomita marl at locality 41 constitutes a new record for that species as a fossil. It has a narrow umbilicus for *Vitrinella* and on one of the three fossils the umbilicus is partly closed by a callus plug. The fossils are a little larger than the type and only Recent specimen, and the umbilicus is slightly wider. *V. salvania* is somewhat intermediate between *Vitrinella* proper and *Docomphala*, as the umbilical wall along the apertural half of the body whorl is faintly puckered; the spire of *V. salvania* is, however, higher and the early whorls lack weak axial ribs.

One specimen of *Cyclostremella coronadoensis* from the San Pedro sand at locality 49 also constitutes a new record for the San Pedro district. The type of that species, from the Pleistocene at Spanish Bight, San Diego, has not been examined. Six specimens from an undesignated San Diego Pleistocene locality and several hundred from the railroad crossing at the foot of 23d Street, San Diego (U. S. G. S. locality 2123), are virtual topotypes. *C. californica* (type locality San Pedro, Recent) is considered a synonym. The type of *Cyclostremella* has a deeper anal sinus adjoining the suture than does *C. coronadoensis* but is otherwise similar to that species.

The genus *Pseudorotella* is represented by the two common California species, *P. invallata* (San Pedro sand,[77] terrace deposits, Palos Verdes sand) and *P. supravallata* (terrace deposits). *P. supravallata*, heretofore not recorded as a fossil, is more abundant in terrace deposits than *P. invallata*.

TURBINIDAE

In the absence of the characteristic ribbed operculum, adult shells of *Pomaulax* may be differentiated from *Pachypoma* by the weakly sculptured base. *Pomaulax undosus* occurs in the Lomita marl (pl. 29, figs. 6–8), the Timms Point silt (small broken specimen), terrace deposits, and the Palos Verdes sand. It is particularly abundant in the Lomita marl at Hilltop quarry (localities 53, 53a). Opercula are as abundant as shells in the Lomita marl and were found also in terrace deposits and the Palos Verdes sand. This species is generally readily distinguishable from *Pachypoma gibberosum*, with which it is associated, by the strong peripheral keel and weakly sculptured base. Young shells may be difficult to differentiate, however, as young shells of both species are keeled and young shells of *Pomaulax undosus* have a more strongly sculptured base than adults.

Pomaulax turbanicus petrothauma [78] (pl. 29, figs. 9–12) was found only in the algal bed of the Lomita marl at Hilltop quarry, where it is fairly common. It resembles closely the Recent *P. turbanicus* [79] proper, represented only by the type dredged off Magdalena Bay Lower California, at a depth of 36 fathoms. The Pleistocene variety has more widely spaced nodes, and the peripheral nodes have a longer base. The figured large fossil operculum is rounded like the operculum of *P. turbanicus* proper, and also as in that form has a narrow, strongly bent, almost smooth inner rib. The fossil operculum (length 29.3 millimeters) is much too large to fit any shell at hand and is larger than the operculum of the type of *P. turbanicus* (length 21.8 millimeters).

Pachypoma gibberosum [80] ("*inaequale*") is found in the three lower Pleistocene units and is recorded from the Palos Verdes sand. Like *Pomaulax undosus* it is most abundant in the Lomita marl at Hilltop quarry (pl. 29, figs. 13–15), where it is represented by shells and the characteristic narrow smooth opercula. The stage at which the peripheral keel of fossil and Recent shells disappears is variable. In the variety *Pachypoma gibberosum pacifica* the keel persists to an exceptionally late stage. This variety and the unfigured variety *barbarense* [81] are of doubtful validity.

Four species of the genus *Homalopoma* are represented in the Pleistocene collections. The largest and most abundant is *H. carpenteri*, which has heavy relatively widely spaced spirals, except on the early whorls of some specimens characterized by a few heavy spirals among fine spirals. The rosy color is preserved on many fossils. This species is found in all the

[73] Willett, George, op. cit., p. 63 ("*Solariella*").
[74] Oldroyd, T. S., The fossils of the lower San Pedro fauna of the Nob Hill cut, San Pedro, Calif.: U. S. Nat. Mus. Proc., vol. 65, art. 22, p. 21, 1924.
[75] Idem.
[76] Dall, W. H., op. cit. (U. S. Nat. Mus. Proc., vol. 56), p. 369, ("*Teinostoma* (*Pseudorotella*)"); South Coronado Island, 3 fathoms).
[77] Already recorded from the San Pedro sand (Oldroyd, T. S., op. cit., p. 21, 1924 ("*Teinostoma*").
[78] Berry, S. S., New Mollusca from the Pleistocene of San Pedro, Calif., I: Bull. Am. Paleontology, vol. 25, No. 94a, pl. 10, pl. 2, figs. 2, 3, 1940.
[79] The type of *P. turbanicus*, minus the operculum, has been figured by Grant and Gale (Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, pl. 31, fig. 2, 1931).
[80] Dillwyn, L. W., A descriptive catalogue of Recent shells, vol. 2, pp. 803–804 1817 ("*Trochus*, New Zealand").
[81] Dall, W. H., op. cit. (U. S. Nat. Mus. Proc., vol. 56), p. 357, 1919 (off Santa Cruz Island, 30 fathoms).

units but is most abundant in the Lomita marl, particularly in the algal bed at Hilltop quarry (pl. 29, fig. 16). *H. bacula*, smaller than *H. carpenteri* and sculptured with finer spirals, occurs in all the units except the Palos Verdes sand. As in *H. carpenteri*, the rosy color is preserved on many fossils. *H. subobsoletum*,[82] recently described on the basis of material from Timms Point, is a minute faintly sculptured form. In the collections at hand it is represented in the Lomita marl and doubtfully in the San Pedro sand. Specimens (maximum length 2.7 millimeters) dredged off Point Loma at depths of 67 to 75 fathoms are identified as this form. They have faint spiral striae and a light-brown color, a little darker than the fossils, as Willett inferred. Both the fossil and Recent shells have a grooved but not denticulate inner lip, suggesting that they are not mature. The readily recognized *H. paucicostatum*, like *H. bacula*, occurs in all the units except the Palos Verdes sand but is less abundant than that species. *H. paucicostatum fenestratum*, characterized by the strengthening of growth threads to form ribs, was found in the Lomita marl and terrace deposits. This variety has not been recorded heretofore as a fossil. It bears the same relation to *H. paucicostatum* that the variety *radiata* does to *Liotia acuticostata*.

TRICOLIIDAE

Exfoliated specimens of *Tricolia* that show a wide umbilicus are likely to be confused with exfoliated specimens of *Lacuna*, but the inner layer of *Tricolia* has faint spiral markings. Fossil *Tricolia* that retain even a small patch of the outer shell layer, presumably calcite, are readily distinguished from *Lacuna*, as the outer layer retains traces of the color pattern. Specific differentiation of the fossil Tricoliae is difficult, for differentiation of the Recent species is based principally on size and color pattern. Though fossils retain the color pattern, it is bleached.[84]

According to the criteria adopted, *Tricolia pulloides* is the most abundant species in the Pleistocene collections, being represented in all the units except the Palos Verdes sand. It is of medium size (maximum length of fossils 5.5 to 5.9 millimeters) and has a mottled rosy color pattern; many specimens have oblique dark stripes. The best fossils are in the collection from the Lomita marl from the central shaft of the Whites Point tunnel (locality 57). An operculum that probably represents this species and a large lot of shells were collected from the San Pedro sand at locality 30. The terrace specimens are small, with the exception of a large shell from locality 106, where an operculum was collected. A lot of 9 Recent shells in the National Museum, collected at Santa Barbara by Jewett, is to be regarded presumably as the type lot of *T. pulloides*.

Tricolia compta is larger and darker colored than *T. pulloides*, Recent shells being greenish and having oblique narrow brownish bands. The greenish color is gone on the fossils identified as *T. compta*, but traces of the brownish bands remain and are well preserved on some specimens. The fossils have a maximum length of 8.8 millimeters. This species is recognized only in the San Pedro sand and Palos Verdes sand. It is particularly abundant in the San Pedro sand at locality 47a, where two isolated opercula were collected. A large lot from locality 48 includes a shell with the operculum in place. Some small shells from the Palos Verdes sand may possibly be *T. pulloides*. It has been suggested[83] that Arnold's *T. compta* from the San Pedro sand and Palos Verdes sand is *T. pulloides*. Arnold's identifications doubtless agree, however, with those adopted in this report. The type lot of *T. compta* consists of two specimens from San Diego.

A minute shell having a naticid spire and open umbilicus, collected from deposits on the fourth terrace at locality 87, represents the subgenus *Eulithidium* or possibly a very young *Tricolia pulloides*. It is identified as *Tricolia rubrilineata?*.[84]

LITTORINIDAE

A small form of *Littorina planaxis* is abundant in terrace deposits, but it is represented at other horizons by only one worn specimen from the San Pedro sand and two worn specimens from the Palos Verdes sand. Arnold recorded this species from the Timms Point silt. The fossils have a maximum length of 9.6 millimeters, whereas a large Recent shell from San Pedro has a length of 20.8 millimeters. The fossils may represent a small race, as it is improbable that several hundred shells from 25 localities are all young. It is virtually impossible to determine the number of whorls, however, for the tip of the spire is generally worn and corroded.

Littorina scutulata has a more slender spire than *L. planaxis* and lacks the flattened area adjoining the inner lip. Both species have spiral striae on at least the early whorls. The fossil *L. scutulata* retain the brownish color more uniformly than *L. planaxis*. *L. scutulata* is abundant in terrace deposits, being represented in more collections than *L. planaxis* and being generally more abundant than that species, except at locality 80. It is represented by two very small worn shells in the Lomita marl, is fairly common in the San Pedro sand, and is common in the Palos Verdes sand. The fossils are somewhat smaller than Recent shells, the maximum length being 12.6 millimeters as compared with 14.6 millimeters for a large Recent San Pedro shell. Carpenter,[85] who had access to the original material, thought that *L. pedroana*, based on Pleistocene material from San Pedro, is *L. "plena,"* that is, *L. scutulata*. The type is lost.

LACUNIDAE

Many of the fossil specimens of *Lacuna* are in poor condition, owing to exfoliation; furthermore, identification of the species is difficult, inasmuch as the characters of many named Recent forms are still undescribed. The common Pleistocene species, found in all the units except the Timms Point silt, is identified as *Lacuna unifasciata*. It is small, relatively slender, and narrowly umbilicate and has faint slightly wavy microscopic striae distinguishable only on fresh Recent shells and observed on a few of the best preserved fossils. Large shells are rounded or carinate; small shells are carinate. The carina is generally colored brown, a character preserved on some fossils. Arnold's *L. compacta* and Oldroyd's *L. unifasciata aurantiaca* are presumably this species. The type lot of *L. unifasciata* consists of four shells from Santa Barbara, all somewhat worn. The largest has a length of 5.7 millimeters and

[82] Willett, George, op. cit. (Southern Calif. Acad. Sci. Bull., vol. 36), p. 63, pl. 25 1937 ("*Leptothyra*").

[83] Strong, A. M., in Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), p. 814, 1931.

[84] Strong, A. M., West American Mollusca of the genus *Phasianella*: California Acad. Sci. Proc., 4th ser., vol. 17, No. 6, p. 197, pl. 10, figs. 8-10, 1928 (Point Loma).

[85] Carpenter, P. P., A supplementary report on the present state of our knowledge with regard to the Mollusca of the west coast of North America: British Assoc. Adv. Sci. Rept. 1863, p. 590, 1864.

a width of 3.3 millimeters. Only the smallest shell shows the brown band on the carina.

Lacuna carinata is larger and stouter than *L. unifasciata*, the body whorl enlarging more rapidly; the umbilical opening is wider; the microscopic striae are stronger; and the inner lip is effuse. It is identified certainly in only one collection, the Palos Verdes sand at Arnold's Crawfish George's locality (locality 108). It is evidently closely related to the Atlantic *L. divaricata*. Arnold's *L. porrecta* and Oldroyd's *L. solidula* are probably this species; if so, it occurs in the San Pedro sand. According to topotype material, *"Modelia" striata* [86] from the Pleistocene Santa Barbara formation at Santa Barbara is *Lacuna carinata*, as Carpenter [87] thought. The two specimens in the type lot of *L. carinata* from Puget Sound were figured by Gould. The larger specimen (fig. 231; length 11 millimeters and width 5.8 millimeters), which is not so distinctly carinate as in the illustration, appears to be exceptional or pathologic, as the body whorl does not enlarge and the umbilicus is reduced to a very narrow opening. The smaller specimen (figs. 231a, 231b; length 6.9 millimeters, width 4.4 millimeters) is normal but immature and is faintly carinate. *L. porrecta*, based on material collected by Swan at Neah Bay at the mouth of the Strait of Juan de Fuca, is considered a synonym of *L. carinata*. A faintly carinate specimen, collected by Swan at Neah Bay but received through Stearns, has been figured [88] as the type of *L. porrecta*. It may be regarded as the lectotype, as it was probably in the lot examined by Carpenter. Forty-five additional specimens collected by Swan at Neah Bay are in the collection of the National Museum.

Lacuna variegata [89] has a wide umbilical opening and effuse inner lip like *L. carinata* but is more slender and has less distinct spiral striae and brown chevrons on the body whorl. Its status is not satisfactorily determined. The type lot, like the type material of *L. porrecta*, collected by Swan at Neah Bay, consists of 23 specimens, the largest having a length of 8.5 millimeters and a width of 5 millimeters. One specimen from the Lomita marl at locality 53a and a few specimens from the Palos Verdes sand at localities 109 and 112 are identified as *L. variegata?*. They resemble *L. carinata* but are more slender. The color pattern is not preserved. Arnold's figured *L. solidula* is exfoliated and unidentifiable on the basis of the illustration. It may be the form identified in this report as *L. variegata?*.

FOSSARIDAE

Iselica fenestrata occurs in all the units except the Timms Point silt but is rare except in the collection from the San Pedro sand at locality 47a (pl. 34, fig. 5). In Oldroyd's Nob Hill collection from that formation it is represented by an extraordinarily large number of specimens.

VALVATIDAE

The fresh-water gastropod *Valvata humeralis californica*, heretofore unrecorded from the San Pedro district, is represented by one specimen from the Palos Verdes sand at locality 114.

RISSOIDAE

The genus *Amphithalamus*,[90] heretofore unrecorded in the fossil state, embraces minute shells less than 2 millimeters in length. *A. inclusus*, the type of the genus, is rare in the Lomita marl and San Pedro sand (localities 53a, 140). The periphery is angulated or has a low spiral cord. Minute shells (length a little more than a millimeter) from the Lomita marl at locality 42d are identified as *"Amphithalamus" lacunatus?*. They agree with the type of *lacunatus*, a Recent shell from San Pedro, in having a narrow umbilical groove, no basal fasciole, and an undetached peristome along the parietal wall. Some of the fossils, however, do not enlarge so rapidly as the type and only available Recent specimen. Most of the fossils are exfoliated and therefore have a misleading deeply sunken suture. The absence of a fasciole and of a detached peristome along the parietal wall indicates that *lacunatus* is not assignable to *Amphithalamus*.

Alvania, as currently used for west coast mollusks, is represented by four species and a variety. *A. acutelirata* [91] is found in all the units except the Timms Point silt but is generally rare. It is relatively slender and has reticulate sculpture, except on the base, which has only spirals, the axials overriding the spirals. In the original description the general region between San Diego and San Pedro was cited. In the 1866 account the only locality mentioned is San Diego, which therefore is considered the type locality. The type material is not in the collection of the National Museum. *A. pedroana*, based on 2 fossils from San Pedro, evidently from the San Pedro sand, is considered a synonym of *A. acutelirata*. These two specimens have a channeled suture and almost flat whorls. Some Recent and fossil specimens of *A. acutelirata* have a channeled suture, depending on whether the axials stop at a spiral just above the base of a spire whorl. The degree of inflation of the whorls of Recent and fossil shells is vairable, some being as flat as *A. pedroana*.

Alvania rosana is considered a stout form of *A. acutelirata*. On adult shells the sculpture generally fades out on the body whorl near the outer lip. This feature was observed, however, on some slender fossils identified as *A. acutelirata* proper. Fossils from the three lower Plesitocene units and the Palos Verdes sand are identified as *A. acutelirata rosana*. This form is widespread in the Lomita marl and locally is exceptionally abundant in that unit. It is estimated that the collection from locality 53b includes more than 1,000 specimens, which is more than the total number of Recent Pacific coast *Alvania* in the collection of the National Museum. The fossils have more closely spaced ribs than the type of the variety *rosana* and other specimens from the same dredging (*Albatross* station 2901, off Santa Rosa Island, 48 fathoms). Some specimens from a nearby dredging (*Albatross* station 2902, off Santa Rosa Island, 53 fathoms) have ribs as closely spaced as on the fossils. *A. acutelirata rosana* is associated with *A. acutelirata* proper in the Lomita marl, San Pedro sand, and Palos Verdes sand.

[86] Gabb, W. M., Descriptions of new species of American Tertiary fossils and a new Carboniferous cephalopod from Texas: Acad. Nat. Sci. Philadelphia Proc., vol. 13, p. 368, 1861 ("Miocene?").

[87] Carpenter, P. P., op. cit. (British Assoc. Adv. Science Rpt., 1863), p. 632, 1864.

[88] Dall, W. H., Summary of the marine shell-bearing mollusks of the northwest coast of America: U. S. Nat. Mus. Bull. 112, p. 216, pl. 14, fig. 2, 1921.

[89] Carpenter, P. P., op. cit., p. 656.

[90] For a description of the California species see Bartsch, Paul, The west American mollusks of the genus *Amphithalamus:* U. S. Nat. Mus. Proc., vol. 41, pp. 263-265 3 figs., 1911.

[91] Carpenter used the spelling *"acutelirata"* in the original description (Carpenter P. P., op. cit., p. 656, 1864; *"Rissoa"*) and in a later work (Descriptions of new marine shells from the coast of California; pt. 3: California Acad. Sci. Proc., vol. 3, p. 217 1866; *"Rissoa"*). The generally adopted alteration *"acutilirata"* is unwarranted.

Inasmuch as some lots contain intermediate doubtful specimens, the identifications are doubtful. *A. fossilis*, based on a fossil shell from San Pedro, evidently from the San Pedro sand, is considered a synonym of *A. rosana*. The whorls are a little flatter than on most Recent and fossil shells, but that character is variable.

Alvania montereyensis was found at three terrace localities. It is slender and has strongly constricted sutures, and well-preserved Recent shells have faint spiral sculpture on the nucleus. Oldroyd found this species to be abundant in the San Pedro sand at Nob Hill. It is the type of *Willettia*, proposed recently as a subgenus of "*Alvania*" by Gordon,[92] according to whom the Pacific coast species referred to *Alvania* are not congeneric with the Mediterranean species that is the type of that genus.

The other two species of *Alvania* have not been recorded heretofore as fossils in the San Pedro district. *A. purpurea* has a somewhat turreted spire, two or three spirals on spire whorls, and strong axials that form swellings at the intersection with spirals on unworn shells. It is rare in the Lomita marl and terrace deposits. *A. almo* is represented by two terrace specimens. This minute species has a thickened outer lip, but the peristome is in one plane, not undulatory as in *Rissoina*.

The Pleistocene specimens of the minute genus *Barleeia*, found in all the units but most abundant in the Lomita marl and terrace deposits, are identified as *B. haliotiphila*. More than one species, however, may be represented. The shells are variable in length, degree of slenderness, degree of whorl inflation, and degree of rounding of the periphery. None of the several hundred fossils are as large as the type of *B. oldroydi* (length 3.3 millimeters). Stout shells are similar to *B. californica*, which has more inflated whorls. The faint color banding generally visible on *B. californica* would presumably be indistinguishable on fossils. The pits on the nuclear whorls described by Bartsch[93] are so minute and so faint that they are generally indistinguishable under high magnification, even on specimens that ordinarily would be considered quite fresh. Both *B. haliotiphila*[94] and *B. oldroydi*[95] have been recorded from the Timms Point silt.

RISSOINIDAE

Five species of the genus *Rissoina* are represented in the Pleistocene collections, whereas Arnold recorded none. *Rissoina kelseyi* has sharply incised spiral striae and heavy ribs that fade out on the penultimate and body whorls. It occurs in the Lomita marl (pl. 29, fig. 17) and in deposits on the second terrace at Malaga Cove (locality 105). The two specimens from the Lomita marl at locality 42d have slightly heavier ribs and more inflated whorls than Recent shells and the other fossils. The terrace fossils consist of a lot of 35 specimens, including very young shells. The spiral striae are very faint on the terrace shells, though most are quite fresh, and on some the axials persist on the penultimate whorl.

Rissoina pleistocena, not heretofore recorded from the San Pedro district, was found in deposits on the second terrace at Malaga Cove at locality 105 and in the Palos Verdes sand at locality 140 (pl. 35, fig. 8). It is stout and has heavy slightly protractive ribs. It is not known to be living but is related to the Mexican *R. nereina* and *R. burragei*, though it has heavier and more widely spaced ribs. *R. coronadoensis*, a slender species sculptured with very fine axial ribs, occurs in the Lomita marl (pl. 29, fig. 18), Timms Point silt, and San Pedro sand. Perhaps the records of the more strongly sculptured *R. dalli* in the Timms Point silt[96] and San Pedro sand refer to *R. coronadoensis*.

Rissoina aequisculpta has a somewhat turreted spire, strong reticulate sculpture, and spiral sculpture on the nucleus. It is represented by an incomplete specimen, showing the sculptured nucleus, from the Lomita marl at locality 53a and is recorded from the San Pedro sand. The minute *R. cosmia*, which has a turreted spire and strong reticulate sculpture, is represented by a broken specimen from terrace deposits at locality 84. It has not been recorded heretofore as a fossil. Both *R. aequisculpta* and *R. cosmia* have been assigned to *Alvania*.[97] The characters of the lip in both species suggest, however, *Rissoina*.

TRUNCATELLIDAE

Both *Truncatella stimpsoni* and *T. californica* are identified in collections from terrace deposits, the former being more abundant. *T. stimpsoni* is stouter than *T. californica* and is generally strongly sculptured, whereas *T. californica* is usually smooth or almost smooth. *T. californica* has been recorded from the San Pedro sand, but *T. stimpsoni* has not heretofore been recorded from the San Pedro district.

SYNCERIDAE

Syncera translucens occurs in terrace deposits and is recorded from the San Pedro sand. This marine species may be distinguished from the fresh-water amnicolids by the relatively thick parietal callus.

AMNICOLIDAE

An imperfect specimen of the stout fresh-water *Amnicola longinqua* was collected from the Palos Verdes sand at locality 120. This species was based on material collected from sediments of ancient Lake Cahuilla in the Colorado Desert. It is living in southern California. The finding of *A. longinqua* in the Palos Verdes sand constitutes a new record for the San Pedro district.

Hydrobia protea, another fresh-water species, was found in the San Pedro sand at locality 47a and in the Palos Verdes sand at locality 113. Like *Amnicola longinqua*, *Hydrobia protea* was based on material from ancient Lake Cahuilla. It also is living in southern California. As its name implies, it is very variable. In sculpture the range is from smooth to strongly reticulate; in outline from slender, the usual form, to moderately slender. The fossils from the San Pedro district are smooth or faintly sculptured. *Paludestrina curta*,[98] based on fossils from San Pedro, is a moderately slender form of *H. protea*. The type shows faint spiral sculpture. *Paludestrina stokesi*,[99] also

[92] Gordon, Mackenzie, Jr., A new subgenus and species of west coast "*Alvania*": Nautilus, vol. 53, p. 31, 1939.

[93] Bartsch, Paul, The west American mollusks of the families Rissoellidae and Synceratidae and the rissoid genus *Barleeia*: U. S. Nat. Mus. Proc., vol. 58, pp. 167–176, 1920.

[94] Clark, Alex, op. cit. (San Diego Soc. Nat. History Trans., vol. 7, No. 4), table op. p. 30, 1931.

[95] Willett, George, op. cit. (Southern California Acad. Sci. Bull., vol. 36?), p. 62, 1937.

[96] Clark, Alex, op. cit. (San Diego Soc. Nat. History Trans., vol. 7, No. 4), table op. p. 30, 1931.

[97] Bartsch, Paul, The Recent and fossil mollusks of the genus *Alvania* from the west coast of America: U. S. Nat. Mus. Proc., vol. 41, pp. 352, 358, 1911.

[98] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 305, pl. 8, fig. 2, 1903.

[99] Idem, p. 305, pl. 8, fig. 3.

based on fossils from San Pedro, is a slender form and has faint spirals on the early whorls. Oldroyd[1] recorded *Hydrobia protea* as *Paludestrina curta* and *Paludestrina* cf. *P. stokesi*. *Alabina io* also is considered a synonym of *Hydrobia protea*. It was described on the basis of a worn fossil from San Pedro that shows subdued axial and faint spiral sculpture. The drawing, therefore, is misleading. The Pleistocene fossils from a locality near Playa del Rey recently recorded as *Rissoella* sp.?[2] are likewise considered as representing slender *Hydrobia protea*.

ALABINIDAE

Alabina tenuisculpta is represented by a young specimen from the Palos Verdes sand at locality 140 and is recorded from the San Pedro sand.[3] The sculpture of this species is evidently variable. The type, from San Diego, has only two widely spaced spirals on the spire whorls. A form that has many fine spirals and relatively weak axials has been named *A. diegensis*. The slender, slowly enlarging nucleus and slight eversion of the basal lip support assignment of *A. tenuisculpta* to the genus *Alabina*, despite the absence of varices. The type species of *Alabina* has weak varices or none, but otherwise similar species have strong varices.

ALABINIDAE?

The systematic position of the California shells assigned to the genus *Diala* is uncertain. The varix on the body whorl near the outer lip and the slight eversion of the basal lip suggest the family Alabinidae, but the nucleus is much stouter than in *Alabina* and the shell is heavier. It is improbable that the California *Diala* is related to *Barleeia*, with which it is generally placed. It is not known whether the California shells are congeneric with the Chinese and Japanese *Diala*.[4] Japanese specimens in the National Museum labeled *Diala varia* have a similar aperture but lack the varix and have spiral sculpture on the base of the body whorl.

Fossils from the Lomita marl, San Pedro sand, terrace deposits, and Palos Verdes sand are identified as *Diala marmorea*, and that species is recorded from the Timms Point silt.[5] The best specimens and the largest number are from terrace deposits at locality 96. It is doubtful whether more than one species of this genus is living along the California coast. The type of *D. marmorea* from San Pedro is relatively stout and has a rounded periphery; the type of *D. acuta* from Catalina is more slender and has an angulated periphery; and the type of "*Barleeia*" *dalli* from Point Loma (71 to 75 fathoms) is stout and has an angulated periphery. Some specimens arranged under *D. marmorea* in the collection of the National Museum have an angulated periphery; some arranged under *D. acuta* have a rounded periphery. Not all the specimens in the lot from which the type of "*Barleeia*" *dalli* was selected are as sharply angulated as the type, and two specimens from the same dredging, evidently the same form, are arranged under *Diala acuta*.

CERITHIIDAE

The Pleistocene specimens of the genus *Bittium* are difficult to identify, owing to the extraordinary number of specimens, the rather variable characters, and the great number of names that have been proposed without adequate consideration of the range of variation. Six species and a variety are identified. On a basis of nuclear characters two groups are recognized. One group (*B. eschrichtii*, *B. rugatum*, and *B. rugatum larum*) has stout rounded nuclear whorls; the other group (*B. armillatum*, *B. attenuatum*, *B. interfossa*, and *B. asperum*) has an angulation at the upper edge of the nuclear whorls, the angulation reaching its maximum development in *B. asperum*. The angulation may be regarded as a spiral; a second spiral is introduced below the periphery, either on the nucleus or at the transition between nuclear and postnuclear whorls. The subgeneric name *Stylidium* has been proposed for a species of the first group (*B. eschrichtii*), and the subgeneric name *Lirobittium* for a form of the second group (*B. catalinense*). It is improbable, however, that *B. rugatum* is closely related to *B. eschrichtii*. The relations of *B. rugatum* to the Eocene *Semibittium*, to which it is currently assigned, are unknown. *B. quadrifilatum* has not been recognized among the fossils. Arnold's *B. quadrifilatum* is evidently *B. attenuatum*. Arnold's phylogenetic series[6] included species of diverse affinities.

Bittium eschrichtii is represented in terrace deposits by a worn specimen from the Palos Verdes sand at locality 107 and is recorded from the San Pedro sand. The best lot, including small shells that show the nucleus, is from terrace deposits at locality 87. This species is large, stout, *Goniobasis*-like and is sculptured with flat spiral bands separated by narrower interspaces. It is the most distinctive of the fossil species of the genus from the San Pedro district. The fossils are presumably *B. eschrichtii montereyensis*, but the characters cited to differentiate that subspecies are unrecognizable in somewhat worn fossils.

The most abundant *Bittium* in the Lomita marl (pl. 29, fig. 19) and Timms Point silt is identified as *B. rugatum*. It is less abundant in the San Pedro sand, relatively rare in the Palos Verdes sand, and was not recognized in collections from terrace deposits. The Palos Verdes specimens are generally broken and worn. More specimens are in the collection from Arnold's Crawfish George's locality (locality 108) than in any other collection from the Palos Verdes sand. The type of *B. rugatum* is from the lower Pleistocene Santa Barbara formation at Santa Barbara. The sculpture is variable but consists of strong axials and spirals. The axials are wide, closely spaced, and strongly curved on the later whorls. The spirals are slightly swollen on the crest of the axials. Secondary spirals of varying strength are present but may be absent or subdued on the later whorls. An exceptionally large coarsely sculptured Pleistocene form from San Diego has been named *B. giganteum*. None of the fossils from the San Pedro district are quite so large, but some have comparable sculpture. *B. subplanatum* and *B. serra* appear to be southern living representatives of *B. rugatum*. For the most part the Recent shells are smaller and have finer sculpture. Some large

[1] Oldroyd, T. S., op. cit. (U. S. Nat. Mus. Proc., vol. 65, art. 22), p. 17, 1924.
[2] Willett, George, An upper Pleistocene fauna from the Baldwin Hills, Los Angeles County, Calif.: San Diego Soc. Nat. History Trans., vol. 8, No. 30, p. 398, 1937.
[3] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 296, pl. 6, fig. 14 1903 ("*Bittium (Styliferina)*"; unrecognizable on basis of figure).
[4] Adams, A., On some new genera and species of Mollusca from the north of China and Japan: Ann. Mag. Nat. History, 3d ser., vol. 8, p. 242, 1861. Subsequently designated type (Cossmann, M., Essais de paléoconchologie comparée, pt. 12, p. 56, 1921), *Diala varia* A. Adams, China and Japan.
[5] Clark, Alex, op. cit. (San Diego Soc. Nat. History Trans., vol. 7, no. 4), table op. p. 30, 1931.
[6] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), pp. 293–294, 1903

coarsely sculptured shells from southern California, arranged under *Tachyrhynchus* in the collection of the National Museum, appear to be indistinguishable from *Bittium rugatum*. Typical representatives of the northern genus *Tachyrhynchus* have a wider and less pronounced canal than *Bittium*. In the absence of opercula, differentiation of these two genera may, however, be difficult.

Fossils that are generally smaller and more slender than *Bittium rugatum* proper and that have fewer, more widely spaced, and straighter axials are identified as *B. rugatum larum*. This form is abundant in the Lomita marl (pl. 29, fig. 20) and Timms Point silt, is rare in the San Pedro sand, is represented by a worn broken terrace specimen, and is not recognized in the Palos Verdes sand. The type of *B. rugatum larum* is from San Pedro Bay. The few Recent shells available are shiny and polished, and many of the fossils have a similar appearance. This form may be a distinct species; among the fossils, however, it appears to intergrade with *B. rugatum* proper.

Bittium armillatum is the only form of the genus recognized in all the Pleistocene units. It is generally rare in the Lomita marl, very rare in the Timms Point silt, very abundant in the San Pedro sand (pl. 34, fig. 6), widespread but not common in terrace deposits, and relatively rare in the Palos Verdes sand. This species has coarse reticulate sculpture, the spirals being beaded on the crest of the axials. The type (lectotype?) is a worn broken Pleistocene fossil from Santa Barbara collected by Jewett. A better specimen, also a Santa Barbara fossil collected by Jewett, arranged under *B. ornatissimum* in the collection of the National Museum, is doubtless the same species. The type material of *B. ornatissimum* is from Deadman Island, presumably from the San Pedro sand, and represents the species identified in this report as *B. armillatum*. *B. armillatum* proper is not known to be living, specimens from San Pedro in the National Museum collection being doubtless detrital fossils. *B. purpureum* (type locality, Monterey) appears to be a small Recent form of *B. armillatum*. The specimen from the type lot figured by Bartsch[7] has a somewhat turreted spire, but the other three specimens do not. Despite its name, the type of *B. catalinense* also is a fossil from Santa Barbara. It has the same kind of sculpture as *B. armillatum*. The nucleus is more strongly angulated by a spiral at the upper edge, the spiral near the base begins at an earlier stage, and the axials begin at a later stage. It is doubtful, however, whether this form deserves nomenclatorial recognition. The Recent shells from Catalina arranged under *B. catalinense* have a nucleus like the type, but the axials begin at an earlier stage, as early as in *B. armillatum*. These Recent shells are more slender than the type of *B. catalinense* and of *B. purpureum*, and the axials are weaker and farther apart; that is, the sculpture is less strongly reticulate

Bittium attenuatum is a readily recognized small slender species sculptured with relatively weak axials and overriding spirals. The sculpture is subdued on the later whorls, the spirals being more persistent than the axials. Recognized in all the Pleistocene units except the Timms Point silt, it is less abundant than *B. armillatum*. The specimen from the type lot of two figured by Bartsch[8] is chosen as the lectotype. It is presumably from Monterey.

[7] Bartsch, Paul, The Recent and fossil mollusks of the genus *Bittium* from the west coast of America; U. S. Nat. Mus. Proc., vol. 40, p. 391, pl. 52, fig. 3, 1911.
[8] Bartsch, Paul, op. cit., p. 393, pl. 54, fig. 5.

Bittium interfossa, rare in the Lomita marl and terrace deposits, is unrecorded as a fossil from the San Pedro district. It is *Rissoina*-like and has a somewhat turreted spire, coarse reticulate sculpture—coarser than the other fossil species—and a heavy basal spiral. The type is a worn shell from Catalina.

Bittium asperum is common in the Lomita marl, rare in the San Pedro sand, is represented by a fragment from the Palos Verdes sand, and is recorded from the Timms Point silt.[9] Both young and adult shells are readily recognized. The nucleus is so strongly carinate at the upper edge of the whorl that it appears to be broken. The spirals are weak, especially between the axials, and shelflike, only the upper edge projecting at right angles to the whorl. The type is a Pleistocene fossil from Santa Barbara. Perhaps the Recent form *B. asperum lomaense* (type locality, off Point Loma, 71–75 fathoms) can be differentiated by its somewhat smaller size and less sharply angulated nucleus.

The new generic name *Elassum* is proposed for "*Bittium* (*Elachista*)" *californicum* (pl. 29, fig. 21). The preoccupied name *Elachista* was used inadvertently for that species.[10] It is not congeneric with the Floridian and West Indian "*Bittium*" *cerithidioide*, which was intended as the type of *Elachista* and is the type of *Alabina*, proposed as a substitute for *Elachista*. *Elassum* is more *Bittium*-like than *Alabina;* it has a larger, heavier shell, stouter nucleus, coarser sculpture, and a more strongly channeled basal lip. The nucleus is stouter than in *Bittium*, and the spiral sculpture consists of only a few finely engraved striae. *Elassum* is not known to be living and so far as known is monotypic. It would not be surprising to find it living, however, in moderately deep water off the coast of southern Califorina. The porcelaneous, polished, and finely engraved shells of *Elassum californicum* are quite distinctive. They are abundant in the Lomita marl and rare in the Timms Point silt and San Pedro sand. The type is from Deadman Island, presumably from the San Pedro sand.

Cerithidea californica, which lives on tidal flats, is locally abundant in the Palos Verdes sand at locality 111 and other localities farther north and northwest. Though recorded from the Timms Point silt of Deadman Island, it was not found in that unit or the Lomita marl. It occurs in the San Pedro sand at localities 48, 49, and 49a.

CERTHIOPSIDAE

The genus *Cerithiopsis* is represented by a small number of specimens but apparently by at least eight species. Unless the material is reasonably complete, identification is difficult. The species are readily classifiable into major groups on the basis of nuclear characters, as emphasized by Bartsch. *C. fatua* (Lomita marl; type from San Pedro sand) is considered a Pleistocene form of the Recent *C. pedroana*. The fossils are a little more slender than Recent shells, and the axials are fewer and farther apart; the nucleus is slender and smooth. According to Arnold's illustration, *C. williamsoni* (type from Palos Verdes sand) appears to be a stout Pleistocene form of the Recent *C. berryi*. It is recognized in several terrace collections. *C. cosmia*, not heretofore recorded from the San

[9] Clark, Alex, op. cit. (San Diego Soc. Nat. History, vol. 7, No. 4), table op. p. 30, 1931.
[10] For discussion and citations see Woodring, W. P., Miocene mullosks from Bowden, Jamaica, part 2, Gastropods and discussion of results: Carnegie Inst. Washington Pub. 385, pp. 338–339, 1928.

Pedro district, is recognized in the three lower Pleistocene units and in terrace deposits. Some of the fossils show the slender nucleus sculptured with very fine curved axial riblets. Without the nucleus it is difficult to distinguish young shells of *C. cosmia* from young shells of *C. pedroana fatua*, which have somewhat more inflated whorls. *C. antemunda* is represented by a specimen from the San Pedro sand. It is probably the species recorded from that unit as *C. diegensis*, [11] a species that has more closely spaced axials. The moderately stout nucleus, sculptured with axials and spirals, is preserved on the fossil. *C. necropolitana* was based on material from the San Pedro sand at Deadman Island and is not known to be living. In the collections at hand it is represented in the Lomita marl. Some of the fossils show the stout nucleus sculptured with heavy curved axial ribs. Fragmentary material from the Lomita marl and Timms Point silt appears to be similar to the Recent *C. gloriosa*. Worn or broken specimens from terrace deposits and the Palos Verdes sand are identified as *C. arnoldi fossilis*, the type of which is a worn incomplete shell from the San Pedro sand of Deadman Island. The Pleistocene form is larger than the Recent *C. arnoldi* and has coarser sculpture. Neither form is, however, well known. Though the name *fossilis* has page precedence, *arnoldi* is arbitrarily given precedence, because it is based on Recent material.

An incomplete large slender shell that has constricted whorls, coarsely reticulate sculpture, and axials that are exceptionally far apart was collected from the Lomita marl at locality 53a. If it is a *Cerithiopsis*, as appears probable, it is a new species. Two incomplete specimens from the Lomita marl at locality 71 represent a *Bittium*-like *Cerithiopsis* unlike any species known to be living on the California coast. This form closely resembles the Recent *C. willetti* from Alaska. The two specimens are a little more slender than the type of *C. willetti*, the axials are narrower and farther apart, and the spirals are a little wider. Two other Recent specimens of *C. willetti* show, however, some variation in these characters. The nucleus of *C. willetti* is like that of *C. necropolitana*. It is not preserved on the fossils.

TRIPHORIDAE

Triphora pedroana is recognized in several terrace collections and in a Palos Verdes collection and is recorded from the Timms Point silt.[12] The Palos Verdes specimen is exceptionally large (length 8.6 millimeters). Specimens from the Lomita marl are identified as *T.* cf. *T. pedroana*. They taper less rapidly than *pedroana*. The recently described Timms Point species *T. fossilis* [13] is characterized by a faint median spiral introduced at a late stage.

VERMETIDAE

"*Vermetus*" *nodosus*, from the San Pedro sand, may be the smooth variety of *Aletes squamigerus*. Specimens from the San Pedro sand at locality 47a show swellings similar to those of *nodosus* but are not "septate within," as described by Oldroyd. Two large thick almost straight tubes collected from the Lomita marl in the central shaft of the Whites Point tunnel resemble tubes of the mud-boring pelecypod *Kuphus*. They are identified as the smooth variety of *Aletes squamigerus*, as one shows the flattened attachment area.

The small strongly sculptured contorted tubes of "*Vermetus*" *anellum* are readily recognized. Found in all the Pleistocene units except the Palos Verdes sand, this species is unrecorded as a fossil from the San Pedro district.

CAECIDAE

Caecum californicum (Lomita marl, San Pedro sand, terrace deposits, and Palos Verdes sand), *Micranellum crebricinctum* (all units), and *Fartulum occidentale* (San Pedro sand, terrace deposits, and Palos Verdes sand) are recorded already from the San Pedro district. In addition, *Caecum grippi* is represented by a specimen from the Lomita marl and *Fartulum orcutti* from terrace deposits. *Caecum grippi* has a few coarse annuli, about 15, that are far apart. According to Arnold's figure, his *Caecum magnum* is probably the young of *Micranellum crebricinctum*—a conclusion reached by Willett.[14] Oldroyd's *Fartulum hemphilli* is considered *F. occidentale*. *F. orcutti* is a short stout species that has a very oblique somewhat contracted aperture.

TURRITELLIDAE

Two species of the genus *Turritella* are represented in the Pleistocene strata—*T. pedroensis* and *T. cooperi*. *T. pedroensis* is locally abundant in the Lomita marl (pl. 29, figs. 22, 23) and Timms Point silt (pl. 32, fig. 4), is less abundant in the San Pedro sand (pl. 34, fig. 7), is represented by two worn, broken specimens from deposits on the third terrace at Hilltop quarry (locality 93), and by a worn, broken specimen in each of two Palos Verdes collections (localities 120, 140). *T. cooperi* is abundant in the Lomita marl, more abundant in the Timms Point silt, is common in the San Pedro sand (pl. 34, fig. 8), and is widespread in the Palos Verdes sand (pl. 35, fig. 9) but is abundant in that unit only at Arnold's Crawfish George's locality (locality 108), where the specimens are worn. Adult shells of the two species are readily distinguishable, *T. pedroensis* having a larger apical angle, less constricted suture, and heavier spirals. Tips are not so readily distinguishable, as the development of the sculpture is similar; tips of *T. pedroensis* have generally, however, a larger apical angle. The two species are associated at numerous localities, but both are abundant only at localities 32c (Timms Point silt) and 30 (San Pedro sand).

The recently described *Turritella pedroensis* [15] is the species for which Arnold used the name *T. jewettii*. The material on which Carpenter based *T. jewettii* was from a locality inland from Santa Barbara. The type material has not been found in the Jewett collection at Cornell University.[16] A small incomplete specimen in the collection of Recent California mollusks in the National Museum (19827; length 15.1 millimeters, width 5.8 millimeters) labeled "*Turritella jewettii* Cpr., Santa Barbara, Jewett-Gabb (also fossil)," evidently was examined by Carpenter, as the handwriting of the entry in the catalog book is identified by Dr. Paul Bartsch as Carpenter's. It is not certain, however, that this specimen is a fossil or that it was in Carpenter's original ma-

[11] Oldroyd, T. S., op. cit. (U. S. Nat. Mus. Proc., vol. 65, art. 22), p. 15, 1924.
[12] Willett, George, op. cit. (Southern California Acad. Sci. Bull., vol. 36), p. 62, 1937.
[13] Willett, George, op. cit., p. 62, pl. 24.
[14] Willett, George, op. cit. (San Diego Soc. Nat. History Trans., vol. 8, No. 30), p. 399, 1937.
[15] Applin, E. R., in Merriam, C. W., Fossil Turritellas from the Pacific Coast region of North America: California Univ., Dept. Geol. Sci., Bull., vol. 26, pp. 121–123, pl. 35, figs. 1–9, 1941.
[16] Merriam, C. W., idem, p. 122, footnote.

terial. That Carpenter had only a small shell or shells is indicated by his description of the sculpture of only the young shell ("t. jun."). The small specimen in the National Museum is large enough to indicate that it is not the flat-whorled *T. jewettii* of Arnold; it is doubtless *T. cooperi*, forms of which are the only representatives of the genus found at localities near Santa Barbara. In view of the uncertain status of *T. jewettii*, it appears to be preferable to use Applin's name for the species from the Pleistocene strata of the San Pedro district.

As shown by the illustrations, the strength of primary and secondary spirals of *Turritella pedroensis* is variable. Specimens from the San Pedro sand of Deadman Island at locality 30, one of which is figured (pl. 34, fig. 7), show diffused brownish blotches. This species is one of the few well-defined Pleistocene species of the San Pedro district that is not known to be living. Arnold thought it was extinct, and, despite published range lists to the contrary, its occurrence as a Recent species has not been confirmed. The Pliocene specimens from a well in San Diego identified by Dall as *T. jewettii* represent forms of *T. cooperi*. The few worn specimens of *T. pedroensis* from late Pleistocene terrace deposits, including the Palos Verdes sand and strata at Playa del Rey[17] correlated with the Palos Verdes sand, may possibly be detrital material.

The sculpture of *Turritella cooperi* is very variable. Specimens from the Palos Verdes sand (pl. 35, fig. 9) are more strongly sculptured than others. Those that have subdued nodes on the spirals, like the figured Palos Verdes shell, resemble the recent *T. mariana* (type locality near Tres Marias Islands, 80 fathoms), but that species is more slender and has two strong spirals on the early whorls. Shells from the San Pedro sand at Deadman Island (locality 30) have diffused brownish blotches, like Recent shells but lighter (pl. 34, fig. 8).

HIPPONICIDAE

The two species of *Hipponix, H. antiquatus* and *H. tumens*, are most abundant in terrace deposits, *H. antiquatus* being the more abundant. *H. antiquatus* is represented also by one specimen from the Lomita marl (locality 61) and by one specimen from each of two Palos Verdes collections (localities 107, 108) and is recorded from the Timms Point silt and San Pedro sand. *H. tumens* is represented in the Palos Verdes sand but is rare in that unit. The shell on which *H. antiquatus* is based is from Barbados.[18] In general features and sculpture California shells closely resemble West Indian shells. The outline, height, and position of the apex are variable. Lots from California include flatter specimens than lots from the West Indies. The 44 specimens from Neah Bay, Washington, constituting the type material of the variety *cranioides*, are divided into four lots showing complete gradation from the high marginal apex of the typical form to the flat subcentral apex of *cranioides*. The type lot of *H. tumens* consists of four specimens from Monterey.

CREPIDULIDAE

The large *Crepidula* collected only from the Timms Point silt is identified as a small variety of *Crepidula princeps* (p. 32, figs. 5, 6). It has been recorded as *C. princeps* and *C. grandis*. The type of *C. princeps* is an incomplete large shell from the lower Pleistocene Santa Barbara formation at Santa Barbara and is in the collection of the National Museum (1839; length 86 millimeters, width 64 millimeters, height 39 millimeters). An exceptionally fine and characteristically large specimen (length 110 millimeters, width 56 millimeters, height 50 millimeters) from the type region was figured by Arnold.[19] In this species the edge of the deck has a wide asymmetric indentation on the adapical side of a median plane. A furrow on the hidden face of the deck, along which the deck is relatively thin, corresponds to the apex of the indentation; elsewhere the deck is thick. The almost complete Timms Point specimen shown on plate 32, figures 5, 6, is as large as any examined from the San Pedro district. It has a length of 55 millimeters, a width of 40.5 millimeters, and a height of 23 millimeters. The edge of the deck is broken or inaccessible on available specimens. The deck is as thick as on Pleistocene specimens of *C. princeps* of the same size from Rincon Point, on the coast between Santa Barbara and Ventura, but the furrow on the inner face is less conspicuous. The identification of the Timms Point form as a small variety of *C. princeps* is based principally on the thickness of the deck. The large typical form of *C. princeps* is not in any available material from the San Pedro district. It occurs in the lower Pleistocene at Santa Barbara and Rincon Point, is widespread in the Pliocene—particularly in the upper Pliocene—and is recorded from the Miocene. Arnold recorded *C. "grandis"* only from the Palos Verdes sand of Deadman Island, but it has not been found elsewhere in the Palos Verdes sand despite extensive collecting. The dimensions cited by Arnold (length 80 millimeters), based presumably on one of his specimens from the San Pedro district, represent a shell considerably larger than the Timms Point specimens collected. *Crepidula grandis* is a moderately large Recent Alaskan and Siberian species, comparable in size to the Timms Point form. The largest specimen in the collection of the National Museum has a length of 55 millimeters, a width of 42 millimeters, and a height of 17 millimeters. The deck is thin and has a very shallow, wide indentation on the adapical side. It is doubtful whether *C. grandis* and *C. princeps* are closely related.

Five other species of *Crepidula* are represented in the Pleistocene strata. *C. onyx* is rare in the Lomita marl and San Pedro sand, fairly common in terrace deposits, and abundant in the Palos Verdes sand. The deck, which is not far below the aperture, has a narrow indentation on the abapical side and a wider indentation on the adapical side. The rich brown color of the interior below the deck is conspicuous in the fossils, as noted by Arnold. *C. adunca* is common in the Lomita marl, San Pedra sand, and terrace deposits, is abundant on the Palos Verdes sand, and is recorded from the Timms Point silt.[20] It is small, deeply cup-shaped, and the cavity above the deck extends into the apex. The deck is far below the level of the aperture, and its edge is simply curved. Specimens from a San Pedro sand collection (locality 30) and from a Palos Verdes collection (locality 108) are identified as *C. excavata*. In this species the apex is at the level of the aperture, and the edge of the deck is almost straight, being slightly arched at the ends.

[17] Willett, George, op. cit. (San Diego Soc. Nat. History Trans., vol. 8, No. 30), p. 399, 1937.
[18] Hanley, Sylvanus, Ipsa Linnaei Conchylia, p. 422, London, 1855.
[19] Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 321, pl 13, figs. 1a-1c, 1921.
[20] Clark, Alex, op. cit. (San Diego Soc. Nat. History Trans., vol. 7, no. 4), table op. p. 30, 1931.

According to Arnold's description of the edge of the deck, his *C. rugosa* is the species identified in this report as *C. excavata*. The Pleistocene form from the Ventura Basin described as *C. saugusensis* should be compared with *C. excavata*. *C. aculeata* is recognized in a few terrace collections and is recorded from the San Pedro sand. This species has spiny ribs, and the deck has an indentation on the abapical side and a double indentation on the adapical side. Specimens of this species from the Pacific coast from Panama to southern California closely resemble West Indian shells. The flat variable *C. nummaria* occurs in all the units but is rare in the Timms Point silt and is not common in the Palos Verdes sand. Shells are thin or thick, and some exceptionally thick shells are lamellar. Arcuate shells of this species that lived in the aperture of gastropods have a striking outline. The deck has a narrow indentation at the abapical edge

Crepipatella,[21] characterized by a peculiar deck, is given generic rank. The deck is deeply concave and has an exceptionally deep indentation at the abapical edge and a minor indentation near the middle that corresponds to a swelling on the outer face. *Crepipatella lingulata* is recognized in all the Pleistocene units except the Timms Point silt and is recorded from that unit.[22] It is most widespread in terrace deposits and is very abundant at locality 105. The apex is *Calyptraea*-like, and the shell is smooth or roughened either irregularly or to form crude radial ribs. The indentation at the abapical edge of the deck is narrow and deeper than in the type of the genus.

Crepipatella charybdis (pl. 29, fig. 24; pl. 32, figs. 7, 8), for which the generic name *Verticumbo* [23] has been proposed, is fairly common in the Lomita marl and Timms Point silt and is represented by a specimen from the San Pedro sand (locality 30). It resembles *C. lingulata*, but the *Calyptraea*-like apex is larger, and the remainder of the shell is sculptured with weak to strong, irregular, and irregularly swollen radial ribs. The deck is perfectly preserved on only one small Timms Point specimen (pl. 32, fig. 8). The abapical indentation is not so narrow nor so deep as in *Crepipatella lingulata*, and the median indentation is very shallow. The adapical edge is strongly bent toward the aperture, a feature observable even on specimens that have an imperfect deck. It is probably most closely related to the unfigured "*Crepidula*" *orbiculata* [24] (type locality, Victoria, Vancouver Island). That species lacks, however, the sculpture, and the adapical edge of the deck is not strongly upturned. *Crepipatella charybdis* is living in moderately deep water off the coast of southern California. The upturned deck edge is preserved on a specimen (224683) in the collection of the National Museum, which was dredged off Santa Cruz Island at a depth of 155 fathoms. On two small specimens (209067) dredged in 55 to 67 fathoms off Point Loma the upturning is not so strong. These three Recent shells have a large apex and deck indentations like the fossils, and the sculpture is moderately strong. This species has recently been dredged by Messrs. Tom and John Q. Burch at a depth of 50 fathoms off Redondo Beach, Calif.

CALYPTRAEIDAE

A rather flat large-tipped *Calyptraea* found in the Lomita marl and San Pedro sand is identified as *C. fastigiata* (type locality, Puget Sound). It is presumably the species recorded from the Timms Point silt [25] and Palos Verdes sand as *C. mamillaris*. *C. mamillaris* is a southern species that has a thicker shell, and the upper part of unbleached specimens is light brown.

The genus *Crucibulum* is represented by *C. spinosum*. It is common in the Palos Verdes sand, present in two terrace collections, and is recorded from the San Pedro sand.

NATICIDAE

The genus *Cryptonatica* is common in the Lomita marl, Timms Point silt, and locally in the San Pedro sand. It is represented but rare in the Palos Verdes sand at two localities (108, 120) and was not found in terrace deposits. The collection from the Lomita marl at locality 67 includes an operculum. Identification of species is uncertain, owing to uncertainty concerning the Recent forms. The fossils represent presumably one species having a spire of variable height. Some specimens are bleached, but numerous others show a brownish color. The Timms Point *Cryptonatica* has been identified recently by Willett [26] as *C. russa* on the grounds that that species has a heavier callus pad and darker color than *C. clausa*, a name that has been used for Pleistocene fossils from the San Pedro district. The largest fossil at hand is from the San Pedro sand at Deadman Island (locality 30) and has a length of 23.7 millimeters and a width of 24 millimeters. The others are considerably smaller or much smaller, with the exception of one specimen from the Palos Verdes sand at Arnold's Crawfish George's locality (locality 108). The best Lomita marl specimens are from the central shaft of the Whites Point tunnel (locality 57). Many specimens from other Lomita marl localities and from the Timms Point silt are partly exfoliated. Other small exfoliated naticids on which the callus is removed are indeterminable generically.

Neverita is the most abundant naticid genus. It is locally common in the Lomita marl, apparently rare in the Timms Point silt, rare in terrace deposits, abundant in the San Pedro sand, and very abundant in the Palos Verdes sand. Two forms are recognized—*N. reclusiana alta*, which occurs in all the Pleistocene units, and *N. reclusiana imperforata*, found only in the Palos Verdes sand. As pointed out by Pilsbry,[27] Recent specimens of *N. reclusiana alta* have a brown callus and generally have a tonguelike extension of callus above the groove. The brown coloration of the callus, lighter than on Recent shells, is preserved on a few fossils from the Lomita marl, San Pedro sand, and Palos Verdes sand. The tonguelike extension of callus appears to be the most satisfactory character to differentiate fossil specimens of the variety *alta* from *N. reclusiana* proper. Despite the name, fossil and Recent shells have a spire of variable height. Pilsbry designated a specimen from the Palos Verdes sand at locality 112 as a neotype of *N. reclusiana alta*, a name first published by Arnold for specimens from the Palos

[21] Lesson, R. P., Voyage de la *Coquille*, Zoologie, vol. 2, pt. 1, p. 389, 1830 (1831, fide Sherborn). Subsequently designated type (Gray, J. E., Zool. Soc. London Proc., 1847, p. 57). *Calyptraea adolphei* Lesson (= *Crepidula dilatata* Lamarck, fide Dall), Recent, Peru. *C. dilatata* was described from an unknown locality. As figured by Delessert, it is reasonably similar to Peruvian shells. Neither Lesson's nor Delessert's illustrations show the minor indentation near the middle of the deck.

[22] Clark, Alex, op. cit. (San Diego Soc. Natural History Trans., vol. 7, No. 4), table op. p. 30, 1931.

[23] Berry, S. S., New Mollusca from the Pleistocene of San Pedro, Calif., I: Bull. Am. Paleontology, vol. 25, No. 94a, p. 8, pl. 1, figs. 6–10, 1940.

[24] Dall, W. H., Descriptions of new species of Mollusca from the North Pacific Ocean in the collection of the United States National Museum: U. S. Nat. Mus. Proc., vol. 56, p. 351, 1919.

[25] Clark, Alex., op. cit.

[26] Willett, George, op. cit. (Southern California Acad. Sci. Bull., vol. 36), p. 63, 1937.

[27] Pilsbry, H. A., *Neverita reclusiana* (Desh.) and its allies: Nautilus, vol. 42, pp 109–113, pl. 6, 1929.

Verdes sand. The only large Lomita specimens are from Hilltop quarry (locality 53a). The few Timms Point specimens are small, poorly preserved, and determinable only generically; in fact, most of the Timms Point naticids are indeterminable generically. Aside from a small shell collected at locality 86, the terrace Neveritae are worn or broken, or both (localities 93, 106). Some from locality 93 show the tongue-like extension of the callus; the other terrace specimens are not determinable beyond the genus. Only a few specimens of *N. reclusiana* proper are in the collection of the National Museum. They represent a range from Santa Barbara to Catalina. *N. reclusiana alta* is represented by many lots and is a southern form, the specimens being from localities ranging from San Diego to Lower California and the Gulf of California. It is recorded by Pilsbry from Newport Bay, between San Pedro and San Diego.

Neverita reclusiana imperforata is characterized by a low spire, generally by a somewhat cylindrical outline, and by a thick callus that fills the umbilicus completely or almost completely. The fossils assigned to this form are readily distinguishable, with the exception of some small shells. This form is widespread and locally abundant in the Palos Verdes sand and is associated with *N. reclusiana alta* at five localities. Arnold's figured *N. reclusiana* from the Palos Verdes sand and the Recent specimen figured by Grant and Gale as the variety *N. reclusiana callosa* represent *N. reclusiana imperforata*. Recent shells in the National Museum represent forms that range from Crescent City to San Diego; that is, the variety *imperforata* appears to range farther north than *N. reclusiana* proper or the variety *alta*. Observations on the habitats and distribution of the three forms of *Neverita*, which, as emphasized by Pilsbry, are needed to determine their status, have not been recorded. Among the fossils, *N. reclusiana imperforata* is more distinct than *N. reclusiana alta*.

The genus *Lunatia*, which has a more northern range than *Neverita*, is represented by *Lunatia lewisii* in the three lower Pleistocene units and in the Palos Verdes sand. It is much less abundant, however, than *Neverita*, unless most of the small and medium-sized indeterminable naticids in the Timms Point silt represent *Lunatia*. *L. lewisii* reaches a much larger size than the forms of *Neverita*, and large shells are more strongly shouldered. The umbilical callus is grooved, as in the forms of *Neverita*, but covers a smaller area. Large or moderately large shells were collected from the Lomita marl at Hilltop quarry (localities 53, 53a), from the San Pedro sand at localities 30 and 48, and from the Palos Verdes sand at localities 112 and 121.

VELUTINIDAE

A small imperfect shell from the Lomita marl at locality 54g appears to represent the Recent Pacific coast species considered conspecific with the north Atlantic *Velutina laevigata*. That species has been recorded recently from the Timms Point silt.[28] At the present time it is not known to range south of Monterey.

Lamellaria stearnsii, a representative of the family Lamellariidae, is recorded from the San Pedro sand at Deadman Island.[29]

[28] Willett, George, op. cit. (Southern California Acad. Sci. Bull., vol. 36), p. 63, 1937.
[29] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 317, 1903.

CYPRAEIDAE

Cypraea spadicea, the only species of the genus living on the California coast, occurs in the Lomita marl at Hilltop quarry and in terrace deposits and is represented in the Palos Verdes sand by a doubtful fragment. The best specimens are from the fourth terrace at locality 82.

One specimen of *Trivia californica* was found in deposits on the fourth terrace at locality 84. The larger and more deeply grooved *T. solandri* occurs in deposits on the second terrace at locality 105, and a fragment from the Palos Verdes sand represents probably that species. Arnold found *T. californica* in the Palos Verdes sand and *T. solandri* in the San Pedro sand. *T. ritteri*, which lacks the dorsal groove, has been recorded recently from the Times Point silt.[30]

Erato vitellina (pl. 30, fig. 3), heretofore not recorded from the Plesitocene of the San Pedro district, is represented by a specimen from the Lomita marl at locality 57. Owing to the absence of most of the denticles usually present on the inner lip, this specimen was mistaken for a marginellid until its affinities were pointed out by Mackenzie Gordon, Jr. Two fragments from deposits on the second terrace at locality 105 are presumably *E. columbella*, which Arnold found to be rare in the Palos Verdes sand.

CYMATIIDAE

Fusitriton oregonensis occurs in the Lomita marl at Hilltop quarry and nearby, in the Timms Point silt (pl. 32, fig. 9), is recorded from the San Pedro sand, and is represented in the Palos Verdes sand by a small broken specimen in the collection from Arnold's Crawfish George's locality (locality 108). It is rare except in the Timms Point silt. In that unit it is represented in three collections from Timms Point, in a collection from San Pedro (locality 40), and in a collection from the north border of the western part of the hills (locality 66). The fossils have the strong varices characteristic of Recent shells. The figured specimen is of medium size, but broken shells from the Timms Point silt and Lomita marl are larger, almost as large as shells from Puget Sound. The southernmost specimen in the collection of the National Museum was dredged at a depth of 1,081 to 1,100 fathoms off San Nicolas Island. Mr. George Willett, of the Los Angeles Museum, dredged a small specimen at a depth of 80 fathoms off Catalina.

BURSIDAE

Bursa californica was found in the Lomita marl (pl. 29, fig. 25) and Palos Verdes sand and is represented by a doubtful fragment in a collection from the third terrace at locality 93. It is abundant in the algal bed of the Lomita at Hilltop quarry, where it is represented by well-preserved specimens of different sizes. The only other Lomita marl material consists of fragments from localities 54g and 61. The Palos Verdes specimens consist of a doubtful fragment from locality 112 and a young shell from locality 126.

EPITONIIDAE, PYRAMIDELLIDAE, AND MELANELLIDAE

The numerous epitonids, pyramidellids, and melanellids have not been identified. Thirteen species of epitonids, two of which are said to be unknown in the living state, are recorded from the Pleistocene strata of the San Pedro district. Forty-four species of pyra-

[30] Willett, George, op. cit. (Southern Calif. Acad. Sci. Bull., vol. 36), p. 62, 1937.

mitrellids are on record, half of which are not reported to be living. The large number of species and the large number of forms thought to be extinct, as compared with other families, strongly suggest that the Pleistocene representatives of this family are overnamed. Eleven species of melanellids are recorded, four of which are not reported to be living.

FUSINIDAE

Three species of the genus *Barbarofusus* are recognized, and a third species generally referred to *Barbarofusus* or *"Fusinus"* is assigned to *Harfordia*. *Barbarofusus barbarensis*, as identified by Arnold, is large and slender and has a relatively long, narrow canal. On large specimens the axial ribs fade out on the penultimate whorl. This species is identified in the Lomita marl and San Pedro sand and is recorded from Timms Point silt and Palos Verdes sand. A well-preserved specimen from the San Pedro sand of Deadman Island (locality 30; pl. 34, fig. 9) is the largest of the fossils. None of the fossils are as large as two exceptionally large shells (length about 130 millimeters) mentioned by Dall,[31] dredged in 30 fathoms off Newport Bay. *B. barbarensis* was based on fossil material from Santa Barbara. According to a communication from Dr. L. G. Hertlein, of the California Academy of Sciences, the type material of the species of *"Fusus"* described by Trask in 1855 is no longer in existence. A specimen from the Santa Barbara formation at Santa Barbara should be designated the neotype of *B. barbarensis*. Inasmuch as no specimens from Santa Barbara are at hand, the usage of the name is based on Arnold's identification of San Pedro specimens.

Barbarofusus arnoldi is stouter than *B. barbarensis* and has strongly shouldered whorls, producing a turreted spire, and a shorter and wider canal. It is recognized in the San Pedro sand (pl. 34, figs. 10, 11) and is represented by a small specimen from the Palos Verdes sand at Arnold's Crawfish George's locality (locality 108). The spirals of well-preserved fossils are colored brown. This species was based on fossil material from San Pedro. The specimen from the San Pedro sand at Deadman Island shown on plate 34, figure 10, is designated the neotype. Both *B. barbarensis* and *B. arnoldi* have a stout nucleus that has a pointed apex, and near the end of the nucleus a few axial ribs merge into the postnuclear sculpture. The upper edge of the first nuclear whorl appears to be more strongly angulated in *B. arnoldi* than in *B. barbarensis*.

The *Barbarofusus* from the Timms Point silt is relatively small and has brown spirals like *B. arnoldi*, but the spire is not turreted. This form is identified provisionally as *Barbarofusus* cf. *B. arnoldi* (pl. 32, fig. 10).

Harfordia monksae is widespread in the Lomita marl (pl. 29, fig. 26) and occurs in terrace deposits and the Palos Verdes sand. It is smaller than the species of *Barbarofusus* and has a short stout pillar and correspondingly short wide canal. The primary spirals are heavy and colored dark brown on well-preserved fossils. The only satisfactorily preserved terrace specimens are from the second terrace at locality 98. This species also was based on fossil material from San Pedro. The best specimens in the collections gathered during the field work for this report are from the Lomita marl. Inasmuch as the Lomita marl was presumably not accessible to Trask, it would be inappropriate to designate a neotype from that unit. The larger of two fossils (124757; length 43.7 millimeters, width 18.5 millimeters) from San Pedro, collected by Miss Monks, in the collection of Recent California mollusks in the National Museum is designated the neotype. These two fossils are labeled "Pliocene," implying the Timms Point silt, but the matrix consists of sand, and they are probably from the Palos Verdes sand, the only unit in which Arnold found this species. *Harfordia monksae* has the short relatively wide canal and heavy spirals of *H. harfordi*, the type of that genus. The nucleus of *H. harfordi* is not known; the nucleus of *H. monksae* is like that of *Barbarofusus arnoldi*.

"Fusinus" luteopictus appears to be represented in terrace deposits by minute young shells from localities 75 and 86 and by an imperfect, presumably adult, shell from locality 77. The nucleus is turreted and near the end is sculptured with a few axial riblets. Arnold found this small species in the San Pedro sand and Palos Verdes sand. It appears to be related to *Harfordia*.

MITRIDAE

The genus *Mitra* is represented by two species, both of which represent the subgenus *Atrimitra*. *Mitra idae* was found in the Lomita marl and in terrace deposits and is recorded from the Timms Point silt, the San Pedro sand, and the Palos Verdes sand. *M. fultoni*, a southern species not recorded heretofore from the San Pedro district but recorded recently nearby,[32] was collected from deposits on the second terrace at locality 105.

"NASSIDAE"

Gastropods of the family "Nassidae" are perhaps the most abundant of the carnivorous gastropods. Seven species and two additional varieties are recognized. They fall into four genera or subgenera, the distinguishing characters of which are as follows:

Outer lip varicose:
- Parietal callus thick ---------- "Nassa" tegula
- Parietal callus not thick ---------- "N." insculpta

Outer lip not varicose:
- Inner lip lirate ------ "N." fossata, "N." fossata coilotera, "N." delosi, "N." cerritensis, "N." perpinguis
- Inner lip swollen above basal fold but not lirate ---- "N." mendica, "N." mendica cooperi

Inasmuch as the generic affinities of the species have not been determined, they are referred to *"Nassa."* It may be pointed out, however, that the first group represents *Nassarius* proper and that *Schizopyga* is available for the third group.

"Nassa" tegula occurs in the Palos Verdes sand and is recorded from the San Pedro sand. *"N." insculpta* was found in the Lomita marl (pl. 29, fig. 27), and Arnold found one specimen in the Palos Verdes sand.

"Nassa" fossata, the largest of the nassids, is common in the San Pedro sand and the Palos Verdes sand and is recorded from the Timms Point silt and deposits on the second terrace. Specimens from Arnold's Crawfish George's locality are exceptionally large and slender and have an exceptionally wide concave area between the shoulder and the suture, characters mentioned by Arnold[33] for specimens from that locality. The new varietal name *"N." fossata coilotera* (pl. 35, figs. 10, 11) is proposed for this form. The

[31] Dall, W. H., Notes on the west American species of *Fusinus*: Nautilus, vol. 29, p. 55, 1915.

[32] Willett, George, op. cit. (San Diego Soc. Nat. History Trans., vol. 8, No. 30), p. 395, 1937.

[33] Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 233, 1903.

largest specimen (length, not quite complete, 50.7 millimeters) is larger than the type. Immature shells are indistinguishable from "*N.*" *fossata* proper, except that they are slightly more slender. This variety is not known to be living. The most similar form in the collection of the National Museum is a stouter shell from Oregon (252997).

The recent species that has been designated "*N.*" *californiana* is presumably not that species and evidently needs a new name. The status of "*N.*" *californiana*, based on fossil material that is lost, is uncertain, however, until a neotype is designated. It is probably the Pliocene species that was later named "*N.*" *moraniana*. That species is stouter and more strongly noded than the Recent "*californiana*," and has more closely spaced ribs and more numerous stronger lirations on the inner lip.

"*Nassa*" *moraniana* and the Recent "*californiana*" are not represented in the collections from the Pleistocene strata of the San Pedro district. Despite records to the contrary, it is doubtful whether the Recent form occurs there. The new name "*Nassa*" *delosi* (pl. 35, figs. 12–15) is proposed for Arnold's figured "*californiana*" from the Palos Verdes sand. That form was found only in the Palos Verdes sand and is not known to be living. It has more numerous and stronger lirations on the inner lip than the Recent "*californiana*," stronger axials, and the axials are farther apart on the later whorls. It is perhaps to be regarded as a form of the Recent "*californiana*"; very young shells are indistinguishable. It is also similar to "*N.*" *cerritensis* but is more slender, and the axials are not so strong on the later whorls. Three specimens of "*N.*" *delosi* in the National Musuem collection of Recent California mollusks are labeled "*Nassa delosi* Oldroyd and Herold," evidently a manuscript name. It is appropriate to validate this name in honor of Delos Arnold, for many years an enthusiastic collector of San Pedro Pleistocene fossils.

"*Nassa*" *cerritensis* (pl. 35, figs. 16–19) is slender and has very strong axials that are far apart on the later whorls; it has a few lirations on the base of the inner lip. The type is from Los Cerritos, or Signal Hill, near Long Beach. Arnold correlated the strata at that locality with the Palos Verdes sand, a correlation that is justified. In the San Pedro district "*N.*" *cerritensis* was found only in the Palos Verdes sand by Arnold and also during the field work on which the present report is based. According to numerous specimens in the National Museum, a small race of "*N.*" *cerritensis* or a closely related species is living along the Lower California coast at Point Abreojos and Ballenas Bay and in the Gulf of California at Guaymas.

"*Nassa*" *perpinguis* is smaller than the Recent "*californiana*" and has more closely spaced axials and spirals. It is common in the Lomita marl and Timms Point silt, is abundant in the San Pedro sand and Palos Verdes sand, and is recorded from the second terrace.

"*Nassa*" *mendica* occurs in the three lower Pleistocene units and in the Palos Verdes sand and is recorded from the second terrace. It is most abundant in the San Pedro sand. The strength and spacing of the ribs is variable. Grant and Gale cited 1851 as the date of publication of this name. In that event it would be replaced by "*N.*" *woodwardi*, published in 1850. The signature of the part of volume three of the Proceedings of the Boston Society of Natural History containing the description of "*N.*" *mendica* is dated January, 1850. The date is, therefore, doubtless earlier than the date of publication of "*N.*" *woodwardi*. The characters of "*N*". *mendica indisputabilis* have apparently not been defined. Two fossils under that name from the San Pedro district, received from Mrs. Oldroyd, which were evidently from the San Pedro sand, are in the collection of the National Museum. They represent a large slender form of "*N.*" *mendica* that has closely spaced axials (length 24.5 millimeters, width 10.5 millimeters). Carpenter[34] thought that the species described as *Nassa interstriata* (or *intastriata*), based on Pleistocene material from San Pedro, was "*N.*" *mendica*. The type material is lost.

"*Nassa*" *mendica cooperi* is the most abundant "*Nassa*," the only one found in all the Pleistocene units and the only one collected from terrace deposits. It is particularly abundant in the San Pedro sand (pl. 34, fig. 12). It is characterized by heavy widely spaced axials but appears to intergrade with "*N.*" *mendica* proper. Its widespread occurrence in terrace deposits suggests that its depth range extends into shallower water than that of the other forms of "*Nassa*."

"*Nassa*" *versicolor hooveri* is not represented in the collections at hand. The type, which according to Arnold was placed in the National Museum, appears to be missing. This form is apparently not closely similar to "*N.*" *versicolor*, which has heavy ribs.

NEPTUNEIDAE

Neptunea tabulata, the only species of the genus in the Pleistocene strata, is common and widespread in the Timms Point silt (pl. 32, fig. 11) and is rare in the Lomita marl and San Pedro sand. An incomplete large specimen was collected from the Lomita marl at Hilltop quarry (locality 53a). The only other Lomita material consists of doubtful fragments from localities 54e and 71. The material from the San Pedro sand consists of a broken large specimen from Deadman Island and fragments from localities 58a and 65. None of the fossils have the strong axial frills bordering the sutural depression of many Recent shells, and none have a sutural depression so deep as on most Recent shells.

Exilioidea rectirostris, also the only species of the genus in the Pleistocene strata, occurs in the Timms Point silt (pl. 32, fig. 12) and is represented in the Palos Verdes sand by a worn broken specimen from Arnold's Crawfish George's locality (locality 108). Arnold recorded the same distribution for this species, with the exception that he found it also in the San Pedro sand at Deadman Island. The figured Timms Point specimen and others are more slender than Recent specimens of the same size; the strength of the spiral sculpture is variable. The type is a partly corroded shell from Puget Sound. The southernmost specimen in the collection of the National Museum is from a depth of 233 fathoms in the Santa Barbara Channel. Mr. George Willett, of the Los Angeles Museum, has in his collection a specimen that he dredged off Catalina at a depth of 80 fathoms.

Kelletia kelletii represents the monotypic genus *Kelletia*. It was found in the Lomita marl and is recorded from the Palos Verdes sand. It is relatively abundant in the algal bed at Hilltop quarry (locality 53a), and some of the specimens collected there are fully as large as the largest Recent shells. *Calicantharus*

[34] Carpenter, P. P., A supplementary report on the present state of our knowledge with regard to the Mollusca of the west coast of North America: British Assoc. Adv. Sci. Rept. 1863, p. 590, 1864.

fortis is widespread and locally abundant in the Lomita marl (pl. 29, figs. 28, 29), is represented in the San Pedro sand at Deadman Island by a partly broken and partly worn specimen—probably the shelter of a hermit crab—and is recorded from the Timms Point silt and Palos Verdes sand. The type material of *C. fortis*, apparently lost, was collected from Pleistocene strata near Santa Barbara. Specimens from the Palos Verdes Hills have a more rounded shoulder and a flat or less concave area between the shoulder and the suture than Pleistocene specimens from Rincon Point, a locality on the coast 12 miles southeast of Santa Barbara; also Palos Verdes Hills specimens are not as large as the largest from Rincon Point. As may be seen from figures 28 and 29 on plate 29, the degree of differentiation of primary and secondary spirals and the stage at which the axial ribs fade out are variable. This species is the type and last known survivor of the recently proposed *Calicantharus*.[35] The strong spirals, separated by deep narrow interspaces, are as characteristic as any feature of the genus and permit identification of fragments. The genus is closely related to *Siphonalia*, *Kelletia*, and the Recent Pacific coast genus currently called *Searlesia*, but the relationship with *Cantharus* is probably remote. *Calicantharus* is represented by several Pliocene species—*Siphonalia gilberti* from the upper part of the Pico formation of Los Angeles (closely related to the Rincon Point form of *Calicantharus fortis* and perhaps to be regarded as a strongly ribbed form of that species), presumably *Chrysodomus diegoensis* from the San Diego formation (the type and only specimen of which is no longer extant), *Thais kettlemanensis* [36] from the Etchegoin formation, *Fusus* (*Buccinofusus*) *portolaensis* from the Etchegoin, and *Neptunea humerosa* and variety *N. humerosa angulata* from the Pliocene strata at Elsmere Canyon. The genus is represented in the upper Miocene by *Chrysodomus pabloensis*. It is doubtful whether the Eocene species assigned to *Calicantharus* are congeneric with *Calicantharus fortis*. The Recent Mexican *Cantharus elegans* ("*insignis*") has been cited as a close relative of *Calicantharus fortis*. Inasmuch as it has a different type of sculpture, weaker and more widely spaced lirations on the interior of the outer lip, fewer and weaker lirations on the inner lip, and a wider siphonal fasciole, the relationship is considered remote.

Macron aethiops kellettii is rare in the San Pedro sand at localities 49 and 49a; Arnold found one specimen in the Palos Verdes sand. An incomplete specimen from the Lomita marl at Hilltop quarry (locality 53a) has strong spiral sculpture on the spire and, therefore, is assigned to *M. aethiops* proper, which has not been recorded from the San Pedro district. The smaller species *M. lividus* occurs in the Palos Verdes sand and in deposits on the sixth and fourth terraces.

MURICIDAE

Muricid gastropods are common in the Pleistocene strata with the exception of the Timms Point silt, in which they are rare and are represented only by the genus *Tritonalia*. According to Adanson's illustration of the type of *Jaton*, it lacks a tooth near the base of the outer lip. That name is used for "*Murex*" *festivus* and its allies, as was done by Grant and Gale. *Jaton festivus* occurs in the Palos Verdes sand, is represented by worn and broken specimens in deposits on the second terrace, and is recorded from the San Pedro sand

Jaton gemma, not previously reported from the San Pedro district, was found in the algal bed of the Lomita marl at Hilltop quarry (pl. 30, fig. 1) and is represented by poorly preserved shells from deposits on the fourth and third terraces. The figured specimen from the Lomita marl shows the characteristic brown spirals. Characters that differentiate the Pliocene *J. eldridgei* from *J. gemma* are not known; the absence of lamellae on the type of *J. eldridgei* is probably due to poor preservation. *J. santarosanus* has a longer canal than *J. gemma* and lacks brown spirals. Heretofore not recorded from the San Pedro district, *J. santarosanus* appears to be represented by an incomplete specimen from deposits on the second terrace at locality 105. Both *J. gemma* and *J. santarosanus* have been found in late Pleistocene strata near Playa del Rey.[37]

The genus *Pterorytis* [38] (emended to the etymologically more correct *Pterorhytis* by some writers), "*Purpura*" of current California literature, is similar to *Jaton* but has a spine near the base of the outer lip. *Pterorytis nuttalli* was found in deposits on the third terrace and in the Palos Verdes sand and is probably represented by a fragment from the Lomita marl.

Tritonalia is the most abundant of the muricids. *T. poulsoni*, the largest of the Pleistocene species, occurs in the Palos Verdes sand and is recorded from the San Pedro sand. *T. squamulifera* [39] (pl. 34, fig. 13) was found only in the San Pedro sand. As pointed out by Willett,[40] Arnold's figured "*Ocinebra*" *barbarensis*, also from the San Pedro, is *T. squamulifera*.

Tritonalia interfossa, which has a turreted spire, coarse reticulate sculpture, and somewhat lamellar axials, is the only species of the genus recognized in all the Pleistocene units. If *T. barbarensis* is represented in the collections, it has not been distinguished from small specimens of *T. interfossa* that have lamellar ribs and spines on the lamellae at the shoulder. *T. keepi*, the type of which is a well-preserved shell from the Palos Verdes sand, is evidently a large strongly lamellar variety of *T. interfossa*. It is represented in the San Pedro sand at locality 58 by an imperfect specimen, but it is not known to be living. Small nonlamellar shells from the San Pedro sand at other localities are identified as *Tritonalia* cf. *T. interfossa keepi*.

A species from the Lomita marl, the fourth and second terraces, and the Palos Verdes sand is identified as *Tritonalia foveolata*. Should that name prove to be unsuitable, *T. fusconotata* (type locality Monterey) is available. Arnold's *T. lurida aspera* is the form identified as *T. foveolata*. The northern *T. lurida* (+ *aspera*) is more slender and has more ribs. A form of *T. circumtexta* from the fifth, fourth, and second terraces is identified as *T. circumtexta aurantia*. The fossils are smaller and more slender than *T. circumtexta* proper, and some show the orange color of *T. circumtexta aurantia*. The fossils are identical with the variety *T. circumtexta citrica*, which appears to be a synonym of *T. circumtexta aurantia*. The type of Arnold's *Ocinebra lurida* var. *cerritensis*, from the Palos Verdes sand at Crawfish George's locality, is considered a worn *T. circumtexta* proper. Despite its

[35] Clark, B. L., Fauna from the Markley formation (upper Eocene) on Pleasant Creek, Calif.: Geol. Soc. America Bull., vol. 49, p. 712, 1938.

[36] Stewart, Ralph, in Woodring, W. P., Stewart, Ralph, and Richards, R. W., op. cit. (U. S. Geol. Survey Prof. Paper 195), p. 87, pl. 31, figs. 1, 7, 1940 [1941], ("*Siphonalia*").

[37] Willett, George, op. cit. (San Diego Soc. Nat. History, Trans., vol. 8, No. 30), p. 397, 1937.

[38] Conrad, T. A., Catalogue of the Miocene shells of the Atlantic slope: Acad. Nat. Sci. Philadelphia Proc., 1862, p. 560. Monotype, *Murex umbrifer* Conrad, Miocene. Virginia.

[39] Carpenter, P. P., in Gabb, W. M., Cretaceous and Tertiary fossils: California Geol. Survey, Paleontology, vol. 2, p. 44, 1869.

[40] Willett, George, Remarks on some west American mollusks: Nautilus, vol. 52, p. 10, 1938.

small size and weak ribs on the body whorl, *T. gracillima* has a heavily varicose outer lip. Two fragments from the twelfth terrace are doubtfully identified as that species. The weakly ribbed *T. lurida munda* was found in the three lower Pleistocene units and in the Palos Verdes sand at Arnold's Crawfish George's locality. Though *T. lurida* proper is recorded from the San Pedro district, it is doubtful whether it occurs there.

The new name *Tritonalia coryphaena* is proposed for a large, stout, round-shouldered species from the Lomita marl at Hilltop quarry (pl. 30, fig. 2), represented by two specimens. It is similar to "*Eupleura*" *grippi*, from a depth of 15 fathoms off San Diego, but has stronger axials and spirals.

The genus *Eupleura* is not represented in the collections at hand. Arnold proposed the varietal name *pleistocenensis* for a form of *Eupleura muriciformis* from the Palos Verdes sand. The status of his variety *E. muriciformis curta*, also from the Palos Verdes sand, is uncertain, as the type is incomplete and badly worn.

A species from the San Pedro sand is identified as *Trophonopsis lasia* (pl. 34, fig. 14). Though the fossils are small, relatively stout, and have few ribs, they appear to represent that variable species, which is generally known as "*Trophon tenuisculptus*."[41] Arnold found "*Trophon tenuisculptus*" in the Timms Point silt. The type of "*Trophon*" *cerritensis*, from the San Pedro sand, is probably a worn strongly sculptured form of *Trophonopsis lasia*.

Small species of the genus *Boreotrophon* are represented by numerous specimens in the Lomita marl and Timms Point silt, are less abundant in the San Pedro sand, and are rare in the Palos Verdes sand. *Boreotrophon pedroanus*, which is not known to be living, is found in the four units, the Palos Verdes specimens being from localities 108 and 121. It is a small slender species and has moderately strong spirals; some specimens have a subangular shoulder and others a rounded shoulder. According to Arnold, the type of *B. pedroanus*, from the San Pedro sand, was placed in the National Museum, but appears to be missing. It is evidently a representative of the round-shouldered form. The type of *B. praecursor*, from the Timms Point silt, is in the National Museum; it represents the subangular form. *B. pedroanus* is smaller and more slender than *B. orpheus;* relatively stout specimens are, however, similar to small specimens of *B. orpheus*.

A stouter species that has faint spiral sculpture, Arnold's "*Trophon*" *multicostatus* and "*T.*" *scalariformis*, is identified as *Boreotrophon* cf. *B. pacificus*. Smaller and more slender than the Alaskan *B. pacificus*, it is not known to be living. It was found in the Lomita marl and is recorded from the Timms Point silt, the San Pedro sand, and the Palos Verdes sand at Crawfish George's locality. A larger species that has a strongly turreted spire, Arnold's "*T.*" *gracilis*, is identified as *B.* aff. *B. multicostatus*. It was found in the Lomita marl, Timms Point silt, and Palos Verdes sand (localities 107 and 108) and is recorded from the San Pedro sand. It may be the same form as a small race of the Alaskan *B. multicostatus*, which ranges from Puget Sound to northern California but is not known to be living off the coast of southern California.

Boreotrophon aff. *B. stuarti*, characterized by strong spirals, is represented by an incomplete small specimen from the Lomita marl. Arnold figured a moderately large specimen from the Timms Point silt and recorded this form from the San Pedro sand. The fossils are smaller and more slender than the Alaskan *B. stuarti*, a small race of which is represented in the collection of the National Museum by specimens dredged off the coast of southern California at depths of 59 to 202 fathoms. A fifth species from the Timms Point silt is identified as *B.* cf. *B. raymondi*. It is stout—stouter than *B. avalonensis* (Catalina Island, 80 fathoms) and the very similar or identical *B. calliceratus* (Point Loma, 120–131 fathoms)—has a strongly concave area adjoining the suture, and has stronger spirals than *B. raymondi* from the upper Pliocene of Los Angeles. It is not known to be living.

[41] Willett, George, op. cit.

THAIDIDAE

Gastropods of the family Thaididae are not abundant, with the exception of *Acanthina* in the Palos Verdes sand. A nonlamellar form of *Nucella lamellosa* is represented by a worn, broken specimen from the Palos Verdes sand at Arnold's Crawfish George's locality and a doubtfully identified worn small specimen from the second terrace. *N. emarginata* is probably represented by small specimens from the fifth and second terraces and is recorded from the Palos Verdes sand as "*Purpura saxicola*". *N. biserialis* occurs in the Palos Verdes sand at locality 142, the northwesternmost locality at which fossils were found in that unit. Heretofore unrecorded from the San Pedro district, it has recently been found in late Pleistocene deposits near Playa del Rey.[42]

Acanthina lugubris (pl. 35, fig. 1), not previously found in the San Pedro district, occurs in deposits on the fourth and second terraces. The mottled brown color pattern is preserved on the fossils. *A. spirata* is rare in the San Pedro sand, is represented by a few small shells from terrace deposits, and is abundant in the Palos Verdes sand. The variety *A. spirata punctulata*, which has a round shoulder and a reticulate brown color pattern preserved on fossils, is represented by one specimen from the Palos Verdes sand at locality 111 and is recorded from the second terrace.

Forreria belcheri (pl. 35, fig. 20) was found only in the Palos Verdes sand by Arnold and also during the field work for this report. It is rare, however, as only one specimen is in the collections at hand.

CANCELLARIIDAE

Cancellarid gastropods are not abundant. "*Cancellaria*" *tritonidea*, a well-defined species that is not known to be living, occurs in the San Pedro sand and Palos Verdes sand (pl. 35, fig. 21) and may be represented by a worn fragment from the third terrace at locality 93. Poorly preserved specimens from the San Pedro sand at locality 50 are the largest collected. Arnold figured a large specimen from the Palos Verdes sand in his San Pedro memoir and in his report on the geology of the Coalinga district. An exceptionally large specimen in an old collection at the National Museum has a length of about 100 millimeters. This species was based on a loose worn shell from San Pedro that has inconspicuous shoulder nodes. Gabb thought, doubtless correctly, that it was a fossil. No closely related living species has been recognized, "*C.*" *cassidiformis*, which ranges from Lower California to Panama, being smaller and stouter and having a higher shoulder.

[42] Willett, George, op. cit. (San Diego Soc. Nat. History Trans., vol. 8, No. 30), p. 397, 1937.

Progabbia cooperi occurs in the Lomita marl and is recorded from the Palos Verdes sand. *Crawfordina crawfordiana,* found by Arnold in the Palos Verdes sand, is not in the collections at hand.

A small *Admete* that shows a considerable range of variation, from slender to moderately stout, occurs in the Lomita marl and Timms Point silt, is recorded from the San Pedro sand, and is represented in the Palos Verdes sand by a worn broken specimen from locality 112. It is presumably *A. gracilior*, which was based on Pleistocene material from Santa Barbara. No specimens from that locality are available. The San Pedro fossils are much smaller than the Alaskan *A. couthouyi* and have stronger spirals. They appear to be identical with the unfigured *A. rhyssa* (South Coronado Island, 55 to 155 fathoms) and to be closely related to the unfigured *A. woodworthi* (Monterey Bay, 10 to 45 fathoms); in fact, specimens from the San Pedro sand were reported by Oldroyd as *A. rhyssa.*

COLUMBELLIDAE

Mitrella carinata, M. carinata gausapata, and *M. tuberosa* are recognized in all the Pleistocene units. Their distribution is, however, uneven. *M. carinata* is the most widespread form and is the most abundant *Mitrella* in the San Pedro sand, terrace deposits, and Palos Verdes sand, but it is rare in the Timms Point silt. *M. carinata gausapata* is rare in every unit except the Timms Point silt (pl. 32, fig. 13). *M. tuberosa* is most abundant in the Lomita marl. *M. carinata gausapata* appears to intergrade with *M. carinata* proper, but it has a more northern range. Specimens of *M. tuberosa* from the San Pedro sand slightly larger than Recent shells were named *M. tuberosa "major"* by Oldroyd. Carpenter [43] thought that *"Nassa" pedroana,* based on Pleistocene material from San Pedro, may be the same as *M. carinata gausapata.* The type is lost.

An *Amphissa* that occurs in all the units is identified as *A. versicolor.* A large stout species, larger and stouter than *A. reticulata,* was found only in the Palos Verdes sand at Arnold's Crawfish George's locality and is identified as *A. columbiana.* It is recorded from other Palos Verdes localities as well as from the Timms Point silt and San Pedro sand. A species from the San Pedro sand described by Arnold as *A. ventricosa* is considered to be *A. undata,* though the type is somewhat stouter than most Recent *A. undata.* It is not represented in the collections at hand.

Anachis pencillata, which is recorded from the San Pedro sand, was found in deposits on the fourth terrace at locality 86. *A. arnoldi* (*"minima"*), from the Palos Verdes sand, is considered a synonym of *A. pencillata.* The type of *A. arnoldi* is, however, rather large and stout.

Aesopus chrysalloides occurs in the San Pedro sand, in deposits on the fourth terrace at locality 86, and in the Palos Verdes sand. *A. idae,* the type and only specimen of which is from the San Pedro sand, is large and thick-shelled and appears to lack spiral sculpture above the lower part of the body whorl. It is not known to be living.

The type of the columbellid that Arnold described as *Columbella solidula* var. *praecursor* is apparently no longer in the National Museum. *"Columbella" solidula* is considered a *Strombina.* It is not known whether the fossil from the Palos Verdes sand is related to it.

[43] Carpenter, P. P., op. cit. (British Assoc. Adv. Sci. Rpt. 1863), p. 590, 1864.

OLIVIDAE

Olivella biplicata is abundant, at least locally, in all the units. Specimens from the Lomita marl are larger than others; those from the Timms Point silt are worn or worn and broken.

A small, moderately slender species that has a moderately thick and definitely limited parietal callus is identified as *O. pedroana.* There has been much confusion concerning this name, as the type is lost and the original description and figure are poor. It was based on material from the so-called post-Pliocene or Recent formation near the mouth of the Los Angeles River [44] before the lower course of the river was changed, that is, from the Palos Verdes sand. A specimen selected from a lot of 22 collected at locality 113 (Arnold's lumber yard locality) is designated the neotype (pl. 35, fig. 22). It agrees reasonably well with Conrad's description and figure. *O. pedroana* occurs in the San Pedro sand but is more abundant in the Palos Verdes sand. The recently described *O. pycna*[45] (type locality, Bolinas Bay) is probably a form of *O. pedroana.* It is stouter than *O. pedroana* and has a thicker parietal callus. Recent shells in the National Museum, representing *O. pycna* from localities between Bolinas Bay and San Quentin Bay, are arranged under *O. intorta.* The type locality of that species is San Juan, presumably San Juan del Sur, Nicaragua, and the description indicates that it is quite different from *O. pycna.* A slender *Olivella* that has a thin or moderately thick parietal callus occurs in all the units. It is the species identified as *O. baetica.*

MARGINELLIDAE

Hyalina californica occurs in the Lomita marl, the terrace deposits, and the Palos Verdes sand and is recorded from the San Pedro sand. *H. jewettii* was found in the San Pedro sand and is recorded from the second terrace and the Palos Verdes sand. Specimens from the San Pedro sand that have minor supplementary columellar folds were given the varietal name *H. jewettii nanella* by Oldroyd. A smaller and more slender form that occurs in the Lomita marl, the terrace deposits, and the Palos Verdes sand is probably *H. regularis.*

The minute *Cypraeolina pyriformis* is the most widespread and locally the most abundant marginellid, having been found in all the units.

TURRIDAE

Gastropods of the family Turridae, represented by numerous genera and species but by relatively few specimens, have not been identified. Forty-six species and varieties are recorded from the Pleistocene strata of the San Pedro district. Nine of these, or 3, depending on the acceptance of questionable synonyms, are not reported to be living. Turrids are most abundant in the Lomita marl and Timms Point silt. The genus *Propebela* (*"Bela"* or *"Lora"*) is rare except in those units. In the collections at hand *Borsonella* is represented only in those units, but it is recorded from the San Pedro sand. *"Taranis"* likewise is represented only in the Lomita marl and Timms Point silt in the collections at hand, but it is recorded from the San Pedro

[44] Blake, W. P., Geological report [Williamson's reconnaissance in California]: U. S. Pacific R. R. Expl., 33d Cong. 2d sess., 5 Ex. Doc. 78 and H. Ex. Doc. 91, vol. 5, pt. 2, p. 186, 1857.

[45] Berry, S. S., An undescribed Californian *Olivella:* Malacol. Soc. Proc., vol. 21, pp. 262–265, 1 fig., 1935.

sand and from the Palos Verdes sand at Arnold's Crawfish George's locality.

TEREBRIDAE

Terebra pedroana has a restricted stratigraphic and geographic distribution. It was not found in the Lomita marl or Timms Point silt, occurs in the San Pedro sand only at localities 49 and 49a, is represented in terrace deposits at locality 86 and by a fragment from locality 105, and is widespread and abundant in the Palos Verdes sand at locality 112 and farther north. Virtually all the specimens have the strong sutural band of the variety *T. pedroana* "*philippiana.*"

CONIDAE

Conus californicus, the only species of the genus living on the California coast, occurs in all the units. Timms Point specimens are, however, rare and are worn and broken. The largest specimens were found in the Lomita marl and San Pedro sand. Oldroyd proposed the varietal name *C. californicus fossilis* for large shells from the San Pedro sand. The largest fossils are not quite as large as the largest Recent shell in the National Museum collection (length 42 millimeters).

TECTIBRANCHIATES

Only one of the tectibranchiate gastropods collected has been identified. *Acteon breviculus* (pl. 30, fig. 4; type locality, off Santa Rosa Island, 53 fathoms), heretofore unreported as a fossil, was found in the Lomita marl at localities 54c and 54g. This species belongs to a group of small moderately deep-water forms for which the name *Microglyphis*[46] was proposed. This group should doubtless be given generic rank. The recently described but unfigured *A. schencki*,[47] from marl of the Lomita overlying the algal bed at Hilltop quarry, is presumably the species identified in this report as *A. breviculus*.

Sixteen other species and varieties of tectibranchs are recorded as Pleistocene fossils from the San Pedro district. One of these, *Acteocina tumida*, from the San Pedro sand is not reported living, but the specimen on which it was based is probably a monstrosity.

PULMONATES

Melampus olivaceus, which lives on tidal flats, was found in the San Pedro sand at locality 49 and occurs in the Palos Verdes sand at locality 112 and other localities farther north and northwest.

The high form of *Williamia peltoides*, heretofore unrecorded from the San Pedro district, is represented by an incomplete specimen from the Lomita marl at locality 54g.

The pulmonate limpet *Gadinia reticulata*, recorded from the second terrace and the Palos Verdes sand,[48] is widespread in terrace deposits.

Fresh-water pulmonates of the genera *Helisoma*, *Gyraulus*, and *Physa* are represented by a few specimens from the Palos Verdes sand at Arnold's lumber yard locality (locality 113) and other localities farther north and northwest. They are recorded also from the San Pedro sand.[49]

PELECYPODS

NUCULIDAE

A sculptured *Nucula* designated by Arnold *N. suprastriata* was found in deposits on the second terrace at Malaga Cove (locality 105), is abundant and widespread in the Palos Verdes sand, and is recorded from the San Pedro sand. The fossils appear to be identical with Recent shells from San Francisco, San Pedro Bay, and Catalina Island arranged under *N. exigua* in the National Museum collection. Schenck[50] considered them to be larger and to have less pronounced radial sculpture than Recent shells from the Pacific coast of North America identified as *N. exigua*, the type locality of which, "Bay of Caracas," is equivocal. A form from Lower California localities is smaller than the fossils and has generally stronger radial sculpture. Should that form prove to be *N. exigua* it appears preferable to cite the fossils and the Recent California form as *N. exigua suprastriata*. Arnold attributed the name *suprastriata* to Carpenter. A slightly inperfect right valve and a fragment of a left valve dredged at a depth of 30 fathoms at Catalina Island (U. S. Nat. Mus. 23247) are labeled as types of Carpenter's *suprastriata*. As pointed out by Grant and Gale, Carpenter evidently never published the name, which is to be attributed to Arnold. His figured specimen from Los Cerritos, or Signal Hill, appears to be lost,[51] and a neotype should be selected from that locality.

A small elongate smooth species, *Nucula* aff. *N. cardara*, from the San Pedro sand at localities 30 and 48 is probably a small form of *N. cardara* (type locality, off San Diego, 1,090 fathoms), the type of which has been figured recently.[52] A minute smooth *Nucula* from the Lomita marl at locality 42d and the San Pedro sand at locality 65 and a shorter form from the Timms Point silt at locality 32a are evidently new species. No smooth *Nucula* has been recorded heretofore from the San Pedro district.

Acila castrensis, the only species of the genus living on the California coast, is abundant locally in the Lomita marl, abundant in the Timms Point silt, occurs in the San Pedro sand at localities 30, 48, and 64, and is represented by a doubtfully identified fragment at each of two Palos Verdes localities, 111 and 121. A specimen from the Timms Point silt has been illustrated recently.[53]

NUCULANIDAE

Cyrilla munita, not previously found in the San Pedro district, occurs in the Lomita marl at localities 54g, 57a, 67, and 71 and in the Timms Point silt at locality 32a. The type material, consisting of three valves dredged at a depth of 30 fathoms off Catalina Island, is in the National Museum (23243). "*Nucula*" *petriola*, from 53 fathoms off Santa Rosa Island, is a synonym.[54]

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[46] Dall, W. H., Illustrations of new, unfigured, or imperfectly known shells, chiefly American, in the U. S. National Museum: U. S. Nat. Mus. Proc., vol. 24, p. 512, 1902. Type, *Acteon curtulus* Dall, Recent, Magellan Strait.

[47] Berry, S. S., New Mollusca from the Pleistocene of San Pedro, Calif., II: Bull. Am. Paleontology, vol. 27, No. 101, p. 3, 1941.

[48] Chace, E. P., and E. M., An unreported exposure of the San Pedro Pleistocene: Lorquinia, vol. 2, No. 6, p. 42, 1919. Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 197, 1903.

[49] Arnold, Ralph, op. cit., pp. 195, 196.

[50] Schenck, H. G., Revised nomenclature for some nuculid pelecypods: Jour Paleontology, vol. 13, pp. 36-37, 1939.

[51] Schenck, H. G., op. cit., p. 36.

[52] Schenck, H. G., op. cit., p. 34, pl. 5, figs. 12, 14, 18, 21.

[53] Schenck, H. G., Nuculid bivalves of the genus *Acila*: Geol. Soc. America Special Paper 4, pl. 10, figs. 5, 7, 1936.

[54] Schenck, H. G., op. cit. (Jour. Paleontology, vol. 13), p. 39, pl. 6, figs. 14, 15.

ANOMIIDAE

The Recent California species identified as *Anomia peruviana* occurs locally in the San Pedro sand north and northwest of San Pedro at localities 49a, 56, 58a, and 59, being abundant at localities 58a and 59. In the Palos Verdes sand it was found at locality 112 and at almost every locality farther north and northwest, being particularly abundant at localities 125, 131, and 132 on the south limb of the Gaffey anticline.

Monia macroschisma, the only other anomid in the collections, is represented in all the units except the terrace deposits.

ARCIDAE

Arca sisquocensis, based on material from the upper Pliocene of the Santa Maria Basin, is recorded from the Lomita marl at Hilltop quarry [55] but is not represented in the collections at hand.

Anadara perlabiata (pl. 35, figs. 23, 24), the only arcid in the collections at hand, was found in the Palos Verdes sand during the field work for this report and also by Arnold. It is rare, however, as it is represented by only a small left valve and an umbonal fragment of another small left valve, both from locality 124. This species is assigned to the subgenus *Cunearca*, *Anadara* proper being unknown in the latitude of San Pedro after the upper Pliocene. The name *A. perlabiata* was proposed by Grant and Gale for the more familiar "*Arca labiata*," which is preoccupied by usage in the Portland Catalogue. The names in that publication accompanied by a citation to an illustration are now generally considered valid.

GLYCYMERIDAE

Glycymeris profunda (pl. 30, figs. 5–8) is widespread in the Lomita marl, being abundant in the algal bed at Hilltop quarry, and is represented in the San Pedro sand by a fragment from locality 47 and by numerous specimens in Oldroyd's Nob Hill collection at the National Museum (his *G. septentrionalis*). It is characterized by strong inflation, pronounced height, narrow full umbo, and markedly asymmetric ligament area. Some specimens (pl. 30, figs. 5, 6) have a more pronounced posterior truncation than others (pl. 30, figs. 7, 8). Well-preserved specimens, such as that shown on plate 30, figures 7, 8, have microscopic radial striae, slightly worn specimens are smooth, and those that are more worn or corroded are ribbed, the usual condition. A specimen in the Nob Hill collection shows a faint pattern of irregular zigzag brown color bands. When this report was first prepared *G. profunda* was thought to be extinct, but it has been found at depths of 25 fathoms off Redondo and 200 fathoms off Catalina Island.[56] Described by Dall [57] in 1879 on the basis of three corroded valves from San Diego (U. S. Nat. Mus. 7935), it has not appeared in lists of California Pleistocene mollusks since then, is omitted in the Grant and Gale catalog,[58] and was not illustrated until the appearance of Willett's recent paper. Two of the specimens in the type lot, the more perfect (lectotype) of which has a length of 30.3 millimeters and a height of 32.2 millimeters, are larger than any from the Lomita marl but are scarcely larger than the largest from the San Pedro sand. The type material was collected evidently from the Pleistocene strata overlying the Pliocene San Diego formation at Pacific Beach.[59] The species is presumably rare in the type region, for it is not represented in numerous collections of Pleistocene fossils from Pacific Beach and other localities in and near San Diego. The high full umbo of Arnold's figure of *G. "barbarensis"* from the Palos Verdes sand suggests *G. profunda*, but the relative height is not great enough for the typical form. The specimen of *G. barbarensis* figured in volume 7 of the Pacific Railroad Reports is in the National Museum (13358). It is imperfect and poorly preserved in a matrix of hard sandy limestone and is probably a small specimen of the species Gabb later described as *G. veatchii*. It therefore is probably Paleocene (Eocene of Dall's nomenclature), as Dall thought, or Upper Cretaceous. A label glued to the rock reads "*Glossus* (*Pectunculus*) *collinus* Con., shore between San Luis and Santa Barbara." Antisell, however, recorded it from the Simi Hills. The figured *G. barbarensis* of volume 6 of the Pacific Railroad Reports is not known to be exant. It was listed from Santa Barbara, is presumably not conspecific with the *G. barbarensis* of volume 7, as Dall thought, and is presumably from the Pleistocene Santa Barbara formation. It has the relative dimensions of the Recent *G. subobsoleta*. The geologic reports, including the paleontology, of both volumes bear the date 1856. Volume 6 was transmitted for publication, however, May 6, 1857, and volume 7 February 9, 1857. Both were issued probably sometime during 1857. Until evidence establishing priority is found the *G. barbarensis* of volume 6 is herewith arbitrarily given precedence. This action may dispose of the troublesome name, as the *G. barbarensis* of volume 6 is a probable synonym of *G. subobsoleta*, and the *G. barbarensis* of volume 7 is automatically a homonym.

A smaller, less inflated, and more elongate *Glycymeris*, Arnold's *G. septentrionalis*, is identified as *G. corteziana* (type locality, Cortez Bank, 67 fathoms). It occurs locally in the San Pedro sand at localities 49, 49a?, and 56?, and in deposits on the second terrace at locality 105 and is widespread but uncommon in the Palos Verdes sand. *G. corteziana* is doubtless a small race of *G. subobsoleta*, ranging farther south (Forrester Island, Alaska to Magdalena Bay, Lower California) than *G. subobsoleta* proper (Alaska to Oregon). In the collection of the National Museum *G. corteziana* is represented by specimens from depths of 8 to 90 fathoms. *G. migueliana* (type locality, San Miguel Island, 53 fathoms) is considered a synonym.

PHILOBRYIDAE

Philobrya setosa, heretofore recorded only from the San Pedro sand, occurs in the Lomita marl at Hilltop quarry (localities 53, and 53b), in the San Pedro sand at locality 30, and in deposits on the sixth terrace at locality 78. In each collection it is represented by one valve.

MYTILIDAE

Small broken valves of *Mytilus californianus* were collected on the fourth terrace at localities 83 and 85 and on the second terrace at locality 95. This species is, however, not as common in terrace deposits as might

[55] Reinhart, P. W., Three new species of the pelecypod family Arcidae from the Pliocene of California: Jour. Paleontology, vol. 11, p. 183, 1937.
[56] Willett, George, Northwest American species of *Glycimeris:* Southern California Acad. Sci. Bull., vol. 42, pt. 3, pp. 111–113, pl. 11, figs. 3, 3a, 1943 [1944].
[57] Dall, W. H., Fossil mollusks from later Tertiaries of California: U. S. Nat. Mus. Proc., vol. 1, p. 13, 1879.
[58] Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, 1931.
[59] Dall, W. H., Distribution of California Tertiary fossils: Op. cit., p. 29.

be expected from its present abundance along rocky coasts in southern California. It was not found in the other Pleistocene units but is recorded from the San Pedro sand.

A small *Botulina*[60] ["*Gregariella*"] is represented by numerous specimens from the second terrace at locality 105. They are identical with a form, dredged at depths of 10 to 50 fathoms along the coast of southern California, labeled *Modiolus opifex* in the National Museum collection. That species was based on material from the Island of Minorca, and it is doubtful whether the California species is conspecific. The genus has not been recorded heretofore from the California Pleistocene.

Septifer bifurcatus is one of the few widespread locally abundant pelecypods in terrace deposits. It is not represented in collections from other units but is recorded from the San Pedro sand.

PECTINIDAE

Pecten stearnsii occurs in the Lomita marl (pl. 30, figs. 9, 10) and in the Timms Point silt (pl. 32, figs. 14, 15) and is probably represented in the San Pedro sand by small left valves from localities 58 and 64. Most of the valves from the Lomita marl and Timms Point silt are broken. This species was based on material from upper Pliocene strata in the San Diego formation at Pacific Beach, near San Diego. It is closely related to *P. diegensis* from moderate depths (14 to 60 fathoms) off the coast of southern California. The fossils reach a slightly larger size than Recent shells and have a few more ribs. On the interior of right (inflated) valves of *P. diegensis* the projections corresponding to the exterior interspaces are bordered near the margin of the valve by a narrow flange, as on the interior of left (flat) valves. Left valves of *P. stearnsii* have the interior flange, but on right valves the flange is absent or is weakly developed only near the anterior and posterior ends of the valve. Whether the Recent form is to be assigned specific or varietal rank is a matter of individual preference. If it is assigned varietal rank, it is to be cited as *P. stearnsii diegensis*, as was done by Grant and Gale, for *stearnsii* has priority. *P. stearnsii* survived from the Pliocene into the Pleistocene and then appears to have become extinct. These two forms are more similar to *Pecten* proper than any other California Pleistocene and Recent species. The right valve, however, is not so inflated as in *Pecten* proper, the ribs are more angular, and secondary ribs are absent on the main part of the shell and on the ears.

Three imperfect valves and a fragment of *Pecten vogdesi* (pl. 35, figs. 2–4) were collected from deposits on the second terrace at Malaga Cove (locality 105). The type of this species is from the Palos Verdes sand, but it is rare in that unit, as Arnold had only one valve, and none was found during the field work for this report. It has been recorded recently from Pleistocene strata near Playa del Rey.[61] *P. vogdesi* is closely related to *P. cataractes* from the Gulf of California and may be indistinguishable from the Recent form. According to Arnold, the left valve of *P. vogdesi* has no secondary riblet in the interspaces or has faint riblets. The incomplete left valve shown on plate 35, figure 3, has one strong riblet and several faint riblets. On some Recent shells riblets are faint or absent in some or most of the interspaces. *P. coalingaensis*,[62] a close relative from the upper Pliocene San Joaquin formation of the San Joaquin Valley, lacks secondary riblets on the left valve. These fossil and Recent pectens do not represent *Pecten* proper. They are to be assigned to the subgenus *Euvola*, the type of which has weaker ribs on the right valve and strong secondary ribs on the left valve, or to a minor group under *Euvola*.

Aequipecten circularis is widespread and abundant in the Palos Verdes sand at locality 112 and localities farther north and northwest and is represented by a doubtfully identified fragment from the Lomita marl at locality 61. Whether the California Pleistocene and Recent form is to be distinguished from *A. circularis* proper (type locality, Gulf of California) as the variety *A. circularis aequisulcatus* appears to be doubtful. The type of "*Pecten*" *newsomi*, from Pleistocene strata at Los Cerritos, or Signal Hill, is a young left valve of this species. "*P.*" *compactus* and "*P.*" *subventricosus*, both from a locality near Ventura and doubtless of Pleistocene age, are additional synonyms. *A. circularis* is the type of the subgenus *Plagioctenium*, which has a more inflated right valve than *Aequipecten* proper and lacks secondary radial riblets. In coastal California *Plagioctenium* is unknown before the Pliocene. In tropical America, however, it is widespread in the Miocene. It occurs in the Imperial formation of the Colorado Desert, of disputed Miocene or Pliocene age.

Chlamys hastatus is abundant in the Lomita marl and Timms Point silt, occurs in the San Pedro sand at localities 64 and 65, and is recorded by Arnold from the Palos Verdes sand at his Crawfish George's locality. Both fossil and Recent shells show perfect gradation between *C. hastatus* proper, characterized by well-differentiated primary ribs that bear well-developed scaly lamellae, and *C. hericius*, which lacks those characters.

Chlamys islandicus jordani occurs in the Lomita marl, is abundant in the Timms Point silt (pl. 32, fig. 16), and is represented in the San Pedro sand at locality 47. Based on material from the Timms Point silt, it is considered a form of *C. islandicus*, of small or medium size, that has split primary ribs, especially on the right valve. It differs from *C. islandicus hindsii* principally in the absence of scaly lamellae on the ribs. As in other forms of the *C. islandicus* group and in other species of *Chlamys*, part or all of the shell has microscopic punctation. The specimen shown on plate 32, figure 16, is exceptionally large. *C. islandicus jordani* is living in Puget Sound but is not known to be living farther south.

A small form of the *Chlamys islandicus* group that has numerous narrow scaly ribs is identified as *C. islandicus hindsii* (+*navarchus*). It occurs in the San Pedro sand at locality 48 and is represented in the Palos Verdes sand by a worn valve from locality 111 and a young valve from locality 113. *C. islandicus hindsii* is somewhat intermediate between *C. islandicus* proper and *C. hastatus*.

Chlamys opuntia is represented by fragments from the Lomita marl at localities 53 and 54g. Based on material from the upper Pliocene part of the San Diego formation at Pacific Beach, it is characterized by very numerous scaly ribs of almost uniform width formed by splitting and intercalation. It is related doubtless to *C. islandicus* and might be considered another form of the *C. islandicus* group. Like *Pecten stearnsii*, *C.*

[60] Dall, W. H., A preliminary catalogue of the shell-bearing marine mollusks and brachiopods of the southeastern coast of the United States: U. S. Nat. Mus. Bull. 37, p. 38, 1889. Monotype, "*Modiola opifex* Say," Recent, Cape Hatteras to Cuba (?=*Chama coralliophaga* Gmelin).

[61] Willett, George, op. cit. (San Diego Soc. Nat. History Trans., vol. 8, No. 30), p. 387, 1937.

[62] Stewart, Ralph, in Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, Calif.: U. S. Geol. Survey Prof. Paper 195, p. 90, pl. 13, figs. 1, 2, 17, 18; pl. 16, fig. 4, 1940 [1941].

opuntia survived from the Pliocene into the Pleistocene and since then appears to have become extinct.

The new name *Chlamys anapleus* (pl. 34, fig. 15) is proposed for a small *Chlamys* represented by a valve from the Lomita marl at locality 53 and another from the San Pedro sand at locality 30. It has 10 or 11 wide primary ribs, a weak secondary riblet in most of the interspaces, and is sculptured with microscopic punctation. The ventral margin of the type is bent, perhaps to form at a later stage a swelling, as in *C. parmeleei*. On the imperfect Lomita specimen some of the ribs are grooved. This *Chlamys* also might be considered a form of the *C. islandicus* group at the opposite extreme from *C. opuntia* in width of ribs. It was identified by Arnold as *Pecten* (*Chlamys*) *hericeus* var. *strategus*. "*P.*" *strategus*, from Alaska, is considered a synonym of *C. islandicus beringianus*, a wide-ribbed Alaskan variety of *C. islandicus*. The ribs of *C. anapleus* do not enlarge so rapidly as in *C. islandicus beringianus*, and secondary ribs are weak or absent. The Pliocene *C. parmeleei* and its close Pliocene relative *C. etchegoini* have only half as many primary ribs. *C. anapleus* is not known to be living.

Patinopecten caurinus is one of the widespread and characteristic species of the Timms Point silt (pl. 32, fig. 17, pl. 33, fig. 1). It occurs, however, in the Lomita marl at localities 62b (doubtfully identified fragments) and 67 (small imperfect valve) and in the San Pedro sand at locality 30 at Deadman Island (small valves). Though Arnold[63] did not mention material from the Palos Verdes sand in the systematic part of his memoir, he listed *P. caurinus* from his Crawfish George's locality. In his consolidated list on page 37 it is recorded from his lumber yard locality but is not included in the faunal list from that locality on page 27. All the large specimens collected during the field work on which this report is based are broken, the large specimen shown on plate 32, figure 17, being selected from an old collection from the Timms Point silt at Deadman Island. None of the fossils are a large as large Recent shells from Alaska and Puget Sound. Young well-preserved valves show traces of camptonectes sculpture on the smooth umbonal part. At the present time this species ranges from Cordova, Alaska, to Point Reyes, central California.[64]

Leptopecten latiauratus, including the variety *L. latiauratus monotimeris*, is locally abundant in the San Pedro sand, is represented by numerous specimens from the second terrace at locality 105 and by fragments from the fourth terrace at locality 86, and is widespread and abundant in the Palos Verdes sand. A small imperfect valve from the Lomita marl at locality 73 and another from the Timms Point silt that has narrow-crested ribs represent probably this species. The variety *L. latiauratus cerritensis* ("*fragilis*"), based on material from the Palos Verdes sand, has fewer and wider ribs than *L. latiauritus* proper. The variety *L. latiauratus delosi*, based on material from the San Pedro sand, has strong concentric lamellae. Neither form is in the collections at hand.

A new species of *Pseudamussium* is represented by imperfect and young valves from the Lomita marl at localities 54c, 54e, and 62b and probably by worn valves from the Timms Point silt at locality 32d. It is larger than *P. bistriatus* (type locality, off San Diego, 822 fathoms), and has weaker concentric sculpture. These two species do not represent *Pseudamussium* proper, which has a thicker shell and coarse radial sculpture on the ears. The genus has not been recorded heretofore from the California Pleistocene.

The genus *Hyalopecten*, also heretofore unrecorded from the California Pleistocene, is represented by a small species identified as *H. vancouverensis*. Imperfect valves and fragments were found in the Lomita marl at localities 54e, 54g (identification doubtful), and 62b and well-preserved valves in the Timms Point silt at localities 32c (pl. 33, fig. 2), 32d, and 44 (pl. 33 fig. 3). This species represents the subgenus *Delectopecten*. As in other fossil and Recent species from California, the strength of the radial sculpture is variable.[65]

A weakly sculptured form of *Propeamussium alaskensis* occurs in the Lomita marl at Lomita quarry (locality 62b). The *Propeamussium* from the San Pedro sand at Deadman Island recorded by Arnold as *Pecten* (*Propeamussium*) *riversi* is doubtless *P. alaskensis*, as Grant and Gale thought, but specimens have not been examined.

OSTREIDAE

A falcate plicate oyster represented by a right valve from the Lomita marl at locality 61 is identified as *Ostrea megodon cerrosensis* (pl. 30, fig. 11). It is relatively wide and has broad shallow plications. According to Sowerby's illustrations,[66] *O. megodon* proper (type locality, Peru) is larger and has narrower and deeper plications. A small shell from Peru, the only one available, has such plications, and large shells from Lower California are similar to Sowerby's figures. The Lomita marl specimen has plications like those of *O. megodon cerrosensis* from the Pliocene of Cedros Island, Lower California, but the shell is wider. No *megodon*-like oyster is living along the Pacific coast north of Scammon's Lagoon, Lower California, and this is the first record from the California Pleistocene. This oyster is probably not so rare as the collections at hand indicate, for the weighmaster at Sidebotham sand and gravel pit near Lomita quarry has several specimens.

Ostrea lurida, the Recent California species, occurs in the San Pedro sand, being locally abundant, and was found at almost all Palos Verdes localities. A minute shell from the Timms Point silt at locality 66, another from the third terrace at locality 92, and numerous small shells from the second terrace at locality 105 are presumably that species.

CRASSATELLIDAE

Eucrassatella fluctuata (pl. 31, figs. 1–8) is characteristic of the Lomita marl, occurring at localities 53, 53a, 54g, and 69 and being most abundant in the algal bed at Hilltop quarry. It is represented, however, in the Timms Point silt by a small thin broken left valve from locality 33 and probably in the San Pedro sand by a fragment of a small left valve from locality 64 that has more closely spaced concentric lamellae than other specimens. The type of *E. fluctuata* is a small right valve from Catalina Island (length 8.2 millimeters). There are no large Recent shells in the National Museum

[63] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, pp. 25, 37, 1905.
[64] Hertlein, L. G., Addition to the range of *Pecten caurinus* Gould: Nautilus, vol. 54, pp. 68–69, 1940.
[65] Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif.: U. S. Geol. Survey Prof. Paper 190, pp. 35–42, 1938.
[66] Sowerby, G. B., Conchologia Iconica, *Ostrea*, Pl. 12, figs. 24a, 24b, 1871

collection. "*Crassatellites*" *lomitensis*, based on a large valve from the Lomita marl, is a synonym.

Crassinella branneri (pl. 36, figs. 1–6) is one of the most abundant of the southern species characteristic of the Palos Verdes sand. It was found at 16 localities between localities 112 and 135, inclusive, and is locally abundant. It occurs also in deposits on the fourth terrace at locality 86. As shown by the illustrations, strong concentric undulations are confined to the umbonal part of the shell or cover the entire shell. Faint microscopic radial striae are visible on unworn specimens. The type material is from the late Pleistocene strata at Los Cerritos, or Signal Hill, correlated by Arnold with the Palos Verdes sand. The Recent Pacific coast Crassinellas in the National Museum are not satisfactorily determined. *C. branneri* is represented by a typical large bleached valve dredged off Coronado, San Diego, by two worn valves of medium size and a small fresh paired shell from a depth of 7 fathoms in San Diego Bay, and by a small race or a closely related species from Scammon's Lagoon, Lower California. Whether the typical large shell from San Diego is a Recent shell or a detrital Pleistocene fossil may be determined by future dredging. The small fresh paired shell indicates that *C. branneri* or a closely related species is living at San Diego.

Crassinella nuculiformis [67] (pl. 36, figs. 7–10) is smaller and more elongate than *C. branneri*. It is the "*Gouldia* aff. *varians*" of the preliminary paper [68] on the terraces. This species has concentric undulations on the umbonal area only, or on a larger part of but not the entire shell of adults. Very faint microscopic radial striae are visible on unworn specimens. *C. nuculiformis* is closely related to a form in the National Museum collection labeled *C. varians*, from Cape St. Lucas and La Paz, at the south end of Lower California, but it is larger, less elongate, and has a wider lunular area. This Recent form is evidently not *C. varians*,[69] which was based on material from Mazatlan on the Pacific coast of Mexico. The only available specimens from Mazatlan are 3 minute trigonal valves glued to a card by their exterior surfaces. Photographic reproductions of Carpenter's drawings in the files of the National Museum also show the interior of 2 small trigonal shells. *C. nuculiformis* is abundant in the Palos Verdes sand, having been found at 12 localities between localities 114 to 135, inclusive, but is less abundant than *C. branneri*. It occurs also in deposits on the second terrace at locality 105, where it is represented by numerous specimens slightly smaller than those from the Palos Verdes sand. The *C.* "*varians*" recently recorded from late Pleistocene strata near Playa del Rey [70] is this species.

A *Crassinella* has been reported recently from Coos Bay, Oreg.[71] Discovery of breeding specimens is desirable to confirm this remarkable 1,000-mile northward extension of the range of the genus on the Pacific coast.

CARDITIDAE

Glans subquadrata is one of the few widespread and abundant pelecypods in terrace deposits. It is present, but uncommon, in the Lomita marl, San Pedro sand, and Palos Verdes sand. The only Palos Verdes material consists of one valve from each of two localities, 107 and 108. If this species is not assigned to *Cardita*, the substitute names *Cardita carpenteri* [72] and *C. minuscula* are unnecessary, for it is improbable that either Conrad's or Gabb's *Cardita subquadrata* is to be assigned to *Glans*. The type material is from Neah Bay, Wash.

Miodontiscus prolongatus occurs in the three lower Pleistocene units but is common only in the algal bed at Hilltop quarry. "*Venericardia*" *yatesi*, from the Pleistocene Santa Barbara formation, is a synonym. Though the range of *M. prolongatus* is cited as Alaska to San Diego, it is not known to be living as far south as San Pedro. The southernmost locality represented in the collection of the National Museum is off the Oregon coast, depth 50 fathoms. The type material of this species also is from Neah Bay, Wash.

Two groups of *Cyclocardia* are recognized in the Pleistocene strata, one group embracing strongly ribbed forms, the other embracing a weakly ribbed species. The strongly ribbed forms are identified as *Cyclocardia* aff. *C. occidentalis*, the weakly ribbed species as *C. barbarensis*.

The strongly ribbed forms are abundant in the Lomita marl and Timms Point silt, uncommon in the San Pedro sand, and rare in the Palos Verdes sand. Most San Pedro and Palos Verdes specimens are worn, with the exception of those from localities 64 and 65 and one of four specimens from locality 108. At least two forms appear to be represented among the strongly ribbed Cyclocardias, but their relations are uncertain. The common form, which is moderately or strongly inflated, has narrow grooves between the ribs and closely spaced nodes that are weak except on the umbonal part of the shell (pl. 31, figs. 9, 10). The largest specimens are from the algal bed at Hilltop quarry and are only moderately inflated (pl. 31, fig. 9). A less abundant form, found in the Lomita and Timms Point, generally in association with the form just described, and in the San Pedro at locality 65, has relatively wide grooves between the ribs, strong widely spaced nodes, and a heavy right middle cardinal (pl. 33, fig. 4). This form closely resembles *Cyclocardia californica*, from the upper Pliocene of the Santa Maria Basin, but is smaller, and the largest specimens are wider than Santa Maria shells of the same size. "*Cardita*" *occidentalis*,[73] the type of which is not known to be extant, was based on material from the Pleistocene Santa Barbara formation at Santa Barbara. "*Cardita*" *monilicosta*, from the same formation and the same locality, is assumed to be a synonym. The only available specimens from Santa Barbara, one of which was figured by Arnold,[74] are small (length 11.2 millimeters), strongly inflated, and have strong ribs and closely spaced nodes. Small strongly inflated specimens from the San Pedro district resemble these small Santa Barbara specimens. "*Cardita*" *ventricosa* was the first name proposed for Recent Cyclocardias from the Pacific coast of the United States, and that name has been used for Pleistocene fossils from the San Pedro district. The type of *Cyclocardia ventricosa*, as selected by Dall, consists of corresponding right and left valves (length 15.1

[67] Berry, S. S., New Mollusca from the Pleistocene of San Pedro, Calif., I: Bull. Am. Paleontology, vol. 25, No. 94a, p. 3, pl. 1, figs. 1, 2, 1940.

[68] Woodring, W. P., Fossils from the marine Pleistocene terraces of the San Pedro Hills, Calif.: Am. Jour. Sci., 5th ser., vol. 29, pp. 301, 303, 1935.

[69] Carpenter, P. P., Catalogue of the Reigen collection of Mazatlan shells, pp. 83–84, 1857.

[70] Willett, George, op. cit. (San Diego Soc. Nat. History Trans., vol. 8, No. 30, p. 387, 1937.

[71] Keen, A. M., New pelecypod species of the genera *Lasaea* and *Crassinella*: Malacol. Soc. Proc., vol. 23, pp. 31–32, pl. 2, figs. 11, 12, 1938.

[72] Lamy, Edouard, Revision des Carditacea vivants du Muséum National d'Histoire Naturelle de Paris: Jour. Conchyl., vol. 66, p. 264, 1921.

[73] Conrad, T. A., Description of eighteen new Cretaceous and Tertiary fossils: Acad. Nat. Sci. Philadelphia Proc., vol. 7, p. 267, 1855; Description of the Tertiary fossils collected on the survey [Williamson's reconnaissance in California and Oregon]: U. S. Pacific R. R. Expl., 33d Cong., 2d sess., S. Ex. Doc. 78 and H. Ex. Doc. 91, vol. 6, pt. 2, p. 73, pl. 5, fig. 24, 1856 [1857].

[74] Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 321, pl. 14, fig. 12, 1907.

millimeters) from Puget Sound. The ribs are moderately strong and the nodes weak. Though it reaches a larger size (length 27 millimeters), the ribs and especially the nodes of *C. ventricosa* are not strong. Dall selected corresponding right and left valves from the type lot of *C. ventricosa* as the type of *C. stearnsii*. These two valves are narrower than *C. ventricosa* and have higher umbos and stronger ribs and nodes. The relations of the two forms are still unknown, the type of *C. stearnsii* being evidently exceptional. Strongly ribbed and noded Cyclocardias, resembling fossils from the San Pedro district and like them showing apparently variation in shape and in strength of ribs and nodes, occur along the southern California coast at depths of 25 to 124 fathoms, a form similar to *C. ventricosa* occurring apparently in that area at slightly greater depths, 61 to 339 fathoms. No Recent specimen available is as large as the large shells from the algal bed at Hilltop quarry, the largest having a length of 24.2 millimeters (Cortez Bank, 90 fathoms). No large Recent specimen examined has the exceptionally strong widely spaced nodes of the *californica*-like form shown on plate 33, figure 4. "*Venericardia*" *nodulosa* was based on small specimens or a small race that has strong closely spaced nodes. The nodes are generally stronger than on the small Santa Barbara *C. occidentalis*. The largest specimen in the type lot of *C. nodulosa*, dredged off Santa Rosa Island at a depth of 48 fathoms, has a length of 10.8 millimeters.

The weakly ribbed *Cyclocardia barbarensis* (pl. 31, figs. 11, 12) was found only in the Lomita marl and only in glauconitic foraminiferal sand and calcareous sand. It is particularly abundant in the glauconitic foraminiferal sand forming the lower part of unit 6a of the section in the canyon west of Hilltop quarry (locality 54e) and is the only abundant mollusk in the glauconitic foraminiferal sand forming unit 6a of the section at Lomita quarry (locality 62b). At locality 60a it is associated with *C.* aff. *C. occidentalis*. *C. barbarensis* is more quadrate and thinner than *C.* aff. *C. occidentalis* and has a less massive hinge, and the right middle cardinal is more conspicuously grooved. The degree of inflation is variable. It is living off the Channel Islands and off Point Loma at depths of 62 to 276 fathoms, generally 175 to 275 fathoms. The type lot is from a depth of 276 fathoms. Though recorded from the Timms Point silt, San Pedro sand, and Palos Verdes sand, *C. barbarensis* is not represented in those units in the collections at hand. Perhaps some of the records are based on worn specimens of *C.* aff. *C. occidentalis*.

Milneria kelseyi is represented by well-preserved specimens from the fourth terrace at locality 86. The genus has not been reported heretofore from the California Pleistocene.

VESICOMYACIDAE

The genus *Calyptogena* has been assigned recently to the Vesicomyacidae.[75] *Calyptogena gibbera*,[76] based on material from the Timms Point silt of Deadman Island, has according to the description and figure a greater height than *C. pacifica*. It is not represented in the collections at hand.

[75] Woodring, W. P., op. cit. (U. S. Geol. Survey Prof. Paper 190), p. 50, 1938.
[76] Crickmay, C. H., On a new pelecypod *Calyptogena gibbera*: Canadian Field Naturalist, vol. 43, No. 5, p. 93, 1 fig., 1929.

THYASIRIDAE

The small Recent species identified as *Thyasira gouldii* is abundant in the Lomita marl and Timms Point silt but is rare in the San Pedro sand, being represented in that unit only by an imperfect specimen from Deadman Island (locality 30). Oldroyd recorded one specimen from the San Pedro sand at his Nob Hill locality.

The relatively gigantic *Thyasira disjuncta* (pl. 33, fig. 5) is perhaps the most characteristic species of the Timms Point silt. It has not been found in any other unit. It is one of the few San Pedro fossils described at an early date and assigned to a definite locality, Deadman Island, where it was abundant in a zone known as the "*Cryptodon* bed." The figured specimen is from an old Deadman Island collection. This species has not been found recently at Timms Point. The only specimens collected during the field work for this report are paired but poorly preserved and are from locality 35, on the west side of Harbor Boulevard, representing strata in the Timms Point silt that are thought to overlie those exposed at Timms Point. Clark[77] recorded it, however, from unit 2 in exposures on the east side of Harbor Boulevard. Arnold and other paleontologists identified this species as *T. bisecta*, which was based on material from the Miocene of Astoria, Oreg. *T. disjuncta* is larger and more quadrate than *T. bisecta*, and the anterior end is more abruptly truncated. The type of *T. bisecta* and four other specimens in the Dana collection have an extended anterior end. The largest specimen has, however, a truncated anterior end, but not so abruptly truncated as in *T. disjuncta*. At the present time *T. disjuncta* is not known to be living south of the Oregon coast. The fossils are larger than the largest Recent shell in the National Museum collection (length 65.5 millimeters). *T. disjuncta* is the type of *Conchocele*. The exceptionally large size appears to be the only shell character to distinguish *Conchocele*. Whether any anatomical characters are correlated with the large size is not known.

Axinopsis viridis, recorded from the Timms Point silt,[78] is locally common in the Lomita marl and Timms Point silt but like *Thyasira gouldii* is rare in the San Pedro sand, being represented in that unit only by a few specimens from localities 30, 48, and 64.

LUCINIDAE

Lucinoma annulata is abundant in the three lower Pleistocene units, but is represented in the Palos Verdes sand by only one valve of medium size from locality 111. Well-preserved large valves were collected from the San Pedro sand at Deadman Island. Recent large shells comparable in size to those from the lower Pleistocene strata are not represented in the National Museum collection from localities south of Puget Sound.

Epilucina californica is the most abundant and widespread of the pelecypods from the terrace deposits older than the Palos Verdes sand. It occurs also in the other Pleistocene units.

UNGULINIDAE

The diplodontid ranging southward from San Diego, identified by Carpenter and Dall as *Diplodonta sericata*,

[77] Clark, Alex, op. cit. (San Diego Soc. Nat. History Trans., vol. 7, No. 4), table op. p. 30 (locality 322), 1931.
[78] Clark, Alex, op. cit.

is characteristic of the Palos Verdes sand (pl. 36, figs. 11–14). It was found at 12 localities between localities 114 and 142, inclusive, and also occurs in deposits on the second terrace at locality 105. Most of the fossils are smaller than Recent Lower California shells, but a few broken specimens are about as large.

LEPTONACEA

The leptonacid pelecypods have not been identified. It may be pointed out that a *Lasaea*, presumably *L. cistula*,[79] is fairly common in terrace deposits. The genus has not been reported heretofore from the Pleistocene of the San Pedro district.

TELLINIDAE

A small *Macoma* that has a short posterior end is identified as a small variety of *Macoma calcarea* (pl. 33, fig. 6). It is abundant and widespread in the Timms Point silt and is characteristic of that unit. This small *Macoma* (maximum length about 31 millimeters) appears to be identical with a small race of *M. calcarea* ranging from British Columbia to Monterey Bay (13 to 51 fathoms along California coast). Perhaps it has been recorded as *M. planiuscula*[80] (Dall's *M. carlottensis*, according to Grant and Gale), but that species is less inequilateral. *M. carlottensis* (Dall's *M. inflatula*, according to Grant and Gale) has been recorded from the Timms Point silt[81] but is not recognized in the collections at hand.

SEMELIDAE

Cumingia lamellosa is locally common in terrace deposits. It also occurs in the other units with the exception of the Timms Point silt. The only Lomita specimen however, is a small valve from locality 53b.

VENERIDAE

Dosinia ponderosa (pl. 36, figs. 15, 16), not found previously in the San Pedro district, is a southern species characteristic of the Palos Verdes sand. It was collected at 9 localities between localities 113 to 135, inclusive. All the specimens are broken and more or less worn. Corresponding right and left valves from San Diego, the only specimens in the National Museum collection from the present northern limit of this species, are small (length 61.5 millimeters).[81a]

Though Arnold reported *Amiantis callosa* to be rare in the Palos Verdes sand along the water front, it is widespread and locally abundant in that unit, but it is not known to occur in the other Pleistocene units.

Katherinella subdiaphana (pl. 33, figs. 7–9) is common in the Timms Point silt. It is represented in the Lomita marl by a fragment from locality 54g and in the San Pedro sand by well-preserved specimens from Deadman Island at locality 30. Arnold's variety *K. subdiaphana pedroana* was based on a small left valve from the San Pedro sand of Deadman Island. No large Recent shells comparable in size to the Pleistocene fossils are in the National Museum collection from localities south of Oregon, the largest from the California coast being a left valve that has a length of 35.3 millimeters (off Santa Rosa Island, 53 fathoms). This species is the type of the subgenus *Compsomyax*, which lacks the anterior lateral of *Katherinella* proper and has a more strongly bifid right posterior cardinal.

[79] Keen, A. M., op. cit. (Malacol. Soc. Proc., vol. 23), pp. 25–26, pl. 2, figs. 7–9, 1938.
[80] Willett, George, op. cit. (Southern California Acad. Sci. Bull., vol. 36), p. 61, 1937.
[81] Idem.
[81a] These two valves are bleached, have no epidermis or ligament, and sand grains are attached to the nymph. They evidently are Pleistocene fossils. The northernmost locality for Recent specimens in the National Museum collection is Scammon's Lagoon, Lower California.

Ventricola fordii (pl. 31, figs. 13–15) was found only in the Lomita marl. It is very abundant in the algal bed at Hilltop quarry (localities 53, 53a), where it is represented by specimens ranging in length from 8 to 77 millimeters. It is also represented by worn fragments from localities 54g and 61. The largest Recent specimen in the National Museum collection has a length of 66 millimeters. Aside from Grant and Gale's indefinite record, this species has not been recorded heretofore from the San Pedro district. *Ventricola* is so closely related to *Venus* that subgeneric rank may be preferable. It has, however, finer and less distinct radial sculpture than *Venus* and a stronger anterior lateral pustule.

Mercenaria perlaminosa (pl. 31, figs. 16, 17), already recorded from the Timms Point silt,[82] is represented by fragments from the Lomita marl at localities 60a, 69, 71 and from the Timms Point silt at locality 32a. The figured specimen was collected from the algal bed at Hilltop quarry, where this species was not found during the field work for this report. All the specimens are corroded, revealing the hidden radial sculpture. This species was based on material from the Pleistocene Santa Barbara formation and is not known to be living. It is closely related to *M. kennerleyi*, which ranges from Alaska to the Santa Barbara Islands, but is less elongate. *M. kennerleyi* is not represented in the National Museum collection from localities south of Carmel Bay. It is the type of the subgenus *Humilaria*, which has a less extended porterior end and a narrower pallial sinus than *Mercenaria* proper.

Chione gnidia (pl. 37, figs. 1, 2) is another southern species characteristic of the Palos Verdes sand. It is not common, however, as it was found only at localities 123, 134, and 135. The small "*Chione*" *picta*[83] (pl. 37, figs. 3, 4) is likewise a southern species characteristic of the Palos Verdes sand. It is fairly common, having been found at 8 localities between localities 113 and 135, inclusive. Mr. E. P. Chace reports that it is common in deposits of the second terrace on Fifteenth Street near Leland Avenue. Heretofore unrecorded from the San Pedro district, this species ranges from Magdalena Bay, Lower California (the type locality), to Panama. The dark-colored interior blotch on the posterior part of the shell is visible on the fossils. This species is not a typical *Chione;* it represents apparently a new subgenus or genus.

CARDIIDAE

The essentially northern cardiid *Cerastoderma nuttallii* occurs in the Lomita marl, Timms Point silt, San Pedro sand (pl. 34, figs. 16, 17), and Palos Verdes sand. It is rare in the Lomita marl, as it was collected only at locality 65. None of the fossils are large, the figured specimen being the largest. All except the figured specimen are more or less corroded, and many are broken. Though moderately large Recent specimens in the National Museum are labeled San Pedro and San Diego, this species has not been found recently at or near San Pedro, according to local collectors. The name *Clinocardium*[84] has been proposed for the Pacific coast Cerastodermae, *C. nuttallii* being the type.

Trachycardium quadragenarium, which ranges from Santa Barbara to Lower California, occurs in the three

[82] Clark, Alex. op. cit. (San Diego Soc. Nat. History Trans., vol. 7, No. 4), table op. p. 30, 1931.
[83] Willett, George, Two new west American pelecypods: Southern California Acad. Sci. Bull., vol. 43, pt. 1, pp. 20–22, pl. 8, 1944.
[84] Keen, A. M., A new pelecypod genus of the family Cardiidae: San Diego Soc. Nat. History Trans., vol. 8, No. 17, pp. 119–120, 1936.

lower Pleistocene units, in deposits on the second and third terraces, and in the Palos Verdes sand. The specimen shown on plate 34, figures 18 and 19, is from the San Pedro sand at Deadman Island (locality 30). This species is the type of the subgenus *Dallocardia*.

Trachycardium procerum (pl. 37, figs. 5–8) is the most abundant of the southern species characteristic of the Palos Verdes sand. It was found at 20 localities between localities 112 and 142, inclusive. Arnold recorded one specimen from the San Pedro sand of Deadman Island. *T. procerum* is the type of the subgenus *Mexicardia*.

Trachycardium elatum also was found only in the Palos Verdes sand. It is rare, however, being represented by fragments of large valves from localities 112 and 130. Though this species has subdued ribs, it is doubtful whether it is closely related to *Laevicardium*.

Trigoniocardia biangulata (pl. 35, figs. 5, 6) is represented by small and medium-sized specimens from deposits on the second terrace at Malaga Cove (locality 105). This species is assigned to the subgenus *Americardia*. Heretofore not found in the Pleistocene of the San Pedro district, it was recorded recently in late Pleistocene strata near Playa del Rey.[85]

A small thin-shelled cardiid is identified as *Pratulum centifilosum*. It is abundant in the Lomita marl and Timms Point silt (pl. 33, figs. 10, 11) and occurs in the San Pedro sand at Deadman Island (locality 30). All the specimens except one of those from the San Pedro sand are more or less corroded, and many are broken. The type material of *P. centifilosum* from Monterey is not in the National Museum. Characters to differentiate *P. richardsoni*, treated as a variety of *P. centifilosum* by Dall, other than its larger size are not apparent. *P. centifilosum* ranges from Forrester Island, Alaska, to Point Abreojos, Lower California. The fossils are comparable in size to large Alaskan shells (length 26.2 millimeters). Specimens from the California coast are smaller than the fossils, the largest in the National Museum (length 19.6 millimeters) being in a lot dredged at a depth of 47 fathoms off the Cortez Bank. The generic assignment of *P. centifilosum* is not entirely certain, as no specimens of the Australian "*Cardium*" *thetidis*, the type of *Pratulum*,[86] are available. If the Australian "*Cardium*" *pulchellum* is a typical *Pratulum*, *P. centifilosum* is at least subgenerically distinct, as "*C.*" *pulchellum* has minute spines on the posterior part of the shell, whereas *P. centifilosum* has concentric lamellae.

MYACIDAE

A small elongate form of the circumpolar *Mya truncata* (pl. 33, fig. 12) is one of the northern species characteristic of the Timms Point silt. It is rare but has been found at localities 44a, 45, and 66 and recorded from unit 2 at Timms Point.[87] The fossils are similar to Recent shells from Puget Sound, the present southern limit of this species on the Pacific coast. A small short form of *M. truncata* occurs in the Pliocene strata at Elsmere Canyon.

PANOPIDAE

A small form of the circumpolar genus *Panomya* is likewise a northern species characteristic of the Timms Point silt. It is identified as a small variety of *Panomya beringianus* (pl. 33, figs. 13, 14). The fossils have been reported as *P. ampla* and have been compared with *P. turgida*.[88] *P. ampla* has a triangular irregular outline, whereas *P. turgida* is more inflated than the fossils and has a less conspicuous central groove. The fossils have the quadrate outline and conspicuous central groove of *P. beringianus* (type locality, near Pribiloff Islands, 56 fathoms), which reaches a length of 155 millimeters. They are most similar to a pair of small valves (length 58 millimeters) dredged at a depth of 80 fathoms at Port Levasheff, Unalaska. At the present time Puget Sound is the southern limit of the genus, and *P. beringianus* is not recorded south of Bering Sea. Grant and Gale figured, however, a similar Puget Sound form under the name *P. ampla*. *Panomya* occurs in the Pliocene (?) Empire formation of Oregon, in Pliocene strata near San Francisco and at Los Angeles, and has been identified doubtfully in the transition zone between the Repetto and Pico formations in the Repetto Hills on the north border of the Los Angeles Basin.[89]

THRACIIDAE

The northern *Thracia trapezoides* occurs in the marl facies of the Lomita in San Pedro (localities 37, 41) and in the Timms Point silt (pl. 33, fig. 15; localities 32a, 44, 45). The fossils are cracked or broken. They are reasonably similar to the type material of *T. trapezoides* from the Miocene at Astoria, Oreg. (U. S. Nat. Mus. 3604) but are considerably larger, and they closely resemble Recent shells from San Juan Island, Wash. According to the National Museum collection, this species now ranges from Sitka, Alaska, to the Santa Barbara Islands, but the specimens from the islands are small. *T. curta*, which ranges farther south, is smaller and shorter and has a less distinct posterior angulation.

PANDORIDAE

Pandora grandis (pl. 33, figs. 16–18) is still another northern species characteristic of the Timms Point silt. It was found at localities 34, 44, and 66. The largest fossils are about as large as large Recent Alaskan shells. At the present time this species ranges from the Pribiloff Islands in Bering Sea to Siletz Bay, Oreg.

BARNACLES

Barnacles of the genus *Tetraclita*, presumably *T. squamosa rubescens*, are common in collections from the rock-cliff and tide-pool facies of terrace deposits older than the Palos Verdes sand. *Balanus* remains, generally fragmentary, occur locally in terrace deposits and other strata.

DECAPOD CRUSTACEANS

Rathbun[90] described 25 species of decapod Crustacea from the Pleistocene of the San Pedro district. Those from Oldroyd's Nob Hill locality are from the San Pedro sand. Localities and horizons for other forms are not specified. Numerous fragmentary remains collected during the field work for this report have not been identified.

[85] Willett, George, op. cit. (San Diego Soc. Nat. History Trans., vol. 8, No. 30), p. 389, 1937.
[86] Iredale, Tom, Results from Roy Bell's molluscan collections: Linnean Soc. New South Wales Proc., vol. 49, pp. 182, 207, 1924.
[87] Clark, Alex., op. cit. (San Diego Soc. Nat. History Trans., vol. 7, No. 4), table op. p. 30, 1931.
[88] Willett, George, op. cit. (Southern Calif. Acad. Sci. Bull., vol. 36), pp. 61–62, 1937.
[89] Woodring, W. P., Lower Pliocene mollusks and echinoids from the Los Angeles Basin, Calif.: U. S. Geol. Survey Prof. Paper 190, p. 20, 1938.
[90] Rathbun, M. J., The fossil stalk-eyed Crustacea of the Pacific slope of North America: U. S. Nat. Mus. Bull. 138, 155 pp., 1926.

BIRDS

Twenty-one species of birds are recorded by Miller [91] from the Palos Verdes sand at Arnold's lumber yard locality (locality 113), now destroyed. The specimens were obtained by sorting great quantities of material. The species include the extinct diving goose *Chendytes lawi*, based on material from late Pleistocene terrace deposits near Santa Monica.

A vertebra, determined by Dr. Alexander Wetmore of the National Museum as the eighth cervical vertebra of an extinct species of vulture of the family Cathartidae allied to *Coragyps* sp., was found at locality 75 in marine deposits on the twelfth terrace.

MARINE MAMMALS

A broken bone from the algal bed of the Lomita marl at Hilltop quarry (locality 53a) is identified by Dr. C. L. Gazin, of the National Museum, as the proximal end of the third metacarpal of a seal. Seal (*Phoca* sp.)[92] and sea lion (*Zalophus* sp.)[93] remains from the Palos Verdes sand at Arnold's lumber yard locality have been described by Kellogg.

LAND MAMMALS

Blake [94] described and figured a mammoth molar from strata representing evidently the Palos Verdes sand. Fragmentary vertebrate remains from the Palos Verdes sand at Arnold's lumber yard locality were listed and discussed by Stock.[95] This material includes remains of dire wolf(?), felid, rodents, ground sloths, horse, cervids, camelid, and bison. Inasmuch as it is improbable that a considerable population of large animals lived on the small island formed by the Palos Verdes Hills during Palos Verdes time, most of these remains probably represent carcasses that floated out from the mainland.

Dr. Gazin identified a toe bone of a small undetermined mammal, possibly a lagomorph, in the collection from the algal bed of the Lomita marl at Hilltop quarry (locality 53). He also identified an immature femur of a gopher, possibly *Thomomys*, from deposits on the third terrace at locality 91.

The weighmaster at Sidebotham No. 1 sand pit, on the north border of the hills along Bent Spring Canyon, has a considerable collection of vertebrate remains reported to have been collected from the San Pedro sand exposed in the pit. This material includes horse teeth and cervid remains. Vertebrate remains, including mammoth and horse teeth, are recorded [96] from the "upper beds" (presumably terrace deposits [97]) at Lomita quarry. Porpoise (*Eurhinodelphis*) and seal (*Allodesmus kernensis*) remains said to occur with the land mammals are doubtless Miocene, as Hay [98] thought, and according to a communication from Dr. Remington Kellogg are probably from Sharktooth Hill in Kern County.

CALCAREOUS ALGAE

Calcareous algae are abundant in the Lomita marl and make up a large proportion of the algal bed at Hilltop quarry. *Mesophyllum?* is recorded from Lomita quarry.[99]

ENVIRONMENT SUGGESTED BY FOSSILS

The Pleistocene marine faunas of the San Pedro district, with relatively few exceptions, consist of species that are still living. They should, therefore, yield information that would permit reasonably certain conclusions concerning the environment in which they lived, provided it be assumed that the species lived in the same environment that they now do. In view of the relatively short lapse of time involved, this assumption is reasonable and is the basis for the following discussion, not only for the species that show no change in morphological characters available to paleontologists but also for species that are not known to be living though closely related to living forms. Nevertheless it should be realized that the assumption does not take into consideration possible changes in physiological characters that may not be correlated with changes in morphological characters but that may affect distribution and habits.[1] Furthermore, in a tectonically unstable region such as coastal southern California marked changes in distribution of land and sea may have taken place recently without leaving much clue in the present geographic pattern but affecting the distribution of marine organisms.

The following discussion is based almost entirely on the mollusks, for they are the most abundant fossils and are perhaps better known than the others.

The shallow-water mollusks of the Pacific coast of North America and their distribution are now fairly well known. The fauna at depths of more than 100 fathoms has been sampled at scattered localities and has been described. The fauna at moderate depths, especially from 50 to 100 fathoms, is less known than either the shallow-water fauna or the deep-water fauna. Collections from dredgings at moderate depths from the islands off southern California and an area off San Diego are, however, fairly numerous. Local collectors are continually adding material, particularly from dredgings in the channel between San Pedro and Catalina Island. The *Albatross* occupied well over 100 stations at depths of 10 to 100 fathoms, mostly 25 to 100 fathoms, off the islands and off San Diego. The mollusks from these dredgings by the *Albatross* are scattered through the systematic west coast collection in the National Museum. Dall described some of the striking species, but for the most part this material is still unidentified. It was used as far as practicable in the identification of the Pleistocene mollusks of the San Pedro district. If the material were worked up and species listed by stations with data covering the depth, temperature, and character of bottom, the results would go a long way toward filling the gap in the knowledge of the moderate-depth fauna of southern California. The hauls from depths of about 50 to 75 fathoms off Point Loma, at the entrance to San Diego Bay, are particularly rich and appear to be significant

[91] Miller, L. H., Bird remains from the Pleistocene of San Pedro, Calif.: California Univ. Dept. Geol. Bull., vol. 8, pp. 31–38, 1914. Further bird remains from the upper San Pedro Pleistocene: Condor, vol. 32, pp. 116–118, fig. 45, 1930. Miller, L. H., and DeMay, Ida, The fossil birds of California: California Univ., Pub. Zoology, vol. 47, No. 4, pp. 57–58, 1942.

[92] Kellogg, Remington, Pinnipeds from Miocene and Pleistocene deposits of California: California Univ., Dept. Geol. Sci., Bull., vol. 13, p. 120, 1922.

[93] Kellogg, Remington, Fossil pinnipeds from California: Carnegie Inst. Washington Pub. 346, pp. 33–35, fig. 7, 1927.

[94] Blake, W. P., Geological report [Williamson's reconnaissance in California]: U. S. Pacific R. R. Expl., 33d Cong. 2d sess., S. Ex. Doc. 78 and H. Ex. Doc. 91, vol. 5, pt. 2, p. 186, 1857.

[95] Stock, Chester, Cenozoic gravigrade edentates of western North America, with special reference to the Pleistocene Megalonychinae and Mylodontidae of Rancho La Brea: Carnegie Inst. Washington Pub. 331, pp. 118–119, 1925.

[96] Jordan, D. S., and Hannibal, Harold, Fossil sharks and rays of the Pacific slope of North America: Southern California Acad. Sci. Bull., vol. 22, p. 65, pls. 9, 10, 1923.

[97] Idem, p. 63.

[98] Hay, O. P., The Pleistocene of the western region of North America and its vertebrated animals: Carnegie Inst. Washington Pub. 322 B, p. 173, 1927.

[99] Howe, M. A., Eocene marine algae (Lithothamnieae) from the Sierra Blanca limestone: Geol. Soc. America Bull., vol. 45, pp. 515, 517, 1934.

[1] Woodring, W. P., op. cit. (U. S. Geol. Survey Prof. Paper 190), p. 12, 1938.

in interpreting the Pleistocene paleoecology of the San Pedro district.

Numerous local lists of shallow-water mollusks are available for localities up and down the Pacific coast. They do not help much in paleoecological studies, however, for most of them lack other than geographic data. During recent years intensive ecological studies have been made at a few localities—studies such as those of the San Juan Island region,[2] Elkhorn Slough [3] (a marine estuary off Monterey Bay), and a rocky coast at Monterey Bay.[4] Studies covering different environments at numerous localities and at the same localities at different times are needed to furnish an adequate basis for paleoecological interpretations. It may be pointed out that ecological investigations that are aimed at recognition of a complex classification of animal associations without a complete census of the population and without data on the habits and life histories of the animals are of little value for paleoecological interpretations.

[2] Shelford, V. E., and others, Some marine biotic communities of the Pacific coast of North America, part 1, General survey of the communities: Ecological Monographs, vol. 5, No. 3, pp. 249-332, figs. 1-10, 1935. Wismer, N. M., and Swanson, J. H., Some marine biotic communities of the Pacific coast of North America, part 2, A study of the animal communities of a restricted area of soft bottom in the San Juan Channel: Idem, pp. 333-354, figs. 11-16, 1935.

[3] MacGinitie, G. E., Ecological aspects of a California marine estuary: Am. Midland Naturalist, vol. 16, pp. 629-765, 21 figs., 3 maps, 1935.

[4] Hewatt, W. G., Ecological studies on selected marine intertidal communities of Monterey Bay, California: Idem, vol. 18, pp. 161-206, 2 pls., 15 figs., 1937.

GEOGRAPHIC DISTRIBUTION OF PLEISTOCENE MOLLUSKS THAT ARE STILL LIVING

Most of the 500 species of Pleistocene mollusks are still living in the latitude of San Pedro. Early investigators soon realized, however, that some of the species are locally extinct in that area, some now living farther north and others farther south. The distribution of the northern and southern species in the Pleistocene strata is shown in the following table, which includes Pleistocene forms that are not known to be living but that are closely related to living forms. Mollusks that have not been identified, notably chitons, epitonids, pyramidellids, melanellids, turrids, tectibranchs, and leptonacids, are not included in this or other tables.

Pleistocene mollusks locally extinct in the latitude of San Pedro but now living farther north or south, including forms that are not known to be living but that are closely related to living forms

Species	Lower Pleistocene			Upper Pleistocene									Present known range
				Terrace deposits									
	Lomita marl	Timms Point silt	San Pedro sand	12	9	8	6	5	4	3	2	Palos Verdes sand	
Northern species													
Gastropods:													
Alvania montereyensis Bartsch [1]									×		×		Alaska to Monterey.
Cerithiopsis willetti Bartsch, n. var.?	×												A form of *C. willetti*, Forrester Island, Alaska, to Puget Sound.
Triphora fossilis Willett		[2] ×											Related to *T. carpenteri*, Neah Bay, Wash.
Lamellaria stearnsii Dall			[3] ×										Puget Sound to Monterey.
Volutina laevigata (Linné)	(?)	[4] ×											Icy Cape, Alaska, to Monterey.
Boreotrophon pedroanus (Arnold)	×	×	×									×	Related to *B. orpheus*, British Columbia to Oregon.
Boreotrophon aff. B. multicostatus (Eschscholtz).	×	×	[5] ×									×	Perhaps identical with a small race of *B. multicostatus*, Puget Sound to northern California.
Nucella lamellosa (Gmelin)											(?)	×	Bering Strait to Santa Barbara.
Pelecypods:													
Chlamys islandicus jordani (Arnold)	×	×	×										Puget Sound.
Patinopecten caurinus (Gould)	×	×	×										Cordova, Alaska, to Point Reyes, Calif.
Miodontiscus prolongatus (Carpenter).	×	×	×										Middleton Island, Alaska, to Oregon.
Thyasira disjuncta (Gabb)		×											Alaska Peninsula to Oregon.
Macoma calcarea (Gmelin), small variety.		×											Apparently identical with small race, British Columbia to Monterey.
Mya truncata Linné		×											Arctic Ocean to Puget Sound.
Panomya beringianus Dall, small variety.		×											Pribiloff Islands, Bering Sea, to Puget Sound.
Pandora grandis Dall		×											Pribiloff Islands, Bering Sea, to Siletz Bay, Oreg.
Southern species													
Gastropods:													
Vitrinella salvania (Dall)	×												South Coronado Island, near San Diego.
Pomaulax turbanicus petrothauma (Berry).	×												Closely related to *P. turbanicus* proper, Magdalena Bay, Lower California.
Rissoina pleistocena Bartsch											×	×	Related to species from Lower California and Gulf of California.
Rissoina coronadoensis Bartsch	×	×	×										Off Point Loma, San Diego, to San Martin Island, Lower California.
Mitra fultoni E. A. Smith											×		Lower California.
"Nassa" cerritensis Arnold												×	A small race or a closely related species, Point Abreojos and Ballenas Bay, Lower California, and Guaymas, Gulf of California.
Macron aethiops (Reeve)	×												Lower California and Gulf of Mexico.
Centrifuga leeana (Dall)												[6] ×	Guadalupe Island, Lower California, to Cedros Island, Lower California.
Pterorytis monoceros (Sowerby)												[7] ×	Lower California.
Eupleura muriciformis (Broderip and Sowerby).			[8] ×									[8] ×	Gulf of California to Panama.
Nucella biserialis (Blainville)												×	Cedros Island, Lower California, to Peru.
Acanthina lugubris (Sowerby)									×		×		San Diego to Magdalena Bay, Lower California.

See footnotes at end of table.

Pleistocene mollusks locally extinct in the latitude of San Pedro but now living farther north or south, including forms that are not known to be living but that are closely related to living forms—Continued

Species	Lower Pleistocene			Upper Pleistocene									Present known range
				Terrace deposits									
	Lomita marl	Timms Point silt	San Pedro sand	12	9	8	6	5	4	3	2	Palos Verdes sand	
Southern species—Continued													
Pelecypods:													
Anadara perlabiata (Grant and Gale)												×	San Diego (?); San Ignacio Lagoon, Lower California, to Costa Rica.
Pecten vogdesi Arnold											×	[9] ×	Closely related to *P. cataractes*, Gulf of California, and perhaps indistinguishable from that form.
Lyropecten subnodosus (Sowerby)												[10] ×	Cedros Island, Lower California, to Ecuador.
Ostrea megodon cerrosensis Gabb	×												Closely related to *O. megodon* proper, Gulf of California to Peru.
Crassinella branneri (Arnold)									×			×	A small race or a closely related species San Diego (?); Scammon's Lagoon, Lower California.
Crassinella nuculiformis Berry											×	×	Closely related to *C.* "*varians*" from Cape San Lucas and La Paz, Lower California.
Diplodonta sericata (Reeve)											×	×	San Diego to Panama.
Tellina rubescens Hanley												[11] ×	Magdalena Bay, Lower California, to Panama.
Mulinia pallida (Broderip and Sowerby)												[12] ×	Magdalena Bay, Lower California, to Ecuador.
Dosinia ponderosa (Gray)												×	Scammon's Lagoon, Lower California, to Peru.
Chione gnidia (Broderip and Sowerby)												×	Cedros Island, Lower California, to Peru.
"Chione" picta Dall											×	×	Magdalena Bay, Lower California, to Panama.
Tracycardium procerum (Sowerby)			[13] ×									×	Scammon's Lagoon, Lower California, to Peru.

[1] Recorded from San Pedro sand by Oldroyd, T. S., U. S. Nat. Mus. Proc., vol. 65, art. 22, p. 17, 1924. His specimens, which were not examined, should be compared with *A. acutelirata*.
[2] Willett, George, Southern California Acad. Sci. Bull., vol. 36, p. 62, 1937.
[3] Arnold, Ralph, California Acad. Sci. Mem., vol. 3, p. 317, 1903.
[4] Willett, George, op. cit., p. 63.
[5] Arnold, Ralph, op. cit., p. 250 ("*gracilis*").
[6] Idem, p. 243.
[7] Idem, p. 246.
[8] Idem, pp. 248–249 (var. *pleistocenensis*).
[9] Idem, pp. 104–105 ("*dentatus*").
[10] Idem, p. 108.
[11] Idem, pp. 159–160.
[12] Idem, p. 175 ("*exoleta*").
[13] Idem, pp. 139–140.

Species that are now living at or close to the southern or northern limits of their range in the latitude of San Pedro also may be regarded as northern and southern species. They are as follows:

Pleistocene mollusks now living at or close to southern or northern limits of their range in the latitude of San Pedro or that are related to such Recent species

Species	Lower Pleistocene			Upper Pleistocene									Present known range
				Terrace deposits									
	Lomita marl	Timms Point silt	San Pedro sand	12	9	8	6	5	4	3	2	Palos Verdes sand	
Northern species													
Gastropods:													
Puncturella galeata (Gould)		[1] ×	[2] ×										Aleutian Islands to Santa Barbara Islands.
Tegula brunnea (Philippi)		(?)		(?)				×	×		×	×	Mendocino County, Calif., to Santa Barbara Islands.
Tegula montereyi ("Fischer" Kiener)	×	[3] ×	×					×	×	×	×	×	Baulinas Bay, Calif., to Santa Barbara Islands.
Tegula marcida (Gould) ["pulligo"]												×	Sitka, Alaska, to Santa Barbara Islands.
Calliostoma ligatum (Gould) ["costatum"].		×	(?)									[4] ×	Do.
Calliostoma virgineum (Dillwyn) ["annulatum"].	(?)	×										×	Victoria, British Columbia, to Santa Barbara Islands.
Calyptraea fastigiata Gould	×	[5] ×	×									[6] ×	Port Eches, Alaska, to Santa Barbara Islands.
Fusitriton oregonensis (Redfield)	×	×	[7] ×									×	Bering Sea to Catalina Island.
Exilioidea rectirostris (Carpenter).		×	[8] ×									×	Forrester Island, Alaska, to Catalina Island.
Pterorytis foliata (Reeve)												[9] ×	Sitka, Alaska, to San Pedro.
Amphissa columbiana Dall		[10] ×	[10] ×									×	Chiacha Islands, Alaska, to San Pedro.
Pelecypods:													
Katherinella subdiaphana (Carpenter)		×	×										Alaska to San Pedro.
Mercenaria perlaminosa Conrad	×	×											Related to *M. kennerlyi*, Alaska to Santa Barbara Islands.
Thracia trapezoides (Conrad)	×	×											Sitka, Alaska, to Santa Barbara Islands.
Southern species													
Gastropods:													
Calliostoma eximium (Reeve)												×	Catalina Island to Mazatlan, Mexico.[11]
Calliostoma gemmulatum Carpenter			×									×	Catalina Island to San Diego.
Vitrinella oldroydi Bartsch			[12] ×								×		San Pedro to Point Abreojos, Lower California.
Amphithalamus inclusus Carpenter	×											×	Catalina Island to San Diego.
Rissoina kelseyi Dall and Bartsch	×										×		San Pedro to Coronados Islands, near San Diego.
Rissoina aequisculpta (Keep)	×												Catalina Island to Todos Santos Bay, Lower California.
Rissoina cosmia (Bartsch)									×				San Pedro to San Martin Island, Lower California.

See footnotes at end of table.

Pleistocene mollusks now living at or close to southern or northern limits of their range in the latitude of San Pedro or that are related to such Recent species—Continued

Species	Lower Pleistocene			Upper Pleistocene										Present known range
				Terrace deposits										
	Lomita marl	Timms Point silt	San Pedro sand	12	9	8	6	5	4	3	2	Palos Verdes sand		
Southern species—Continued														
Gastropods—Continued.														
Truncatella stimpsoni Stearns								×	×		×			Catalina Island to San Diego.
Alabina tenuisculpta (Carpenter)			[13] ×									×		San Pedro to Magdalena Bay, Lower California.
Bittium rugatum Carpenter	×	×	×									×		Probably identical with forms ranging from Santa Barbara Islands to Lower California.
Bittium rugatum larum Bartsch	×	×	×						×					San Pedro to San Bartolome Bay, Lower California.
Bittium asperum (Gabb)	×	[14] ×	×									×		Closely related to *B. asperum lomaense*, Catalina Island to San Diego, and perhaps indistinguishable from that form.
Cerithiopsis pedroana fatua Bartsch	×		[15] ×											Closely related to *C. pedroana* proper, San Pedro to Point Abreojos, Lower California.
Cerithiopsis antemunda Bartsch			×											San Pedro to San Diego.
Cerithopsis necropolitana Bartsch	×	(?)	[16] ×											Closely related to *C. gloriosa*, San Diego.
Triphora pedroana Bartsch	(?)	[17] ×		×					×		×	[18] ×		San Pedro to Coronado Islands, near San Diego.
Caecum grippi Bartsch	×													San Diego.
Fartulum occidentale Bartsch			×		×		×		×		×	×		San Pedro to Lower California.
Fartulum orcutti (Dall)							×					×		Do.
Crepipatella charybdis (Berry)	×	×	×											Santa Barbara Islands to San Diego.
Neverita reclusiana alta (Arnold)	×	×	×						(?)	×		×		Newport Bay, Calif., to Lower California and Gulf of California.
Trivia solandri Gray			[19] ×								×	(?)		Catalina Island to Panama.
Macron aethiops kellettii (Forbes)			×									[20] ×		Catalina Island (?); Lower California to Gulf of California.
Tritonalia circumtexta aurantia (Stearns).								×	×	×				Santa Barbara Islands to Scammon's Lagoon, Lower California.
Forreria belcheri (Hinds)												×		San Pedro to Scammon's Lagoon, Lower California.
Aesopus chrysalloides (Carpenter)			×						×			×		San Pedro to San Diego.
Hyalina californica (Tomlin)	×		[21] ×				×		×			×		San Pedro to Puerto Libertad, Mexico.
Williamia peltoides (Carpenter)	×													Catalina Island to Gulf of California.
Pelecypods:														
Cyrilla munita Dall	×	×	×											Santa Barbara Islands to San Diego.
Anomia peruviana d'Orbigny			×									×		San Pedro to Peru.
Cyclocardia barbarensis (Stearns)	×													Santa Barbara Islands to San Diego.
Semele decisa (Conrad)			×								×	×		San Pedro to Point Abreojos, Lower California.
Amiantis callosa (Conrad)												×		Santa Monica, Calif., to Gulf of Tehuantepec, Mexico.
Chione succincta (Valenciennes)			×								×	×		San Pedro to Panama.
Trachycardium elatum (Sowerby)												×		Do.
Trigoniocardia biangulata (Sowerby)											×			Do.

[1] Arnold, Ralph, California Acad. Sci. Mem., vol. 3, p. 341, 1903. Clark, Alex, San Diego Soc. Nat. History Trans., vol. 7, No. 4, table op. p. 30, 1931. Willett, George, Southern California Acad. Sci. Bull., vol. 36, p. 64, 1937.
[2] Arnold, Ralph, op. cit.
[3] Arnold, Ralph, op. cit., p. 326. Clark, Alex, op. cit.
[4] Arnold, Ralph, op. cit., p. 330.
[5] Clark, Alex, op. cit. ("*mamillaris*").
[6] Arnold, Ralph, op. cit., p. 307 ("*mammillaris*.")
[7] Idem, pp. 286–287.
[8] Idem, p. 228.
[9] Idem, p. 245.
[10] Idem, p. 241 ("*corrugata*").
[11] There are no specimens in the National Museum from localities between Catalina Island and Magdalena Bay, Lower California.
[12] Oldroyd, T. S., U. S. Nat. Mus. Proc., vol. 65, art. 22, p. 21, 1924.
[13] Arnold, Ralph, op. cit., p. 296.
[14] Idem, p. 291. Clark, Alex, op. cit.
[15] Bartsch, Paul, U. S. Nat. Mus. Proc., vol. 40, pp. 331–332, 1911. Oldroyd, T. S. op. cit., p. 15.
[16] Bartsch, Paul, op. cit., pp. 345–346. Oldroyd, T. S., op. cit.
[17] Willett, George, Southern California Acad. Sci. Bull., vol. 36, p. 62, 1937.
[18] Bartsch, Paul, U. S. Nat. Mus. Proc., vol. 33, pp. 250–251, 1907.
[19] Arnold, Ralph, op. cit., p. 289.
[20] Idem, p. 230.
[21] Idem, p. 222 ("*varia*").

During Pleistocene time the Palos Verdes Hills formed an island. That unknown factors correlated with a marine insular habitat may affect the distribution and abundance of some species is suggested by the occurrence in the Palos Verdes Hills of species that now are more abundant along the islands off the southern California coast than along the adjoining mainland or are unreported along the mainland. These species include *Tegula brunnea*, *T. montereyi*, *T. marcida* ["*pulligo*"], *Calliostoma ligatum* ["*costatum*"], *C. virgineum* ["*annulatum*"], *Liotia fenestrata*, *L. acuticostata*, *Amphithalamus inclusus*, *Alvania acutelirata rosana*, and *Jaton gemma*.

DEPTH DISTRIBUTION OF PLEISTOCENE MOLLUSKS THAT ARE STILL LIVING

Most of the species of mollusks found in the Pleistocene strata are now living in shallow water, less than 10 fathoms, along the California coast or in water that ranges from shallow to a depth of about 25 fathoms. A considerable number are known to occur only at moderate depths, 10 to 100 fathoms. None of the species are now confined to deep water, more than 100 fathoms, but about half of the moderate-depth species range into deep water, some to depths as great as 1,000 fathoms. The species of moderate depth and moderate to deep-water depth are listed in the following table, in which the known depth range is based for the most part on material in the National Museum. The marine terrace deposits older than the Palos Verdes sand are not included in the table, as those deposits do not contain such species, with the exception of an imperfect specimen, probably *Jaton santarosanus*, which was collected from deposits on the second terrace at locality 105. That species has a known depth range of 16 to 82 fathoms.

Pleistocene mollusks now living at moderate depths and at moderate to deep-water depths off the California coast or that are closely related to Recent forms having that depth range

Species	Lower Pleistocene			Upper Pleistocene, Palos Verdes sand	Present known depth range off California coast (fathoms)
	Lomita marl	Timms Point silt	San Pedro sand		
Gastropods:					
Acmaea funiculata (Carpenter)	×	×	×		30–67.
Puncturella galeata (Gould)		[1] ×	[2] ×		48.
Puncturella cucullata (Gould)	×	×	[3] ×	[4] ×	34–110.
Puncturella cooperi Carpenter	×	×	×		16–95.
Puncturella delosi Arnold	×	×	×		Probably identical with *P. caryophylla*, 67–81.
Cidarina cidaris (A. Adams)	(?)	×			53–822.
Turcica caffea (Gabb)		×	[5] ×		20.
Solariella peramabilis Carpenter	×	×			32–239.
Solariella rhyssa Dall	×				81.
Macheroplax cf. M. varicosa (Mighels and Adams)		×			South of Puget Sound range of genus is 68–243.
Homalopoma subobsoletum (Willett)	×	[6] ×	(?)		67–71.
Alvania acutelirata rosana Bartsch	×	×	×	×	30–53.
Bittium rugatum Carpenter	×	×	×	×	Probably identical with forms ranging from 50–181.
Bittium asperum (Gabb)	×	[7] ×	×	×	Closely related to *B. asperum lomaense* and perhaps indistinguishable from that form, which ranges from 20–71.
Crepipatella charybdis (Berry)	×	×	×		50–155.
Cryptonatica russa (Gould)?	×	×	×	×	48–795.
Trivia ritteri Raymond		[8] ×			32–60.
Fusitriton oregonensis (Redfield)	×	×	[9] ×	×	80–1,081.
Barbarofusus barbarensis (Trask)	×	×	×	[10] ×	30–218.
Neptunea tabulata (Baird)	×	×	×		68–211.
Exilioidea rectirostris (Carpenter)		×	[11] ×	×	80–389.
Trophonopsis lasia (Dall)		[12] ×	×		71–376.
Boreotrophon cf. B. pacificus (Dall)	×	[13] ×	[14] ×	[14] ×	Related evidently to *B. pacificus*, 67–92.
Boreotrophon aff. B. stuarti (Smith)	×	[15] ×	[16] ×		50–202.
Admete gracilior (Carpenter)	×	×	×	×	Probably identical with *A. rhyssa*, 53–81.
Acteon breviculus Dall	×				48–110.
Pelecypods:					
Nucula aff. N. cardara Dall			×		55–1,090.
Acila castrensis (Hinds)	×	×	×	(?)	16–233.
Glycymeris profunda (Dall)	×		×	(?)	25–200.
Cyrilla munita Dall	×	×			30–80.
Pecten stearnsii Dall	×	×	(?)		Closely related to *P. stearnsii diegensis*, 14–266.
Chlamys hastatus (Sowerby)	×	×	×		21–110.
Pseudamussium n. sp.	×	(?)			Related to *P. bistriatus*, 822.
Hyalopecten vancouverensis (Whiteaves)	×	×			40–200.
Propeamussium alaskensis (Dall)	×		[17] ×		20.
Eucrassatella fluctuata (Carpenter)	×	×	(?)		45–48.
Cyclocardia aff. C. occidentalis (Conrad)	×	×	×	×	25–110.
Cyclocardia barbarensis (Stearns)	×				62–276.
Calyptogena gibbera Crickmay		[18] ×			Related evidently to *C. pacifica*, 30–506.
Thyasira gouldii (Philippi)	×	×	×		16–167.
Axinopsis viridis Dall	×	×	×		30.
Macoma calcarea (Gmelin), small variety		×			Apparently identical with a small race, 13–51.
Katherinella subdiaphana (Carpenter)		×	×		13–270.
Pratulum centifilosum (Carpenter)	×	×	×		16–108.
Thracia trapezoides (Conrad)	×	×			16–51.

[1] Arnold, Ralph, California Acad. Sci. Mem., vol. 3, p. 341, 1903. Clark, Alex, San Diego Soc. Nat. History Trans., vol. 7, No. 4, table op. p. 30, 1931. Willett, George, Southern California Acad. Sci. Bull., vol. 36, p. 64, 1937.
[2] Arnold, Ralph, op. cit.
[3] Idem. Oldroyd, T. S., U. S. Nat. Mus. Proc., vol. 65, art. 22, p. 21, 1924.
[4] Arnold, Ralph, op. cit.
[5] Arnold, Ralph, op. cit., pp. 327–328.
[6] Willett, George, op. cit., p. 63, pl. 25.
[7] Arnold, Ralph, op. cit., p. 291. Clark, Alex, op. cit.
[8] Willett, George, op. cit., p. 62.
[9] Arnold, Ralph, op. cit., pp. 286–287.
[10] Idem, pp. 224–225.
[11] Idem, p. 228.
[12] Idem, p. 253 ("*tenuisculptus*").
[13] Idem, p. 252 ("*scalariformis*"). Clark, Alex, op. cit.
[14] Arnold, Ralph, op. cit., p. 251 ("*multicostatus*"), p. 252 ("*scalariformis*").
[15] Idem, pp. 252–253. Clark, Alex, op. cit.
[16] Arnold, Ralph, op. cit., pp. 252–253.
[17] Arnold, Ralph, U. S. Geol. Survey Prof. Paper 47, pp. 126–127, 1906 ("*riversi*").
[18] Crickmay, C. H., Canadian Field Naturalist, vol. 43, No. 5, p. 93, 1 fig., 1929.

The number of species in the preceding table would be considerably larger if all the mollusks were identified. Turrids of the genera *Propebela* ["*Lora*"], "*Taranis*," and *Borsonella* occur in the Lomita marl and Timms Point silt but are rare or absent in the other Pleistocene units. At the present time these genera belong to the moderate-depth and moderate-depth to deep-water groups.

LOMITA MARL

The Lomita marl includes several faunal associations, which are interpreted as different depth associations ranging from shallow water to about 100 fathoms.

A shallow-water facies representing a depth of 10 fathoms or less is identified at locality 61, near Lomita quarry. At locality 61 the fossils occur in gravel and coarse-grained calcareous sand, many of the specimens being broken and worn. This is the only locality where an oyster, *Ostrea megodon cerrosensis*, was found in the Lomita marl, and none of the species characteristic of moderate depths are present. A heavily sculptured form of *Turritella pedroensis* and *Olivella biplicata* are abundant.

The algal bed at Hilltop quarry is thought to represent a depth of between 25 and 50 fathoms. The following species are particularly abundant in that bed:

Most abundant mollusks in algal bed of Lomita marl at Hilltop quarry (localities 53, 53a)

Gastropods:

- Pupillaria optabilis (Carpenter).
- Pomaulax undosus (Wood).
- Pachypoma gibberosum (Dillwyn).
- Homalopoma carpenteri (Pilsbry).
- Bittium rugatum Carpenter.
- Bittium attenuatum Carpenter.
- Bittium asperum (Gabb).
- Bursa californica (Hinds).
- Kelletia kelletii (Forbes).
- Mitrella tuberosa (Carpenter).
- Amphissa versicolor Dall.
- Conus californicus Hinds.

Pelecypods:

- Glycymeris profunda (Dall).
- Cyclocardia aff. C. occidentalis (Conrad).
- Ventricola fordii (Yates).

There are no shallow-water Littorinas, Anomias, mussels, Aequipectens, oysters, or large chamids in the algal bed, but the following moderate-depth species are present:

Moderate-depth species in algal bed of Lomita marl at Hilltop quarry (localities 53, 53a)

Gastropods:
- Acmaea funiculata (Carpenter)?
- Puncturella delosi Arnold.
- Solariella rhyssa Dall.
- Homalopoma subobsoletum (Willett).
- Alvania acutelirata rosana Bartsch.
- Bittium rugatum Carpenter.
- Bittum asperum (Gabb).
- Fusitriton oregonensis (Redfield).
- Neptunea tabulata (Baird).
- Admete gracilior (Carpenter).

Pelecypods:
- Pecten stearnsii Dall.
- Eucrassatella fluctuata (Carpenter).
- Cyclocardia aff. C. occidentalis (Conrad).

The algal bed represents evidently an exceptional environment. Though calcareous algae are abundant in some layers of the Lomita elsewhere, they do not elsewhere play such an overwhelming part among the constituents. Seven species of mollusks, notably *Pomaulax turbanicus petrothauma* and *Tritonalia coryphaena*, were not found elsewhere.

The calcareous sand and gravel at locality 54g, constituting unit 7 of the section in the canyon adjoining Hilltop quarry, is thought to represent the same depth range as the algal bed. For unknown reasons calcareous algae are much less abundant than in the algal bed. The fossils in calcareous sand and marl at other localities indicate essentially the same depth range, between 25 and 50 fathoms. All the Lomita moderate-depth species are present in those strata, with the exception of *Pseudamussium*, *Hyalopecten*, *Propeamussium*, and *Thracia trapezoides*. In some layers of both calcareous sand and marl, such as the calcareous sand at locality 42d, only small and minute shells, particularly herbivorous gastropods, and young shells are present, suggesting current sorting. The most perfectly preserved fossils were collected from the dump of the central shaft of the Whites Point tunnel (locality 57). *Bittium rugatum*, *Turritella pedroensis*, *"Nassa" mendica cooperi*, *Olivella biplicata*, *Conus californicus*, and *Cyclocardia* aff. *C. occidentalis* are abundant at locality 57. Three species of *Boreotrophon* are present.

The glauconitic foraminiferal sand and foraminiferal calcareous sand in the lower part of the section exposed in the canyon adjoining Hilltop quarry and forming the exposed section at Lomita quarry are thought to represent a greater depth, between 50 and 100 fathoms. *Cyclocardia barbarensis* is generally abundant in those strata (localities 54, 54a, 54c, 54e, 54f, 62b). *Cyclocardia* off *C. occidentalis* occurs, however, in some layers (localities 54a, 54c). In the dark-colored glauconitic sand at Lomita quarry (locality 62b) *Cyclocardia barbarensis* is the only abundant mollusk, and it is associated with *Pseudamussium* n. sp., *Hyalopecten vancouverensis*, and *Propeamussium alaskensis*, an association suggesting a depth of about 100 fathoms. The marl in San Pedro containing *Thracia trapezoides* (localities 37, 41) also represents probably a depth greater than 50 fathoms.

Wherever more than one inferred depth facies is represented in the same section, the deeper facies underlies the more shallow facies. This relation is well shown in the section exposed in the canyon near Hilltop quarry, where *Cyclocardia barbarensis*-bearing glauconitic foraminiferal sand and foraminiferal calcareous sand thought to represent a depth of between 50 and 100 fathoms, is overlain by calcareous sand and gravel characterized by fossils whose depth range is inferred to be between 25 and 50 fathoms. The large-cobble calcareous gravel at the top of the section represents doubtless a shallow facies, but no fossils were found in it. The shallow-water gravel and calcareous sand at locality 61 is younger evidently than the 50-fathom to 100-fathom facies at Lomita quarry; intervening strata are not exposed.

As shown in the tables on pages 87–89, the Lomita marl contains 12 identified northern species, 6 of which are locally extinct, but are living farther north. The northern *Fusitriton oregonensis*, *Chlamys islandicus jordani*, *Patinopecten caurinus*, *Thracia trapezoides*, and the essentially northern *Neptunea tabulata*—all of which occur in the Lomita marl—have been considered characteristic of the Timms Point silt. On the contrary the Lomita contains 20 identified southern species. Of the southern species still living only one, *Macron aethiops*, is more than 100 miles north of its present range. *Pomaulax turbanicus petrothauma* and *Ostrea megodon cerrosensis*, which are not known to be living, are closely related to species living hundreds of miles farther south. An early statement[5] that the Lomita marl includes a fauna of warmer facies than the fauna of the Palos Verdes sand is now considered erroneous. The temperature of the water was probably essentially the same as at the present time in this region. Inasmuch as the sediments were deposited on the leeward side of an island, the temperature of the shallower water between the island and the mainland may have been higher than at the present time, owing to protection from upwelling cold water. It is not known, however, whether the leeward side of Catalina and other nearby islands is so protected. Gale[6] assigned the Lomita marl to the first interglacial stage. This matter is considered under the heading "Glacial-interglacial assignments," page 100.

The Lomita sediments at most localities indicate clear water. An environment evidently comparable to that of parts of the Lomita has been found on the leeward side of Catalina Island, where calcareous sediments are accumulating on a shelf at a depth of about 40 to 50 fathoms.[7] A sample of the calcareous sediments from a depth of 45 fathoms off Avalon is available through the kindess of Professor Shepard. The proportion of detrital nonorganic material, estimated to be 25 percent, is larger than in much of the Lomita. The principal organic constituents in approximate order of decreasing abundance are as follows: Foraminifera, calcareous algae, mollusks, echinoid spines, Bryozoa. Mollusks are represented by about 50 species. With few exceptions, notably some valves of *Cyrilla munita*, the specimens are bleached, worn, and broken. As in much of the Lomita, the specimens are small, consisting of adult small shells and young shells or small fragments of larger species. Species of considerable size, such as *"Nassa" mendica cooperi?*, *Glycymeris* sp., *Eucrassatella fluctuata?*, and *Pratulum centifilosum?*, are represented, but the specimens are minute young shells or fragments not more than a few millimeters

[5] Woodring, W. P., Warm-water faunas of the so-called Pliocene of San Pedro (abstract): Geol. Soc. America Bull., vol. 41, pp. 211–212, 1930.
[6] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), p. 71, 1931.
[7] Shepard, F. P., and Wrath, W. F., Marine sediments around Catalina Island: Jour. Sedimentary Petrology, vol. 7, pp. 45, 48, 1937.

long. The faunal association resembles that of much of the moderate-depth facies of the Lomita. *Boreotrophon*, *Admete*, *Thyasira*, and *Axinopsis*, which are abundant generally in that facies of the Lomita, are, however, not represented.

Along the north border of the Palos Verdes Hills, west of the Gaffey anticline, the Lomita calcareous sediments contain a considerable amount of silty sand and sand. The fauna is, however, essentially the same as in purer calcareous sand farther east.

TIMMS POINT SILT

The Timms Point silt contains several faunal associations that are not strikingly different. They are inferred to represent a moderate-depth range of between 50 and 100 fathoms.

At Timms Point pockets of calcareous silt at the base of the formation contain a fauna of small and young shells indistinguishable from that in calcareous sand of the Lomita marl. This material may represent detrital constituents from the Lomita marl, but the fossils are as fresh as those in the undisturbed Lomita marl. It represents more probably a nondetrital facies during the early stage of the marine transgression. The size sorting of the fossils suggests current sorting.

The remainder of the section at Timms Point contains a fauna characterized by the abundance of the moderate-depth and northern species listed on pages 87–89. This association is thought to represent a depth close to 100 fathoms, a conclusion reached by Bagg [8] from a study of the Foraminifera. The northern *Thyasira disjuncta* and *Mya truncata* have been found in unit 2 but not in unit 1. The slight faunal distinction between units 1 and 2 is probably of doubtful value, for *Trachycardium quadragenarium*, formerly thought to be characteristic of unit 1, and *Pandora grandis*, thought to be characteristic of unit 2, occur together at locality 34 on Harbor Boulevard. The stratigraphic relations at locality 34 are uncertain, but the strata represent probably unit 2. On Deadman Island Crickmay [9] found *Thyasira disjuncta* only in his zone 5, which is therefore faunally similar to unit 2 so far as the occurrence of that species is concerned. The occurrence of *Pandora grandis* at locality 44 on Second Street likewise suggests unit 2.

The Timms Point silt is identified doubtfully on lithologic grounds at locality 52, immediately west of Gaffey Street. The few fossils collected are inconclusive, however, as they might represent the Lomita, Timms Point, or San Pedro. A Timms Point fauna at locality 66, on the north border of the hills near Agua Magna Canyon, suggests unit 2 at Timms Point, as it includes *Mya truncata* and *Pandora grandis*.

A marked feature of the Timms Point fossils is the prevalence of moderate-depth species, most of which occur also in the Lomita marl, and the scarcity or absence of shallow-water species. The only oyster is a minute shell from locality 66. There are no Anomias, mussels, or large chamids. The specimens of *Olivella biplicata*, though locally abundant, are worn and broken, and the few specimens of *Conus californianus* are likewise worn and broken, suggesting transportation from an area of shallow water.

Owing to the relatively large number of northern species, the northern aspect of the Timms Point fossils has been emphasized repeatedly. Arnold [10] considered the fauna boreal, Smith [11] thought the temperature of the water was about the same as that of Puget Sound, and Gale [12] assigned the Timms Point silt to the second glacial stage. This matter is considered under the heading "Glacial-interglacial assignments," page 100.

The Timms Point silt is inferred to represent the same depth range as the lower part of the Lomita marl. Whether the difference in faunal associations may be accounted for by the clearer water indictaed by the Lomita is not known. All except one of the locally extinct northern species that give the Timms Point fauna its individuality are pelecypods, the presence or absence of which may be controlled by the character of the bottom.

SAN PEDRO SAND

The San Pedro sand contains several well-marked faunal associations, which like the associations in the Lomita marl are attributed to different depth facies.

A shallow-water facies is recognized along and near Harbor Boulevard at localities 49, 49a, and 50. At these localities the fossils include *Cerithidea californica*, *Macron aethiops kellettii*, "*Cancellaria*" *tritonidea*, *Terebra pedroana*, *Melampus olivaceus*, *Anomia peruviana*, *Ostrea lurida*, and large sand dollars, most of which were not found in the San Pedro sand in San Pedro. A shallow-water *Anomia-Ostrea* facies, characterized by the abundance of *Anomia peruviana* and *Ostrea lurida*, is represented on the south limb of the Gaffey syncline at localities 58a and 59 and in less characteristic form at locality 56. *Tegula ligulata* was found in the San Pedro sand only at localities 58a and 59. All the shallow-water species mentioned and the other species represented at those localities occur also in the younger Palos Verdes sand. In fact, this Palos Verdes-like shallow-water facies of the San Pedro sand is so similar to the usual Palos Verdes facies that there is some doubt about the age assignment, the stratigraphic evidence being inconclusive. At localities 49 and 58a, however, fossiliferous sand and gravel containing southern species characteristic of the Palos Verdes overlie the strata identified as the San Pedro sand. The Palos Verdes-like facies represents evidently protected shallow water lying in the lee of the growing Gaffey anticline. It includes, like the usual Palos Verdes facies, tide-flat species—*Cerithidea californica* and *Melampus olivaceus*.

Localities 47 and 47a in San Pedro and Oldroyd's nearby Nob Hill locality [13] are thought to represent shallow water. The water was deeper, however, than at the localities just described, or species from depths greater than 10 fathoms were washed in by storm waves, as Oldroyd [14] inferred. Whether the fresh-water *Hydrobia protea* from locality 47a and the fresh-water pulmonates recorded by Arnold lived in streams on the Pleistocene Palos Verdes Hills island or were derived from the mainland is not known. If they lived on the island, the climate was more humid than at present.

At localities 30 on Deadman Island, 48 in northwestern San Pedro, 58 on Western Avenue, and 64 and 65 on the north border of the hills along Bent Spring Canyon, the San Pedro sand includes moderate-depth species not found elsewhere in that unit. Those

[8] Bagg, R. M., Jr., Pliocene and Pleistocene Foraminifera from southern California: U. S. Geol. Survey Bull. 513, p. 13, 1912.

[9] Crickmay, C. H., The anomalous stratigraphy of Deadman's Island: Jour. Geology, vol. 37, pp. 626–627, 1929.

[10] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, p. 16, 1903.

[11] Smith, J. P., Climatic relations of the Tertiary and Quaternary faunas of the California region: California Acad. Sci. Proc., 4th ser., vol. 9, p. 151, 1919.

[12] Grant, U. S., IV, and Gale, H. R., op. cit., p. 71.

[13] Oldroyd, T. S., The fossils of the lower San Pedro fauna of the Nob Hill cut, San Pedro, Calif.: U. S. Nat. Mus. Proc., vol. 65, art. 22, 39 pp., 2 pls., 1924.

[14] Idem, p. 1.

localities therefore are inferred to represent a moderate depth, probably between 25 and 50 fathoms. These species are as follows:

Moderate-depth species found in San Pedro sand at localities 30, 48, 58, 64, and 65 but not elsewhere in that unit

Species	Locality				
	30	48	58	64	65
Gastropods:					
Acmaea funiculata (Carpenter)	×				
Puncturella cooperi Carpenter	×				
Puncturella delosi Arnold					×
Turcica caffea (Gabb)	[1] ×				
Alvania acutelirata rosana Bartsch	×			×	×
Bittium rugatum larum Bartsch	×				
Elassum californicum (Dall and Bartsch) [2]	×				
Crepipatella charybdis (Berry)	×				
Neptunea tabulata (Baird)	×		×		×
Pelecypods:					
Nucula aff. N. cardara Dall	×	×			
Acila castrensis (Hinds)	×	×		×	
Pecten stearnsii Dall?			×	×	
Chlamys hastatus (Sowerby)				×	×
Patinopecten caurinus (Gould) [3]	×				
Eucrassatella fluctuata Carpenter				×	
Thyasira gouldii (Philippi)	×				
Axinopsis viridis Dall	×	×		×	
Katherinella subdiaphana (Carpenter)	×				
Pratulum centifilosum (Carpenter)	×				

[1] Arnold, Ralph, California Acad. Sci. Mem., vol. 3, pp. 327–328, 1903.
[2] Not known to be living. Associated with intermediate-depth species in Lomita marl and Timms Point silt.
[3] A northern species associated with intermediate-depth species in Lomita marl and Timms Point silt.

At locality 64 the fossils occur in silty sand containing lenses of coarse sand and gravel resting on Miocene strata on the north flank of the Gaffey anticline. At locality 65 nearby they occur in marly silty sand overlying about 100 feet of coarse sand and gravel. At both localities the faunal association closely resembles that in the Lomita marl at numerous places. The strata at locality 64 are in the stratigraphic position of the Lomita marl and Timms Point silt; those at locality 65 are at the exposed top of the San Pedro sand. The sand containing moderate-depth species at locality 58 underlies the shallow-water *Anomia-Ostrea* facies of locality 58a. The fossils from locality 73a, in the fifth ravine west of Hawthorne Avenue, represent apparently shallower water than those just described.

The San Pedro sand contains 6 locally extinct northern species but no locally extinct southern species far north of its present range, with the exception of Arnold's record of *Trachycardium procerum*, which may perhaps be questioned. It contains both northern and southern species now at or close to the limits of their range in the latitude of San Pedro. Arnold [15] considered the fauna of the San Pedro sand to be transitional cool-water; Smith [16] considered it cool-water and thought it corresponded to the time of maximum glaciation; Gale [17] assigned it to the second interglacial period. This matter is discussed under the heading "Glacial-interglacial assignments," page 100.

MARINE TERRACE DEPOSITS OLDER THAN PALOS VERDES SAND

Fossils have been found in marine deposits on 8 of the 12 main terraces older than the first or lowest terrace. With the exception of a few localities, the fossils represent a more uniform facies than those already described. The usual facies and the only facies now known from the twelfth to fifth terrace, inclusive, consists of species that live on rocks and in tide pools but includes species living below low-tide line. This facies has been designated a tide-pool facies.[18] It is more appropriate, however, to designate it a facies that represents both rock-cliff and tide-pool environments. The most abundant species in this facies and their present habitat are as follows:

[15] Arnold, Ralph, op. cit., p. 20.
[16] Smith, J. P., op. cit., pp. 136–137.
[17] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), p. 71, 1931.
[18] Woodring, W. P., Fossils from the marine Pleistocene terraces of the San Pedro Hills, Calif.: Am. Jour. Sci., 5th ser., vol. 29, p. 297, 1935.

Most abundant species in rock-cliff and tide-pool facies of marine terrace deposits older than Palos Verdes sand and their present habitat

Species	Present habitat
Gastropods:	
Acmaea limatula Carpenter	Rock, intertidal.
Acmaea scabra (Gould)	Rock, from upper edge of spray to low-tide line.
Acmaea asmi (Middendorff)	On *Tegula*.
Haliotis cracherodii Leach	In crevices and under rocks, intertidal and below low-tide line.
Fissurella volcano Reeve	Rock, intertidal.
Tegula funebralis (Adams)	Rock, intertidal and tide pools.
Tegula gallina (Forbes)	Rock, at high-tide line and intertidal.
Pseudorotella invallata (Carpenter)	Tide pool, under loose rocks and among eel grass roots.
Pseudorotella supravallata (Carpenter)	(same as above)
Homalopoma carpenteri (Pilsbry)	Tide pool, under loose rocks.
Homalopoma bacula (Carpenter)	(same as above)
Littorina planaxis Philippi, small form	Rock, in spray zone.
Littorina scutulata Gould	Rock, intertidal.
Barleeia haliotiphila Carpenter	In "moss" on abalones.
Truncatella stimpsoni Stearns	Under loose rocks near high-tide line.
Truncatella californica Pfeiffer	(same as above)
Syncera translucens (Carpenter)	In vegetation just above high-tide line.
Spiroglyphus lituella (Mörch)	Rocks, interdial.
Hipponix antiquatus (Linne)	Tide pool, in rock crevices.
Hipponix tumens Carpenter	(same as above)
Gadinia reticulata (Sowerby)	Rock, in crevices, intertidal.
Pelecypods:	
Septifer bifurcatus (Conrad)	Tide pool, in rock crevices and under loose rocks.
Glans subquadrata (Carpenter)	Attached to under side of rocks, intertidal.
Epilucina californica (Conrad)	Tide pool, in sand between rocks.

Gastropods greatly outnumber pelecypods in the rock-cliff and tide-pool facies, the average ratio of pelecypod species to gastropod species in 28 collections being 1 : 5.2. In no collection are there more than 7 species of pelecypods.

The fossils from the twelfth terrace at an altitude of 1,215 feet above sea level are representative of the rock-cliff and tide-pool facies. This collection is of exceptional interest, as it represents the greatest altitude at which Pleistocene marine terrace fossils have been found along the California coast. The species are as follows:

Fossils from marine deposits on twelfth terrace, altitude 1,215 feet above sea level (locality 75)

Species	Abundance and condition
Gastropods:	
Acmaea limatula Carpenter	Common, worn.
Acmaea scabra (Gould)	Abundant, well-preserved.
Acmaea pelta "Eschscholtz" Rathke	Common, worn.
Acmaea insessa Hinds?	Rare, 1 worn small.
Haliotis cracherodii Leach	Common, 1 well-preserved, others worn fragments.
Fisurella volcano Reeve	Abundant, well-preserved.
Lucapinella callomarginata ("Carpenter" Dall)?	Rare, 1 small fragment.
Diodora aspera ("Eschscholtz" Rathke)	Rare, 1 worn.
Norrisia norrisi (Sowerby)	Common, small, broken.
Tegula gallina (Forbes)	Abundant, apex generally broken.
Tegula brunnea (Philippi)?	Rare, 1 worn, broken.
Pupillaria succincta (Carpenter)	Rare, well-preserved.
Pomaulax undosus (Wood)?	Rare, columellar fragments.
Homalopoma carpenteri (Pilsbry)	Common, broken and fragments.
Homalopoma bacula (Carpenter)	Rare, 1 well-preserved, 2 broken.
Homalopoma paucicostatum fenestratum (Bartsch)	Common, broken.
Littorina planaxis Philippi, small form	Abundant, mostly somewhat worn.
Littorina scutulata Gould	Abundant, some well-preserved, others broken.
Bittium armillatum Carpenter	Common, worn or broken.
Bittium interfossa (Carpenter)	Common, 1 well-preserved, others broken.
Cerithiopsis williamsoni (Arnold)	Rare, broken or worn.
Seila montereyensis Bartsch	Common, broken and worn.
Triphora pedroana Bartsch	Common, broken and somewhat worn.
Aletes squamigerus Carpenter	Abundant, pieces.
Hipponix antiquatus (Linné)	Abundant, mostly well-preserved.
Hipponix tumens Carpenter	Abundant, mostly well-preserved.
Crepidula aculeata (Gmelin)	Rare, worn.
Crepipatella lingulata (Gould)	Rare, worn.
Harfordia monksae (Dall)?	Rare, 1 worn fragment.
"Fusinus" luteopictus Dall?	Rare, 1 well-preserved, very small.
Mitra idae Melvill	Rare, 1 broken and worn.
"Nassa" mendica cooperi Forbes	Rare, 1 small, broken, worn.
Tritonalia interfossa (Carpenter)	Common, small, broken.
Tritonalia gracillima (Stearns)?	Rare, 2 apertural fragments.
Amphissa versicolor Dall	Common, broken and worn.
Olivella biplicata (Sowerby)	Abundant, broken or worn, or both.
Pseudomelatoma torosa (Carpenter)?	Rare, 2 small, broken, worn.
Mangelia cf. M. rhyssa (Dall)	Rare, 2 somewhat worn.
Mitromorpha filosa (Carpenter)	Rare, 1 worn.
Mitromorpha gracilior ("Hemphill" Tryon)	Rare, 1 broken, worn.
Mitromorpha aspera (Carpenter)	Rare, 2 well-preserved, 1 broken, worn.
Conus californicus Hinds	Abundant, worn, or worn and broken.
Gadinia reticulata (Sowerby)	Rare, somewhat worn.
Pelecypods:	
Septifer bifurcatus (Conrad)	Abundant, well-preserved.
Glans subquadrata (Carpenter)	Common, well-preserved, or somewhat worn.
Epilucina californica (Conrad)	Common, well-preserved, or somewhat worn and broken.

The fossils recorded by the Chaces [19] from deposits on the second terrace near Point Fermin (locality 94) also represent the rock-cliff and tide-pool facies. The abundance of chitons is, however, exceptional.

Most of the species that are now abundant along rocky stretches of the coast of the Palos Verdes Hills are present in the rock-cliff and tide-pool facies. *Acmaea digitalis* and *Mytilus adamsianus* are notable exceptions, and *Mytilus californicus* is rare among the fossils. On the contrary, the fossils include shallow-water species that live below low-tide line, species that live at moderate depths in the latitude of San Pedro (*Acmaea mitra*, *Diodora aspera*), species that are almost extinct locally though abundant a little farther north (*Tegula funebralis*), northern and southern species that are close to the present limits of their range, a locally extinct northern species, and a locally extinct southern species.

Two localities are notable exceptions to the prevailing terrace facies. At Bluff Cove, 69 species of gastropods and 19 of pelecypods were collected from deposits on the fourth terrace (locality 86). In addition to expectable terrace species this collection includes *Terebra pedroana*, *Bulla gouldiana*, *Haminoea*, *Crassinella branneri*, *Lucinisca nuttallii*, *Macoma nasuta*, *Macoma secta*, and *Cryptomya californica*, all of which are well-preserved. These species indicate protected shallow water. The faunal association is therefore a mixture of rock-cliff, tide-pool, and protected shallow-water facies. The protected shallow-water species were transported presumably from a locality nearby. A similar mixed faunal association was found on the second terrace in the Malaga Cove residential district (locality 105). At that

19 Chace, E. P., and E. M., An unreported exposure of the San Pedro Pleistocene: Lorquinia, vol. 2, No. 6, pp. 41-43, 1919.

locality 70 species of gastropods and 39 of pelecypods were collected from coarse sand trapped in a niche and sealed by boulders. The fossils include *Rissoina kelseyi*, *R. pleistocena*, *Crucibulum spinosum*, *Trivia solandri*, *Mitra fultoni*, *Jaton santarosanus?*, *Nucula suprastriata*, *Sacella taphria*, *Yoldia*, *Glycymeris corteziana*, *Anomia peruviana*, *Botulina* "*opifex*", *Crenella*, *Pecten vogdesi*, *Ostrea lurida*, *Crassinella nuculiformis*, *Diplodonta sericata*, *Semele decisa*, *Chione succincta*, and *Trigoniocardia biangulata*, in addition to usual terrace species. Most of the exceptional species indicate protected shallow water, but a few suggest water of moderate depth. At Hilltop quarry (locality 93) a few poorly preserved fossils collected from deposits on a terrace identified as the third, but possibly representing the second, include *Turritella pedroensis*, *Bursa californica?*, and "*Cancellaria*" *tritonidea?*. This is the only locality where those species were found in terrace deposits older than the Palos Verdes sand. All the specimens are broken and battered and may be detrital.

The distribution of northern and southern terrace species is shown in the tables on pages 87–89. The one northern species now locally extinct is from the rock-cliff and tide-pool facies of the fourth and second terraces. The eight southern locally extinct species are from the fourth and second terraces and with two exceptions are from the unusual localities 86 and 105 just described. The exceptions are *Acanthina lugubris* from rock-cliff and tide-pool facies on the fourth terrace at localities 82, 84, and 85, and from the same facies on the second terrace at localities 94 and 106, and "*Chione*" *picta* reported orally by Chace from a protected shallow-water facies on the second terrace at Fifteenth Street near Leland. Northern species at or close to the southern limit of their present range were found on the fifth to second terraces, inclusive, and similar southern species on the sixth to second, inclusive. Owing to the presence of several chitons now rare as far south as San Pedro, Berry [20] thought that the deposits on the second terrace near Point Fermin are to be correlated with the San Pedro sand. This matter is discussed under the heading "Glacial-interglacial assignments," page 100.

PALOS VERDES SAND

The 38 fossil localities representing the Palos Verdes sand, the marine deposits on the first or youngest terrace, are on the leeward (east and northeast) side of the hills. The prevailing faunal association, and the only association from localities 110, 111, and 112 northward and northwestward to locality 142, consists principally of species that indicate protected shallow water. Locally extinct southern species, notably *Crassinella branneri*, *Crassinella nuculiformis*, and *Trachycardium procerum*, are characteristic of this facies. During Palos Verdes time shallow-water bays evidently extended into the island formed by the Palos Verdes Hills from the strait separating the island from the mainland. Tide-flat species, *Cerithidea californica* and *Melampus olivaceus*, occur at numerous localities. Most of the material is not in place and represents current-strewn debris. It is generally necessary to sort great quantities of broken shells and fragments to find well-preserved shells. *Macoma* and *Macoma*-"*Paphia*" layers at localities 113 and 114 and nearby in northeastern San Pedro represent protected shallow-water species that are essentially in place. Rock-cliff and tide-pool species are generally rare, though most of the species in that facies on the older terraces occur also in the Palos Verdes sand. Their scarcity in the Palos Verdes sand is attributed to the prevalence of soft Miocene and Pleistocene rocks along much of the Palos Verdes coast on the leeward side of the hills. Fresh-water snails—*Valvata humeralis californica*, *Amnicola longinqua*, *Hydrobia protea*, and pulmonates of the genera *Helisoma*, *Gyraulus*, and *Physa*—are rare constituents. If these snails lived in streams on the island, the climate was more humid than at present.

The mixed faunal association at Arnold's lumber yard locality (locality 113), more thoroughly explored than any other Palos Verdes locality, has been discussed by Miller.[21] Marine mollusks, mostly broken shells in a matrix of coarse-grained sand and gravel, form the bulk of the fossil material. Remains of sting rays are fairly common. Fossil shore and ocean birds (loon, grebe, albatross, shearwater, fulmar, cormorant, goose, mallard, teal, surf scooter, diving goose, gull, and murrelet) and mammals (seal, sea lion, and whale), all represented by rare fragmentary remains, are expectable in marine strata. Fresh-water mollusks and mud turtle are fresh-water constituents. Land animals are represented by rare fragmentary remains of birds (vulture, eagle, quail, and meadowlark) and mammals (canid, felid, rodent, ground sloth, horse, cervid, camelid, bison, and mammoth). It is inferred that this material was deposited in shallow current-swept marine water. Most of the fresh-water and land animals, except birds, were probably derived from the mainland and represent presumably drift carcasses stranded on the shore of the island formed by the Palos Verdes Hills during Palos Verdes time.

A beach facies, in which fossils occurred in cross-laminated sand, was formerly represented at locality 109 in San Pedro, at Palos Verdes and Eighth Streets. The fossils, all more or less worn and broken, include numerous specimens of small gastropods, "*Nassa*" *perpinguis*, *Mitrella carinata*, *Olivella biplicata*, and *Olivella pedroana*. None of the southern species characteristic of the protected shallow-water facies were found at this locality, but the collection consists of only 48 species.

An exceptional faunal association occurs at localities 108 (Arnold's Crawfish George's locality) and 107. Both localities are on the east coast, near Cabrillo Beach, and are farther south than other Palos Verdes localities. None of the characteristic southern species occur at these localities. On the contrary, the collections include *Fusitriton oregonensis*, *Exilioidea rectirostris*, *Boreotrophon* aff. *B. multicostatus*, *Nucella lamellosa*, and *Amphissa columbiana*, all northern species not found at other Palos Verdes localities. The northern *Boreotrophon pedroanus* occurs at locality 108 and also at locality 121, where it is associated with the southern *Crassinella* and *Trachycardium procerum*. A similar mixed association was represented at Deadman Island, where Crickmay [22] found the northern or essentially northern *Fusitriton oregonensis* ["*Argobuccinum*"], *Neptunea tabulata* ["*Chrysodomus*"], *Boreotrophon* "*pacificus*" ["*Trophon*"], *Nucella lamellosa* ["*Thais*"], and *Amphissa columbiana* associated with the southern *Crassinella branneri*.

[20] Berry, S. S., Fossil chitons of western North America: California Acad. Sci. Proc. 4th ser., vol. 11, pp. 408–409, 1922.

[21] Miller, L. H., Further bird remains from the upper San Pedro Pleistocene: Condor, vol. 32, pp. 116–117, 1930.

[22] Crickmay, C. H., op. cit. (Jour. Geol., vol. 37), pp. 631–632, 1929.

Owing to the prevalence of southern species in the Palos Verdes at most localities, Arnold [23] thought that during Palos Verdes time the temperature of the water was as warm as at San Pedro at the present time and probably warmer. Smith [24] estimated that the temperature was 4° F. higher than at present and that the fauna is probably interglacial, and Gale [25] assigned it to the last interglacial period. This matter and the exceptional faunal association at localities 107 and 108 are considered under the heading "Glacial-interglacial assignments," page 100.

AGE AND CORRELATION

CORRELATION WITHIN PALOS VERDES HILLS

Wherever the Lomita marl and Timms Point silt are found they are at the base of the Pleistocene strata. In one area, central San Pedro, the Timms Point silt overlies the Lomita marl. The Lomita marl is interpreted as representing deposition in clear water during a period of varying duration from place to place beginning with the early stage of the Pleistocene transgression and resulting in calcareous sediments ranging in thickness from a few inches to about 275 feet. The greatest thickness of calcereous sediments is in the Gaffey syncline, which was protected from the flood of granitic sand derived from the north by the growing Gaffey anticline.[26] The Timms Point silt is interpreted as representing deposition in less clear water during a period also of varying duration, beginning with the early stage of the Pleistocene transgression. In central San Pedro the deposition of silt began after the deposition of calcareous sediments ended. Though representing varying duration and despite the superposition in central San Pedro, the Lomita marl and Timms Point silt are thought to be essentially synchronous on both stratigraphic and paleontologic grounds. The faunas of these two formations have much in common, owing doubtless to the prevailing moderate-depth facies of both formations. The principal faunal differences are attributed to the absence of shallow-water and 25-fathom to 50-fathom facies in the Timms Point silt and to the presence in that formation of northern pelecypods. The calcareous silt occurring in pockets at the base of the Timms Point silt at Timms Point is lithologically and faunally indistinguishable from parts of the Lomita marl. The marl in the lower part of the Lomita in central San Pedro is probably the equivalent of the lower part of the Timms Point silt at Timms Point. Both marl and silt contain the northern *Thracia trapezoides*, not found elsewhere in the Lomita.

Much of the San Pedro sand is younger than the Lomita marl and Timms Point silt, but locally parts of the San Pedro are clearly of the same age as those formations. Fossiliferous San Pedro sand in San Pedro is younger than the Lomita and Timms Point of that area. Fossils occur, however, at the base of the San Pedro sand immediately above the contact with Miocene mudstone, at locality 64, on the north flank of the Gaffey anticline, along Bent Spring Canyon. The fossiliferous silty sand at that locality and overlying sand and gravel are without any reasonable doubt the equivalent of calcareous strata of the Lomita marl on the opposite flank of the Gaffey anticline. Despite the difference in the character of the sediments, the faunal association in the San Pedro sand at locality 64 is virtually indistinguishable from that in calcareous Lomita sediments indicating a depth of between 25 and 50 fathoms. Furthermore, the same faunal association is found nearby at locality 65 in marly silty sand at the very top of about 100 feet of San Pedro sand and gravel. This does not mean necessarily that the intervening 100 feet of sand and gravel were deposited at depths of between 25 and 50 fathoms, for the fossiliferous strata at locality 65 may represent a period when rate of subsidence outran rate of deposition of sand and gravel. The occurrence of the fossils in silty sand or marly silty sand at localities 64 and 65 indicates a different environment from that of the intervening clean coarse sand and gravel.

The marine terrace deposits, even those on the oldest terraces, are thought to be younger than the lower Pleistocene formations. If it be assumed that the entire present area of the Palos Verdes Hills acted as a unit during the intermittent emergence that produced the terraces, the present east and north borders of the hills, where the lower Pleistocene strata are found at or near sea level, were submerged to a depth of at least 1,300 feet when the emergence began. No sediments in the lower Pleistocene formations are interpreted as representing a depth as great as that. The Timms Point silt and the lower part of the Lomita marl are interpreted, however, as representing depths of between 50 and 100 fathoms (300 to 600 feet). So far as inferred depth is concerned, such sediments qualify as being contemporaneous with some of the intermediate terraces. It may be argued that the terrace deposits are younger than the deformation assigned to the middle Pleistocene. The absence of deformation of intermediate and oldest terraces is not opposed, however, to this possible correlation, for the lower Pleistocene strata, aside from tilting resulting probably from uplift, are not deformed except along the north border of the hills, where the youngest terrace itself is mildly or moderately deformed. The presence of large cobbles and boulders in the Lomita marl where it rests on its basement and the occurrence of a shallow-water facies in that formation are opposed to the correlation. In view of these relations it is inferred that the thin veneer of deep-water and moderate-depth sediments deposited during the relatively brief episodes when the oldest and intermediate terraces were formed was removed by marine erosion during the formation of successively younger terraces.

AGE

The formations in the San Pedro district that are considered of Pleistocene age are assigned to that epoch because they contain a fauna more modern than that of Coast Range formations assigned to the upper Pliocene. The division of Pleistocene into lower, middle, and upper parts is relative and more or less arbitrary. It is adopted for convenience and is based on events in the geologic history of the Palos Verdes Hills. Both lower and upper Pleistocene strata may include deposits of middle Pleistocene age.

It was formerly thought that the marine Pleistocene formations contain no extinct genera of mollusks. *Elassum* and *Calicantharus* are, however, not known to be living. *Elassum* is associated with species of moderate-depth facies and may be found to be living when the moderate-depth fauna of southern California

[23] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, p. 29, 1903.
[24] Smith, J. P., Climatic relations of the Tertiary and Quaternary faunas of the California region: California Acad. Sci. Proc., 4th ser., vol. 9, p. 137, 1919.
[25] Grant, U. S., IV, and Gale, H. R., op. cit. (San Diego Soc. Nat. History Mem., vol. 1), p. 73, 1931.
[26] Reed, R. D., Geology of California, p. 259, Am. Assoc. Petroleum Geologists. Tulsa, Okla., 1933.

is better known. *Calicantharus* is associated with species of shallow-water and moderate-depth facies. Inasmuch as the shallow-water mollusks of southern California and adjoining regions are fairly well known, *Calicantharus* is quite certainly extinct in shallow water. As it is much larger than *Elassum*, it would probably be known by this time if it were living at moderate depths.

The percentage of species that are not known to be living is low, not more than 5 to 10 percent. The percentage is, however, of little value, for it depends on what is meant by the expression "not known to be living." Many species and varieties generally placed under that category are so similar to Recent forms that they could readily be rated as still living. Others are based on only one specimen and are questionable, as the range of variation is unknown. The number of well-defined apparently extinct species not closely related to known Recent species is quite small. This group includes *Elassum californicum*, *Turritella pedroensis*, *Calicantharus fortis*, and *"Cancellaria" tritonidea*. The identified mollusks not known to be living, including well-defined, less well-defined, and doubtful forms, and their stratigraphic distribution, are shown in the following table. The number would be increased to about 50 if all the species were identified.

Pleistocene mollusks not known to be living

Species	Lower Pleistocene			Upper Pleistocene									Remarks
				Terrace deposits									
	Lomita marl	Timms Point silt	San Pedro sand	12	9	8	6	5	4	3	2	Palos Verdes sand	
Gastropods:													
Pupillaria optabilis knechti (Arnold)[1]			×									×	Closely related to Recent *P. optabilis* proper.
Vitrinella thomasi Bartsch			×										Related to Recent *V. williamsoni*.
Pomaulax turbanicus petrothauma (Berry).	×												Closely related to Recent *P. turbanicus* proper.
Rissoina pleistocena Bartsch											×	×	Related to Recent species from Lower California and Gulf of California.
Bittium asperum (Gabb)	×	[2] ×	×									×	Closely related to Recent *B. asperum lomaense* and perhaps indistinguishable from that form.
Elassum californicum (Dall and Bartsch).	×	×	×										Genus not known to be living.
Cerithiopsis pedroana fatua Bartsch	×		[3] ×										Closely related to Recent *C. pedroana* proper.
Cerithiopsis necropolitana Bartsch	×	(?)	[4] ×										Closely related to Recent *C. gloriosa*.
Cerithiopsis arnoldi fossilis Bartsch			[5] ×						×			×	Closely related to Recent *C. arnoldi* proper.
Triphora fossilis Willett		[6] ×											Related to Recent *T. carpenteri*.
Turritella pedroensis Applin	×	×	×							×		×	Not closely related to any known Recent species.
Crepidula princeps Conrad, small var.		×										[7] ×	A form of *C. princeps* proper, which is widespread in Pliocene and occurs in lower Pleistocene.
"Nassa" fossata coilotera Woodring, n. var.												×	Closely related to Recent *"N." fossata* proper.
"Nassa" delosi Woodring, n. sp.												×	Related to Recent *"N. californiana"*.
Calicantharus fortis (Carpenter)	×	[8] ×	×									[9] ×	Genus not known to be living.
Tritonalia interfossa keepi (Arnold)			×									[10] ×	Closely related to Recent *T. interfossa* proper.
Tritonalia coryphaena Woodring, n. sp.	×												Related to Recent *T. grippi*.
Boreotrophon pedroanus (Arnold)	×	×	×									×	Related to Recent *B. orpheus*.
Boreotrophon cf. B. pacificus (Dall)	×	[11] ×	[12] ×									[12] ×	Related evidently to Recent *B. pacifica*.
Boreotrophon aff. B. multicostatus (Eschscholtz).	×	×	[13] ×									×	Perhaps identical with a small Recent race of *B. multicostatus* ranging from Puget Sound to northern California.
Boreotrophon aff. B. stuarti (Smith)	×	[14] ×	[15] ×										Closely related to Recent *B. stuarti*.
Boreotrophon cf. B. raymondi (Moody)		×											Related evidently to upper Pliocene *B. raymondi*.
"Cancellaria" tritonidea Gabb			×							(?)		×	Not closely related to any known Recent species.
Pelecypods:													
Pecten stearnsii Dall	×	×	(?)										Closely related to Recent *P. stearnsii diegensis*.
Pecten vogdesi Arnold											×	[16] ×	Closely related to Recent *P. cataractes* and perhaps indistinguishable from that form.
Chlamys opuntia (Dall)	×												Related to Recent *C. islandicus*.
Chlamys anapleus Woodring, n. sp.	×		×										Do.
Pseudamussium n. sp	×	(?)											Related to Recent *P. bistriatus*.
Ostrea megodon cerrosensis Gabb	×												Closely related to Recent *O. megodon* proper.
Crassinella nuculiformis Berry											×	×	Closely related to Recent *C. "varians"*
Calyptogena gibbera Crickmay		[17] ×											Related evidently to Recent *C. pacifica*.
Mercenaria perlaminosa Conrad	×	×											Related to Recent *M. kennerlyi*.

[1] According to a recent communication from George Willett, of the Los Angeles Museum, his collection from Forrester Island, Alaska, includes four Recent specimens of this form.
[2] Arnold, Ralph, California Acad. Sci. Mem., vol. 3, p. 291, 1903. Clark, Alex, San Diego Soc. Nat. History Trans., vol. 7, No. 4, table opposite p. 30, 1931.
[3] Bartsch, Paul, U. S. Nat. Mus. Proc., vol. 40, pp. 331–332, 1911. Oldroyd, T. S., U. S. Nat. Mus. Proc., vol. 65, art. 22, p. 15, 1924.
[4] Bartsch, Paul, op. cit., pp. 345–346. Oldroyd, T. S., op. cit.
[5] Bartsch, Paul, op. cit., p. 353.
[6] Willett, George, Southern California Acad. Sci. Bull., vol. 36, p. 62, pl. 24, 1937.
[7] Arnold, Ralph, op. cit., pp. 309–310. Arnold's record of *C. "grandis"* in his upper San Pedro series of Deadman Island can no longer be verified.
[8] Clark, Alex, op. cit.
[9] Arnold, Ralph, op. cit., p. 227.
[10] Idem, p. 256.
[11] Idem, p. 252 (*"scalariformis"*). Clark, Alex, op. cit.
[12] Arnold, Ralph, op. cit., p. 251 (*"multicostatus"*), p. 252 (*"scalariformis"*).
[13] Idem, p. 250 (*"gracilis"*).
[14] Idem, pp. 252–253. Clark, Alex, op. cit.
[15] Arnold, Ralph, op. cit., pp. 252–253.
[16] Idem, pp. 104–105 (*"dentatus"*).
[17] Crickmay, C. H., Canadian Field Naturalist, vol. 43, No. 5, p. 93, 1 fig., 1929.

More of the apparently extinct forms occur in the lower Pleistocene strata than in the upper Pleistocene. The difference is probably of little significance, owing to difference in faunal facies. The absence of any apparently extinct species from the twelfth to fifth terrace, inclusive, their reappearance in deposits on the fourth to first, and the far greater number from the first than from the fourth, third, and second show conclusively the effect of faunal facies and number of species. Fossils from the twelfth to fifth terrace, inclusive, represent one facies, rock-cliff and tide-pool, and the number of species in that facies is small, not more than about 60. The apparently extinct species from the fourth, third, and second terraces are from the exceptional localities 86, 93, and 105, with the exception of *Cerithiopsis arnoldi fossilis*. The Palos Verdes sand is the only terrace deposit that has a fauna of large size, about 250 species, comparable to that of the Lomita, Timms Point, and San Pedro. It includes, however, a much smaller number of moderate-depth species than the lower Pleistocene faunas.

LOWER PLEISTOCENE

The Lomita marl, Timms Point silt, and San Pedro sand are assigned to the lower Pleistocene. They constitute a well-defined stratigraphic and chronologic unit. Owing to the presence of apparently extinct species generally considered characteristic of the Pliocene, Arnold [27] and Smith [28] assigned the Timms Point silt to the upper Pliocene, and Grant and Hertlein [29] refer the Lomita marl and possibly part of the Timms Point to the upper Pliocene. The species generally considered characteristic of the Pliocene are as follows:

Fossils apparently extinct that are generally considered characteristic of Pliocene, which occur in strata of San Pedro district assigned to lower Pleistocene

Species	Lower Pleistocene		
	Lomita marl	Timms Point silt	San Pedro sand
Brachiopod: Terebratalia hemphilli Dall	(?)	(?)	
Gastropod: Crepidula princeps Conrad		×	
Pelecypods:			
Pecten stearnsii Dall	×	×	(?)
Chlamys opuntia (Dall)	×		
Ostrea megodon cerrosensis Gabb	×		

None of the preceding species are recorded from the Palos Verdes sand, with the exception of Arnold's record of *Crepidula princeps* [*"grandis"*], an occurrence not now subject to verification owing to the destruction of Deadman Island.

If the Lomita marl is assigned to the upper Pliocene, it follows, from the interpretations adopted in the present report, that the Timms Point silt and also a varying thickness of the San Pedro sand, depending on the faunal facies, and the entire exposed thickness at Bent Spring Canyon also are to be assigned to the upper Pliocene. That is, the division between Pliocene and Pleistocene would have no satisfactory faunal or stratigraphic basis in the San Pedro district. If, on the contrary, the preceding species are regarded as survivors from the Pliocene and the locally extinct *Anadara* proper and the extinct *Lyropecten* are considered characteristic of the upper Pliocene,[30] the division between Pliocene and Pleistocene in the Coast Range marine section has a more satisfactory faunal basis. Faunal criteria for distinguishing marine Pliocene and Pleistocene strata are necessarily local and may be selected on a basis of greatest practical utility. The suggested faunal division has the practical advantage of agreeing with diastrophic history to the extent that as thus delimited the Pleistocene begins with a marine transgression both in the San Pedro district and on the borders of the Ventura Basin. In an area of continuous Pliocene-Pleistocene marine deposition such as the western part of the Ventura Basin there are bound to be transitional strata, and the lower part of the Palos Verdes Hills strata assigned to the lower Pleistocene also is more or less transitional. Regardless of age designations paleontologists are in essential agreement concerning correlation of the faunal zones.

Of the identified mollusks, the following were found only in each of the three lower Pleistocene units:

Mollusks found only in Lomita marl

Gastropods:
- Acmaea ochracea Dall.
- Solariella rhyssa Dall.
- Vitrinella sylvania (Dall).
- Pomaulax turbanicus petrothauma (Berry).
- "Amphithalamus" lacunatus Carpenter?
- Cerithiopsis cf. C. gloriosa Bartsch.
- Cerithiopsis willetti Bartsch, n. var.?
- Caecum grippi Bartsch.
- Macron aethiops (Reeve).
- Tritonalia coryphaena Woodring, n. sp.
- Acteon breviculus Dall.
- Williamia peltoides (Carpenter).

Pelecypods:
- Chlamys opuntia (Dall).
- Ostrea megodon cerrosensis Gabb.
- Ventricola fordii (Yates).

Mollusks found only in Timms Point silt

Gastropods:
- Pupillaria cf. P. salmonea (Carpenter).
- Macheroplax cf. M. varicosa (Mighels and Adams).
- Velutina laevigata (Linné)?
- Boreotrophon cf. B. raymondi (Moody).

Pelecypods:
- Thyasira disjuncta (Gabb).
- Macoma calcarea (Gmelin), small var.
- Mya truncata Linné.
- Panomya beringianus Dall, small var.
- Pandora grandis Dall.

Mollusks found only in San Pedro sand

Gastropods:
- Vitrinella thomasi Bartsch.
- Cyclostremella coronadoensis (Arnold).
- Cerithiopsis antemunda Bartsch.

The most distinctive Lomita marl species are apparently extinct (*Pomaulax turbanicus petrothauma, Tritonalia coryphaena, Chlamys opuntia, Ostrea megodon cerrosensis*), belong to the moderate-depth group (*Solariella rhyssa, Acteon breviculus*), or represent evidently an exceptional environment (*Ventricola fordii*). The most distinctive Timms Point species are northern (*Velutina laevigata*, all the pelecypods) or represent the moderate-depth group (*Macheroplax*). The three species from the San Pedro sand are not particularly distinctive. The faunal similarity between the Lomita marl and Timms Point silt is shown by the following table, in which species found only in those units are listed:

Mollusks found in Lomita marl and Timms Point silt but not in other Pleistocene units

Gastropods:
- Solariella peramabilis Carpenter.

Pelecypods:
- Cyrilla munita Dall.
- Hyalopecten vancouverensis (Whiteaves).
- Mercenaria perlaminosa Conrad.
- Thracia trapezoides Conrad.

[27] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, p. 16, 1903.
[28] Smith, J. P., Climatic relations of the Tertiary and Quaternary faunas of the California region: California Acad. Sci. Proc., 4th ser., vol. 9, pp. 150-151, 1919.
[29] Grant, U. S., IV, and Hertlein, L. G., Pliocene correlation chart: California Div. Mines Bull. 118, pt. 2, pp. 201-202, 1941.
[30] Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, Calif.: U. S. Geol. Survey Prof. Paper 195, p. 114, 1940 [1941].

The species in the preceding list belong in the moderate-depth group, with the exception of the apparently extinct *Mercenaria perlaminosa*.

Little significance can be attached to the apparently restricted occurrence of the species in the preceding lists, except insofar as faunal facies has a restricted distribution. The effect of faunal facies is well shown by the table on page 93, which lists 19 species found in the San Pedro sand only at localities inferred to represent a moderate-depth facies. All except one of the 19 species occur in the Lomita or Timms Point, and all except 3 occur in both.

UPPER PLEISTOCENE

The marine terrace deposits are assigned to the upper Pleistocene. They are thought to be considerably younger than the lower Pleistocene strata. Duration of the time interval inferred to have intervened between deposition of the lower Pleistocene and planation of the oldest terrace is, however, not known. That interval is considered arbitrarily to represent approximately the middle third of Pleistocene time. There is no faunal basis for referring the marine terrace deposits to more than one division of the Pleistocene, though it is improbable that terrace deposits of lower Pleistocene age could be distinguished from those of upper Pleistocene age on faunal grounds.

Fossils from the terraces that represent a rock-cliff and tide-pool facies are indistinguishable regardless of whether they are from the twelfth or second terrace, with the exception that a southern species (*Acanthina lugubris*) was found on the fourth and second terraces. That facies is not known to occur, however, on the first terrace. Deposits on the fourth to first terraces are the only terrace deposits now known to contain a protected shallow-water facies, a facies that includes southern species in the faunas from those deposits. The occurrence of certain southern species affords a basis for distinguishing a protected shallow-water facies of at least the fourth to first terraces from the same facies in the next older Pleistocene strata in which that facies occurs—the San Pedro sand. It is, however, of doubtful value as a basis for correlation, for the duration of the unknown conditions that determined the northward extension of range of the southern species is not known. They were formerly not known to occur in terrace deposits older than the Palos Verdes sand.

The following identified species were found only in terrace deposits older than the Palos Verdes sand:

Mollusks found only in upper Pleistocene marine terrace deposits older than Palos Verdes sand

Species	Terrace							
	12	9	8	6	5	4	3	2
Gastropods:								
Acmaea persona "Eschscholtz" Rathke						×		×
Haliotis cracherodii Leach	×		(?)	(?)	(?)	×	×	×
Pseudorotella supravallata (Carpenter)	×	×		×		×	×	
Alvania almo Bartsch		×					×	
Rissoina cosmia (Bartsch)						×		
Truncatella stimpsoni Stearns					×	×		×
Fartulum orcutti (Dall)			×					×
Mitra fultoni E. A. Smith								×
Jaton santarosanus (Dall)								(?)
Tritonalia circumtexta aurantia (Stearns)					×	×	×	
Tritonalia gracillima (Stearns)?	×							
Acanthina lugubris (Sowerby)						×		×
Pelecypods:								
Botulina "opifex (Say)"								×
Milneria kelseyi Dall						×		
Trigoniocardia biangulata (Sowerby)								×

Identified species found only in the large Palos Verdes fauna are as follows. This list would be larger if Arnold's records included in the tables on pages 87–89 were added.

Mollusks found only in upper Pleistocene Palos Verdes sand

Gastropods:
- Tegula marcida (Gould) ["pulligo"].
- Calliostoma eximium (Reeve).
- Neverita reclusiana imperforata Dall.
- "Nassa" fossata coilotera Woodring, n. var.
- "Nassa" delosi Woodring, n. sp.
- "Nassa" cerritensis Arnold.
- Nucella biserialis (Blainville).
- Forreria belcheri (Hinds).

Pelecypods:
- Anadara perlabiata (Grant and Gale).
- Dosinia ponderosa (Gray).
- Amiantis callosa (Conrad).
- Chione gnidia (Broderip and Sowerby).
- "Chione" picta Dall.[31]
- Trachycardium procerum (Soerby).[32]
- Trachycardium elatum (Sowerby).

A considerable number of additional species were found in terrace deposits but not in the lower Pleistocene strata.

[31] Reported orally by Chace from second terrace on Fifteenth Street near Leland.
[32] One specimen reported by Ralph Arnold from San Pedro sand at Deadman Island (Arnold, Ralph, op. cit. (California Acad. Sci. Mem., vol. 3), p. 139, 1903).

Mollusks found in upper Pleistocene terrace deposits, including Palos Verdes sand, but not in lower Pleistocene strata

Species	Terrace								
	12	9	8	6	5	4	3	2	1 (Palos Verdes sand)
Gastropods:									
Tegula aureotincta (Forbes)						X		X	X
Liotia acuticostata Carpenter						X		X	X
Rissoina pleistocena Bartsch								X	X
Trivia californica Gray						X			X
Erato columbella Menke								(?)	X
Macron lividus (A. Adams)				X		X			X
Pterorytis nuttalli (Conrad)							X		X
Nucella lamellosa (Gmelin)								X	X
Nucella emarginata (Deshayes)				X				X	X
Acanthina spirata punctulata (Sowerby)								X	X
Gadinia reticulata (Sowerby)	X			X	X	X	X	X	X
Pelecypods:									
Nucula suprastriata Arnold								X	X
Pecten vogdesi Arnold								X	X
Crassinella branneri Arnold						X			X
Crassinella nuculiformis Berry								X	X
Diplodonta sericata (Reeve)								X	X

The most distinctive species of the terrace deposits older than the Palos Verdes sand are representative of the rock-cliff and tide-pool facies. *Trigoniocardia biangulata* is a southern species, close to the present northern limit of its range, from the exceptional second terrace locality 105. The most characteristic Palos Verdes species are southern species either well north of their present northern limit or close to it. *Pecten vogdesi*, *Crassinella branneri*, *Crassinella nuculiformis*, and *Diplodonta sericata* are additional southern species of the Palos Verdes found also in deposits on the fourth and second terraces at the exceptional localities 86 or 105. The Palos Verdes list includes one northern species close to the present southern limit of its range (*Tegula marcida*). The apparently restricted occurrence of terrace fossils, like the occurrence of the lower Pleistocene species, is evidently controlled principally by facies restriction.

GLACIAL-INTERGLACIAL ASSIGNMENTS

If the strata in the San Pedro district are Pleistocene, they are presumably synchronous with Pleistocene glacial and interglacial stages. There is, of course, no direct evidence of synchroneity, for Pleistocene glaciation is not certainly recognized in southern California below altitudes of about 10,000 feet. Eaton's views [33] represent those of geologists who assign glaciation to the upper Pleistocene and, therefore, consider the lower Pleistocene marine strata preglacial. In the present report Pleistocene time is accepted by definition as beginning with the advance of the first continental ice sheet and ending with the withdrawal of the last, an admittedly unsatisfactory definition for the Coast Range marine section.

The occurrence of northern species, particularly in the Timms Point silt, and of southern species, particularly in the Palos Verdes sand, has stimulated consideration of temperature facies and glacial-interglacial assignments. Opinions are summarized in tabular form as follows:

[33] Eaton, J. E., Divisions and duration of the Pleistocene in southern California: Am. Assoc. Petroleum Geologists Bull., vol. 12, pp. 132–133, 1928.

Estimated temperature facies and glacial-interglacial assignments of Pleistocene strata of San Pedro district

Pleistocene unit	Arnold, 1903 [1]	Smith, 1919 [2]	Hay, 1927 [3]	Crickmay, 1929 [4]	Gale, 1931 [5]	Grant, 1937 [6]
Palos Verdes sand	As warm as at present time or warmer.	Temperature about 66° F., about 4° higher than at present. Probably interglacial.	Aftonian interglacial stage.	Only about 5 percent of species in Arnold's upper San Perdo of Deadman Island are autochthonous, and they indicate a temperature like that of San Pedro at present.	Later part of third interglacial stage (Sangamon).	Mean annual sea surface temperature about 63° F. Present mean annual sea surface temperature at San Pedro 61° F.
San Pedro sand	Cold-water, transitional from earlier northern.	Temperature probably about same as that of Puget Sound, 50° F. Probably corresponds to time of maximum galciation.	Nebraskan glacial stage.	Arnold's lower San Pedro of Deadman Island represents climate as warm as that of San Pedro at present or slightly warmer. Cold-water species derived from older strata.	Early part of second interglacial stage (Yarmouth).	Temperature fluctuating, possibly 50° to 60° F.
Timms Point silt	Assigned to upper Pliocene. Decidedly northern or boreal.	Assigned to upper Pliocene. Temperature probably about same as that of Puget Sound, 50° F.	Glacial period was approaching.	6 zones of different temperature facies only 1 of which, zone 5, is decidedly cold-water and doubtless represents a glacial stage.	Second glacial stage (Kansan).	Mean annual water temperature possibly 50° to 52° F.
Lomita marl					First interglacial stage (Aftonian), assigned to Las Posas zone.	Temperature about 60° to 62° F.

[1] Arnold, Ralph, California Acad. Sci. Mem., vol. 3, pp. 16, 20, 29, 1903.
[2] Smith, J. P., California Acad. Sci. Proc., 4th ser., vol. 9, pp. 136–137, 151, pl. 9, 1919.
[3] Hay, O. P., Carnegie Inst. Washington Pub. 322B, pp. 166–173, 1927.
[4] Crickmay, C. H., Jour. Geology, vol. 37, pp. 622–632, 1929.
[5] Grant, U. S., IV, and Gale, H. R., San Diego Soc. Nat. History Mem., vol. 1, pp. 71–74, table 3 (p 75), 1931.
[6] Grant, U. S., Am. Assoc. Petroleum Geologists, Program 22d Ann. Meeting, pp. 69, 71, 1937.

It is apparent from the preceding table that opinions concerning the temperature facies vary widely. The writers cited agree, however, that the Timms Point fauna represents cool water, or at least includes a cool-water zone, and is doubtless glacial, and most of them agree that the Palos Verdes fauna represents warm water and is doubtless interglacial. Assignment to definite glacial and interglacial stages is so speculative that it is not considered further.

That interpretation of the temperature facies is not a simple matter is evident from the varying opinions. If the Timms Point fauna and San Pedro sand fauna represented a southward displacement of the isotherms of 1,500 miles and the Palos Verdes fauna represented a northward displacement of about 650 miles, as Smith thought, there would be no argument about the matter. It is quite clear that the faunas of the Timms Point and the San Pedro are not Puget Sound faunas and that the Palos Verdes fauna is not a Magdalena Bay fauna, despite the presence of species now living in those areas and not at San Pedro. All the faunas considered by the writers cited contain both northern and southern species. Most of the writers who have considered the matter relied on the preponderance of one group and ignored the other. Crickmay [34], who protested justly against such treatment, thought the problem could be resolved to at least a certain extent by careful zoning and discrimination of detrital (derived) fossils and fossils that lived at the time the sediments were deposited (autochthonous). Detrital fossils are expectable particularly in the Palos Verdes sand, which in extensive areas bevels fossiliferous lower Pleistocene strata. Before Deadman Island was destroyed the Pleistocene strata exposed there yielded fossils that were buried in sediments accumulating off shore. Many San Pedro extra-limital records of Recent mollusks are based doubtless on these detrital fossils. Crickmay's criteria for the recognition of detrital fossils are, however, of doubtful value. Should broken and worn specimens be represented in a collection of otherwise well-preserved specimens, the broken and worn specimens may very well be detrital. Unequivocal examples of such occurrence are not recognized in the collections at hand. Crickmay's opinion [35] that 95 percent of the species in the sand and gravel of the Palos Verdes at Deadman Island are detrital because they are represented by wave-worn or broken specimens is considered erroneous. A large proportion of specimens that occur in gravel are certain to be worn and broken regardless of whether they are detrital or not. His opinion [36] that all the specimens of *Cerastoderma nuttallii* ["*Cardium corbis*"] in the Timms Point silt and San Pedro sand of Deadman Island are detrital and derived probably from a hypothetical cold-water zone does not take into consideration the corroding of *Cerastoderma* shells, which is due presumably to peculiarities of shell structure. Fossil Cerastodermae are generally corroded. Nevertheless the uncorroded and perfectly fresh specimen of the essentially northern *Cerastoderma nuttallii* shown on plate 34, figures 16 and 17 was collected from the San Pedro sand at Deadman Island in association with the equally well-preserved specimen of the essentially southern *Trachycardium quadragenarium* shown in figures 18 and 19 on the same plate.

[34] Crickmay, C. H., The anomalous stratigraphy of Deadman's Island, Calif.: Jour. Geology, vol. 37, pp. 618–621.
[35] Idem, p. 632.
[36] Idem, p. 630.

A ready solution of the problem of the occurrence of northern and southern species in the same strata is not apparent. Consideration of the following subjects may, however, aid in reaching a solution. It will be observed that none of the writers cited considered the terrace faunas older than the Palos Verdes sand, as those faunas were unknown to them.

FAUNAL FACIES

Comparison of the same faunal facies is an essential requirement for interpretation of temperature facies in terms of latitude. Several faunal facies are represented in the Pleistocene strata. A shallow-water facies is recognized in the Lomita marl, San Pedro sand, and Palos Verdes sand. A particular type of shallow-water facies (rock-cliff and tide-pool) is recognized in terrace deposits older than the Palos Verdes sand. The shallow-water facies of the Lomita marl contains an apparently extinct oyster (*O. megodon cerrosensis*) closely related to a Recent southern species. The shallow-water faunas in the San Pedro sand and in the Palos Verdes sand are so similar that there is some doubt about the age assignments. Nevertheless they have been discriminated, whether correctly or not, by the presence of southern species in the Palos Verdes sand and their absence in the San Pedro sand. The rock-cliff and tide-pool facies of the twelfth to fifth terraces, inclusive, contains no species entirely beyond its present range but includes northern and southern species close to the limits of their range. The same facies on the fourth to second terraces, inclusive, includes northern and southern species of both groups.

A moderate-depth facies is thought to characterize much of the Lomita marl and Timms Point silt and also the San Pedro sand at a few localities. The cool-water aspect of the Timms Point fauna and locally of the faunas of the Lomita and San Pedro is attributed in large measure to this depth facies. The Timms Point silt contains Puget Sound species, but many Timms Point species do not range as far north as Puget Sound, and others are not found in shallow water in Puget Sound.

MIXED FAUNAL FACIES

Most fossil assemblages, at least most large Tertiary and Pleistocene marine assemblages, represent death associations, not life associations. Though it is frequently difficult or impossible to recognize members of different life associations in a mixed fossil assemblage, some aspects of this matter deserve consideration.

The shallow-water *Olivella biplicata* and *Conus californicus* are represented in Timms Point collections. The specimens are, however, worn and broken. Inasmuch as shallow-water to moderate-depth and moderate-depth species in the same collections also are represented by some broken or worn specimens, the evidence is inconclusive that the shallow-water species did not live with the others.

The rock-cliff and tide-pool facies of terrace faunas older than the Palos Verdes sand includes species that live below low-tide line in the latitude of San Pedro. For that reason Berry [37] thought that the chiton fauna from the Chaces' locality on the second terrace near Point Fermin is like that living along the shore of Monterey and San Luis Obispo Counties farther north. The Chaces [38] thought, however, that the species of mollusks now living below low-tide line were carried in by storm waves and mixed with tide-pool species.

[37] Berry, S. S., op. cit. (California Acad. Sci. Proc., 4th ser., vol. 11), p. 409, 1922.
[38] Chace, E. P., and E. M., op. cit. (Lorquinia, vol. 2, No. 6), p. 43, 1919.

That explanation is preferred to Berry's interpretation. The fauna from the fourth terrace at locality 86 and that from the second terrace at locality 105 represent mixed rock-cliff and tide-pool and off-shore shallow-water associations with the probable addition of some moderate-depth species at locality 105. This mixture is attributed to storm-wave and along-shore current transportation. The off-shore shallow-water species include southern species found also in the Palos Verdes sand.

The unusual Palos Verdes fossils from localities 107 and 108 (Arnold's Crawfish George's locality) may represent a mixed shallow-water and moderate-depth association. Inasmuch as these localities faced the open ocean during Palos Verdes time whereas the localities containing the usual Palos Verdes association faced the strait separating the island from the mainland, it has been suggested that the northern and moderate-depth species from localities 107 and 108 were transported into shallow-water by storm waves.[39] Mollusks that live below low-tide line are washed up frequently on beaches during storms. The usual finds represent species that live just below low-tide line or at depths of a few fathoms. Species that are not known to live at depths of less than 10 fathoms are also found rarely after storms. They represent evidently unusual occurrences, such as those found clinging to the holdfast of long kelp stalks. *Jaton santarosanus*, which has been dredged at depths of 16 and 82 fathoms but is not known to live at shallower depths, is reported to have been found on kelp washed in by storm waves. That species is represented probably by an imperfect specimen from the second terrace at locality 105. Storm transportation could not account, however, for the occurrence at locality 108 of *Fusitriton oregonensis* and *Exilioidea rectirostris*, the present known minimum depth of which at the latitude of San Pedro is 80 fathoms, unless these species lived at shallower depth during Pleistocene time. Contrary to expectation on the hypothesis of storm transportation, markedly northern and intermediate-depth forms have not been found in terrace deposits on the exposed south and west coasts. The unusual species from localities 107 and 108 may be detrital fossils derived from the lower Pleistocene strata in which they are known to occur. Nevertheless, in physical condition they are indistinguishable from other species collected at those localities. If they are detrital, they are expectable in greater abundance at localities farther north where the Palos Verdes sand rests on lower Pleistocene strata. A specimen of *Boreotrophon pedroanus* from locality 121 is the only representative of the northern and moderate-depth group in the Palos Verdes of that area. Arnold [40] realized that the fauna from his Crawfish George's locality is exceptional, but he did not discuss its unusual features. Owing to the unusual faunal association, the deposits at that locality have been referred to the Timms Point silt [41] and San Pedro sand.[42]

EFFECTS OF CHANGES IN OUTLINE OF COAST

The Pleistocene elephants found on the Channel Islands,[43] off the coast northwest of the Palos Verdes Hills, indicate that during a still undetermined part of Pleistocene time these islands were joined to the present western terminus of the Santa Monica Mountains. During early Pleistocene time northern species, such as *Patinopecten caurinus*, had a range extending southward at least to the San Pedro district. If the peninsula came into existence after the lower Pleistocene strata were deposited, the northern species may have become extinct locally owing to changes in oceanic circulation and then were not reestablished in the area of local extinction after disappearance of the peninsula.

The peninsula would protect coastal water to the south from southward-drifting cold water, as has been suggested by Gale.[44] A land mass farther south—a relic of ancient Catalinia—joining the islands of Catalina, Santa Barbara, San Nicolas, and San Clemente also would have an effect in providing a suitable habitat for the markedly southern species characteristic of the Palos Verdes Hills. Land areas off the coast of southern California are, however, probably not later than middle Pleistocene, for marine terraces on the Channel Islands and on the islands farther south, except Catalina, show partial or complete submergence, presumably during late Pleistocene time. At all events Santa Monica is the northernmost known locality for the occurrence of southern species characteristic of the Palos Verdes sand, indicating that the inferred peninsula was in existence during late Pleistocene time and that it had a profound effect on the distribution of marine animals.

EFFECTS OF LOCAL TEMPORARY CHANGES IN OCEAN TEMPERATURE

The occurrence of northern or of southern species in strata characterized by the preponderance of species of the other group may be due to local changes in ocean temperature caused by temporary changes in oceanic circulation. Local fluctuations of this character result in the distribution of marine animals but not of breeding communities beyond their normal range, particularly in temperate regions. The reported occurrence of the southern *Anadara multicostata* in Balboa Bay, almost 100 miles north of its usual northern limit, may be an example of a temporary extension of range.

POSSIBLE CHANGES IN GEOGRAPHIC AND DEPTH RANGE SINCE PLEISTOCENE TIME

Perhaps paleontologists are mistaken in attempting to interpret these Pleistocene faunas in terms of the present geographic range of the species still living and of closely related Recent forms. If it be assumed that the range of some species has changed since Pleistocene time owing to changes in physiological characters not correlated with changes in available morphological characters, difficulties would vanish. That this matter is not entirely speculative is indicated by the occurrence in the Pliocene strata at Elsmere Canyon of a form of the circumboreal *Mya truncata*,[45] a northern species characteristic of the Timms Point silt. At Elsmere Canyon it is associated with the essentially northern *Fusitriton oregonensis* and with *Lyropecten* and other forms considered of warm-water aspect. Changes in depth range may also have taken place since Pleistocene time. Extensive changes of that character would invalidate conclusions based on present depth range. It is improbable, however, that changes in either geo-

[39] Woodring, W. P., op. cit. (Am. Jour. Sci., 5th ser., vol. 29), p. 304, 1935.
[40] Arnold, Ralph, The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, Calif.: California Acad. Sci. Mem., vol. 3, p. 26, 1903.
[41] Ashley, G. H., The Neocene stratigraphy of the Santa Cruz Mountains of California: California Acad. Sci. Proc., 2d ser., vol. 5, p. 341, 1895.
[42] Berry, S. S., op. cit. (California Acad. Sci. Proc., 4th ser., vol. 11), p. 411, 1922
[43] Stock, Chester, Exiled elephants on the Channel Islands, Calif.: Sci. Monthly. vol. 41, pp. 205–214, 10 figs., 1935.
[44] Grant, U. S., IV, and Gale, H. R., Catalogue of the marine Pliocene and Pleistocene Mollusca of California: San Diego Soc. Nat. History Mem., vol. 1, pp. 39, 64, 1931
[45] Arnold, Ralph, New and characteristic species of fossil mollusks from the oil bearing Tertiary formations of southern California: U. S. Nat. Mus. Proc., vol. 32 p. 527, pl. 50, fig. 1, 1907.

graphic or depth range have taken place in many of the species of a large fauna like that of the Timms Point silt and the moderate-depth facies of the Lomita marl.

INTERPRETATION OF TEMPERATURE FACIES IN TERMS OF POSSIBLE GLACIAL AND INTERGLACIAL ASSIGNMENTS

In summary it may be said that interpretation of the temperature facies in terms of possible glacial and interglacial assignments is so complicated by other possible factors that assignments are questionable. It is not unreasonable to expect faunal changes in the San Pedro district due to glaciation and deglaciation, even though it is 1,500 miles south of the southern limit of sea-level Pleistocene glaciers. Faunal stratification in the sediments of areas as far from glaciated regions as the equatorial Atlantic is interpreted in terms of interglacial, glacial, and post-glacial succession.[46] The occurrence in Pleistocene strata at Tomales Bay, immediately north of San Francisco Bay, of species north of their present range, including *Chione undatella* and *Trachycardium quadragenarium*,[47] suggests an interglacial fauna. The shallow water faunas of the Lomita marl, San Pedro sand, deposits on the fourth to second terrace, inclusive, and the Palos Verdes sand may be interglacial despite apparently conflicting evidence. The Timms Point fauna can hardly be interpreted as a shallow-water glacial fauna; it may be a moderate-depth glacial or interglacial fauna. The faunas from the twelfth to fifth terraces, inclusive, might be considered interglacial. Inasmuch, however, as they do not include a southern species (*Acanthina lugubris*) found in the same facies on the fourth and second terraces they might be interpreted as glacial. A shallow-water northern fauna of the character expectable during a glacial stage is not recognized in the entire succession of 12 Pleistocene faunas.

Perhaps the importance of the moderate-depth association has been overemphasized in the present report because it was undervaluated previously in interpretations of the Pleistocene faunas of the San Pedro district. Some writers have briefly discussed this matter. Crickmay[48] considered the possibility that at least parts of the Timms Point silt represent moderate depths. He thought his zone 3 may have been deposited in water between 50 and 100 fathoms deep and that his zone 4 suggests a depth of 100 fathoms or perhaps more—estimates agreeing closely with those for the entire Timms Point silt in the present report. According to Reed,[49] most of the Lomita Foraminifera indicate a depth of 50 to 100 fathoms. Grant[50] thought the Lomita fauna indicates a depth of possibly 100 to 300 feet (approximately 15 to 50 fathoms). A marked feature of the Lomita and Timms Point faunas and locally of the San Pedro is the occurrence of species or closely related forms known only from *Albatross* dredgings at depths of 67 to 81 fathoms off Point Loma near San Diego (*Puncturella delosi*, *Solariella rhyssa*, *Homalopoma subobsoletum*) and of species from *Albatross* dredgings at depths of 55 to 110 fathoms in the same area and 48 to 155 fathoms off the California islands (*Crepipatella charybdis*, *Acteon breviculus*). These species were formerly thought to be no longer living or were not known heretofore as fossils.

Owing to the tradition of temperature facies resulting from Arnold's and Smith's pioneer work, when only the strata and fossils along the San Pedro water front were known, inferred temperature facies has been and still is used for age assignments. That errors may arise from such assignments is evident from Berry's assignment of deposits on the second terrace at Point Fermin and the Palos Verdes sand at Arnold's Crawfish George's locality to the San Pedro sand, though they are relatively speaking much younger than the San Pedro sand. It is unlikely that during the brief period of time represented by a terrace deposit different marine invertebrate faunas corresponding to those now living in the same environment at different latitudes were represented at different localities in the San Pedro district. Latitude interpretation in terms of the rigid application of present geographic range proposed by Schenck and Keen[51] is unsuitable for an interpretation of the Pleistocene faunas of the San Pedro district, as it fails to take into consideration depth range, which can be evaluated within the limits of present knowledge, and possible changes in geographic and depth range since Pleistocene time, which cannot be evaluated.

CORRELATION WITH OTHER AREAS

LOWER PLEISTOCENE

Los Angeles Basin subsurface section.—Pleistocene strata in the Los Angeles Basin have a variable thickness ranging from a few hundred to perhaps 1,800 feet. Wissler[52] subdivided the Pleistocene section of the basin oil fields into two parts, designated lower Pleistocene and upper Pleistocene. The lower Pleistocene strata were correlated with the Lomita marl, Timms Point silt, and San Pedro sand; the upper Pleistocene, differentiated principally on the basis of a lignitic zone at the base, were thought to include the equivalent of the Palos Verdes sand. Synclinal areas in the basin contain probably not only the equivalent of the thin marginal deposits of the Palos Verdes Hills, including strata deposited during the plantation of the numerous marine terraces of the Palos Verdes Hills, but also a complete Pleistocene record. In such areas differentiation of the main Pleistocene divisions represented in the Palos Verdes Hills would be difficult, if not impossible.

The Pleistocene sea evidently covered most, or perhaps all, of the Los Angeles Basin. In a recent discussion of ground water in the basin, Morse[53] mentioned marine Pleistocene strata at outcrop localities in the Coyote Hills and at subsurface localities near Santa Ana, and near Bell—that is, at localities near the eastern and northern borders of the basin. Some of the localities are designated as Arnold's lower San Pedro, others as Arnold's upper San Pedro, and still others as either. It may be pointed out that undoubted faunal differentiation of Arnold's two divisions, corresponding to the San Pedro sand and Palos Verdes sand of the present report, is impossible unless southern species characteristic of the Palos Verdes are

[46] Schott, W., Die Foraminiferen in dem equatorialen Teil des Atlantischen Ozeans: Deutschen Atlantischen Exped. *Meteor*, 1925–27, Wiss. Ergebnisse, vol. 3, pt. 3, pp. 120–130, 1935.

[47] Dickerson, R. E., Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles: California Acad. Sci. Proc., 4th ser., vol. 11, pp. 559–570, 1922. Mason, H. L., Pleistocene floras of the Tomales formation: Carnegie Inst. Washington Pub. 415, pp. 85–87, 104–105, tables op p. 104, 1934.

[48] Crickmay, C. H., op. cit., pp. 624, 626.

[49] Reed, R. D., Geology of California, p. 259, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1933.

[50] Grant, U. S., Some observations on the Pleistocene of the Los Angeles region (abstract): Am. Assoc. Petroleum Geologists, Program 22d Ann. Meeting, p. 71, 1937.

[51] Schenck, H. G., and Keen, A. M., An index method for comparing molluscan faunas: Am. Philos. Soc. Proc., vol. 77, pp. 161–166, 1937.

[52] Wissler, S. G., Stratigraphic formations [relations] of the producing zones of the Los Angeles Basin oil fields: California Div. Mines Bull. 118, pt. 2, pp. 210 (table), 211–212, 1941.

[53] Morse, R. R., The nature and significance of certain variations in composition of Los Angeles Basin groundwaters: Econ. Geology, vol. 38, pp. 478–479 (footnote), 1943.

represented, and the probability of finding one or more of these few southern species in a small collection of fossils from cores or ditch samples is remote.

Signal Hill.—Sand, gravel, and silt underlying strata correlated with the Palos Verdes sand at Signal Hill, near Long Beach, have recently been found to be fossiliferous and are correlated with the San Pedro sand.[54]

Santa Monica.—Pleistocene mollusks, mostly of moderate-depth facies, occur in deformed strata at localities near Santa Monica.[55] The faunal association suggests the Lomita and Timms Point and also parts of the San Pedro sand.

Ventura Basin.—An exceptionally thick continuous and uniformly deformed section of 20,000 feet of marine Pliocene and Pleistocene strata is represented in the western part of the Ventura Basin. The part of this section assigned to the Pleistocene is about 6,000 feet thick and overlies *Andara*-bearing upper Pliocene. Various names have been proposed or used for the Pleistocene strata: Santa Barbara formation or Santa Barbara horizon, upper part of Pico formation, Saugus formation, San Pedro formation, Eaton's Hall Canyon formation, Pressler's Las Posas formation and Kalorama member, and his Long Canyon horizon. Lists of fossils have been published by Arnold,[56] Eaton,[57] Waterfall,[58] and Pressler,[59] and selected species were mentioned by Bailey.[60]

According to Bailey's description,[61] the lower part of the Pleistocene strata—assigned by him to the Santa Barbara formation, Waterfall's upper Pico, and Pressler's Santa Barbara horizon and his Kalorama member of his Las Posas formation—is 2,900 to 3,500 feet thick and consists principally of mudstone and shale. Locally, lenses of sand and gravel or sandstone and conglomerate are at the base and at higher horizons. The lower part of the section contains northern and moderate-depth species, including *Patinopecten caurinus*, *Thracia trapezoides*, and *Pandora glacialis*, the first two of which occur in the Lomita marl and Timms Point silt. In view of the recent finding of sand and gravel at considerable depths off the California coast, the occurrence of these species locally in sandy and pebbly strata cannot be regarded as conclusive evidence of shallow-water deposition.[62] The upper part of the section—assigned by Bailey[63] to the San Pedro formation, Kew's and Waterfall's Saugus, Eaton's San Pedro and Hall Canyon formations, and Pressler's Las Posas formation and his Long Canyon horizon—is 3,000 to 3,500 feet thick and consists principally of coarse-grained sand and gravel, or sandstone and conglomerate, with some sandy silt, silty clay, and clay. It contains a shallow-water fauna essentially like that of the shallow-water facies of the San Pedro sand. Bailey[64] found that toward the north and northeast, around the plunging axis of the Ventura anticline and Ventura syncline, a tongue of sandstone 300 feet below the top of his Santa Barbara formation and another tongue of sandstone and conglomerate 550 feet lower contain fossils characteristic of his San Pedro formation. The close correlation between lithology and faunas shows as conclusively as such matters can be shown that the faunas represent different environmental associations, and it is reasonably certain that they represent different depth associations, as Bailey[65] thought.

The 6,000-foot section in the western part of the Ventura Basin is considered the essential equivalent of the lower Pleistocene formations of the San Pedro district, but it includes probably younger strata. As in the San Pedro district, a moderate-depth facies is prevalent in the lower part of the section and a shallow-water facies in the upper part. Also as in the San Pedro district, the two facies interfinger. Arnold[66] correlated fossiliferous strata in the shallow-water facies of the Ventura Basin with the Palos Verdes sand. Eaton's objection[67] to that correlation on stratigraphic and physiographic grounds is justified. The absence of southern species characteristic of the Palos Verdes sand cannot be regarded as an objection to Arnold's correlation, as they are unknown also in younger marine terrace deposits that on stratigraphic and physiographic grounds are the probable equivalent of the Palos Verdes sand.

In the Las Posas Hills, on the south border of the basin, lower Pleistocene strata unconformably overlap the Sespe formation, indicating events similar to those in the Palos Verdes Hills, where lower Pleistocene deposits unconformably lap onto different parts of the Miocene.

Santa Barbara and Rincon Point.—Santa Barbara and Rincon Point, between Santa Barbara and Ventura, are located along the north border of the Ventura Basin. At both localities the Santa Barbara formation unconformably overlaps formations older than Pliocene (Monterey shale or Sespe formation). Incomplete lists of fossils from Santa Barbara, the type locality of the Santa Barbara formation, have been published by Arnold.[68] At both localities[69] the formation may be divided into a lower *Pecten bellus* zone and an upper *Patinopecten caurinus* zone. The lower zone indicates a shallow-water facies, the upper zone a moderate-depth facies, that is, the age relations of the two facies are the opposite of those near Ventura and in the San Pedro district. Santa Barbara is the type locality of many species found in the lower Pleistocene strata of the San Pedro district, notably *Terebratalia hemphilli*, *Puncturella delosi*, *Bittium rugatum*, *Bittium armillatum*, *Bittium asperum*, *Crepidula princeps*, *Barbarofusus barbarensis*, *Callicantharus fortis* (type locality inland from Santa Barbara), *Admete gracilior*, *Cyclocardia occidentalis*, and *Mercenaria perlaminosa*. These species occur in the Lomita marl or Timms Point silt, or both; some occur also in the San Pedro sand. *Pecten bellus*, based on material from Santa Barbara, is not represented in the collections at hand but is reported from the Lomita marl.[70] The Santa Barbara formation is considered the essential equivalent of the lower Pleistocene strata of the San

[54] De Long, J. H. Jr., The paleonotolgy and stratigraphy of the Pleistocene at Signal Hill, Long Beach, Calif.: San Diego Soc. Nat. History Trans., vol. 9, No. 25, pp. 229–252, 4 figs., 1941.

[55] Arnold, Ralph, op. cit. (Calif. Acad. Sci. Mem., vol. 3), p. 56. Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, p. 120, 1931.

[56] Arnold, Ralph, op. cit., p. 55.

[57] Eaton, J. E., Divisions and duration of the Pleistocene in southern California: Am. Assoc. Petroleum Geologists Bull., vol. 12, pp. 126–129, 1928.

[58] Waterfall, L. N., A contribution to the paleontology of the Fernando group, Ventura County, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 18, table op. p. 78, 1929.

[59] Pressler, E. D., The Fernando group of the Las Posas-South Mountain district, Ventura County, Calif.: idem, pp. 336–338, 1929.

[60] Bailey, T. L., Lateral change of fauna in the lower Pleistocene: Geol. Soc. Am. Bull., vol. 46, pp. 495–497, 1935.

[61] Bailey, T. L., op. cit., pp. 492–494.

[62] Bailey, T. L., op. cit., p. 494.

[63] Bailey, T. L., op. cit., pp. 490–492.

[64] Bailey, T. L., op. cit., pp. 494–497.

[65] Bailey, T. L., op. cit., pp. 496, 499.

[66] Arnold, Ralph, op. cit., p. 54.

[67] Eaton, J. E., op. cit., p. 124.

[68] Arnold, Ralph, op. cit., p. 52. Geology and oil resources of the Summerland district, Santa Barbara County, Calif.: U. S. Geol. Survey Bull. 321, p. 32, 1907.

For a recent discussion of the Santa Barbara formation see Keen, A. M., and Bentson, Herdis, Check list of California Tertiary marine Mollusca: Geol. Soc. Am., Special Paper 56, pp. 11–15, 1944.

[69] Bailey, T. L., op. cit., p. 494.

[70] Grant, U. S., op. cit., p. 71.

Pedro district. The close faunal similarity between the *Patinopecten caurinus* zone and the Lomita, Timms Point, and moderate-depth facies of the San Pedro is doubtless an expression of a similar moderate-depth facies. The Santa Barbara formation is generally assigned to the upper Pliocene, or the lower part to the upper Pliocene and the upper part to the lower Pleistocene.

San Francisco Peninsula.—The upper part of the Merced formation of the San Francisco Peninsula[71] is generally considered of Pleistocene age. The fauna is perhaps too small for a satisfactory comparison with the Pliocene *Anadara*-bearing main part of the Merced or for a comparison with the Pleistocene faunas of the San Pedro district.

UPPER PLEISTOCENE

Marine terraces along the California coast are with little doubt the equivalent of terraces in the Palos Verdes Hills assigned to the upper Pleistocene. Similarity in physiographic history may furnish a basis for correlation. Faunal data are likely to be inconclusive. Terrace deposits containing southern species were formerly and quite naturally correlated with the Palos Verdes sand. At least some of the southern species characteristic of the Palos Verdes sand are now known to have been living in the San Pedro district as early as the time when the fourth terrace was formed. Whether they were living still earlier in this district is not known now, as a suitable faunal facies has not been found on terraces older than the fourth. The absence of southern species in the rock-cliff and tide-pool facies on terraces older than the fourth and the presence of a southern species (*Acanthina lugubris*) in that facies on the fourth and second terraces suggest, however, that the time when southern species lived in this district may have begun when the fourth terrace was formed.

San Diego and nearby localities.—Pleistocene terrace fossils from San Diego and nearby localities have been listed and discussed by Arnold,[72] Berry,[73] Stephens,[74] and Webb.[75] Arnold's and Stephens' lists include southern species characteristic of the Palos Verdes sand ("*Nassa*" *cerritensis*, *Crassinella branneri*, *Diplodonta sericata*, *Dosinia ponderosa*, and *Trachycardium procerum*), and Arnold pointed out the faunal similarity. Webb listed 102 species from localities on the windward (western) side of Point Loma, which was an island[76] at the time when the terrace was formed. The Point Loma fossils are characteristic of a rock-cliff and tide-pool facies, but the fauna is somewhat larger than that in the same facies in the Palos Verdes Hills. As in the Palos Verdes Hills, the fossils include off-shore species, suggested by Webb to have been washed in, and one locally extinct northern species (*Tegula montereyi*), found on the fifth to first terraces in the Palos Verdes Hills. A southern species (*Acanthina lugubris*) is listed by Berry from a Point Loma locality. None of the southern species listed by Arnold and Stephens are represented in the Point Loma collections, though the deposits are presumably of the same age. The southern species are, however, from localities on the leeward side of the Pleistocene Point Loma island[77] and represent a different facies.

Capistrano Beach.—Willett[78] listed and discussed recently 153 species of Pleistocene mollusks from Capistrano Beach, between San Diego and Long Beach. He estimated that the fossiliferous strata were deposited in shallow water at a depth of probably less than 5 fathoms. Owing to the presence of a few species not living in shallow water in this latitude at the present time, he thought that the water was colder than it now is. The fossils may, however, represent a mixed association. It is not clear from Willett's description whether the fossiliferous strata are terrace deposits, but they presumably are. If they are terrace deposits, his suggestion that they are of San Pedro age may need reconsideration.

Los Angeles Basin subsurface section.—Upper Pleistocene strata in the Los Angeles Basin subsurface section are mentioned under the heading "Lower Pleistocene."

Signal Hill.—Arnold[79] described 160 species of mollusks from Pleistocene strata on Signal Hill, or Los Cerritos, near Long Beach, and the stratigraphy and paleontology of that area have been discussed recently by De Long.[80] The fossils described by Arnold and listed by De Long include southern species characteristic of the Palos Verdes sand—"*Nassa*" *cerritensis*, *Crassinella branneri*, *Dosinia ponderosa*, *Chione gnidia*, *Trachycardium procerum*, and *Trachycardium elatum*—Signal Hill being the type locality of the first two species mentioned. The abundance of *Amiantis callosa* also suggests the Palos Verdes sand. Arnold correlated these strata with the Palos Verdes, and that correlation has been repeated by De Long. Eaton,[81] not realizing that the Palos Verdes sand is mildly or moderately deformed along the north border of the Palos Verdes Hills, objected to the correlation on the grounds that the strata on Signal Hill are deformed and was inclined to assign them to the lower Pleistocene. On physiographic, stratigraphic, and faunal grounds the strata at Signal Hill and the Palos Verdes sand are essential equivalents. The Palos Verdes sand and overlying nonmarine terrace deposits dip down to the level of the Los Angeles Plain at the north border of the Palos Verdes Hills, and the strata at Signal Hill have a similar physiographic position. Whether the fossiliferous strata in the two areas are exactly synchronous is uncertain, for several terraces may have been formed in the rapidly emerging Palos Verdes Hills area while one terrace was forming in the Newport-Long Beach area. Correlations of individual Pleistocene terrace deposits would represent a far greater refinement than ordinary Coast Range correlations—a refinement that may never be attained by ordinary methods.

Playa Del Rey.—In a recent publication[82] Willett listed and discussed a large and interesting fauna of 296 species of Pleistocene mollusks from a locality on Lincoln Avenue, two miles northeast of Playa Del Rey. The fossils include the following southern species found in the Palos Verdes sand or on the second and fourth terraces: *Mitra fultoni*, "*Nassa*" *cerritensis*, *Centrifuga leeana*, *Nucella biserialis*, *Forreria belcheri*, *Pecten vogdesi*, *Crassinella branneri*, *Crassinella nuculiformis*

[71] For the latest list of fossils see Martin, Bruce, The Pliocene of middle and northern California: California Univ. Dept. Geol. Bull., vol. 9, pp. 229–230, 1916.
[72] Arnold, Ralph, op. cit. (Calif. Acad. Sci. Mem., vol. 3), pp. 58–64.
[73] Berry, S. S., Fossil chitons of western North America: California Acad. Sci. Proc., 4th ser., vol. 11, p. 413, 1922.
[74] Stephens, Frank, Notes on the marine Pleistocene deposits of San Diego County, Calif.: San Diego Soc. Nat. History Trans., vol. 5, No. 16, pp. 245–256, 1 fig., 1929.
[75] Webb, R. W., Paleontology of the Pleistocene of Point Loma, San Diego County, Calif.: Idem, vol. 8, No. 24, pp. 337–348, 1937.
[76] Stephens, Frank, op. cit., fig. 1.

[77] Webb, R. W., op. cit., p. 341.
[78] Willett, George, Report on Pleistocene molluscan fauna at Capistrano Beach, Orange County, Calif.: Southern California Acad. Sci. Bull., vol. 36, pp. 105–107, 1938.
[79] Arnold, Ralph, op. cit., pp. 30–32.
[80] De Long, J. J. Jr., op. cit.
[81] Eaton, J. E., op. cit., p. 135.
[82] Willett, George, An upper Pleistocene fauna from the Baldwin Hills, Los Angeles County, Calif.: San Diego Soc. Nat. History Trans., vol. 8, No. 30, pp. 379–406 pls. 25, 26. 1937.

("*varians*"), *Mulinia pallida modesta*, *Trachycardium procerum*, *Trachycardium elatum*, and *Trigoniocardia biangulata*. They include also two southern species not known to occur in the San Pedro district, *Engina strongi* and "*Cancellaria*" *bullata*. According to Willett's interpretation, the fossils lived on a sandy bottom at a depth of 10 to 12 fathoms near the mouth of a bay or slough, the source of tide-flat and fresh-water species. Ten northern and moderate-depth species, represented by more or less fragmentary and much eroded specimens, are interpreted by Willett as detrital fossils. Three of the northern and moderate-depth species are found in the Palos Verdes sand at Arnold's Crawfish George's locality. Aside from the occurrence of northern and moderate-depth species, the fauna from the locality near Playa Del Rey closely resembles that from Signal Hill, and the strata near Playa Del Rey are considered the essential equivalent of the Palos Verdes sand. At the northwest border of the Palos Verdes Hills the first terrace dips down to the Los Angeles Plain and extends northward along the coast to Playa Del Rey under a cover of dune sand. At the northwest border nonmarine terrace deposits rest directly on the terrace platform, marine deposits being absent. Willett correlated the fossiliferous sand with Tieje's Centinela gravel,[83] which Tieje considered younger than strata he identified as the Palos Verdes sand. Inasmuch as Tieje's Centinela gravel and the strata he identified as the Palos Verdes sand were not found in the same section, they may be of the same age.

Santa Monica.—Marine sand lying on the platform (Davis' Dume platform)[84] of the lowest terrace along the coast of the Santa Monica Mountains contains at a locality near the head of Potrero Canyon,[85] 2½ miles from the Santa Monica business district, a fauna like that described by Willett from the locality near Playa Del Rey. The southern species *Trachycardium procerum* is recorded from the locality near Santa Monica. An enormous collection from this locality, gathered during a period of many years by Dr. F. C. Clark, is now in the Department of Geology of the University of California at Los Angeles. According to a communication from Prof. U. S. Grant, of that institution, the collection includes other southern species, namely, *Engina strongi*, *Nucella biserialis*, *Acanthina lugubris*, *Dosinia ponderosa*, and *Chione gnidia*. The marine terrace deposits at the localities near Santa Monica and Playa del Rey are doubtless of the same age, but in the intervening area the terrace platform is evidently below sea level owing to slight deformation.

Search for marine fossils in deposits lying immediately above the rock platform farther inland along the foot of the Santa Monica Mountains is justified, for the smooth profile of the platform, exposed in street and highway cuts, suggests marine planation.

The fossiliferous gravel in the northwestern part of Palms,[86] 4½ miles east-northeast of the Santa Monica business district, may be of the same age as the fossiliferous sand in Potrero Canyon, but the faunal evidence is meager and inconclusive.

Localities northwest of Santa Monica.—The southern species occurring in late Pleistocene terrace deposits at San Diego, Signal Hill, the Palos Verdes Hills, Playa Del Rey, and Santa Monica have not been found at localities farther north. Grant[87] concluded that mollusks from terraces at altitudes of 500 and 700 feet in the Ventura district indicate a temperature environment essentially like the present environment at Ventura. Mollusks from the thin veneer of marine sand lying on the platform of the lowest terrace at Carpenteria, 10 miles east of Santa Barbara, are interpreted by Grant and Strong [88] as indicating a marine temperature slightly cooler than the present one along the coast of Santa Barbara County. The nonmarine cover overlying the marine sand contains fossil vertebrates and plants. It may be essentially contemporaneous with the marine deposits or may be considerably younger. According to Oldroyd and Grant,[89] mollusks from marine deposits on the lowest terrace near Goleta, 10 miles west of Santa Barbara, including the northern and moderate-depth *Fusitriton oregonensis*, indicate a temperature probably cooler than the present one. The age relations of the terrace deposits at these localities, and at localities still farther north, to the Palos Verdes sand appear to be indeterminable. Despite the difference in faunal association they may be of the same age, or they may be older or younger.

PLEISTOCENE TO RECENT SERIES

NONMARINE TERRACE COVER

STRATIGRAPHY AND LITHOLOGY

Poorly sorted or unsorted rudely stratified sand, rubble, and gravel overlie marine deposits on terraces in the Palos Verdes Hills or in their absence lie immediately on the platform. These deposits are designated the nonmarine terrace cover. They represent cliff talus rubble, stream fan and channel material, and rill and slope wash. This debris was derived from the cliff backing a terrace and the highland farther inland, and it accumulated after emergence of the terrace. The origin and physiographic aspects of the nonmarine cover of terraces along the California coast were first clearly described by Davis [90] in his account of the terraces along the Santa Monica Mountains, the next highland area up the coast from the Palos Verdes Hills. Its physiographic aspects in the Palos Verdes Hills are discussed under the heading "Physiography," page 113.

Deposits of the nonmarine cover are steeply banked against the cliff at the rear of a terrace, and they slope toward the seaward edge with decreasing dip and thickness. Toward the rear of a terrace their thickness is as much as 100 feet, but an exposed thickness greater than 50 feet is exceptional. As shown in figure 15, the cover may extend uninterruptedly across more than one terrace and effectively conceal the sea cliff between successive platforms.

The bulk of the cover on a terrace accumulated soon after emergence of the terrace. According to the age classification adopted for the terraces, the cover immediately overlying marine deposits or resting on the platform is of upper Pleistocene age. Ever since emergence of the terrace accumulation of nonmarine debris has continued, however, at least at the rear of a terrace, and at places deposits of markedly different

[83] Tieje, A. J., The Pliocene and Pleistocene history of the Baldwin Hills, Los Angeles County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 10, p. 510, 1926.
[84] Davis, W. M., Glacial epochs of the Santa Monica Mountains, Calif.: Geol. Soc. America Bull., vol. 44, pp. 1101-1104, 1933.
[85] Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, pp. 121-122, 1931.
[86] Idem, p. 122.
[87] Grant, U. S., in Putnam, W. C., Geomorphology of the Ventura region, Calif.: Geol. Soc. Am. Bull., vol. 53, pp. 699-700, 1942.
[88] Grant, U. S., and Strong, A. M., Fossil mollusks from the vertebrate-bearing asphalt deposits at Carpenteria, Calif.: Southern California Acad. Sci. Bull., vol. 33, pp. 7-11, 1934.
[89] Oldroyd, T. S., and Grant, U. S., IV, A Pleistocene molluscan fauna from near Goleta, Santa Barbara County, Calif.: Nautilus, vol. 44, pp. 91-94, 1931.
[90] Davis, W. M., Glacial epochs of the Santa Monica Mountains, Calif.: Geol. Soc. America Bull., vol. 44, pp. 1055-1056, 1058-1061, figs. 5, 6, 1933.

age extend over an entire terrace. There is, therefore, every gradation between Pleistocene deposits and deposits still accumulating. On the other hand, the highest terraces have lost much or virtually all of their original cover through erosion.

The statement that the nonmarine cover on a terrace accumulated after emergence of the terrace needs the following qualification. In the event that talus rubble accumulated against the cliff formed by marine planation and was not removed prior to emergence, that part of the cover antedates emergence and is contemporaneous with marine deposits on the terrace. Indeed, a mixture of contemporaneous marine deposits and talus rubble was observed at several localities, and marine constituents were found in talus rubble.

The best exposures of the nonmarine cover are along the present sea cliff and in highway cuts. It forms steep or vertical slopes that are rilled and fluted. It is generally characterized by a reddish-brown color, which is due to a coating of iron oxide on sand grains and larger constituents, the result of oxidation of iron compounds. Soil formed by the cover is also reddish-brown. It resembles soil of similar color formed on basaltic rocks but is more sandy than residual basaltic soil. The nonmarine terrace cover is shown on the geologic maps (pls. 1, 14, 21) at localities where it is thick enough and of sufficient extent to completely conceal underlying formations.

The greatest observed thickness of nonmarine terrace cover is exposed in the present sea cliff along Portuguese Bend at and near locality 99, where it is about 100 feet thick. The basal foot or two, overlying marine fossiliferous gravel and shingle a foot or two thick, consists of small stones, pebbles, and sand. The remainder is made up of reddish-brown sand that includes lenses of poorly rounded and angular stones.

Banking of rudely stratified rubble and sand against the cliff at the rear of the fourth terrace is well shown at the south end of the cut at Bluff Cove, on Palos Verdes Drive West. It is also shown at the rear of the second terrace in a highway cut north of Point Fermin, near locality 94. At that locality about 25 feet of rubble, decreasing in coarseness upward, is banked against the face of the cliff, which has a slope of 60°. The upper surface of the rubble dips 20°. The rubble is overlain by 15 feet of reddish-brown sand. A worn fragment of a marine snail (*Olivella*) was found in the rubble 10 feet from the face of the cliff.

Examples of a mixture of talus rubble and contemporaneous marine deposits toward the rear of a terrace are described under the heading "Marine terrace deposits," pages 53–55. Marine material derived from earlier terraces or more probably hurled by storm waves far above hightide line was observed at the rear of the second terrace at the locality near Point Fermin just described; on the west side of Gaffey Street, near Thirty-ninth (locality 95), a few worn and broken shells were found in rubble 5 to 6 feet thick banked against the cliff at the rear of the terrace; and at locality 97, on the north side of Thirty-seventh Street, near Averill, worn and broken shells and echinoid spines were collected from talus rubble 10 feet thick. The rubble lies against the face of the cliff, which has a slope of 60°.

FOSSILS

Marine fossils are rare in the nonmarine terrace cover and are thought to be extraneous. They represent rock-cliff and tide-pool species that are abundant in the marine terrace deposits. Remains of land mammals were found in the nonmarine cover of the first terrace at two localities. Horse molar teeth fragments were found repeatedly at a locality on the north limb of the Gaffey anticline, 2,000 feet southeast of the intersection of Palos Verdes Drive East and Western Avenue. A bison foot bone, identified by Dr. Chester Stock, was collected in San Pedro, on the north side of Third Street 150 feet west of Pacific, where the nonmarine cover rests directly on the platform of Miocene mudstone. Ground sloth remains from the nonmarine cover on the first terrace at Second and Beacon Streets have been described as *Megalonyx milleri*.[91] Mr. M. Stockton, formerly superintendent of the Dicalite Co., reports that an elephant tusk and camel bone were found in a lens of gravel and rubble exposed in the workings of that company.

PLEISTOCENE (?) SERIES

STREAM TERRACE GRAVEL

The bench on the east side of Gaffey Street, 2,000 feet north of the intersection of Harbor Boulevard and Pacific Avenue, is underlain by gravel composed principally of flat schist pebbles 1 to 3 inches long. This material is considered as stream gravel deposited by the stream draining the schist area, the present George F Canyon. The contact between the gravel and the nonmarine cover on the first terrace is not exposed. The gravel probably truncates the cover, however, and is therefore probably younger than the cover. The adjoining higher bench is probably a stream terrace, but no stream terrace deposits were recognized on it. The southeastward-sloping bench farther inland on the north side of George F Canyon may also represent a stream terrace, but the strata forming the bench are not exposed.

Stream terrace gravel forms a little bench along the lower course of Agua Magna Canyon about 30 feet above the stream floor. The gravel consists mostly of poorly rounded and angular pieces of cherty shale and sandstone, one sandstone slab being about 15 feet long.

RECENT SERIES

DUNE SAND

The strip of dune sand extending along the coast southward from Playa Del Rey, 12 miles north of Malaga Cove, overlaps the northwest end of the Palos Verdes Hills. The limits of the dune sand in the Palos Verdes Hills are uncertain, as it grades into the first terrace nonmarine cover, which underlies it and furnished presumably some, or most, of the material for it. The dune sand has a cover of vegetation, even in areas where the natural vegetation is not greatly disturbed, and is no longer actively moving except near the edge of the sea cliff, where vegetation is scanty.

E. F. Walker, of the Southwest Museum, has found three human culture levels in the dune sand at Malaga Cove and a fourth level in the uppermost 3 feet of the underlying nonmarine terrace cover.[92] At that locality the nonmarine cover of the first terrace, 25 feet thick, lies directly on Miocene and Pliocene formations and is

[91] Lyon, G. M., *Megalonyx milleri*, a new Pleistocene ground sloth from southern California: San Diego Soc. Nat. History Trans., vol. 9, No. 6, pp. 15-30, pl. 1, figs. 1-7, 1938.

[92] Walker, E. F., Sequence of prehistoric material culture at Malaga Cove, Calif.: Masterkey, vol. 11, No. 6, pp. 210-214, 2 figs., 1937.

overlain by 25 to 30 feet of dune sand (fig. 7). The uppermost 3 feet of the nonmarine terrace cover containing the oldest culture is contaminated with much black organic material. The first terrace is considered of late Pleistocene age, and the cover on it at this locality, at a considerable distance from the highlands to the south that furnished the debris, is also considered late Pleistocene. As shown in figure 7 and plate 26, the terrace is arched over the strongly deformed Tertiary formations and slopes toward the highland source of the nonmarine cover. The deposition of the cover antedates, of course, deformation of the terrace and its cover. If the human inhabitants responsible for the lowest culture level lived during the deposition of the uppermost 3 feet of the cover, that culture represents a considerable antiquity—late Pleistocene according to the age classification adopted in the present report. If, on the contrary, the lowest culture represents human occupancy after deposition of the cover but before deposition of the dune sand, its antiquity is correspondingly less. During a field conference at the site in the spring of 1938 Mr. Walker and Dr. Hildegarde Howard, of the Los Angeles Museum, reported that the material collected from this culture level includes mineralized bones of the extinct diving goose *Chendytes lawi,* which occurs in the Palos Verdes sand in San Pedro, and nonmineralized bones of species of birds and other animals now living. Whether the remains of the extinct goose at Malaga Cove represent an animal that was a contemporary of the human inhabitants or represent older material concentrated at the culture site by natural or human agencies is not known. In view of the occurrence of nonmineralized remains of species of animals now living, however, the extinct goose is probably older than the human inhabitants.

The other three culture levels are in the dune sand. Glass trade beads were found at the top of the uppermost level, about 5 feet below the top of the dune sand.

The dune sand is considered of Recent age. All except the uppermost part antedates the historic period. The age of the remainder is a matter of inference based on the succession of geologic events and the uncertain dating of the Pleistocene record. The present inactivity of the dunes suggests that they were formed during a period when the present protective cover of vegetation was lacking. Whether the change from actively moving dunes to inactive dunes is to be correlated with a change from greater to less aridity or is to be correlated with unknown changes resulting in cutting off of the supply of sand is a matter that deserves consideration in any attempt to work out a succession of events in the post-Pleistocene history of the Pacific coast and its human inhabitants. The three culture levels in the dune sand at Malaga Cove indicate a considerable time span.

ALLUVIUM

Alluvium, presumably of Recent age, was mapped along the lower course of some streams, especially George F Canyon and the stream that flowed in the valley followed by Gaffey Street. Narrow bands of alluvium, too narrow to be mapped, are found also along many streams at the north border of the hills and elsewhere. As explained under the heading "Physiography," page 117, at the north border of the hills the nonmarine cover lying on the first terrace does not dip under modern alluvium but continues as the upper part of the older alluvium of the Los Angeles Plain.

BASALTIC ROCKS OF MIOCENE AGE

Intrusive basaltic rocks occur in the lower and middle parts of the Altamira shale member of the Monterey shale but are not known to penetrate younger units. Most of the igneous bodies are sills, ranging in thickness from a foot to several hundred feet, or irregular bodies more or less concordant to the bedding. A thick sill may be seen on the south limb of the Bluff Cove anticline in a cut on Palos Verdes Drive West and another on the Miraleste anticline in cuts on Palos Verdes Drive East. At some localities tongues of basalt extend into the sedimentary rocks, as shown on plate 6, *C,* a view near Point Vicente.

The underlying and overlying sedimentary rocks are generally altered in a zone of variable thickness ranging from less than a foot to several feet. Cherty shale is altered to more dense nearly black chert containing scattered crystals of ankerite, and altered limestone is dark and hard. At many places both basalt and sedimentary rocks are brecciated, irregular tongues of basalt are numerous, the basalt contains inclusions of cherty shale and limestone, the sedimentary rocks contain inclusions of basalt, and limestone dikes penetrate brecciated basalt. One of these localities, in the sea cliff northward from Point Vicente, was described by Macdonald,[93] who concluded that the relations indicate intrusion near the sea floor under a thin cover of Miocene sediments. Perhaps a better example of intrusion into a thin cover of nearly unconsolidated sediments is afforded by the reefs exposed at low tide 0.35 mile northwest of Whites Point. At that locality masses of basalt are embedded in a limy and sandy matrix containing poorly preserved marine mollusks, Foraminifera, and small fragments of basalt. Some of the basalt may have reached the surface in the form of a submarine flow.

The basalt is generally much weathered and altered. The weathered rock is dark brown and soft and at some localities is powdery and characterized by bright hues of yellow, pink, and lavender. The fresh rock is dark gray to black. A fresh specimen from a highway cut 0.6 mile east of Point Vicente is an almost black basalt composed principally of labradorite and augite, the larger phenocrysts being labradorite. Magnetite is relatively rare, pyrite is common. A thin film of opal lines cavities and fills some of the smaller interstices. Dolomite fills some of the larger cavities within the opal film. Another specimen collected from material excavated in the highway cut at Bluff Cove is a basalt or diabase. The rock is greenish gray, owing to a large amount of interstitial chloritic material. Labradorite and augite form a more nearly equigranular texture than in the specimen just described, but some of the larger augite crystals show ophitic intergrowth with the labradorite. Pyrite is present, but magnetite is relatively rare. Interstitial opal and cavity-filling dolomite are less abundant than in the other specimen. Part of the chloritic material shows indices of refraction and a birefringence too high for common chloritic minerals and may represent an iron-rich variety of chlorite. The petrology of the basalt immediately north of Point Vicente was described by Macdonald.[94]

The greatly weathered igneous rock resting on the schist or close to the schist in the main schist area in-

[93] Macdonald, G. A., An intrusive pépérite at San Pedro Hill, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 24, pp. 329–338, 6 figs., 1939.
[94] Macdonald, G. A., op. cit., pp. 332–334.

cludes volcanic agglomerate or breccia that appears to be in part of andesitic composition.

STRUCTURE

STRUCTURAL HISTORY

Miocene.—The pre-Miocene and early Miocene structural history of the Palos Verdes Hills is unknown except insofar as it is inferred from the stratigraphic record and the history of nearby regions.[95] The absence of Cretaceous, early Tertiary, and early Miocene formations suggests that during those periods the present Palos Verdes Hills were part of an extensive schist highland. The northward overlap of middle Miocene deposits indicates progressive subsidence of the schist highland during Miocene time. The different members of the Monterey shale in the Palos Verdes Hills, of late middle Miocene to late upper Miocene age, are conformable to each other. In the Santa Monica Mountains early upper Miocene deposits (lower part of Modelo formation, or Monterey shale of some geologists) rest with marked discordance on middle Miocene deposits (Topanga formation), aside from local exceptions.[96] This period of deformation has not been recognized in the Palos Verdes Hills.[97] In the Point Fermin area the upper part of the Altamira shale member of the Monterey, which is correlated with the lower part of the Modelo of the Santa Monica Mountains contains coarse-grained schist debris. Strata of that age are not known to rest on the schist in the Palos Verdes Hills. The decrease in coarseness and thickness of the schist debris northward from Point Fermin indicates derivation from a now submerged schist area farther south. The great quantity of schist detritus, which is less abundant in underlying strata in the Point Fermin area, suggests deformation of the schist area during early upper Miocene time. These schist-bearing sediments are of the same age as strata resting on schist in the Playa Del Rey and adjoining oil fields. The middle Miocene San Onofre-like schist breccia at Bluff Cove may represent debris derived from a local schist area.

Late Pliocene deformation.—At Malaga Cove the lower Pliocene Repetto siltstone disconformably overlies the upper Miocene Malaga mudstone member of the Monterey (pl. 10, *A*; fig. 7). Elsewhere in the Palos Verdes Hills the relations between those two units are uncertain, owing to difficulty in distinguishing bedding in meager exposures of massive mudstone and equally massive siltstone. Upper Pliocene deposits, represented in the Los Angeles Basin by the Pico formation, are not recognized anywhere in the Palos Verdes Hills. Wherever the relations are clearly shown, the lower Pleistocene strata, consisting of the Lomita marl, Timms Point silt and San Pedro sand, rest unconformably on underlying formations. This relation is particularly well shown in the combined surface and subsurface (Whites Point tunnel) structure section *E—E′* of plate 1. At the only localities where the lower Pleistocene strata rest on the lower Pliocene Repetto, localities in the western part of the Gaffey anticline and Gaffey syncline, the relations are uncertain, owing to the massive character of the Repetto. At Malaga Cove sand doubtfully identified as the San Pedro unconformably overlies the upper Miocene Malaga mudstone.

The well-defined relations at Malaga Cove show that no deformation took place there before deposition of the lower Pliocene Repetto siltstone. The equally well-defined relations of structure section *E—E′* show that strong deformation took place in the northeastern part of the hills before deposition of the lower Pleistocene formations. In view of the small size of the area involved, these relations are considered representative of the northern part of the hills. It follows then that the deformation took place during late Pliocene time. This was the period of strongest deformation in the known geologic history of the Palos Verdes Hills, at least in the northern part of the hills and also by inference elsewhere in the hills where lower Pleistocene strata are not now present.

The subsurface section in the Wilmington oil field,[98] a few miles east of the Palos Verdes Hills, also shows a period of deformation during late Pliocene time.

Middle Pleistocene deformation.—The lower Pleistocene formations are deformed and are overlain unconformably by the upper Pleistocene Palos Verdes sand or by slightly older marine terrace deposits also considered of upper Pleistocene age. In San Pedro the lower Pleistocene strata are tilted northeastward at angles ranging from a degree or two to 22° (pl. 15, *A*, *B*). Inasmuch as the dip decreases away from the hills, even in single exposures as on Second Street and on the destroyed Deadman Island, and inasmuch as no folds are known in the area covered by Pleistocene strata in San Pedro, the deformation in that area is regarded as the result of uplift of the hills. Indeed, an undetermined part of the relatively steep dips adjoining and close to the Miocene basement represents probably depositional dips. Along the Gaffey anticline and syncline, however, the lower Pleistocene strata are folded (sections *D—D′*, *E—E′*, pl. 1) and along the north border of the hills farther west they are strongly deformed (pl. 20; fig. 13; pl. 1, section *B—B′*).

According to the age assignments of the formations above and below the unconformity, this deformation is middle Pleistocene. It is thought to antedate the oldest marine terraces, which are assigned to the upper Pleistocene.

The middle Pleistocene deformation in the Palos Verdes Hills, which is of the same age as strong deformation in the Ventura Basin and presumably elsewhere in the Coast Ranges, has been emphasized in recent discussions of Coast Range deformation,[99] whereas the stronger pre-Pleistocene, that is, late Pliocene, deformation is not considered in those discussions.

Late Pleistocene and Recent deformation.—In San Pedro the upper Pleistocene Palos Verdes sand, constituting the marine deposits on the youngest terrace, and the overlying nonmarine terrace cover have the expectable gentle seaward dip. Along the Gaffey anticline and Gaffey syncline those deposits are gently folded (pl. 1, sections *D—D′*, *E—E′*), and along the north border of the hills west of the Gaffey anticline they are moderately deformed, dipping northward at angles of as much as 26° (fig. 13; pl. 1, sections *B—B′*,

[95] For a discussion of the pre-Miocene and Miocene history of the Los Angeles Basin and its borders see Reed, R. D., and Hollister, J. S., Structural evolution of southern California, pp. 115–124, 133–135, Am. Assoc. Petroleum Geologists, Tulsa, Okla., 1936.

[96] Hoots, H. W., Geology of eastern part of Santa Monica Mountains, Los Angeles County, Calif.:U. S. Geol. Survey Prof. Paper 165, pl. 17, (structural sections), 1931

[97] Reed and Hollister (op. cit., fig. 44. p. 119) show an unconformity in the Palos Verdes Hills at the base of the Valmonte diatomite member of the Monterey and correlate the Valmonte with the lower part of the Modelo formation of the Santa Monica Mountains. This unconformity was not recognized during the field work on which the present report is based, and the Valmonte is considered younger than the lower part of the Modelo of the Santa Monica Mountains

[98] Bartosh, E. J., Wilmington oil field. Los Angeles County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 22, p. 1056, fig. 3, 1938.

[99] Stille, Hans, Der derzeitige tektonische Erdzustand: Preuss. Akad Wiss., Phys.-math. Kl., Sitzungsber., 1935, pp. 205–206. (Translation under title "Present tectonic state of the earth": Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 868, 1936.) Reed, R. D., and Hollister, J. S., op. cit., p. 49, 1936.

C—C′); that is, the relative degree of deformation in those areas is the same as for the lower Pleistocene formations. The post-Palos Verdes deformation along the north border of the hills is of late Pleistocene or Recent age, more probably the former. Elsewhere in the Palos Verdes Hills deformation in the form of successive episodes of uplift took place during late Pleistocene time.

A later, presumably not only Recent but quite modern, episode of post-Palos Verdes deformation is probably represented by slight deformation of alluvium along the crest of the Gaffey anticline. In fact, the anticline may still be growing.

REGIONAL RELATIONS

The Palos Verdes Hills form a conspicuous uplift at the south border of the Los Angeles Basin. In the schist basement and also in the immediately overlying sediments the boundary between the hills and the basin is thought to be marked by a fault. A fault at that boundary is generally shown on small-scale structural maps,[1] and a fault zone is shown on the fault map of California issued in 1922 by the Seismological Society of America. The inferred subsurface fault has been designated the San Pedro fault.[2] A major structural feature corresponding to the inferred subsurface fault has not been found at the surface. The north border of the hills is, nevertheless, the most mobile region in the entire area. Late Pliocene deformation was strong in that region, middle Pleistocene deformation was stronger there than in other parts of the hills, and late Pleistocene and Recent deformation other than uplift are recognized only in that region. Furthermore, wells drilled along the north border of the hills encounter sheared and steeply dipping Pliocene and Miocene strata. Two wells in that area are reported to have penetrated Miocene strata, then Pliocene, and then Miocene again, indicating an anticlinal fold overturned northward or a reverse fault dipping steeply southward.

If the inferred fault along the north border of the hills is a structural reality, it is presumably not pre-Miocene. The Miocene section in the Palos Verdes Hills is somewhat thinner than that in the part of the Los Angeles Basin between the hills and the syncline immediately south of the Newport-Inglewood uplift but includes strata older than any known in that part of the basin. The northward overlap of successively younger parts of the Miocene on the schist basement in the Palos Verdes Hills continues to the Torrance oil field, where upper Miocene strata rest on the schist.[3] Also in the El Segundo and Playa Del Rey oil fields, farther north, upper Miocene overlies schist. (For location of areas mentioned see fig. 1.) Middle Miocene strata may be present in the syncline between the Torrance and El Segundo anticlines, but that possible exception does not affect the comparative history of the Palos Verdes Hills and the adjoining part of the Los Angeles Basin. Nor is it probable that the inferred fault is of pre-Pliocene age, as has been claimed.[4] The stratigraphic data on which that opinion was based are erroneous. Though the lower Pliocene section in the Palos Verdes Hills is much thinner than in the adjoining part of the basin, it includes equivalents of a considerable part of the thick basin section and consists of deposits of deep-water facies. The inferred fault does not antedate presumably the late Pliocene deformation.

The relatively straight steep submarine slope parallel to the trend of the Palos Verdes Hills 2 to 4 miles off the south coast, Shepard and Emery's San Pedro escarpment,[5] suggests a fault, as indicated on some of the small-scale structural maps already cited. The inferred fault is more hypothetical than that just described.

GENERAL FEATURES

In general the greater part of the Palos Verdes Hills is characterized by relatively simple structure, the major folds being broad and gentle, but in certain areas—the entire north border, the area between western San Pedro and Palos Verdes Drive East, and a small area on the south coast at Whites Point and nearby—the structure is complex, the folds being narrow, steep, and locally overturned. Apparently simplicity in some areas may be due to lack of adequate exposures. In areas of generally simple structure sea-cliff and highway exposures show an abrupt change to local complex structure. These local exceptions do not affect, however, the broad classification of areas of simple and complex structure.

Only a few of the strike and dip measurements determined and plotted in the field are shown on the geologic map (pl. 1). It would be confusing rather than helpful to show a great number of these measurements on a map of the scale of plate 1. Local details could not be shown on a map of any scale in areas where the structure is markedly different at different levels in a vertical plane at a single exposure. That there are many such areas is apparent in even a casual examination of highway cuts and natural exposures. The folds shown on plate 1 were selected to represent the trend of folds considered of more than local extent. Some of them may be misinterpreted, and folds of equal extent may be omitted.

Owing to the failure to find persistent recognizable lithologic units through hundreds of feet of Miocene strata, only a few faults are shown on plate 1. Faults and brecciated zones were recognized at numerous other localities in both surface exposures and the Whites Point tunnel. At places the displacement at those localities is demonstrably slight, at other places it may be scores or hundreds of feet.

The folds and the few faults shown on plate 1 have a general northwestward trend roughly parallel to the trend of the hills. In two areas, however, the trend is notably different. Near the north border in the northwestern part of the hills the structural features trend westward, in the Bluff Cove and adjoining areas they trend southwestward. The structurally highest anticlines are in the east-central part and at Bluff Cove. In both areas the general direction of plunge is eastward.

NORTH BORDER OF HILLS

The north border of the hills includes the entire area of lower Pleistocene deposits with the exception of the

[1] Ferguson, R. N., and Willis, C. G., Dynamics of oil-field structure in southern California: Am. Assoc. Petroleum Geologist Bull., vol. 8, fig. 1 (p. 578), 1924. Clark, B. L., Tectonics of the Coast Ranges of middle California: Geol. Soc. America Bull., vol. 41, pl. 16 (op. p. 770), 1930 [1931]; Age of primary faulting in the Coast Ranges of California: Jour. Geology, vol. 40, p. 400, fig. 1, 1932; Folding of the California Coast Range type illustrated by a series of experiments: Idem, vol. 45, fig. 16 (pp. 314–315), 1937. Willis, Bailey, San Andreas rift in southwestern California: Jour. Geology, vol. 46, fig. 1 (p. 1018), 1938.

[2] The San Pedro fault zone of Willis (op. cit.) is a different inferred subsurface feature generally designated the Newport-Inglewood fault or fault zone.

[3] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), fig. 3 (p. 140), 1936.

[4] Clark, B. L., Age of primary faulting in the Coast Ranges of California: Jour. Geology, vol. 40, p. 400, 1932.

[5] Shepard, F. P., and Emery, K. O., Submarine topography off the California coast: Geol. Soc. America Special Papers 31, chart 1, 1941.

San Pedro district, where those strata dip northeastward at a rate decreasing in that direction.

The Gaffey anticline and accompanying Gaffey syncline are the most extensive structural features along the north border of the hills. They have a northwestward trend parallel to the border and plunge southeastward. The relatively wide band of the Malaga mudstone member of the Monterey along Agua Magna Canyon suggests that the anticline and syncline may emerge in that area. They evidently do not affect, however, the nonmarine terrace cover between Agua Magna Canyon and Bent Spring Canyon. Eastward from Bent Spring Canyon the Palos Verdes sand and overlying nonmarine cover are gently folded, the lower Pleistocene Lomita marl and San Pedro sand are more strongly folded, and the Malaga mudstone and presumably also the Repetto siltstone are still more strongly folded, as shown in structure sections *D—D'* and *E—E'* of plate 1; that is, the anticline and syncline are persistent structural features, and deformation took place along them during each period of deformation. In the Whites Point tunnel and at nearby outcrop localities the Malaga mudstone is complexly folded and probably faulted in the core of the anticline, more complexly then can be shown on structure section *E—E'* of plate 1. Owing to inadequate exposures it is not known whether the structure is complex in the area represented by structure section *D—D'*. On Western Avenue a minor thrust fault along the contact between lower Pleistocene and Miocene formations on the south limb of the anticline displaces the base of the nonmarine cover on the lowest terrace (pl. 17, *B*). At that locality the lower Pleistocene strata appear to dip more steeply than the Miocene, owing presumably to truncation of a minor fold in the Miocene strata. Between Palos Verdes Drive East and Gaffey Street the surface slope, formed by the nonmarine cover, is virtually a dip slope. East of Gaffey Street the surface slope does not agree with the dip of the youngest formations or there are two anticlinal bulges, one closer to the border of the hills than the crest of the Gaffey anticline farther west.

During construction of the part of the Whites Point tunnel where the Malaga mudstone was penetrated along the Gaffey anticline, particularly on the south limb of the anticline, the floor of the tunnel buckled and less marked movement took place on the walls and roof. The Malaga mudstone is perhaps the most plastic formation encountered in the tunnel, and the squeezing ground may have resulted from plastic flow due to weight of the overburden. Release of elastically stored energy resulting from deformation along the anticline may have been a contributing or major factor.

West of the Gaffey anticline and Gaffey syncline the Tertiary and Pleistocene formations are strongly deformed. The Miocene and lower Pliocene strata are strongly folded, the lower Pleistocene strata dip northeastward at angles ranging from a few degrees to almost vertical, the upper Pleistocene strata dip in the same direction at angles of as much as 26°, and faults affect the youngest formations (pl. 1, sections *B—B'*, *C—C'*; pl. 20, fig. 13). In most of the area between Hawthorne Avenue and the strip of dune sand a fault or series of closely spaced faults dips steeply northward (pl. 1, sec. *B—B'*; fig. 13). The vertical displacement, down to the north, is the same as in the hypothetical subsurface fault bordering the hills. The surface fault zone is, however, a minor feature and may not be directly connected with the hypothetical major subsurface fault. In the sixth and ninth ravines west of Hawthorne Avenue the Malaga mudstone rests on sand and gravel of the nonmarine terrace cover along a virtually horizontal contact north of the falls that mark the fault, as though the mudstone were thrust northward over the terrace cover. The relations at those localities are due presumably to flowage of water-soaked mudstone. The upper part of the mudstone south of the fault is lubricated by water that seeps through the overlying sand and moves northward along the contact between sand and mudstone.

Strong deformation of Miocene and lower Pliocene formations along the north border of the hills is well shown in the sea cliff at Malaga Cove (pls. 10, *A*, 11, 12; fig. 7). At that locality, however, doubtfully identified lower Pleistocene strata and the nonmarine cover on the lowest terrace are mildly deformed. Two steeply dipping faults are visible in the Miocene strata, and a third fault is probably concealed. Farther north three minor faults, two of which are shown on plate 12, *A*, *B*, displace the base of the San Pedro (?) sand 10 to 15 feet vertically and extend down into the Malaga mudstone along bedding planes dipping 75° northward. The hanging wall is displaced upward, but the relative relations of hanging wall and footwall may be due to horizontal or oblique movement.

NORTHWESTERN PART OF HILLS

The closely spaced steeply tilted folds characteristic of the northwest border of the hills extend farther south into the Malaga Cove and Valmonte residential districts (pl. 1, sec. *B—B'*). The folds have a westward trend, and plunge eastward as they approach the southeastward-trending border of the hills. A fault extending to the border of the hills may separate these westward-trending folds from the northeastward-trending and northwestward-tending folds farther south. Until persistent lithologic units are found in the Altamira shale member of the Monterey it would be difficult, however, to establish a fault on other than doubtful physiographic grounds.

BLUFF COVE AND NEARBY AREAS

At Bluff Cove and nearby the structural features have a southwestward trend, swinging more toward the west. The northeastward-plunging Bluff Cove anticline and the basin-shaped syncline farther inland, in which the Valmonte diatomite member of the Monterey shale is mapped, are examples. The syncline just mentioned is part of a general synclinal area trending almost at right angles to the trend of the hills and bending westward near the coast. Faults are recognized or inferred to be present in the sea cliff in the Bluff Cove (pl. 1, sec. *A–A'*) and Flatrock Point areas but were not detected inland. The minor isoclinal anticline shown in figure 6 is thought to be due to localization of movement during deformation along a bentonitic tuff, which may have acted as a lubricant.

AREA BETWEEN WESTERN SAN PEDRO AND PALOS VERDES DRIVE EAST

In the area between western San Pedro and Palos Verdes Drive East the northwestward-trending folds appear to bend southward and converge. Where they appear to converge, especially along San Pedro Canyon and its tributaries, the structure is very complex and irregular. The Altamira shale is strongly folded and the strata are crushed and broken. In Averill Canyon they are locally overturned westward. Two faults in this area shown on the geologic map of the preliminary paper[6] are omitted on the geologic map of the present report (pl. 1), as they are considered too uncertain.

During construction of the Whites Point tunnel, squeezing ground, manifested by buckling of the tunnel floor and movement of the walls and roof, was encountered in the area under discussion. The movement was evidently not due to weight of the overburden, for squeezing ground was not encountered farther north, where the overburden is as great or greater and the rock formations are essentially similar. It was due probably to release of elastically stored energy resulting from unexplained localization of strong deformation. Minor movement detected during construction of the tunnel at localities other than the Gaffey anticline and the area just mentioned appears to have been related to local zones of brecciated rock and fracture planes.

WHITES POINT AREA

In the Whites Point area the structure is complex. The fan-shaped anticline shown in figure 14 and in part on plate 24, *B*, is exposed along the road on the east side of the point. A syncline 0.3 mile farther west is overturned southward. Its relations to the southward-overturned syncline south of the anticline shown in figure 14 are uncertain. The warm sulfur water at Whites Point Hot Springs rises presumably along a fracture in this area of complex structure. Sharp folds were observed in the Whites Point tunnel between the south portal and a locality about 1,600 feet inland from the coast (pl. 1, sec. *E—E′*). These sharp folds stop abruptly at a series of shear zones that may mark a reverse fault, but that interpretation is uncertain.

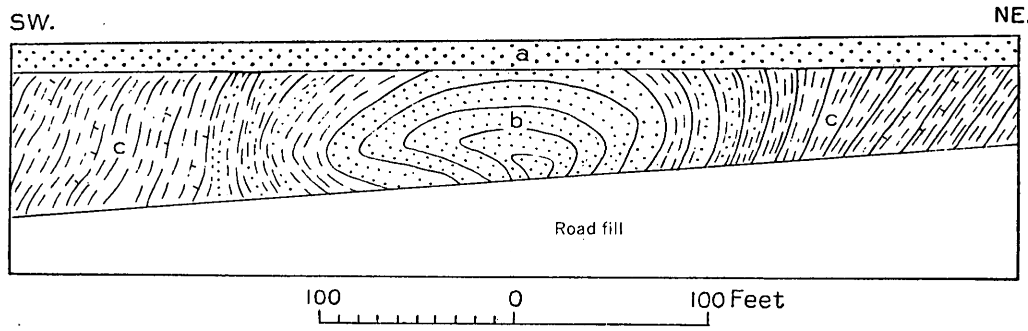


FIGURE 14.—Fan-shaped anticline at Whites Point. a, Pleistocene terrace deposits; b, sandstone, conglomerate, and silty shale (middle (?) part of Altamira shale member Monterey shale, middle (?) Miocene); c, silty shale, silty sandstone, porcelaneous shale, and limestone (middle (?) and upper parts of Altamira shale member of Monterey shale, middle (?) and upper Miocene).

REMAINDER OF HILLS

In the remaining parts of the Palos Verdes Hills the structure is relatively simple, the main folds being broad and gentle. Their prevailing trend is northwest, but in the western part this trend is more westward and the folds merge into the southwestward-trending folds of the Bluff Cove and adjoining areas. At many places there are sharp minor folds of local extent, and locally, as at Bluff Cove (fig. 5), sharp minor folds are overturned. An example of local differential deformation is shown on plate 7, *A*. In the area shown diatomite and diatomaceous shale are more strongly deformed than underlying cherty shale and limestone.

[6] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., op. cit. (Am. Assoc. Petroleum Geologists Bull., vol. 20), fig. 1 (pp. 128-129).

The main schist area is in the northern part of a broad anticline, on which minor folds are superimposed. The crest of the hills in the San Pedro Hill area is marked by a shallow syncline. A general synclinal area, including the basin-shaped syncline at the head of Altamira Canyon, extends farther west along the crest of the hills. Toward the coast the synclinal area bends westward and merges into the extension of the synclinal area east of Bluff Cove.

The southeastward-plunging Miraleste anticline is a well-defined fold in the Miraleste district. Its extension as one fold as far west as shown on plate 1 may not be justified. The southeastward-plunging Point Fermin anticline is not well-defined in the area of apparently irregular structure west of Fort McArthur Upper Reservation.

The Cabrillo fault is the only fault of considerable extent shown on plate 1. At Cabrillo Beach, where the fault emerges on the coast, it dips 50° northeastward at the base of the sea cliff and more steeply toward the top (pl. 6, *D*). At that locality cherty and phosphatic shale in the upper part of the Altamira member of the Monterey is exposed on the hanging wall and buff siltstone in the middle part of the Altamira on the footwall. The displacement at Cabrillo Beach is estimated to be between 100 and 200 feet. The entire blue-schist detrital facies of the upper part of the Altamira, about 300 feet thick at Point Fermin but thinning rapidly northward, and an undetermined thickness of the middle part of the Altamira are cut out. The abrupt termination of the thick basalt sill on the north limb of the Miraleste anticline in the Miraleste district is interpreted as evidence of a fault of similar displacement. No stratigraphic data were observed to substantiate the presence of a fault in the area between Cabrillo Beach and Miraleste, though at least a sharp flexure is evident. A fault of the extent shown on plate 1 is therefore hypothetical. A fault recognized in the Whites Point tunnel is correlated with the Cabrillo fault, as shown in structure section *E—E′* of plate 1. The fault so correlated is thought to cut off the 195-foot basalt sill penetrated in core hole 4. Other nearby faults recognized in the tunnel might, however, with equal plausibility be correlated with the inferred surface fault. In a considerable part of the area between Cabrillo Beach and Miraleste the inferred fault is drawn near the foot of a prominent scarp corresponding roughly to the boundary between soft rocks to the north and hard rocks to the south. The scarp is thought to mark hard-rock cliffs formed during cutting of the Pleistocene marine terraces; that is, it is thought to be a structural inheritance, not a modern fault scarp. Near the coast the scarp is at the boundary of the lowest terrace. It is improbable that the scarp in that area is the result of recent displacement of the lowest terrace, for, other considerations aside, at Cabrillo Beach the fault is not at the foot of the scarp. The minor faults along Agua Negra Canyon are based on mapping of the Miraleste tuff bed. In many other areas faults or brecciated zones were observed, but stratigraphic data are lacking at those localities.

PHYSIOGRAPHY

Marine terraces are the most striking physiographic feature in the Palos Verdes Hills. An old surface of considerable relief preserved as a rolling upland along the crest and upper slopes of the hills is thought to have been formed before the submergence and emergence that produced the terraces.

MARINE TERRACES

The marine terraces of the Palos Verdes Hills were described more than 50 years ago by Lawson,[7] who on the basis of the inadequate map then available recognized 11 terraces. Thirteen main terraces are recognized in this report. Their designation is slightly different from that set forth in a preliminary paper,[8] owing to differentiation of the lowest terrace on the windward (west and southwest) and leeward (east and northeast) slopes and to consolidation of the terraces designated fourth and fifth in the preliminary paper. At least two other terraces are represented locally, but the total number is uncertain, owing to uncertainty in correlations.

The distribution, designation, and correlation of the terraces and profiles are shown on plate 22. It is not certain that all the benches so designated on that map represent marine terraces. Fossiliferous marine deposits, however, have been found on the bench platforms at so many localities shown on plates 1 and 22 that the benches are with considerable confidence considered marine terraces or remnants. Ill-defined benches not represented as terraces on plate 22 are doubtless terrace remnants, and at other localities terraces are unrecognizable, owing to masking of any topographic expression. Fossil localities 84, 88, 91, and 92 are known, for example, to represent terraces without definite topographic expression.

The terraces are designated by number in ascending altitudinal order. This is not a logical arrangement, for the first terrace was the last to be formed. Nevertheless it is a convenient arrangement, as the lower terraces are better preserved and are correlated with greater confidence than the upper terraces. Furthermore, the thirteenth or highest terrace recognized may not be the oldest. The gentle slopes on San Pedro Hill above an altitude of 1,425 feet may represent an eroded higher terrace formed during complete submergence of the hills, as suggested by Lawson.[9] The 13 main terraces range in altitude from approximately 100 to 1,300 feet. The average interval between them is, therefore, about 100 feet. The apparent intervals, as determined by the surface altitude at the rear of successive terraces, range from 75 to 200 feet. The actual intervals, as determined by the altitudes of the platforms at the rear of successive terraces, are for the most part indeterminable. A terrace intermediate between the seventh and eighth, designated 7a, is recognized inland from Point Vicente (pl. 22, profile *E—E'*), and another intermediate between the fifth and sixth, designated 5a, is recognized inland from Flatrock Point.

The terraces are most clearly visible on the windward west coast (pls. 8, 22, profiles *A–A'* to *E–E'*, 24*C*, 25, 26) and on the windward southwest coast from the south slope of San Pedro Hill to Point Fermin (pl. 22, profile *G–G'*). In both areas the prevailing platform rock is hard Miocene cherty shale. The continuity of the terraces in the intervening area is broken by the steep greatly eroded slope and by landslides. On the leeward east and northeast slopes the first terrace truncates unconsolidated lower Pleistocene sediments and soft Miocene mudstone and diatomaceous shale and is, therefore, exceptionally wide. On the leeward east slope in San Pedro the fourth and fifth terraces are also wide, as the platforms truncate relatively soft Miocene shale, the scarp from Miraleste to Cabrillo Beach marking in general the boundary between soft rocks and hard rocks. Elsewhere on the leeward slopes, where the prevailing platform rock is hard cherty shale, as it is on the windward slopes, the terraces, with a few notable exceptions, are less well-defined than on the windward slopes.

The apparent merging of terraces, as shown on plate 22 on both map and profiles, is due to the cover of nonmarine debris, designated the nonmarine terrace cover, that accumulated on the platform and its marine deposits following emergence. This phase of marine terrace development along the mountainous California coast was first clearly described and analyzed by Davis [10] in his description of the terraces along the coast of the western Santa Monica Mountains. Nonmarine deposits on marine terraces had been described previously, of course, as by Trask [11] in his description of the terraces along the coast of the Santa Lucia Mountains and by Hoots [12] in his description of the Santa Monica Plain. The nonmarine cover, described under the heading "Nonmarine terrace cover," page 106, ranges in thickness from a thin veneer near the seaward edge of a terrace that has not been eroded far back to an observed maximum of about 100 feet near the rear of a terrace. As shown in figure 15, a thick nonmarine cover may extend seaward over the next lower terrace, or still lower terraces, forming a multiple cover and concealing the sea cliff between successive terraces, as was observed by Trask [13] and inferred by Davis.[14] An illustration of a multiple cover that conceals the sea cliff between the fourth and third terraces may be seen in a highway cut near Point Vicente (plate 23). Depending on the thickness of the nonmarine cover, the surface altitude at the rear of a terrace may be close to the platform or may be 100 feet or more above it. With few exceptions the nonmarine cover on terraces older than the fifth is not shown on the geologic map (pl. 1). On the upper terraces the cover is so thin owing to erosion that it was not differentiated from ordinary surficial debris; in fact, at and near the

[7] Lawson, A. C., The post-Pliocene diastrophism of the coast of southern California: California Univ. Dept. Geol. Bull., vol. 1, pp. 122–128, 1893.
[8] Woodring, W. P., Fossils from the marine Pleistocene terraces of the San Pedro Hills, Calif.: Am. Jour. Sci., 5th ser., vol. 29, p. 295, 1935.
[9] Lawson, A. C., op. cit., p. 127.
[10] Davis, W. M., Glacial epochs of the Santa Monica Mountains, Calif.: Geol. Soc. America Bull., vol. 44, pp. 1055–1056, 1058–1061, figs. 5, 6, 1933.
[11] Trask, P. D., Geology of the Point Sur quadrangle, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 16, pp. 158–159, 1926.
[12] Hoots, H. W., Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, Calif.: U. S. Geol. Survey Prof. Paper 165, pp. 122–123, 1931.
[13] Trask, P. D., op. cit.
[14] Davis, W. M., op. cit., pp. 1,086–1,087, figs. 19, 20.

rear of a terrace the uppermost part of the cover is ordinary surficial debris.

Correlations of terrace remnants are doubtful, owing to discontinuity on the windward slopes, to poor development on much of the leeward slopes, and above all to the varying thickness of the nonmarine cover and to the masking effect of multiple covers. Terrace platforms are well exposed along the present sea cliff and in canyons as much as a few hundred feet inland. The platform of the first terrace, which covers an extensive area, is visible in many natural exposures. With few exceptions, natural exposures of platforms older than the first were not seen any distance inland from the present sea cliff, even in areas where the terraces were well-defined. All the fossil localities shown on plate 22 more than a few hundred feet inland from the present sea cliff represent highway cuts or other artificial excavations. In the absence of information on numerous platform altitudes at the foot of the sea cliff at the rear of terrace correlations are dubious.

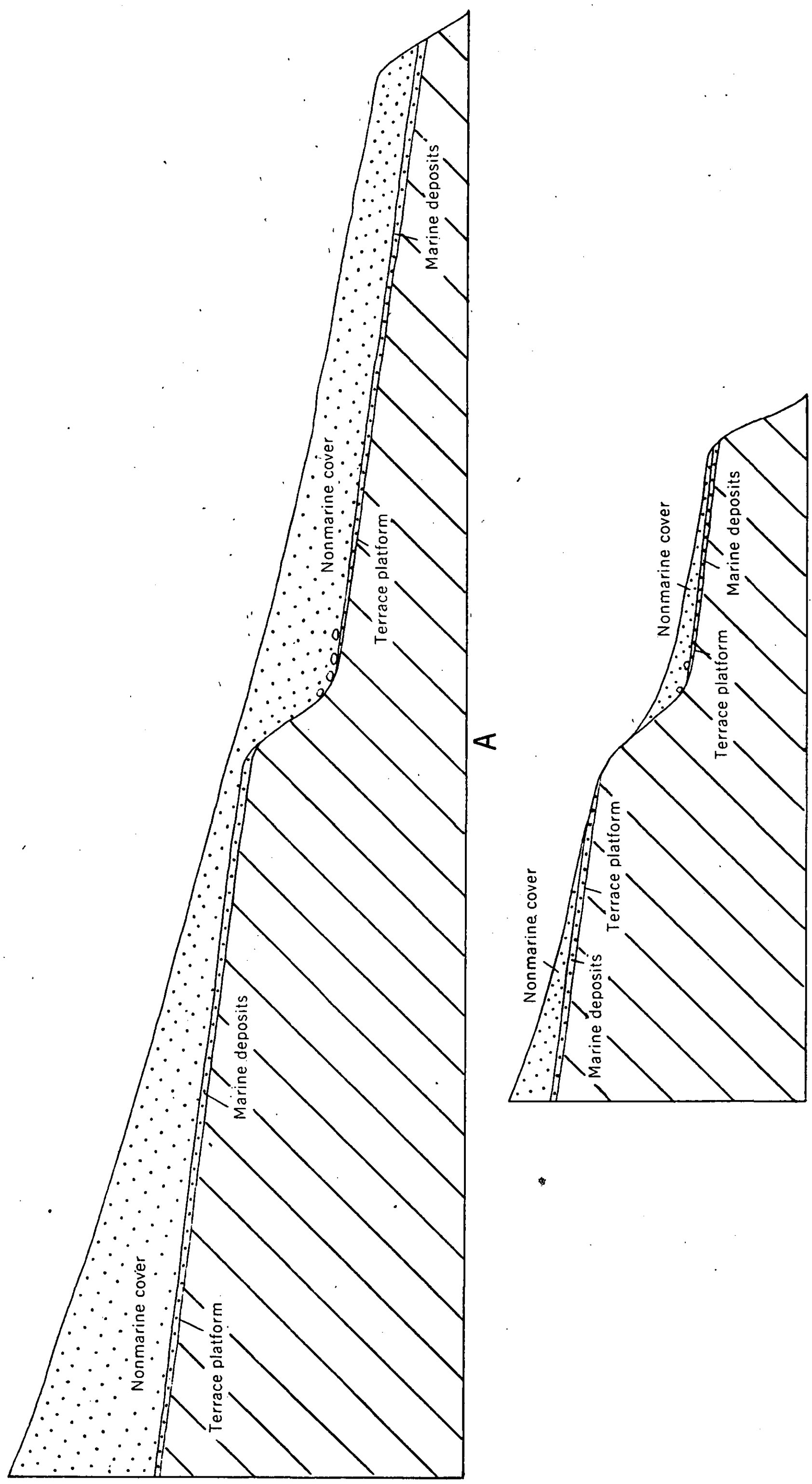
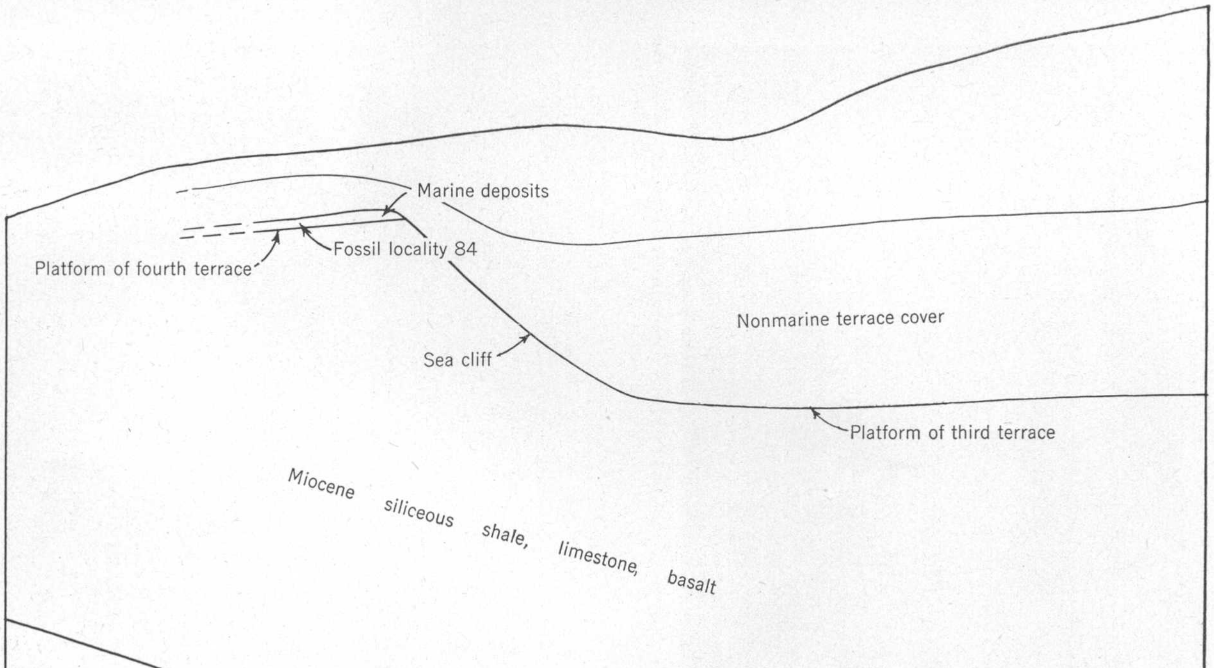


FIGURE 15.—Marine terrace platforms, marine deposits, and nonmarine cover. A, Multiple nonmarine cover concealing sea cliff between successive terrace platforms. B, Single nonmarine cover not concealing sea cliff between successive terrace platforms.

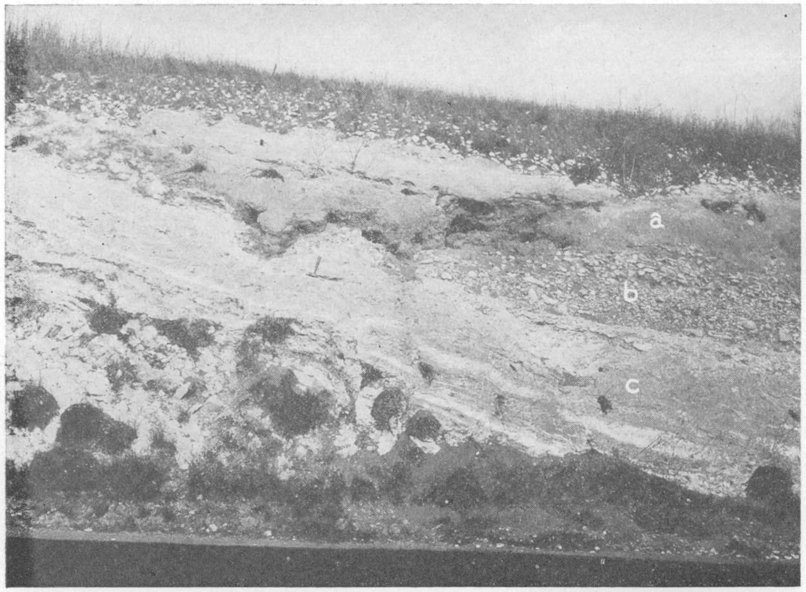
A.



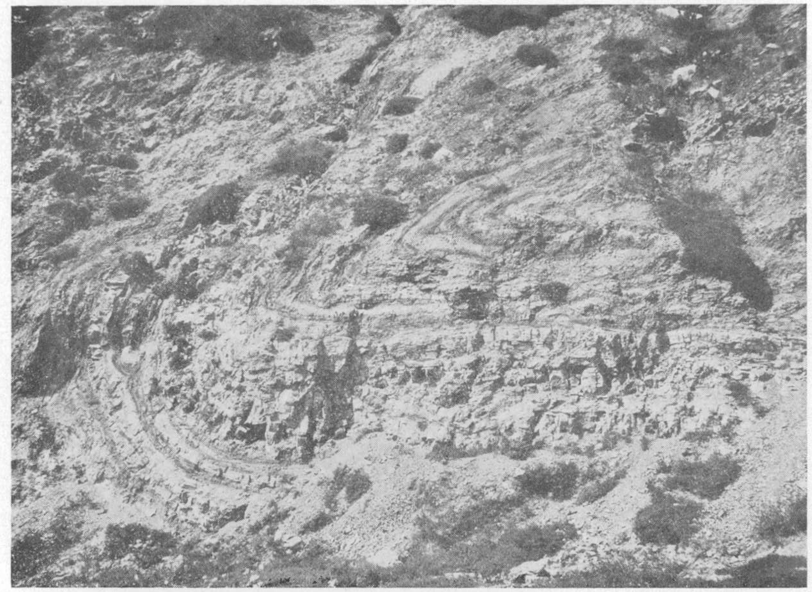
B.

CUT ON PALOS VERDES DRIVE SOUTH, NEAR POINT VICENTE, SHOWING PLATFORMS OF FOURTH AND THIRD TERRACES AND INTERVENING SEA CLIFF.

Owing to foreshortening, platform of fourth terrace appears to slope to left.



A. PALOS VERDES (?) SAND (b) AND OVERLYING NONMARINE TERRACE COVER (a) RESTING UNCONFORMABLY ON MIOCENE SHALE (c) IN CUT ON PALOS VERDES DRIVE EAST, NEAR GEORGE F CANYON.



B. SOUTH LIMB OF FAN-SHAPED ANTICLINE AT WHITES POINT.

C. NORTHWARD VIEW ON WEST COAST SHOWING MARINE TERRACES. FOURTH TERRACE IN FOREGROUND, FIFTH AND SEVENTH ON SKYLINE.

D. HANGING VALLEY AT HEAD OF VALMONTE CANYON.

TERRACE DEPOSITS AND STRUCTURAL AND PHYSIOGRAPHIC FEATURES OF THE PALOS VERDES HILLS.

AIRPLANE VIEW ON WEST COAST OF PALOS VERDES HILLS LOOKING FROM BLUFF COVE SOUTHWESTWARD TOWARD LUNADA BAY.

Numbers represent marine terrace designations. (See pl. 22.) Photograph by Fairchild Aerial Surveys.

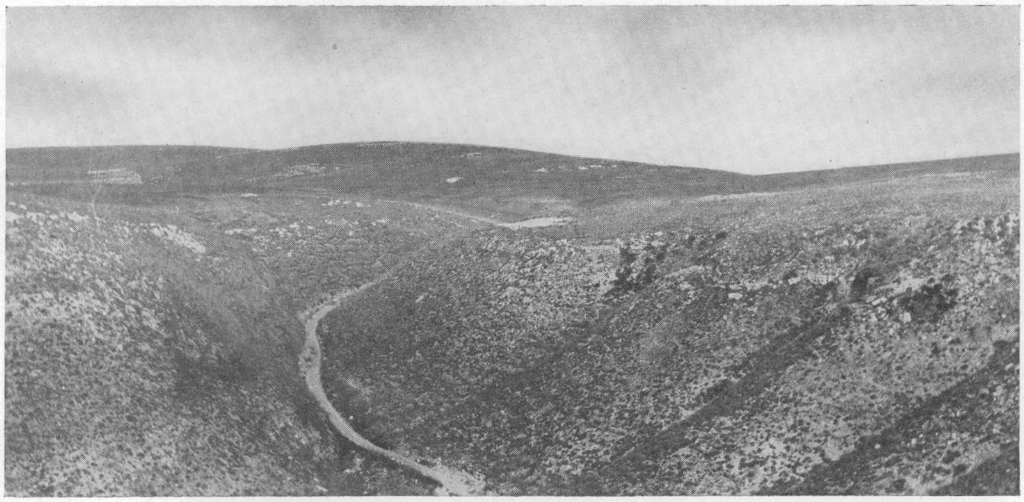
VIEW ON WEST COAST OF PALOS VERDES HILLS LOOKING SOUTHWESTWARD FROM MALAGA COVE.

Terrace at top of cliff at the left, the lowest terrace in the Palos Verdes Hills, is deformed; it slopes toward the hills, not away from them. In middle of view and toward right it has normal seaward slope. Lowest building on skyline is on fifth terrace, building with tower is on sixth. Photograph by Palos Verdes Estates.

A. UNDRAINED DEPRESSION ALONG CREST OF WESTERN PART OF HILLS.

B. HANGING VALLEY AT HEAD OF ALTAMIRA CANYON.

Lip of valley is in right middle foreground. Contrary to appearance it drains to right.



C. HEAD OF ALTAMIRA CANYON TAPPING HANGING VALLEY SHOWN IN *B.*

ROLLING UPLAND ALONG CREST OF PALOS VERDES HILLS.

Those shown on plate 22 are based on relative width of terrace treads and on the assumption that the terraces are not deformed to any notable extent except along and near the north border of the hills, an assumption that appears to be justified by benches identified as remnants of the seventh terrace. The correlations are, however, far from satisfactory, others may be equally plausible or more plausible. Recognition of specific terraces and their correlation in the Ventura district also were found by Putnam [15] to be difficult.

The thirteenth, twelfth, and eleventh terraces are identified with reasonable certainty only on the slopes of San Pedro Hill, where they form narrow spur benches. The platform of the twelfth terrace is exposed at locality 75 in a cut on Crest Road. The marine and nonmarine terrace deposits described on page 54 are visible at that locality, and the marine fossils listed on page 94 were collected there. The crest and upper slopes of the hills northwest of San Pedro Hill include presumably eroded remnants of these uppermost terraces.

The tenth, ninth, and seventh terraces are well-defined on the west slope of the hills, and the tenth, ninth, eighth, and seventh are well-represented on the slopes of San Pedro Hill. The tenth and ninth are identified locally on the northeast slope, and the eighth and seventh in the greater part of that area. The seventh is the widest terrace on the west slope, disregarding apparent merging of the second and third, and is the highest terrace identified around the northwest end of the hills. At most places on the west slope the eighth evidently was removed during cutting of the wide seventh. On the east and northeast slopes the eighth as identified is wider than the seventh, for example, in the Miraleste district and along Agua Negra Canyon, which cleanly cuts a wide bench correlated with the eighth. Perhaps the eighth terrace of the east and northeast slopes corresponds to the seventh of the west slope, but the correlations adopted appear to agree better with identifications of the seventh around the northwest end of the hills. Another possibility is that the eighth and seventh terraces shown on plate 22 represent more than two terraces. An intermediate terrace (7a) is recognized inland from Point Vicente. If it is represented on the east and northeast slopes, it has not been differentiated. According to surface altitudes at the rear of the seventh terrace, it slopes gently southward on the west coast. As the relation is uniform and is shown, though to less marked degree, by the ninth and tenth, it indicates slight tilting.

The sixth terrace is well-defined at the northwest end of the hills (pl. 22, profile *A—A*), is represented by a few remnants on the west slope, and is identified on the ridge extending southeastward from San Pedro Hill and at localities farther west and north, but is not recognized on the northeast slope.

The fifth and fourth terraces are well-developed at the northwest end and on the west slope of the hills. There these terraces form treads of moderate width that appear to be tilted slightly southward like the higher terraces in that area. A terrace intermediate between the fifth and sixth (5a) is recognized at the northwest end. On the northeast slope the fourth and fifth as identified rise southeastward until in the central part of that area they reach altitudes 225 and 250 feet higher than at the northwest end. Southeastward and southward on the northeast and east slopes the altitude drops, and on the southwest coast inland from Whites Point it is the same as at the south end of the west slope. As the altitudes are not based on platform altitudes, misidentifications of terraces and failure to differentiate terrace 5a may be involved. Nevertheless the apparent arching appears to be uniform. Inasmuch as the upper terraces do not show the same relation, the arching is to be correlated presumably with proximity to the mobile north border of the hills, where the first terrace is interpreted as showing similar arching to a more marked extent.

The third is a narrow terrace. It would be grouped probably with the minor terraces 7a and 5a were it not for its younger age and consequently more perfect preservation at more numerous localities on both the west and east slopes of the hills. Along most of the south coast the fourth merges apparently into the second. That this relation is due to a multiple nonmarine cover is shown by the exposure at fossil locality 84 near Point Vicente already mentioned (pl. 23). At fossil locality 99, on Portuguese Bend, the nonmarine cover at a location corresponding approximately to the rear of the second terrace is about 100 feet thick, the greatest observed thickness. On the east slope inland from Fort McArthur Lower Reservation in southern San Pedro the third terrace forms a narrow steeply sloping bench northward from fossil locality 90 but no perceptible bench at localities 91 and 92, where the platform and the marine deposits resting on it are exposed in street cuts.

The second terrace is the lowest terrace along the windward coasts except at Long Point, where a landward remnant of the first terrace represented principally by a bare rock platform is identified, and at Malaga Cove, where the first terrace is well-preserved. In San Pedro the second is differentiated locally from the first, but it generally merges apparently into the first. It is improbable that the second terrace at Point Fermin is the first terrace at Cabrillo Beach uplifted along the Cabrillo fault, for at the coast the fault emerges on the rise between these two terraces.

The first terrace is extensive in San Pedro and on the northeast border of the hills. In areas where mapped marine and nonmarine deposits lie on the platform, the terrace map (pl. 22) agrees with the geologic map (pl. 1). The platform and the deposits lying on it are undeformed in San Pedro. Along the northeast border they are gently folded along the Gaffey anticline and Gaffey syncline. Farther west they are abruptly bent upward at the border of the hills and are at places faulted. In both areas of deformation the platform and the surface have no longer the usual physiographic features of a terrace tread. In fact, the abrupt bending at the border of the hills produces the physiographic effect of a terrace rise. South of the areas where the terrace is deformed the first terrace as identified rises northwestward from San Pedro and southeastward from Malaga Cove, until it reaches altitudes 275 or 300 feet greater than in San Pedro and at Malaga Cove. Perhaps apparently merging terraces representing the second and third as well as the first are confused in this apparent arching. The exceptionally great thickness of marine sand and gravel along the north border near Hawthorne Avenue (p. 59) may include deposits laid down during cutting of the first and one or more older terraces. At several localities, however, as along Palos Verdes Drive North, only one terrace platform

[15] Putnam, W. C., Geomorphology of the Ventura region, Calif.: Geol. Soc. Am. Bull., vol. 53, p. 739, 1942.

and only one set of terrace deposits appear to be involved. The second and third terraces are, therefore, inferred to have been removed along most of the northeast slope during cutting of the first. The absence of an exceptionally high cliff at the rear of the first may be due to masking by the nonmarine cover. Unfortunately, in the area between Malaga Cove and Valmonte, where the first terrace is thought to rise eastward about 300 feet in a distance of 1½ miles, the terraces are concealed by dune sand. At Malaga Cove the first terrace is plainly arched over the strongly deformed Miocene and Pliocene formations (pl. 26; fig. 7). The platform is, however, not abruptly bent downward at the border of the hills, as it is east of the dune sand area.

ROLLING UPLAND

The crest and upper slopes of the hills are characterized by wide swalelike valleys of gentle gradient that stand in marked contrast to the narrow steep-gradient canyons at lower levels. The wide valleys and intervening low smoothly rounded divides form a rolling upland. Plate 4 shows the upland skyline and the deep canyons trenching the upland surface in the area inland from Inspiration Point. Other views of the upland are shown on plate 27. The swalelike valleys are left hanging where the deep canyons advancing inland tap them. Examples of such hanging valleys are shown on plates 24, *D* and 27, *B*, *C*. Profiles of Valmonte Canyon and Altamira Canyon, shown in those views, are reproduced in figure 16. In the eastern part of the hills terrace remnants are found at altitudes as great as 1,300 feet above sea level. On the west slope the rolling upland is limited by the tenth terrace, which is at an altitude of 1,050 feet above sea level. On parts of the north slope the upland surface is identified at altitudes corresponding to the eighth and seventh terraces.

As has already been pointed out,[16] the rolling upland has the features of an old erosion surface. It is improbable that this erosion surface, which has a relief of about 700 feet, was developed on a small island emerging after the almost complete, or complete, submergence during which the high-level terraces were formed. An erosion surface of this character is not expectable on a small island emerging at a relatively rapid rate. Furthermore, it is unlikely that terrace platforms and the thin veneer of unconsolidated marine sediments, such as those on the platform of the twelfth terrace at locality 75, would escape destruction during development of the surface. The erosion surface was formed presumably during the period between the early Pliocene submergence and the late Pleistocene submergence. That it was probably the result of erosion of an area larger than the present Palos Verdes Hills is indicated by the stream profiles of figure 16. If the hanging valleys along the upper course of Altamira Canyon and Valmonte Canyon were graded to the same base level, the hanging valley of Altamira Canyon is to be projected a considerable distance to represent that base level. The high-level terraces may be the result of relatively brief periods during which the old erosion surface was modified by terracing of exposed headlands. Under that hypothesis the ninth and tenth terraces are exceptionally well developed on the west slope of the hills. That coast of the emerging island was, however, evidently most exposed to marine erosion, as lower terraces are more uniformly well-developed there than in any other part of the hills.

The rolling upland contains several undrained depressions, which are most numerous at the northwest end of the hills. Plate 27, *A*, is a view of the largest depression in that area, filled with water after winter rains. The hanging valley in plate 27, *B*, also has a slight closure, evidently less than 5 feet, for after rains water stands in its lower part. One of the depressions is on the tread of the tenth terrace on the west slope, another, 1½ miles northeast of Long Point, is on a flat surface representing probably an eroded remnant of the twelfth terrace. It has been suggested[17] that these depressions are the result of drainage changes caused by downward tilting toward the east. Some of the depressions support that interpretation, but others, such as that 0.2 mile northeast of the 1,216-foot hill near the northwest end of the upland, appear to indicate tilting in the opposite direction. It is more probable that the depressions are the result of underground solution of thin beds of limestone and settling along the gentle-gradient valleys of the rolling upland. Decrease of the drainage areas and consequently the run-off which resulted from the tapping of the drainage basins of the upland by steep-gradient canyons may have played a

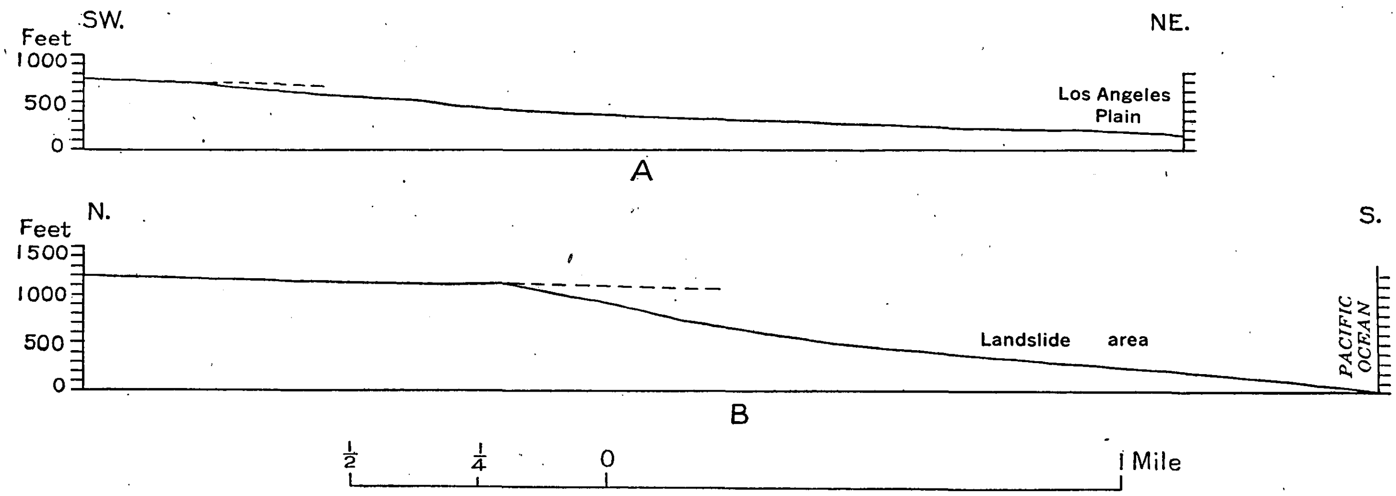


FIGURE 16.—Stream profiles showing hanging valleys. A, Valmonte Canyon, north slope of hills. B, Altamira Canyon, south slope of hills.

[16] Kew, W. S. W., Geologic and physiographic features in the San Pedro Hills, Los Angeles County, Calif.: Oil Bull., vol. 12, No. 5, pp. 517-518, 1926.

[17] Kew, W. S. W., op. cit., p. 518.

part in the development of some of the depressions. It is unlikely, however, that drainage modifications had anything to do with the depression on the tenth terrace. The peculiar cirquelike valley head just north of the crest of the hills, opposite the head of Agua Amarga Canyon, may represent a stage in the development of a depression.

MINOR PHYSIOGRAPHIC FEATURES

Landslides.—An extensive landslide area forms the hummocky topography inland from Portuguese Point and Inspiration Point (pl. 5). As explained on page 18, the landslide is attributed to movement into a structural basin along a gliding plane formed by water-soaked bentonitic tuff. Smaller landslides found elsewhere on steep slopes are not known to be related to particular rock types.

Landsliding or slumping of a different type took place a quarter of a mile east of Point Fermin in 1929. A semielliptical area extending 1,000 feet along the 100-foot sea cliff and 400 feet inland moved seaward as a body, leaving a main fissure 5 to 10 feet wide and an irregularly fissured zone as much as 50 to 100 feet wide. The sliding was attributed by Miller[18] to seaward down-dip movement on slippery shale on the south limb of the Point Fermin anticline. Soon after it was formed, the fissure was filled with fossiliferous San Pedro sand from Second and Beacon Streets. Movement that took place again in 1940 suggests that the slumped mass rotated upward as it moved toward the ocean and that stability has not yet been reached. As a result of exceptionally heavy rains the Point Fermin slide was active again in March 1941.

Dune sand.—The extreme northwestern part of the hills is covered with dune sand and forms the south end of a dune-sand strip extending northward along the coast about 10 miles to Playa Del Ray.

EVENTS SINCE EMERGENCE OF LOWEST TERRACE

Along the north border of the hills the lowest terrace was deformed following emergence and deposition of the nonmarine cover. On most of the west coast and along virtually the entire south coast the lowest terrace has been destroyed by cutting of the present off-shore platform. The valley followed by Gaffey Street was cut across the warped lowest terrace by an antecedent stream or by a stream that breached the Gaffey anticline by headward erosion and captured a stream formerly draining southeastward north of the anticline. The natural features of the floor of this valley have been altered by construction of a sump. It appears probable, however, that slight recent growth of the Gaffey anticline has resulted in the impounding of water in Bixby Slough north of the anticline. The stream formerly had a greater flow to keep pace with the rising anticline, or recent upwarp was more rapid than formerly.

RELATIONS TO NEARBY AREAS

At the north border of the hills the marine and overlying nonmarine deposits of the lowest terrace dip down to the level of the Los Angeles Plain. The nonmarine deposits merge into the older alluvium of the Los Angeles Plain and other parts of the Los Angeles Basin. Lithologically and physiographically the nonmarine cover is indistinguishable from the older alluvium of the basin. They are essentially equivalent, though the older alluvium may represent a time interval corresponding to several of the lowest terraces in the Palos Verdes Hills. Eight miles northeast of the Palos Verdes Hills the older alluvium is arched over the Dominguez anticline forming Vickery's Dominguez surface.[19] The famous Rancho La Brea asphalt deposits, on Wilshire Boulevard in western Los Angeles 20 miles north of the Palos Verdes Hills, are in alluvium that is probably of essentially the same age as the older alluvium arched over Dominguez Hill but was deposited north of a valley along a former course of the Los Angeles River. The Rancho La Brea mammals are now generally considered late Pleistocene. The fragmentary mammalian remains from the marine deposits on the lowest terrace in San Pedro are not inconsistent with the view that they are of essentially the same age as the Rancho La Brea mammals.[20] Grant and Sheppard[21] presented arguments indicating that on physiographic grounds the alluvium at Rancho La Brea is of late Palos Verdes or possibly post-Palos Verdes age.

Two marine terraces along the coast of the western Santa Monica Mountains, 20 to 45 miles northwest of the Palos Verdes Hills, were attributed by Davis[22] to the effects of rising sea level during two periods of Pleistocene deglaciation with uplift between the two periods and after the later period. Owing to the great thickness of the nonmarine cover on the lower terrace and to the extensive erosion represented by the present offshore platform, the present platform was attributed to the effects of the last two nonglacial periods (the last being the present period), between which no uplift took place. Davis[23] pointed out that the terraces may be attributed to land movements and that assignment of the present offshore platform to two instead of one period of deglaciation is doubtful. Tilting of the lower terrace downward to the west 200 or 300 feet within a distance of 30 miles shows that uplift took place after the platform was formed. The terraces were attributed by Davis to the effects of delgaciation, because they are Pleistocene and because, if they were explained by land movement only, no account would be taken of the effects of rising and lowering sea level resulting from Pleistocene deglaciation and glaciation.

That the marine terraces of the Palos Verdes Hills are due principally to uplift is suggested not only by their number and great altitude but also by deformation of the lower terraces along the north border of the hills. The effects of Pleistocene glaciation and deglaciation are unrecognizable, or at least unrecognized, in this actively emerging area. As pointed out by Davis,[24] uplift may increase, decrease, or neutralize effects of changes of sea level produced by glaciation and deglaciation. He[25] suggested that if a sufficient number of examples of Pleistocene terraces are studied at altitudes of as much as 1,000 feet or more along the California coast a correlation between terraces and periods of glaciation and deglaciation may be evident

[18] Miller, W. J., The landslide at Point Fermin, Calif.: Sci. Monthly, vol. 32, pp. 464–469, 5 figs., 1931.

[19] Vickery, F. P., The interpretation of the physiography of the Los Angeles coastal belt: Am. Assoc. Petroluem Geologists Bull., vol. 11, pp. 417–419, fig. 1, 1927.

[20] Stock, Chester, Cenozoic gravigrade edentates of western North America, with special reference to the Pleistocene Megalonychinae and Mylodontidae of Rancho La Brea: Carnegie Inst. Washington Pub. 331, p. 119, 1925.

[21] Grant, U. S., IV, and Sheppard, W. E., Some recent changes of elevation in the Los Angeles Basin: Seismological Soc. Am. Bull., vol. 29, p. 308, 1939.

[22] Davis, W. M., Glacial epochs of the Santa Monica Mountains, Calif.: Geol. Soc. America Bull., vol. 44, pp. 1,044–1,048, 1933.

[23] Idem, pp. 1,044–1,045, 1052, 1060, 1,067, 1,075.

[24] Idem, p. 1045.

[25] Idem, pp. 1107–1108.

on the grounds that terraces formed during rising sea level would be wide, whereas those formed during lowering sea level would be narrow. The seventh terrace in the Palos Verdes Hills, which is exceptionally wide on the west slope and is identified around the northwest end of the hills, may represent a period of rising sea level. On the contrary, it may represent a relatively long period of crustal stability. Even if a sufficient number of examples were found to justify Davis' suggested analysis, effects of varying deformational history in different areas may have obliterated or obscured effects of rising and lowering of sea level.

MINERAL RESOURCES

OIL POSSIBILITIES

Asphalt is abundant locally in the Altamira member of the Monterey shale and occurs at places in the Valmonte diatomite and Malaga mudstone members. Bedding and joint planes in blue-schist sandstone in the upper part of the Altamira on the east side of Point Fermin contain much asphalt and some layers of sandstone are impregnated with it. Fractures and joints in sandy limestone at the junction of the main branches of Agua Amarga Canyon contain asphalt. Beds of vitric volcanic ash exposed in Peck Park in strata assigned to the Altamira and similar material in the Valmonte along the coast between Cabrillo Beach and Fort McArthur Lower Reservation are stained black with asphalt. During construction of the Whites Point tunnel asphalt was observed at numerous localities in the Altamira shale and at a few localities in the Malaga mudstone member. The most conspicuous deposits in the tunnel are in fractured diatomaceous shale of the Altamira immediately below the unconformity with the Pleistocene Lomita marl on the south limb of the Gaffey syncline. Elsewhere in the tunnel asphalt was observed in sandstone, along bedding planes in shale, and in fractures in limestone. A thin layer of asphalt was found at the contact between mudstone and schist conglomerate on the north limb of the anticline, along the crest of which schist was penetrated, but no asphalt was observed in the conglomerate. The fractured basaltic rock encountered farther south is impregnated with asphalt.

The indications of oil in the Palos Verdes Hills and the widespread occurence of oil in upper Miocene and Pliocene formations in Los Angeles Basin fields nearby have encouraged prospecting in the hills. Data on wells that have been drilled in the hills and near the north border are summarized in the following table. The table does not include several shallow wells in or near San Pedro nor two wells reported to have been drilled during 1910 and 1911 near Malaga Cove to depths of 1,100 and 1,285 feet.[26]

[26] Prutzman, P. W., Petroleum in California: California Mining Bur. Bull. 63, p. 328, 1913. The location of the wells is shown on a small-scale map of southern California in the pocket.

Wells drilled for oil in Palos Verdes Hills and near north border of hills

No. on plate 1	Name	General location	Approximate altitude (feet)	Depth (feet)	Approximate altitude of schist basement (feet)	Date drilled	Remarks
1	Traders Oil Co., Weston No. 1.	North of north border of hills along Redendo-Wilmington Blvd.	130	3,392	----------	1919–22	Penetrated base of Pleistocene strata at depth of 1,800 feet. Brown shale with shows of oil from that depth to bottom. Brown shale includes presumably Pliocene and upper Miocene formations.
2	Petroleum Securities Co., Weston No. 1.	North border of hills west of Sepulveda Canyon.	175	3,256	----------	1927	Penetrated calcareous sediments lithologically and faunally similar to Lomita marl at depth of 1,000 to 1,318 feet. Almost vertical upper Pliocene strata at depth of 1,500 to 3,063 feet. Miocene strata, dipping 55° to 60°, from that depth to bottom. Pliocene and Miocene formations in fault contact.
3	Harbor Crude Oil Co., Wheat No. 1.	-----do------------------	250	3,866	----------	1912–14	Penetrated mostly brown shale from depth of 800 feet to bottom. Some oil shows below 1,800 feet. Redrilled in 1937. Lower Pliocene-Miocene contact reported at estimated depth of 1,960 feet.
4	Rolling Hills Petroleum Co., Weston No. 1.	-----do------------------	180	6,580	----------	1937–40	Penetrated upper Miocene strata at depth of about 1,200 feet, lower Pliocene dipping 30° to 35° at depth of 1,975 to 2,650 feet, and reentered almost vertical upper Miocene at depth of about 3,000 to 4,000 feet. Miocene from depth of 4,100 feet to bottom dipping 15° to 40°. Oil shows in nodular shale below 5,800 feet and in conglomerate below 6,450 feet.
5	A. T. Jergins Trust, Palos Verdes No. 1.	Near north border of hills between Agua Magna Canyon and Bent Spring Canyon.	410	2,782	−1,785	1925–26	Penetrated mostly brown shale, presumably Miocene, greatly sheared and dipping from 20° to almost vertical. Altered igneous rock at depth of 2,037 to 2,050 feet. Schist from depth of 2,195 feet to bottom.
6	Petroleum Securities Co., Narbonne No. 1.	Near north border of hills immediately west of Palos Verdes Drive East.	276	4,554	----------	1925–26	Penetrated Miocene strata at depth of about 350 to 2,600 feet, then lower Pliocene, and reentered upper Miocene at depth of about 3,100 feet. Miocene consists mostly of sheared and steeply dipping hard brown shale.
7	Petroleum Securities Co., Palos Verdes.	Near north border of hills west of Gaffey St.	261	2,521	----------	1926	Penetrated mostly Miocene brown shale, sheared and generally dipping 25° to 75°.
8	E. G. Lewis, Palos Verdes No. 1.	Near north border of hills east of Gaffey St.	155	4,498	----------	1922–23	Penetrated sand and gravel to a depth of 605 feet and mostly brown shale, presumably Pliocene and Miocene, below that depth. Oil shows below depth of 1,800 feet.
9	McAdams Exploration Co., Palos Verdes No. 1.	-----do------------------	40	4,496	----------	1935–36	Penetrated thick section of lower Pliocene shale above depth of about 4,300 feet and upper Miocene brown shale below that depth. Average dip about 10°.
10	Keck Syndicate, Burkhard No. 6–2.	Near north border of hills west of Gaffey St.	210	3,300	----------	1923–25	Penetrated mostly brown shale, presumably Miocene.
11	Southern California Drilling Co., Burkhard No. 1.	Valley of lower George F Canyon.	112	1,440	−1,263	1937	Penetrated Pleistocene-Miocene contact at depth of about 500 feet. Miocene strata consist of diatomaceous shale, brown shale, cherty shale, and silty phosphatic shale, mostly sheared and dipping 20° to 90°. Decomposed schist or schist conglomerate at depth of 1,317 feet, schist at 1,375 feet.
12	Hogan Petroleum Co., Burkhard No. 1.	Northeastern part of hills near Harbor Blvd.	25	2,556	----------	1938	Penetrated Pleistocene strata to depth of 1,039 to 1,092 feet and Miocene below 1,092 feet. Miocene strata fractured and sheared, average dip 60°.
13	Hogan Petroleum Co., Burkhard No. 2.	-----do------------------	65	3,734	----------	1938	Penetrated upper Pliocene at depth of 1,800 to 2,040 feet, lower Pliocene at depth of 2,192 feet, and upper Miocene at depth of 3,159 to 3,301 feet. Average dip of lower Pliocene 45°; average dip of Miocene 75°.

Wells drilled for oil in Palos Verdes Hills and near north border of hills—Continued

No. on plate 1	Name	General location	Approximate altitude (feet)	Depth (feet)	Approximate altitude of schist basement (feet)	Date drilled	Remarks
14	J. K. Wehrman Oil Co.	West central San Pedro	270	1,654	−893	1931–34	Penetrated mostly brown shale, presumably Miocene. Entered schist conglomerate at depth of about 800 feet and schist at depth of 1,163 feet.
15	San Pedro-Point Fermin Oil and Gas Co.	Near Point Fermin	15	3,750	−3,285	1922–26	Penetrated schist at depth of 3,300 feet.
16	Los Angeles Harbor Development Co.	Southwestern San Pedro	225	2,044	−1,800	1922	Penetrated schist at depth of 2,025 feet.
17	Surety Holding Co., Sepulveda No. 1.	Near Whites Point	155	1,480		1941–42	
18	Newton Development Co., Palos Verdes No. 1.	Near Long Point	70	4,500	−3,830	1941	Penetrated schist at depth of 3,900 feet.

Most of the wells located well within the hills penetrated the schist basement. Schist may be expected, except in the extreme northeastern part of the hills, at altitudes ranging from 1,000 feet above sea level to about 5,000 feet below sea level, depending on location. In most of the area depth to the schist basement may be estimated with a reasonable degree of certainty. South of San Pedro Hill and farther west on the south slope estimates are uncertain, owing to the undetermined rate of southward thickening of Miocene strata indicated by wells drilled near Point Fermin and Long Point. The Burkhard well of the Southern California Drilling Co., near the trough of the Gaffey syncline, reached solid schist at a depth of 1,263 feet below sea level and decomposed schist or schist conglomerate 58 feet higher. The altitude of the schist basement in this well agrees with the combined surface and Whites Point tunnel structure section *E—E′* of plate 1.

Four wells were drilled along or close to the north border of the hills west of the eastward bend in the border in southern Harbor City. In each of the wells for which adequate records are available strongly deformed strata were penetrated. Two of the wells are reported to have passed from upper Miocene strata into lower Pliocene and then reentered upper Miocene. The abnormal stratigraphic relations show overturning or more probably penetration of a thrust fault.

Six wells are located in the extreme northeastern part of the hills. The McAdams well penetrated a thick gently dipping lower Pliocene section. Drilled to a depth of 4,456 feet below sea level, only about the lowermost 196 feet is reported to represent Miocene. A mile west-southwest of the McAdams well Pleistocene strata rest directly on upper Miocene. The thick lower Pliocene section encountered in this well, therefore, thins rapidly westward, owing presumably to the unconformity at the base of the Pleistocene. It is not known whether the Lewis well, which reached a depth of 4,343 feet below sea level, penetrated deposits of lower Pliocene age, but it presumably did. The Keck well reached a depth of 3,090 feet below sea level and the Petroleum Securities Palos Verdes well a depth of 2,260 feet below sea level. The Keck well is located near the surface crest of the Gaffey anticline. According to structure section *E—E′*, plate 1, and the record of the Burkhard well of the Southern California Drilling Co., schist might be expected on the crest of the Gaffey anticline along the line of structure section *E—E′* at a depth of about 1,000 feet below sea level. The record of the Keck well shows, however, that the schist basement is at a greater depth. A subsurface fault of considerable displacement with downthrow to the north corresponding in position approximately to the axis of the Gaffey syncline is indicated by these relations. The sheared and steeply dipping brown shale reported in the Petroleum Securities Palos Verdes well shows steep dips on the north limb of the anticline close to the crest. Similar features are apparent in the Malaga mudstone at the surface nearby and in the Whites Point tunnel. Steep dips and probable faults were encountered in the two wells drilled by the Hogan Petroleum Co. near Harbor Boulevard. Nicholson [27] concluded that changes in level in the harbor district indicate a fault in the northern part of the district.

The results of drilling are not encouraging. The possibility of finding oil within the hills in sandstone and conglomerate resting on schist at structurally favorable localities and at localities where overlap may be effective has not, however, been tested thoroughly. Strongly deformed Miocene and Pliocene strata are to be expected along the north border of the hills at least as far east as the eastward bend in the border. If sandy beds are present in the Miocene or at the contact between Miocene sediments and schist, oil may have moved southward up dip from the syncline between the hills and the Torrance anticline and accumulated at the border of the hills, where the schist basement is abruptly upturned or faulted. Oil showings in the Rolling Hills well indicate that there is some oil in that area. Prospecting in the expectation of finding possible accumulation of this type is likely to be uncertain and expensive, at least until the subsurface structure is more definitely determined. The subsurface structure in the extreme northeastern part of the hills is evidently not simple. Sand is reported to be absent in the lower Pliocene Repetto formation of that area and the adjoining part of the Los Angeles Basin. If it is absent, it is improbable that oil is trapped in the Repetto, owing to overlap of Pleistocene deposits. If a subsurface feature, a fold or a fault, corresponding to the Gaffey anticline continues southeastward beyond the outcrop area of Malaga mudstone, oil may be found in the Miocene at or above the schist basement, provided suitable reservoir rocks are present. The record of the Hogan wells shows, however, that in at least part of this area the subsurface structure is complex. East of Gaffey Street the schist basement is estimated to be at depths of 5,000 to 6,000 feet below sea level, according to subsurface data in the nearby Torrance and Wilmington fields.

DIATOMITE

Diatomite in the upper part of the Valmonte diatomite member of the Monterey shale is mined by the Dicalite Co. in surface and underground workings along

[27] Nicholson, G. F., Variations in level, 1919 to 1927, in Los Angeles Harbor: Seismological Soc. America Bull., vol. 19, pp. 200–205, 3 figs., 1929.

the lower course of Agua Negra Canyon and in surface workings between Agua Negra Canyon and Crenshaw Boulevard. The upper part of the Valmonte of this area consists of alternating units of laminated diatomite and massive diatomaceous mudstone. Material from selected diatomite units is processed in the company's plant at the junction of Agua Negra and Valmonte Canyons. The product is used for filtration, as filler for paint, rubber, paper, molded plastics, and other products, and for heat insulation.

The Valmonte diatomite member crops out along the north and east slopes of the hills or is inferred to be present in those areas beneath a cover of overlapping Pleistocene strata. Diatomite of the quality mined is, however, not found generally in commercial quantity.

SAND AND GRAVEL

Sand and gravel from the lower Pleistocene San Pedro sand are mined, washed, and screened at several localities along the north border of the hills. The Sidebotham plant on Bent Spring Canyon and the Richard Ball plant immediately east of Hawthorne Avenue are active at the time of writing. At the Sidebotham plant the lighter constituents in the gravel grades, consisting of limestone, cherty shale, and cemented San Pedro sand, are removed by jigging. The product consists of granitic and quartzitic pebbles.

There are extensive deposits of sand and gravel in the San Pedro sand along the entire north and northeast borders of the hills.

OTHER PRODUCTS

Calcareous material in the Lomita marl was formerly mined at Lomita quarry and Hilltop quarry. The product is reported to have been used for soil dressing and as a source of calcium carbonate for poultry. The Lomita marl has a thickness of as much as 275 feet in the Gaffey syncline.

Greatly weathered basalt from the Miraleste district and Bluff Cove has been used locally as a dressing for secondary roads. It appears to bind well, but the wearing quality is probably poor.

Porcelaneous shale, cherty shale, and limestone from the Altamira member of the Monterey shale are used locally for garden walls and flagstones. In 1940 the only active operations were on the coast half a mile northwest of Whites Point, where laminated limestone concretions are quarried and split. Most of the hard Miocene shale in the Palos Verdes Hills is brittle, fractured thin-bedded cherty shale unsuitable for quarrying. Deposits of more thickly bedded porcelaneous shale, such as is quarried in the Monterey district,[28] are not extensive.

FOSSIL LOCALITIES

In the following list the fossil localities are described, and the locality numbers used in this report are correlated with the permanent locality numbers in the Cenozoic register of the Geological Survey and with the field numbers. The fossil localities described, with the exception of a few localities where the maps are congested, are plotted on plates 1, 14, and 21. Locality and stratigraphic data for the numbers not plotted are sufficient to identify the localities in the field. To avoid confusion, the locality numbers for the collections of Miocene fossils are the same as those in the preliminary paper.[29] Collections not considered in the preliminary paper are intercalated in the numbered series by means of letter designations. The units cited refer to the units of the geologic section given in other parts of the report.

[28] Galliher, E. W., Geology and physical properties of building stone from Carmel Valley, Calif.: Mining in California (Div. Mines), vol. 28, No. 1, pp. 21–41, 1932.
[29] Woodring, W. P., Bramlette, M. N., and Kleinpell, R. M., Miocene stratigraphy and paleontology of Palos Verdes Hills, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 2, pp. 125–149, 1936.

Fossil localities

No. used in this report	Permanent Geological Survey No.	Field No.	Description of locality
			MIOCENE
			Lower part of Altamira shale member of Monterey shale
1		B42	Portuguese Canyon area, Portuguese Canyon 2,375 feet northwest of 318-foot bench mark north of Portuguese Bend. Limy layer in mudstone 110 feet below base of Portuguese tuff bed.
2		B45a	Miraleste area, immediately north of Palos Verdes Drive East, 3,275 feet east-southeast of triangulation station on San Pedro Hill. Silty shale underlying basalt sill on south limb of Miraleste anticline.
2a		W11–31	Bluff Cove area, foot of sea cliff at Bluff Cove, 675 feet northwest of 295-foot bench mark on Palos Verdes Drive West near Bluff Cove. Silty shale in almost vertical strata on north limb of Bluff Cove anticline.
			Middle part of Altamira shale member of Monterey shale
2b	13123	W4–33	Bluff Cove-Malaga Cove area, slope above beach at Bluff Cove, 750 feet north-northeast of 295-foot bench mark on Palos Verdes Drive West near Bluff Cove. Sandstone on north limb of Bluff Cove anticline about 150 feet stratigraphically below base of basalt sill.
3		W12–31	Bluff Cove-Lunada Bay area, Palos Verdes Drive West near Bluff Cove, 1,125 feet southwest of 295-foot bench mark. Limestone a foot above top of basalt sill on south limb of Bluff Cove anticline.
3a		B30	Altamira Canyon-Portuguese Canyon area, east fork of Altamira Canyon, 1,325 feet south of 1,215-foot hill south of Crest Road. Limestone 48 feet above probable equivalent of Miraleste tuff bed.
4		B45	Miraleste-San Pedro Hill area, Crest Road on east slope of San Pedro Hill, 1,250 feet southeast of triangulation station on San Pedro Hill. Silty shale.

Fossil localities—Continued

No. used in this report	Permanent Geological Survey No.	Field No.	Description of locality
			MIOCENE—Continued
			Middle part of Altamira shale member of Monterey shale—Continued
5		W125-30	Miraleste-San Pedro Hill area, branch of San Pedro Canyon east of Miraleste Drive, 5,350 feet east-southeast of triangulation station on San Pedro Hill. Diatomaceous silt, evidently part of soft rocks associated with Miraleste tuff bed.
6		W22-33	San Pedro area, south side of branch of San Pedro Canyon 100 feet west of Weymouth St., in block north of Seventh St. Diatomaceous silt containing pebbles and slabs of schist.
7		W21-33	San Pedro area, path in Peck Park on north side of main canyon, 1,175 feet east of 406-foot hill. Steeply dipping calcareous sandstone.
8		W6-33; SPH-14	Point Fermin area, crest of Point Fermin anticline at foot of sea cliff, 2,000 feet east-northeast of Point Fermin lighthouse. Thin-bedded silty shale interbedded with siliceous shale.
9		W61-30	Point Fermin area, foot of sea cliff at Cabrillo Beach, 50 feet south of Cabrillo fault. Massive buff siltstone.
10		W34-33	Bluff Cove-Malaga Cove area, foot of sea cliff 1,450 feet southwest of beach clubhouse at Malaga Cove. Granular limestone.
11		W130-30	Miraleste-San Pedro Hill area, ravine near foot of steep slope south of Cabrillo fault, 8,375 feet southeast of triangulation station on San Pedro Hill. Buff sandstone.
12		W132-30	Point Fermin area, near north end of cut on west side of Alma St., 1,075 feet northeast of Thirty-seventh St. Buff siltstone.
12a	14060	B37	Whites Point area, north limb of fan-shaped fold on east side of Whites Point. Sandstone overlying schist conglomerate. (Not plotted on pl. 1.).)
12b		B21	Whites Point area, low-tide reefs 1.2 miles northwest of Whites Point. Calcareous mudstone.
12c			Whites Point tunnel, station 53+56 feet, 250 feet north of south portal. Mudstone. (Not plotted on pl. 1.)
12d			Whites Point tunnel, station 54+58 feet, 355 feet north of south portal. Mudstone. (Not plotted on pl. 1.)
13	13127	W26-33	George F Canyon-Miraleste Canyon area, west side of George F Canyon 1,925 feet northwest of 732-foot hill near Palos Verdes Drive East. Limy lens in sandstone overlying schist, 20 feet above canyon floor.
13a		W19-29	George F Canyon-Miraleste Canyon area, west side of first canyon east of Palos Verdes Drive East, 2,000 feet southeast of 732-foot hill near Palos Verdes Drive East. Near top of sandstone overlying schist. California Inst. Tech. invertebrate locality 348.
			Upper part of Altamira shale member of Monterey shale
14		B36	Point Fermin-Whites Point area, at top of sea cliff along road leading to Whites Point. Silty shale.
15		SPH-11	Point Fermin-Whites Point area, Dodson Ave. north of Whites Point, 1,000 feet northwest of 371-foot bench mark at southwest corner of military reservation. Silty shale interbedded with porcelaneous shale.
16		B46	Point Fermin-Whites Point area, foot of path leading down to beach on west side of Point Fermin, 1,550 feet northwest of Point Fermin lighthouse. Silty shale about 65 feet below base of upper sandstone unit.
17		B43	San Pedro area, Cabrillo Beach, 200 feet north of Cabrillo fault. Silty shale interbedded with limestone, porcelaneous shale, and phosphatic shale.
			Valmonte diatomite member of Monterey shale
18		W60-30	San Pedro area, Cabrillo Beach, 300 feet northwest of driveway. Diatomite. (Now inaccessible.)
18a		W2-33	San Pedro area, Cabrillo Beach, 150 feet south of driveway. Diatomite.
19		B44	San Pedro area, Cabrillo Beach, 750 feet northwest of driveway. Diatomite.
19a		W24-33	San Pedro area, Cabrillo Beach, 550 feet northwest of driveway. Diatomite.
20	13837	W9-35; W38-33; W91a-30.	San Pedro area, Peck Park, foot of cliff on north side of ravine at north edge of park, 12 feet above floor of ravine. Diatomite.
20a		W39-33	Same locality, 20 feet higher stratigraphically. Diatomite.
21		W14-4	San Pedro area, deep ravine immediately west of Bandini Ave. and east of Peck Park. Diatomite 45 feet above base of exposed section.
21a		W14-5	Same locality, 80 feet higher stratigraphically. Diatomite.
21b		W14-6	Same locality, 2 feet higher stratigraphically. Diatomite.
22		W10-35	San Pedro area, north side of San Pedro Canyon, 100 feet east of Meyler Ave. Diatomite.
			Malaga mudstone member of Monterey shale
23		W36-33	Malaga Cove area, north limb of southern syncline about 30 feet above beach. Limestone concretion 18 feet above base of Malaga mudstone. (Not plotted on pl. 1.)
24		W49-33; SPH 10	San Pedro area, west side of Cabrillo Ave. 75 feet north of Fourth St. Mudstone.
25		W59-30	San Pedro area, south face of cliff at Timms Point, 100 feet west of point. Limestone concretion. (Now inaccessible.)

Fossil localities—Continued

No. used in this report	Permanent Geological Survey No.	Field No.	Description of locality
			PLIOCENE
			Repetto siltstone
26			Malaga Cove, south limb and trough of northern syncline. Twenty-five samples from lower 85 feet of the Repetto siltstone, each sample representing a thickness of about 3 feet. (Not plotted on pl. 1.)
27	13838	W19-35	Malaga Cove, north limb of northern syncline just north of trough, 5 to 10 feet below lower bed of volcanic ash. (Not plotted on pl. 1; see fig. 9.)
28		W100-30	Road leading from Palos Verdes Drive East to prospect excavation in marl, 1,050 feet west of 367-foot hill east of Palos Verdes Drive East.
			PLEISTOCENE
			Lomita marl, Timms Point silt, and San Pedro sand
30	12530	W50-28	Deadman Island, east side. Basal part of San Pedro sand. (Same as California Inst. Tech. invertebrate locality 130; not plotted on pl. 1; now inaccessible.)
31	12529	W5-27	Deadman Island, west side. Basal part of San Pedro sand. (Same as California Inst. Tech. invertebrate locality 31; not plotted on pl. 1; now inaccessible.)
32	12269	W7-30	Timms Point. Base of unit 1 of Timms Point silt at point. (Not plotted on pl. 14; coincides with geologic boundary; now inaccessible.)
32a	12203	W4-30	Timms Point, from point northwestward along bluff to within 50 feet of retaining wall. Unit 1 of Timms Point silt.
32b	12214	W50-30	Timms Point, foot of bluff 100 feet south of shanty. Pocket of rich calcareous material near base of unit 1 of Timms Point silt.
32c	12213	W49-30	Timms Point, foot of bluff from retaining wall to locality 100 feet southeast of retaining wall. Unit 1 of Timms Point silt.
32d	12215	W51-30	Timms Point, about 175 feet north of point on north and south sides of stairs. Unit 2 of Timms Point silt.
32e	12204	W5-30	Timms Point, at drain pipe about 150 feet southeast of retaining wall. Unit 2 of Timms Point silt.
33	12211	W47-30	Timms Point area, east side of Harbor Blvd., 150 feet south of projection of Fourteenth St. Unit 2 of Timms Point silt. (Since current edition of Wilmington topographic map was issued Harbor Blvd. has been extended from business district of San Pedro to Timms Point.)
34	12205	W6-30	Timms Point Area, west side of Harbor Blvd. about 100 feet north of Fourteenth St. Unit 1 (?) of Timms Point silt. (See note under locality 33.)
35	12212	W48-30	Timms Point area, west side of Harbor Blvd. about 150 feet north of projection of Thirteenth St., along path leading to Beacon St. Timms Point silt. (See note under locality 33.)
36	12241	W43-30	Central San Pedro, north side of Eighth St., 100 feet west of Mesa St. Lomita marl.
37	12242	W44-30	Central San Pedro, south side of alley between Seventh and Eighth Sts., about 150 feet west of Mesa St. Lomita marl.
38	12210	W42-30	Central San Pedro, south side of Eighth St., 25 feet east of Center St. Timms Point silt.
39	12209	W39-30	Central San Pedro, east side of Mesa St., 50 feet north of Seventh St., excavation along sidewalk. Timms Point silt.
40	12208	W38-30	Central San Pedro, south side of Third St., at southwest corner of Third and Mesa Sts. Timms Point silt.
41	12239	W29-30	Central San Pedro, abandoned quarry off alley 150 feet east of Pacific Ave. and 50 feet south of Second St. Lomita marl.
42	12229	W21-30	Central San Pedro, south side of Second St., 150 feet east of Pacific Ave. Unit 1 of Lomita marl.
42a	12230	W22-30	Same locality. Unit 2a of Lomita marl. (Localities 42a to 42i are on progressively younger strata and progressively farther east on Second St. between Pacific Ave. and Mesa St., 42i being 350 feet east of Pacific Ave. They are not plotted on pl. 14.)
42b	12231	W23-30	Same locality. Unit 2b of Lomita marl.
42c	12232	W24-30	Same locality Unit 3a of Lomita marl.
42d	12233	W54-30	Same locality. Coarse-grained calcareous sand at base of unit 3c of Lomita marl.
42e	12234	W55-30	Same locality. Coarse-grained calcareous sand 2 feet 10 inches above base of unit 3c of Lomita marl.
42f	12235	W25-30	Same locality. A foot above base of unit 4a of Lomita marl.
42g	12236	W26-30	Same locality. 7½ feet above base of unit 4a of Lomita marl.
42h	12237	W56-30	Same locality. Unit 4b of Lomita marl.
42i	12238	W27-30	Same locality. 3 feet below top of unit 4b of Lomita marl.
43	12240	W30-30	Central San Pedro, north side of Second St., 150 feet east of Pacific Ave. Coarse-grained calcareous sand 6 feet above base of Lomita marl.
43a	12247	W62-30	Same locality, 125 feet east of Pacific Ave., and in adjoining alley. Lomita marl. (Not plotted on pl. 14.)
44	12206	W27a-30	Central San Pedro, south side of Second St., 350 feet east of Pacific Ave. Unit 1 of Timms Point silt. (Not plotted on pl. 14; coincides with geologic boundary.)
44a	12207	W28-30	Same locality. Unit 3 of Timms Point silt. (Not plotted on pl. 14.)
45	12216	W63-30	Central San Pedro, north side of Second St., 150 feet west of Mesa St. Unit 7 of Timms Point silt.
46	12202	W94-30	Same locality, 100 feet west of Mesa St. Thin bed of sand 7½ feet above base of San Pedro sand. (Not plotted on pl. 14; coincides with geologic boundary on map of that scale.)
47	12196	W2-30	Central San Pedro, west side of Harbor Blvd. at southwest corner of Harbor Blvd. and Second St. Unit 3 of San Pedro sand..

Fossil localities—Continued

No. used in this report	Permanent Geological Survey No.	Field No.	Description of locality
			PLEISTOCENE—Continued
			Lomita marl, Timms Point silt, and San Pedro sand—Continued
47a	12197	W3-30	Same locality. Unit 4 of San Pedro sand.
48	12198	W65-30	Northwestern San Pedro, foot of bluff along Harbor Blvd. opposite end of Grand St. San Pedro sand.
49	12628	W1-31	Gaffey anticline, Harbor Blvd. opposite San Pedro Lumber Co., 4,200 feet northeast of intersection of Harbor Blvd. and Pacific Ave. Unit 1 of San Pedro sand.
49a	12629	W2-31	Same locality. Unit 3 of San Pedro sand.
50	12199	W70-30	Gaffey anticline, south side of ravine opposite loading platform on siding of Western Oil and Refining Co., 2,200 feet southwest of intersection of Harbor Blvd. and Frigate Ave. San Pedro sand.
51	13777	W4-35	Gaffey anticline, abandoned sand pit on west side of Gaffey St., 1,775 feet southwest of 151-foot bench mark east of Gaffey St. San Pedro sand.
52	12264	W140-30	Gaffey anticline, ravine west of Gaffey St., 3,150 feet south of intersection of Gaffey St. and Anaheim Blvd. Timms Point silt (?).
53	12218	W8-30	Hilltop quarry, algal bed in fault block on southeast face of quarry. Lomita marl. (Localities 53, 53a, and 53b are not plotted on pl. 1, but the quarry is shown.)
53a	12220	W12-30	Same locality. Algal bed at level of floor at northwest end of quarry. Lomita marl.
53b	12219	W10-30	Same locality. 2-inch shell-bearing lens in marl overlying algal bed on southeast face of quarry. Lomita marl.
54	12221	W13-30	Floor and east side of canyon immediately west of Hilltop quarry. Unit 3 of Lomita marl.
54a	12222	W14-30	Same locality. Unit 4a of Lomita marl.
54b	12223	W15-30	Same locality. Unit 5b of Lomita marl.
54c	12224	W16-30	Same locality. Unit 5c of Lomita marl.
54d	12225	W17-30	Same locality. Unit 5d of Lomita marl.
54e	12226	W18-30	Same locality. Unit 6a of Lomita marl.
54f	12227	W19-30	Same locality. Unit 6c of Lomita marl.
54g	12228	W20-30	Same locality. Unit 7 of Lomita marl.
55	12248	W80-30	West side of canyon immediately west of Hilltop quarry. Lomita marl.
56	12200	W83-30	Standard Oil Co. tank farm, 50 feet inside fence at east boundary. San Pedro sand
57	13803		Dump of central shaft of Whites Point tunnel. Probably from upper 90 feet of Lomita marl penetrated in shaft.
57a	13802		Whites Point tunnel, 90 feet north of central shaft and 12 feet below sea level. Lomit marl.
58	14068	W1-37	Cut on east side of Western Ave., 900 feet south of valley of lower George F Canyon. Gray sand at base of cut; San Pedro sand.
58a	14069	W2-37	Same locality. *Anomia-Ostrea* layer in San Pedro sand overlying that at 58.
59	12201	W84-30	Bluff on south side of valley of lower George F Canyon, 550 feet west of Western Ave. San Pedro sand.
60	12250	W99a-30	Gaffey syncline, prospect pit in calcareous beds 500 feet west of Palos Verdes Drive East. Unit 4 of Lomita marl.
60a	12251	W99b-30	Same locality. Unit 7 of Lomita marl.
60b	12252	W99c-30	Same locality. Unit 13 of Lomita marl.
61	12253	W103-30	Gaffey syncline, cut along road above prospect shaft in calcareous beds, 1,500 feet south-southeast of Lomita quarry. Lomita marl.
62	12245	W45b-30	Gaffey syncline, Lomita quarry. Unit 2 of Lomita marl. (Not plotted on pl. 1, but the quarry is shown.)
62a	12244	W45a-30	Same locality. Unit 5 of Lomita marl.
62b	12243	W45-30	Same locality. Unit 6a of Lomita marl.
63	12455	W144-30	Gaffey syncline, ravine 600 feet northwest of Lomita quarry. San Pedro (?) sand.
64	12246	W46-30	Gaffey anticline, between tank and loading hopper of Sidebotham No. 2 sand pit on east side of Bent Spring Canyon 1,625 feet east-northeast of Lomita quarry. San Pedro sand. (Not plotted on pl. 1; coincides with geologic boundary.)
65	12254	W104-30	Gaffey anticline, near top of northwest face of Sidebotham No. 1 sand pit on west side of Bent Spring Canyon. San Pedro sand.
66	12217	W105-30	North border of hills, ravine 1,000 feet east of Crenshaw Blvd. Timms Point silt.
67	12256	W109-30	North border of hills, southwest face of abandoned gravel pit on east side of Agua Negra Canyon. Lomita marl.
68	12255	W108-30	North border of hills, east side of Agua Negra Canyon 500 feet below warehouse of Floatstone Products Co. Lomita marl.
69	12263	W119-30	North border of hills, 461-foot hill 800 feet southeast of Hawthorne Ave. Lomita marl.
70	12261	W117-30	North border of hills, second ravine northwest of Hawthorne Ave. Lomita marl.
71	12262	W118-30	North border of hills, head of fourth ravine northwest of Hawthorne Ave. Lomita marl.
72	12259	W113-30	North border of hills, foot of waterfall in fourth ravine northwest of Hawthorne Ave. Lomita marl.
72a	12260	W114-30	North border of hills, southwest face of abandoned sand pit on north side of fourth ravine northwest of Hawthorne Ave. Lomita marl.
73	12257	W110-30	North border of hills, foot of waterfall in fifth ravine northwest of Hawthorne Ave. Lomita marl. (Not plotted on pl. 21; see fig. 13.)
73a	12258	W111-30	Same locality, south side of ravine about 75 feet below waterfall. San Pedro sand. (Not plotted on pl. 21; see fig. 13.)
73b	12454	W123-30	Same locality, 30 feet upstream from waterfall. Lomita marl. (Not plotted on pl. 21; see fig. 13.)
74	12249	W94-30	Malaga Cove, upthrown side of northernmost minor fault at north end of cove (pl. 13, *A*). 7 feet above base of San Pedro (?) sand. (Not plotted on pl. 1.)

Fossil localities—Continued

No. used in this report	Permanent Geological Survey No.	Field No.	Description of locality
			PLEISTOCENE—Continued
			Marine terrace deposits older than Palos Verdes sand
75	13126	W25–33	Southwest slope of San Pedro Hill, Crest Road 1,750 feet southest of triangulation station on San Pedro Hill. Twelfth terrace.
76	12186	W131a–30	Palos Verdes Drive East, 1,300 feet northeast of intersection of Crest Road, foot of cut. Ninth terrace.
76a	12187	W131b–30	Same locality, top of cut 50 feet to southwest. Ninth terrace.
77	13137	W50–33	Palos Verdes Drive East, Miraleste district, 900 feet northwest of intersection of Miraleste Drive. Eighth terrace.
78	12184	W124–30	Miraleste district, Colinta Road, 300 feet southwest of intersection of Miraleste Drive. Sixth terrace.
79	12194	W141–30	Malaga Cove district, Del Monte Road, 500 feet southwest of La Venta Inn. Sixth terrace.
80	13136	W48–33	Crest Road, 2,550 feet northeast of Point Vicente lighthouse. Fifth terrace.
81	12193	W139–30	Malaga Cove district, Montemar Road, 1,125 feet southeast of 278-foot bench mark near Flatrock Point. Fifth terrace.
82	12182	W53–30	Southern San Pedro, west side of Peck St., 375 feet north of Thirty-sixth St. Fourth terrace.
83	13782	W12–35	Southern San Pedro, west side of Gaffey St., 50 feet north of Thirty-eighth St. Fourth terrace.
84	12189	W135–30	Palos Verdes Drive South, 1,950 feet east-northeast of Point Vicente lighthouse, about 50 feet above level of highway. Fourth terrace.
85	13135	W47–33	Palos Verdes Drive West, 1,050 feet east of 157-foot bench mark between Resort Point and Point Vicente. Fourth terrace.
86	13134	W46–33	Bluff Cove, near top of sea cliff 475 feet north of 295-foot bench mark. Fourth terrace.
87	12195	W142–30	Malaga Cove district, Campesina Road at intersection of Segunda Road. Fourth terrace.
88	13796	W8–35	Palos Verdes Drive North, 4,400 feet southeast of Palos Verdes Golf Club. Fourth terrace.
89	13780	W7–35	Palos Verdes Drive North, 3,500 feet west-southwest of intersection of Palos Verdes Drive East. Fourth terrace.
90	13783	W13–35	Southern San Pedro, west side of Gaffey St., 100 feet north of Thirty-first St. Third terrace.
91	13784	W14–35	Southern San Pedro, south side of Hamilton Place, 100 feet southeast of Gaffey St. Third terrace.
92	13785	W15–35	Southern San Pedro, south side of Twenty-first St., 200 feet west of Cabrillo St. Third terrace.
93	12133	W11–30	Southwest face of Hilltop quarry. Third terrace. (Not plotted on pl. 1; coincides with geologic boundary at southeast end of quarry.)
94	12190	W136–30	Southern San Pedro, top of sea cliff 950 feet northwest of Point Fermin lighthouse. Second terrace. (Chaces' chiton bed locality.)
95	13781	W11–35	Southern San Pedro, west side of Gaffey St., 100 feet north of Thirty-ninth St. Nonmarine cover banked against cliff at rear of second terrace.
96	13131	W42–33	South coast, 3,600 feet northwest of Point Fermin lighthouse. Second terrace.
97	12185	W126–30	Southwestern San Pedro, north side of Thirty-seventh St., 225 feet east of Averill St. Nonmarine cover banked against cliff at rear of second terrace.
98	13130	W43–33	South coast, 2,800 feet northwest of Whites Point. Second terrace.
99	12188	W133–30	South coast, Portuguese Bend, 3,500 feet east of Inspiration Point. Second terrace.
100	13132	W44–33	South coast, 3,600 feet northeast of triangulation station at Long Point. Second terrace.
101	13133	W45–33	West coast, 3,750 feet northwest of Point Vicente lighthouse. Second terrace.
102	13129	W31–33	West coast, Lunada Bay, south side of Agua Amarga Canyon. Second terrace.
103	12191	W137–30	Same locality, north side of Agua Amarga Canyon. Second terrace.
104	12192	W138–30	West coast, near Flatrock Point. Second terrace.
105	12183	W122–30	Malaga Cove district, Corta Road 900 feet northwest of Malaga Cove business district. Second terrace.
106	13125	W19–33	Northwestern San Pedro, path in Peck Park 650 feet south-southeast of 252-foot hill. Second terrace.
			Palos Verdes sand
107	12162	W127–30	San Pedro, Cabrillo Beach, 500 feet northwest of driveway.
108	12138	W52–30	San Pedro, north side of ravine at north edge of Fort McArthur Lower Reservation. (Arnold's Crawfish George's locality.)
109	12137	W41–30	San Pedro, vacant lot near northwest corner of Palos Verdes and Eighth Sts. (Now inaccessible.)
110	13779	W6–35	San Pedro, west side of Mesa St., 100 feet south of Third St.
111	12134	W35–30	San Pedro, east side of Palos Verdes St., 75 feet north of Third St.
112	12132	W1–30	San Pedro, west side of Pacific Ave., midway between Oliver and Bonita Sts.
113	12135	W37–30	San Pedro, east side of 48-foot mesa, 1,000 feet southeast of intersection of Harbor Blvd. and Pacific Electric tracks. (Arnold's lumber yard locality; now inaccessible.)
114	12136	W40–30	San Pedro, south side of Harbor Blvd. immediately south of crossing of Pacific Electric tracks.
115	12148	W77–30	San Pedro, north side of street leading westward from Gaffey St., at north edge of town, 1,000 feet west of Gaffey St.
116	12147	W76–30	South limb of Gaffey syncline, 3,200 feet northwest of intersection of Harbor Blvd. and Pacific Ave.
117	12149	W81–30	South limb of Gaffey syncline, cattle trail 50 feet south of fence at south boundary of Standard Oil Co. tank farm.

Fossil localities—Continued

No. used in this report	Permanent Geological Survey No.	Field No.	Description of locality
			PLEISTOCENE—Continued
			Palos Verdes sand—Continued
118	12150	W82–30	South limb of Gaffey syncline, road in Standard Oil Co. tank farm, 350 feet west of fence at east boundary.
119	12140	W66–30	Gaffey syncline, Harbor Blvd. 2,200 feet north-northwest of intersection of Harbor Blvd. and Pacific Ave.
120	12141	W68–30	Gaffey anticline, Harbor Blvd. opposite San Pedro Lumber Co., 4,300 feet northeast of intersection of Harbor Blvd. and Pacific Ave.
121	12142	W69–30	Gaffey anticline, south side of ravine along siding of Western Oil and Refining Co. immediately west of Harbor Blvd., 2,150 feet southwest of intersection of Harbor Blvd. and Frigate Ave.
122	12139	W67–30	Gaffey anticline, ravine on east side of valley along Gaffey St., 3,500 feet north-northwest of intersection of Harbor Blvd., and Pacific Ave.
123	12146	W74–30	Gaffey anticline, east side of valley along Gaffey St., 300 feet south of Anaheim Blvd.
124	12145	W73–30	Gaffey anticline, east side of valley along Gaffey St., immediately north of Anaheim Blvd.
125	12152	W87–30	Gaffey anticline, ravine on north side of valley of lower George F Canyon, 4,650 feet south-southwest of intersection of Anaheim Blvd. and Gaffey St.
126	12163	W128–30	Gaffey anticline, ravine on west side of valley along Gaffey St., 4,800 feet south of intersection of Anaheim Blvd. and Gaffey St.
127	12154	W89–30	Gaffey anticline, abandoned sand pit on west side of valley along Gaffey St., 3,600 feet south of intersection of Anaheim Blvd. and Gaffey St.
128	12153	W88–30	Gaffey anticline, ravine on west side of valley along Gaffey St., 900 feet southwest of intersection of Anaheim Blvd. and Gaffey St.
129	12143	W71–30	Gaffey anticline, west side of Gaffey St., 350 feet southeast of Anaheim Blvd. Isolated pocket of Palos Verdes sand 3 feet below top of San Pedro sand.
130	12144	W72–30	Gaffey anticline, south side of Anaheim Blvd. 300 feet southeast of bridge across Pacific Electric tracks. (Area of Palos Verdes sand exposed in cut too small to show on pl. 1.)
131	12151	W86–30	Gaffey anticline, north side of valley of lower George F Canyon, 1,150 feet west of Western Ave.
132	12155	W90–30	Gaffey anticline, ravine on north side of valley of lower George F Canyon, 1,100 feet west of Western Ave.
133	13786	W16–35	West side of Palos Verdes Drive East 800 feet south of intersection with Palos Verdes Drive North. Palos Verdes (?) sand. (Now inaccessible.)
134	13778	W5–35	Gaffey anticline, west side of Palos Verdes Drive North 450 feet southwest of Anaheim Blvd.
135	12156	W98–30	Gaffey anticline, east side of ravine near head of Senator St., 1,400 feet west-southwest of intersection of Anaheim Blvd. and Palos Verdes Drive North.
136	12157	W101–30	Gaffey anticline, head of ravine 1,100 feet southeast of Bent Spring Canyon.
137	13776	W3–35	Gaffey anticline, near head of ravine 500 feet southeast of Bent Spring Canyon.
138	12158	W102–30	Gaffey anticline, cut on west side of Cypress St., Lomita, opposite settling basin of waterworks. (Area of Palos Verdes sand exposed in cut too small to show on pl. 1.)
139	13774	W1–35	North border of hills, east face of first sand pit (Graham Bros.) west of Agua Magna Canyon. Top of basal gravel of Palos Verdes sand.
139a	13775	W2–35	Same locality. Top of upper gravel of Palos Verdes sand.
139b	12159	W107–30	Same locality, 200 feet to southwest. Upper gravel of Palos Verdes sand.
140	12631	W21–31	North border of hills, cut at workings of Dicalite Co., 300 feet east of Agua Negra Canyon.
141	12162	W116–30	North border of hills, Hawthorne Ave.
142	12160	W112–30	North border of hills, fifth ravine northwest of Hawthorne Ave. Upper gravel of Palos Verdes sand. (Not shown on pl. 21; see fig. 13.)

PLATES 28-37

592787—45——10

PLATE 28

[Specimens from locality 13 unless otherwise designated]

FIGURE 1. *Turritella ocoyana* Conrad. Guttapercha squeeze, small specimen. Length (incomplete) about 13 mm, width 7 mm. U. S. Nat. Mus. 497069.

2. *Turritella ocoyana* Conrad. Guttapercha squeeze, small specimen. Length (incomplete) about 21 mm., width about 6 mm. U. S. Nat. Mus. 497070.

3. *Strombus* cf. *S. gatunensis* Toula. Guttapercha squeeze. Length (incomplete) about 19 mm., width about 9.5 mm. U. S. Nat. Mus. 497071.

4. *Strombus* cf. *S. gatunensis* Toula. Guttapercha squeeze. Length (incomplete) about 11.5 mm., width about 9 mm. U. S. Nat. Mus. 497072.

5. "*Phos*" *dumbleanus* Anderson. Guttapercha squeeze. Length (incomplete) about 7.5 mm., width about 4.5 mm. U. S. Nat. Mus. 497075.

6. "*Phos*" *dumbleanus* Anderson. Guttapercha squeeze. Length (incomplete) about 11.5 mm., width 6 mm. U. S. Nat. Mus. 497074.

7. *Anachis* (*Costoanachis*) sp. Guttapercha squeeze. Length (almost complete) 5 mm., width 2 mm. U. S. Nat. Mus. 497073.

8. *Cancellaria* cf. *C. condoni* Anderson. Guttapercha squeeze. Length (incomplete) about 17 mm., width about 17 mm. U. S. Nat. Mus. 497076.

9. "*Clavatula*" cf. "*C.*" *labiata* (Gabb). Guttapercha squeeze. Length (incomplete) about 17 mm., width 8.3 mm. U. S. Nat. Mus. 497080.

10. *Aequipecten* cf. *A. sancti-ludovici* (Anderson and Martin). Guttapercha squeeze, right valve. Length about 23 mm., height about 22 mm. U. S. Nat. Mus. 497082.

11. *Aequipecten andersoni* (Arnold). Guttapercha squeeze, small right valve. Length 12.5 mm., height 11 mm. U. S. Nat. Mus. 497081. Locality 2b.

12. *Crassinella* cf. *C. mexicana* Pilsbry and Lowe. Right valve. Length 2.5 mm., height 2.3 mm. U. S. Nat. Mus. 497083.

13. *Knefastia* cf. *K. funiculata* (Valenciennes). Guttapercha squeeze. Length (almost complete) about 41 mm., width 14.5 mm. U. S. Nat. Mus. 497079.

14. *Conus owenianus* Anderson. Guttapercha squeeze. Length (almost complete) about 15.5 mm., width about 9.8 mm. U. S. Nat. Mus. 497078.

15. *Conus owenianus* Anderson. Guttapercha squeeze. Length (virtually complete) 15 mm., width 9.8 mm. U. S. Nat. Mus. 497077.

16. *Miltha sanctaecrucis* Arnold. Guttapercha squeeze, left valve. Length 50 mm., height about 47 mm. U. S. Nat. Mus. 497087.

17. *Divaricella* cf. *D. eburnea* (Reeve). Internal mold, right valve. Length 15.8 mm., height 15.5 mm. U. S. Nat. Mus. 497084.

18. *Dosinia* aff. *D. ponderosa* (Gray). Guttapercha squeeze, left valve. Length (incomplete) 32 mm., height (incomplete) 23 mm. U. S. Nat. Mus. 497090.

19. *Macrocallista* cf. *M. maculata* (Linné). Internal mold, right valve. Length (almost complete) 41.2 mm., height 27.8 mm. U. S. Nat. Mus. 497091.

20. *Divaricella* cf. *D. eburnea* (Reeve). Guttapercha squeeze, right valve. Length (incomplete) 9 mm., height 10 mm. U. S. Nat. Mus. 497086.

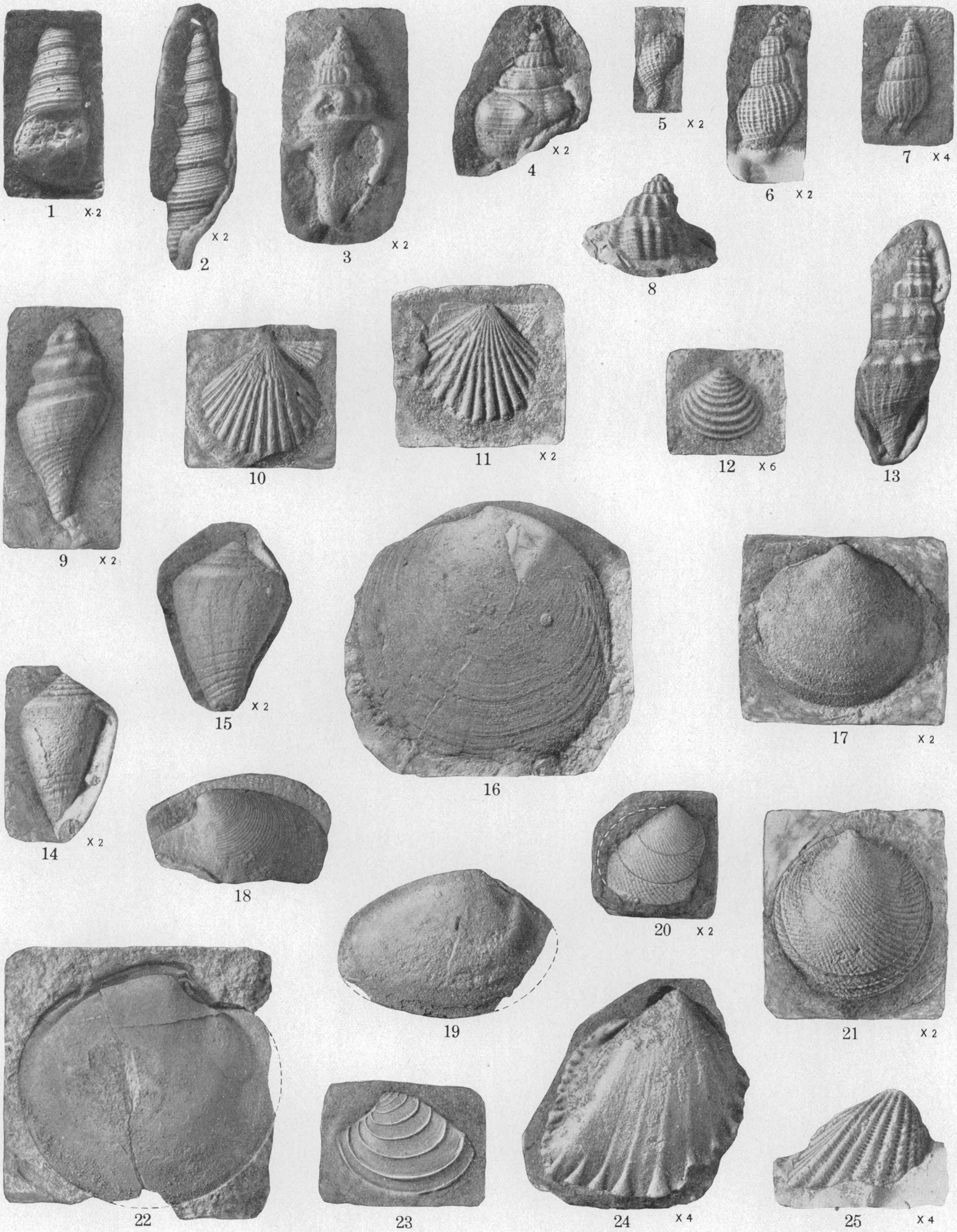
21. *Divaricella* cf. *D. eburnea* (Reeve). Guttapercha squeeze, left valve. Length 15.5 mm., height about 15.5 mm. U. S. Nat. Mus. 497085.

22. *Dosinia* aff. *D. ponderosa* (Gray). Internal mold, right valve. Length (almost complete) 48 mm., height about 44 mm. U. S. Nat. Mus. 497089.

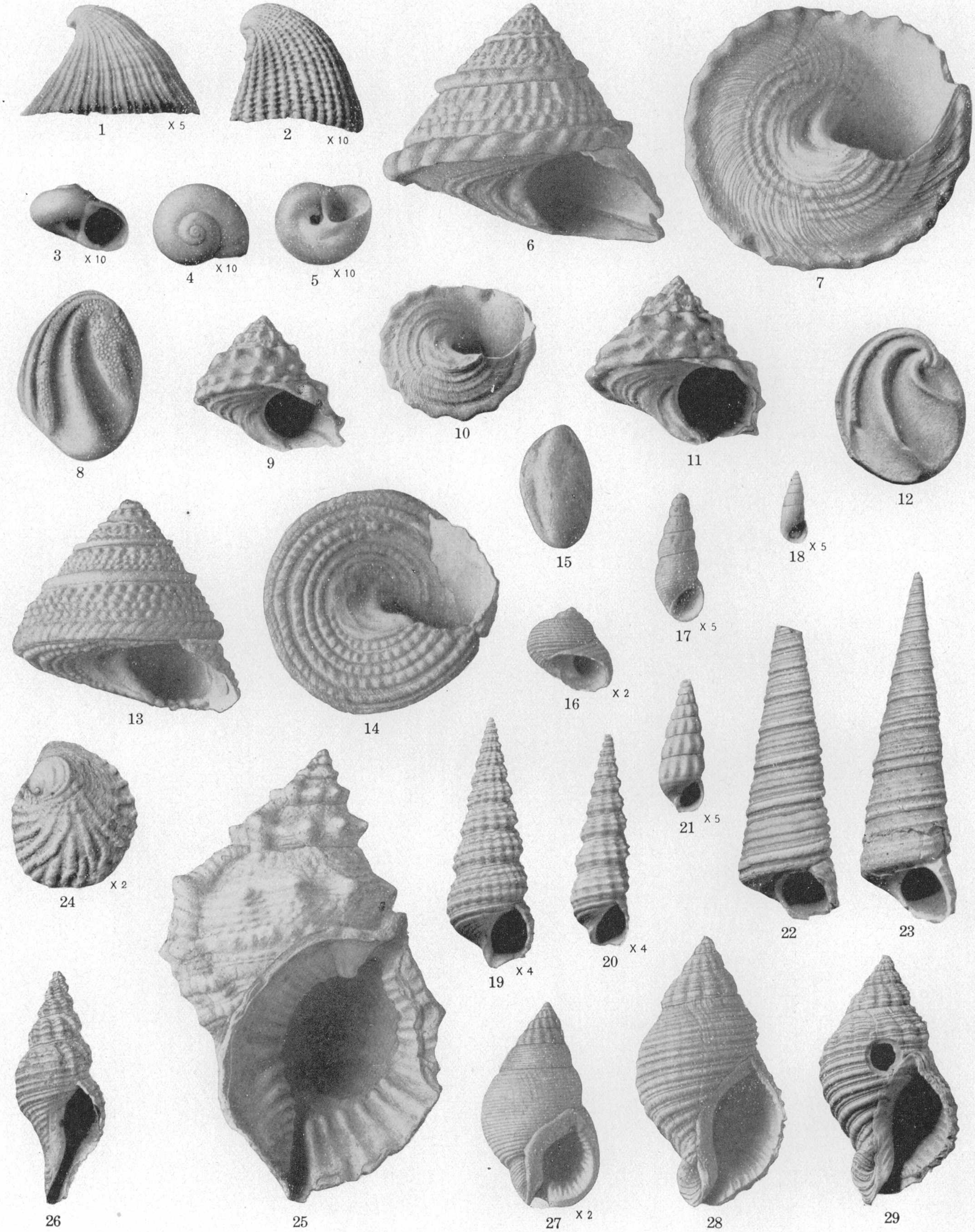
23. *Chione* (*Lirophora*) aff. *C. mariae* (d'Orbigny). Guttapercha squeeze, left valve. Length 26 mm., height 19 mm. U. S. Nat. Mus. 497088.

24. *Trigoniocardia* aff. *T. antillarum* (d'Orbigny). Internal mold, right valve. Length 9.9 mm., height 9.7 mm. U. S. Nat. Mus. 497092.

25. *Trigoniocardia* aff. *T. antillarum* (d'Orbigny). Guttapercha squeeze, right valve. Length (incomplete) 5.5 mm., height (incomplete) 5.5 mm. U. S. Nat. Mus. 497093.



MIOCENE MOLLUSKS FROM MIDDLE PART OF ALTAMIRA MEMBER OF MONTEREY SHALE.



PLEISTOCENE MOLLUSKS FROM LOMITA MARL.

PLATE 29

[Species and varieties illustrated are still living unless otherwise specified]

FIGURE 1. *Puncturella cooperi* Carpenter. Length 6.8 mm., width 5.6 mm., height 4.5 mm. U. S. Nat. Mus. 498562. Locality 54g. Found also in Timms Point silt and San Pedro sand.

2. *Puncturella delosi* Arnold. Length 2.5 mm., width 1.8 mm., height 2.3 mm. U. S. Nat. Mus. 498563. Locality 54g. Found also in Timms Point silt and San Pedro sand.

3–5. *Vitrinella salvania* Dall. Length 1.1 mm., width 1.9 mm. U. S. Nat. Mus. 498564. Locality 41.

6–7. *Pomaulax undosus* (Wood). Length 44.5 mm., width 54.5 mm. U. S. Nat. Mus. 498565. Locality 53a. Found also in Timms Point silt, marine deposits on twelfth (identification doubtful), ninth, fourth, and second terraces, and Palos Verdes sand.

8. *Pomaulax undosus* (Wood). Operculum. Length 24 mm., height 31.7 mm. U. S. Nat. Mus. 498566. Locality 53a.

9, 10. *Pomaulax turbanicus petrothauma* (Berry). Length 26.7 mm., width 30 mm. U. S. Nat. Mus. 498567. Locality 53a. Not known to be living.

11. *Pomaulax turbanicus petrothauma* (Berry). Length 32.5 mm., width (incomplete) 36 mm. U. S. Nat. Mus. 498568. Locality 53a.

12. *Pomaulax turbanicus petrothauma* (Berry). Operculum. Length 24.8 mm., height 29.6 mm. U. S. Nat. Mus. 498569. Locality 53a.

13, 14. *Pachypoma gibberosum* (Dillwyn). Length (not quite complete) 40 mm., width 43.5 mm. U. S. Nat. Mus. 498570. Locality 53a. Found also in Timms Point silt and San Pedro sand, and reported from Palos Verdes sand.

15. *Pachypoma gibberosum* (Dillwyn). Operculum. Length 14 mm., height 23 mm. U. S. Nat. Mus. 498571. Locality 53a.

16. *Homalopoma carpenteri* (Pilsbry). Length 7.8 mm., width 8 mm. U. S. Nat. Mus. 498572. Locality 53a. Found also in Timms Point silt, San Pedro sand, marine deposits on twelfth, ninth, and fifth to second terraces, inclusive, and Palos Verdes sand.

17. *Rissoina kelseyi* Dall and Bartsch. Length 5 mm., width 1.9 mm. U. S. Nat. Mus. 498573. Locality 53a. Found also in marine deposits on second terrace.

18. *Rissoina coronadoensis* Bartsch. Length 2.8 mm., width 1.2 mm. U. S. Nat. Mus. 498574. Locality 42d. Found also in Timms Point silt and San Pedro sand.

19. *Bittium rugatum* Carpenter. Length 11.8 mm., width 4.3 mm. U. S. Nat. Mus. 498575. Locality 37. Found also in Timms Point silt, San Pedro sand, and Palos Verdes sand.

20. *Bittium rugatum larum* Bartsch. Length 10 mm., width 3 mm. U. S. Nat. Mus. 498576. Locality 37. Found also in Timms Point silt, San Pedro sand, and marine deposits on fourth terrace.

21. *Elassum californicum* (Dall and Bartsch). Length 5 mm., width 1.9 mm. U. S. Nat. Mus. 498577. Locality 53b. Found also in Timms Point silt and San Pedro sand. Genus not known to be living.

22. *Turritella pedroensis* Applin. Heavily sculptured form. Length (incomplete) 56 mm., width 24 mm. U. S. Nat. Mus. 498578. Locality 57. Found also in Timms Point silt, San Pedro sand, marine deposits on third terrace, and Palos Verdes sand. Not known to be living.

23. *Turritella pedroensis* Applin. Length (not quite complete) 66 mm., width 18.5 mm. U. S. Nat. Mus. 498579. Locality 73.

24. *Crepipatella charybdis* (Berry). Length 14.3 mm., width 12.4 mm., height 4.2 mm. U. S. Nat. Mus. 498580. Locality 67. Found also in Timms Point silt and San Pedro sand.

25. *Bursa californica* (Hinds). Length 84 mm., width 53 mm. U. S. Nat. Mus. 498581. Locality 53a. Found also in marine deposits on third terrace (identification doubtful) and Palos Verdes sand.

26. *Harfordia monksae* (Dall). Length (not quite complete) 43.7 mm., width 18.5 mm. U. S. Nat. Mus. 498582. Locality 53a. Found also in marine deposits on fifth (identification doubtful), fourth, and second terraces, and Palos Verdes sand.

27. *"Nassa" insculpta* (Carpenter). Length 18.8 mm., width 11.4 mm. U. S. Nat. Mus. 498583. Locality 53a. Reported from Palos Verdes sand.

28. *Calicantharus fortis* (Carpenter). Length (not quite complete) 50.5 mm., width 30 mm. U. S. Nat. Mus. 498584. Locality 53. Found also in San Pedro sand and reported from Timms Point silt and Palos Verdes sand. Genus not known to be living.

29. *Calicantharus fortis* (Carpenter). Strongly sculptured form. Length (not quite complete) 48 mm., width 28 mm. U. S. Nat. Mus. 498585. Locality 57.

PLATE 30

[Species and varieties illustrated are still living unless otherwise specified]

FIGURE 1. *Jaton gemma* (Sowerby). Length 30 mm., width 20 mm. U. S. Nat. Mus. 498586. Locality 53a. Found also in marine deposits on fourth and third terraces.

2. *Tritonalia coryphaena* Woodring, n. sp. Type. Length (almost complete) 34.3 mm., width 20.5 mm. U. S. Nat. Mus. 498587. Locality 53a. Not known to be living.

3. *Erato vitellina* Hinds. Length 16 mm., width 10.5 mm. U. S. Nat. Mus. 498588. Locality 57.

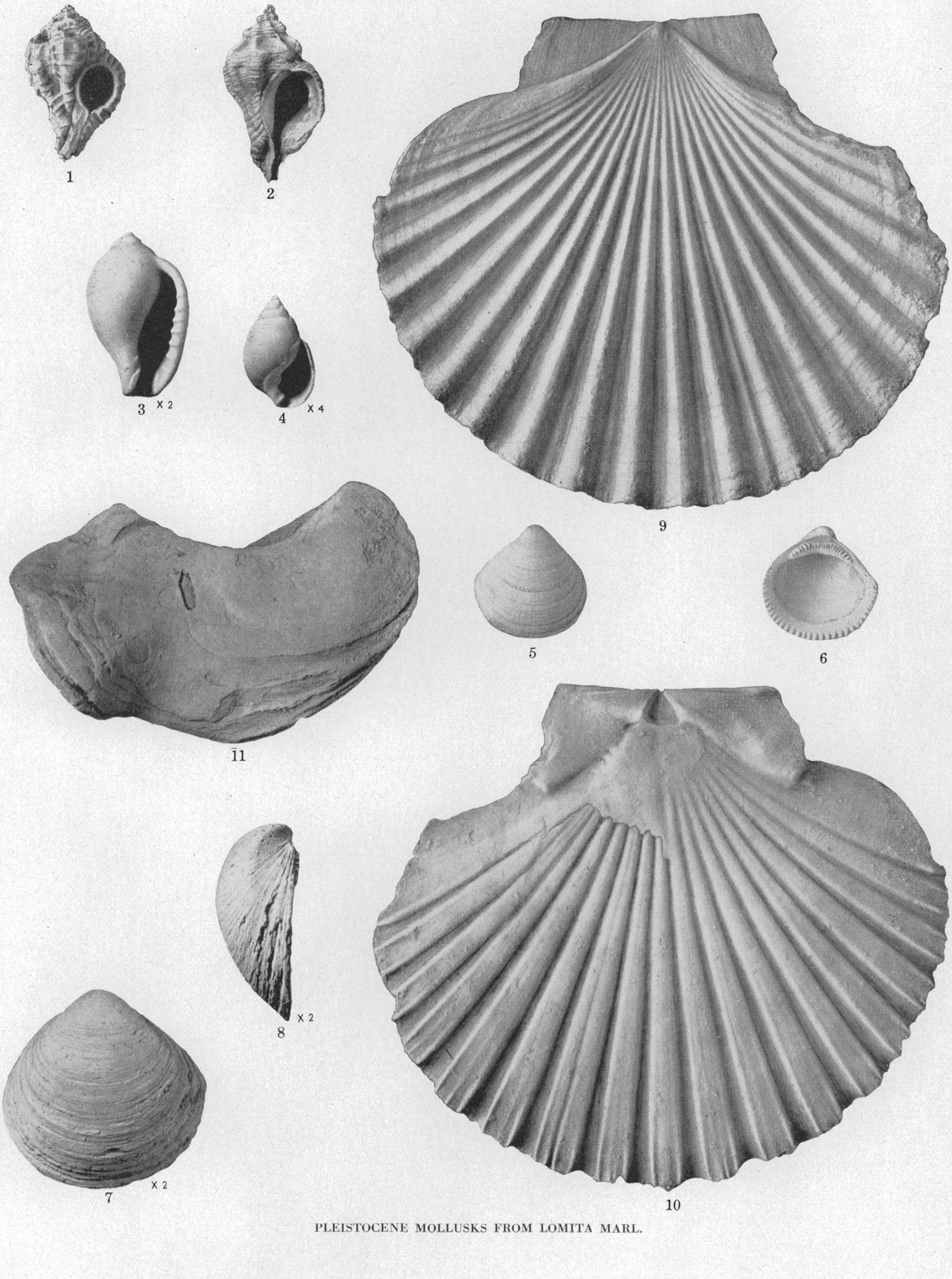
4. *Acteon breviculus* Dall. Length 5.3 mm., width 3.4 mm. U. S. Nat. Mus. 498589. Locality 54g.

5, 6. *Glycymeris profunda* (Dall). Partly corroded right valve. Length 22.4 mm., height 22 mm., diameter 7.6 mm. U. S. Nat. Mus. 498590. Locality 53a. Found also in San Pedro sand and reported apparently from Palos Verdes sand.

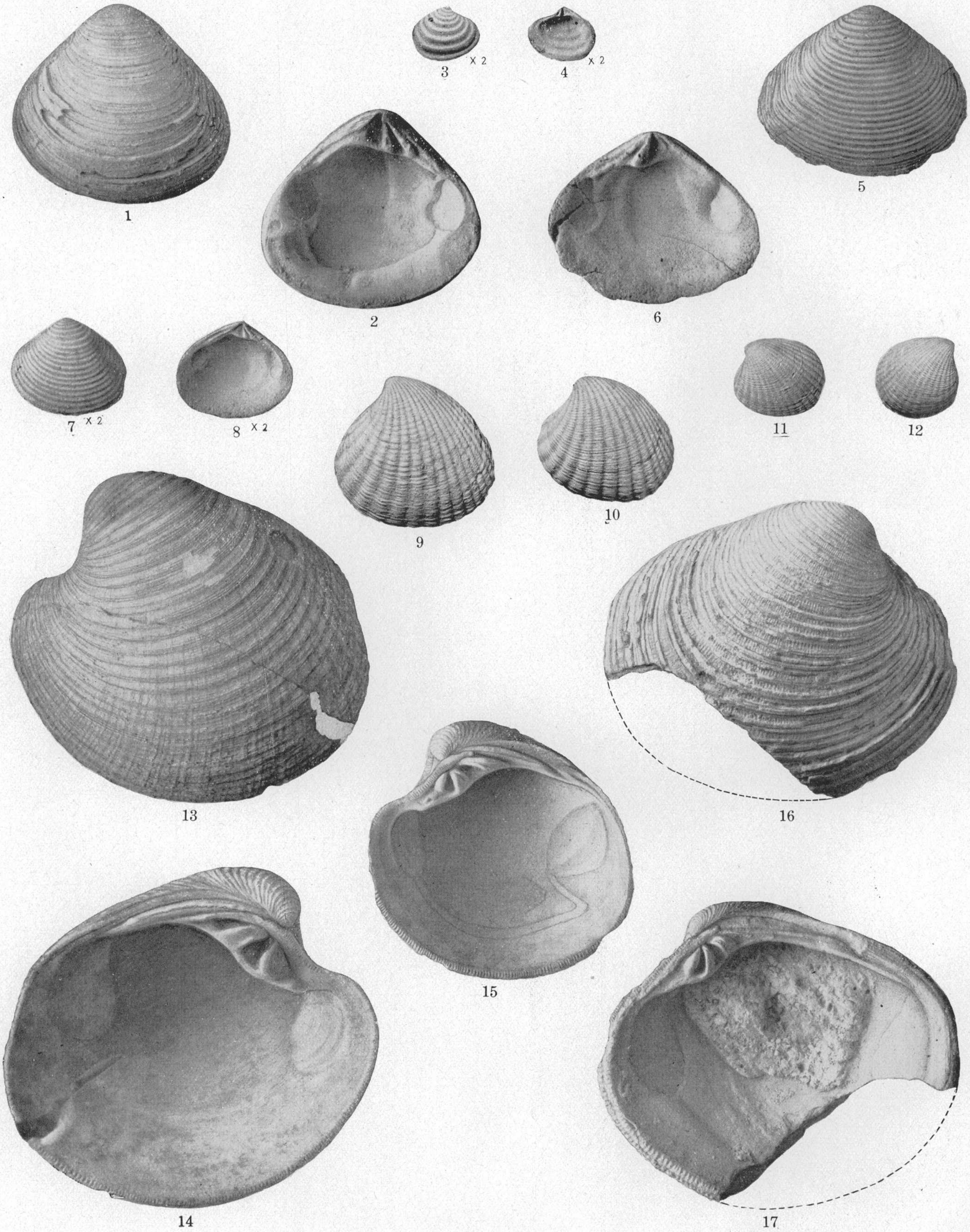
7, 8. *Glycymeris profunda* (Dall). Uncorroded left valve. Length 19.7 mm., height 19.2 mm., diameter 8 mm. U. S. Nat. Mus. 498591. Locality 73.

9, 10. *Pecten stearnsii* Dall. Large left valve. Length 108.5 mm., height 93.5 mm., diameter about 6 mm. Calif. Inst. Tech. 3417. Calif. Inst. Tech. locality 107 (same as locality 53 of this report). Found also in Timms Point silt and San Pedro sand (identification doubtful). Not known to be living.

11. *Ostrea megodon cerrosensis* (Gabb). Right valve. Length 79.5 mm., height 49 mm., diameter 18 mm. U. S. Nat. Mus. 498592. Locality 61. Not known to be living.



PLEISTOCENE MOLLUSKS FROM LOMITA MARL.



PLEISTOCENE MOLLUSKS FROM LOMITA MARL.

PLATE 31

[Species and varieties illustrated are still living unless otherwise specified]

FIGURES 1, 2. *Eucrassatella fluctuata* (Carpenter). Large, thick-shelled corroded left valve. Length 41 mm., height 37.5 mm., diameter 11.5 mm. U. S. Nat. Mus. 498593. Locality 53a. Found also in Timms Point silt and San Pedro sand (identification doubtful).

3, 4. *Eucrassatella fluctuata* (Carpenter). Small right valve similar to type. Length 6.6 mm., height 5 mm., diameter 1 mm. U. S. Nat. Mus. 498594. Locality 53a.

5, 6. *Eucrassatella fluctuata* (Carpenter). Large right valve. Length 39.8 mm., height 32 mm., diameter 9 mm. U. S. Nat. Mus. 498595. Locality 54g.

7, 8. *Eucrassatella fluctuata* (Carpenter). Small left valve. Length 21.7 mm., height 18.3 mm., diameter 5 mm. U. S. Nat. Mus. 498596. Locality 54g.

9. *Cyclocardia* aff. *C. occidentalis* (Conrad). Large right valve. Length 30.3 mm., height 28.9 mm., diameter 8.7 mm. U. S. Nat. Mus. 498597. Locality 53a. Found also in Timms Point silt, San Pedro sand, and Palos Verdes sand.

10. *Cyclocardia* aff.. *C. occidentalis* (Conrad). Moderately large left valve. Length 26.2 mm., height 24.1 mm., diameter 9.7 mm. U. S. Nat. Mus. 498598. Locality 71.

11. *Cyclocardia barbarensis* (Stearns). Elongate strongly inflated left valve. Length 16 mm., height 15.5 mm., diameter 6.3 mm. U. S. Nat. Mus. 498599. Locality 54e. Reported from Timms Point silt, San Pedro sand, and Palos Verdes sand.

12. *Cyclocardia barbarensis* (Stearns). Short right valve. Length 17.7 mm., height 16.6 mm., diameter 5.5 mm. U. S. Nat. Mus. 498600. Locality 54e.

13, 14. *Ventricola fordii* (Yates). Left valve. Length 70 mm., height 65 mm., diameter 28 mm. U. S. Nat. Mus. 498601. Locality 53a.

15. *Ventricola fordii* (Yates). Right valve. Length 50 mm., height 48.5 mm., diameter 19.7 mm. U. S. Nat. Mus. 498602. Locality 53a.

16, 17. *Mercenaria perlaminosa* (Conrad). Right valve. Length 67 mm., height (incomplete) 53 mm., diameter 18 mm. Calif. Inst. Tech. 3414. Calif. Inst. Tech. locality 316 (same as locality 53 of this report). Found also in Timms Point silt. Not known to be living.

PLATE 32

[Species and varieties illustrated are still living unless otherwise specified]

FIGURE 1. *Turcica caffea* (Gabb). Length 23.6 mm., width 18.5 mm. U. S. Nat. Mus. 498603. Locality 32a. Reported also from San Pedro sand.

2. *Turcica caffea* (Gabb). Length 17.3 mm., width 15.2 mm. U. S. Nat. Mus. 498604. Locality 32c.

3. *Solariella peramabilis* Carpenter. Length 12.8 mm., width 13.7 mm. U. S. Nat. Mus. 498605. Locality 32d. Found also in Lomita marl.

4. *Turritella pedroensis* Applin. Length (not quite complete) 63.7 mm., width 17.5 mm. U. S. Nat. Mus. 498606. Locality 66. Found also in Lomita marl, San Pedro sand, deposits on third terrace, and Palos Verdes sand. Not known to be living.

5, 6. *Crepidula princeps* Conrad, small var. Length (not quite complete) 55 mm., width 40.5 mm., height 23 mm. Calif. Inst. Tech. 3413. Calif. Inst. Tech. locality 136 (Timms Point). Reported also from Palos Verdes sand. Not known to be living.

7. *Crepipatella charybdis* (Berry). Length 10.6 mm., width 11.5 mm., height 3.4 mm. U. S. Nat. Mus. 498607. Locality 32c. Found also in Lomita marl and San Pedro sand.

8. *Crepipatella charybdis* (Berry). Length 5.3 mm., width 4.9 mm., height 2.3 mm. U. S. Nat. Mus. 498608. Locality 32c.

9. *Fusitriton oregonensis* (Redfield). Length (incomplete) 47 mm., width 26 mm. U. S. Nat. Mus. 498609. Locality 32c. Found also in Lomita marl and Palos Verdes sand, and reported from San Pedro sand.

10. *Barbarofusus* cf. *B. arnoldi* (Cossmann). Length 51.3 mm., width 18.5 mm. U. S. Nat. Mus. 498610. Locality 32c.

11. *Neptunea tabulata* (Baird). Length 70.3 mm., width 30.5 mm. U. S. Nat. Mus. 498611. Locality 32c. Found also in Lomita marl and San Pedro sand.

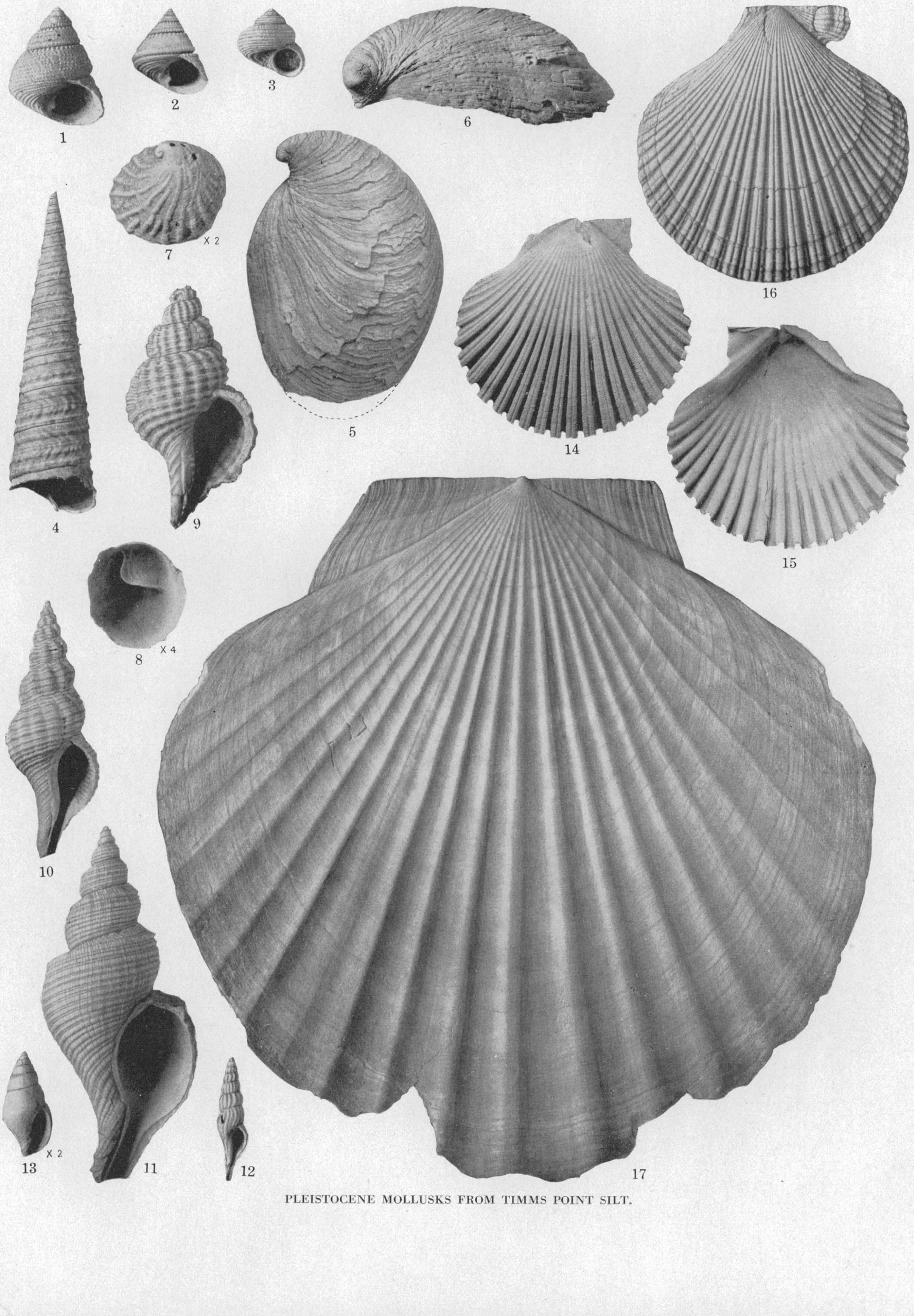
12. *Exilioidea rectirostris* (Carpenter). Length (not quite complete) 24 mm., width 16.3 mm. U. S. Nat. Mus. 498612. Locality 32c. Found also in Palos Verdes sand and reported from San Pedro sand.

13. *Mitrella carinata gausapata* (Gould). Length 10.2 mm., width 4.7 mm. U. S. Nat. Mus. 498613. Locality 32c. Found also in Lomita marl, San Pedro sand, in deposits on fourth and second terraces, and Palos Verdes sand.

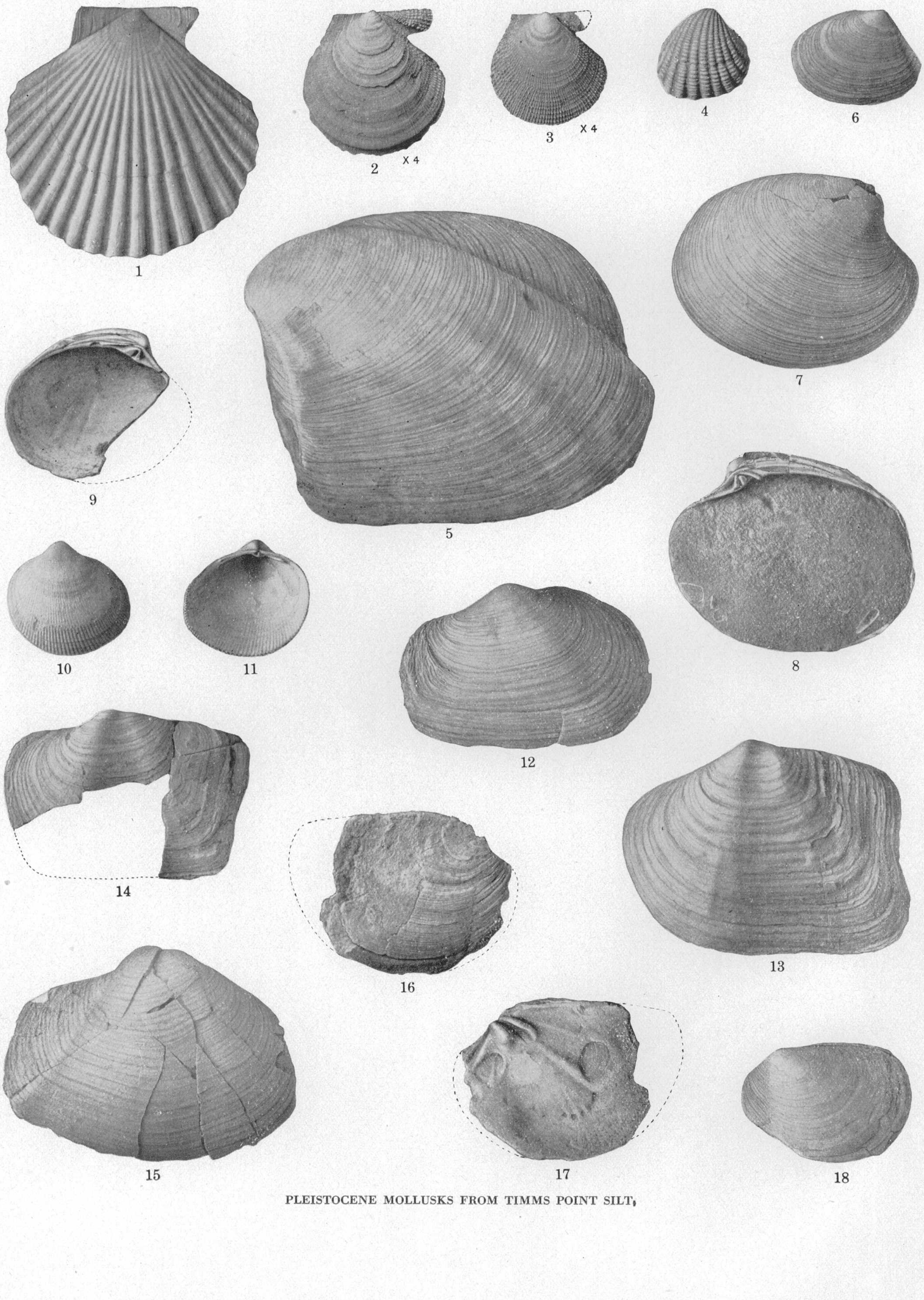
14, 15. *Pecten stearnsii* Dall. Small right valve. Length 47.8 mm., height 43.6 mm., diameter 10 mm. U. S. Nat. Mus. 498614. Locality 32c. Found also in Lomita marl and San Pedro sand (identification doubtful). Not known to be living.

16. *Chlamys islandicus jordani* (Arnold). Exceptionally large right valve. Length 53.5 mm., height 53.7 mm., diameter 9 mm. U. S. Nat. Mus. 498617. Locality 32a. Found also in Lomita marl and San Pedro sand.

17. *Patinopecten caurinus* (Gould). Large left valve. Length 141 mm., height (almost complete) 139 mm., diameter 11 mm. U. S. Nat. Mus. 498615. U. S. Geol. Survey locality 7333, Deadman Island. Found also in Lomita marl and San Pedro sand.



PLEISTOCENE MOLLUSKS FROM TIMMS POINT SILT.



PLEISTOCENE MOLLUSKS FROM TIMMS POINT SILT.

PLATE 33

[Species and varieties illustrated are still living unless otherwise specified]

FIGURE 1. *Patinopecten caurinus* (Gould). Small right valve. Length 49.5 mm., height 49 mm., diameter 5 mm. U. S. Nat. Mus. 498616. Locality 32c. Found also in Lomita marl and San Pedro sand.

2. *Hyalopecten vancouverensis* (Whiteaves). Right valve with weak radial sculpture. Length 7.2 mm., height 7.1 mm. U. S. Nat. Mus. 498618. Locality 32c. Found also in Lomita marl.

3. *Hyalopecten vancouverensis* (Whiteaves). Right valve with strong radial sculpture. Length 5.9 mm., height 5.7 mm. U. S. Nat. Mus. 498619. Locality 44.

4. *Cyclocardia* aff. *C. occidentalis* (Conrad). Strongly noded form similar to *C. californica* (Dall), right valve. Length 18.7 mm., height 17.7 mm., diameter 8.2 mm. U. S. Nat. Mus. 498620. Locality 66. Found also in Lomita marl and San Pedro sand.

5. *Thyasira disjuncta* (Gabb). Left valve of paired specimen. Length 82 mm., height 68 mm., diameter (both valves) 48.5 mm. U. S. Nat. Mus. 498621. U. S. Geol. Survey locality 2481, Deadman Island.

6. *Macoma calcarea* (Gmelin), small var. Left valve. Length 25.6 mm., height 18.9 mm., diameter 4.3 mm. U. S. Nat. Mus. 498622. Locality 40.

7, 8. *Katherinella subdiaphana* (Carpenter). Right valve. Length 49.5 mm., height 39.5 mm., diameter 13.5 mm. U. S. Nat. Mus. 498623. Locality 40. Found also in Lomita marl and San Pedro sand.

9. *Katherinella subdiaphana* (Carpenter). Left valve. Length (incomplete) 32 mm., height 30.5 mm., diameter 10.2 mm. U. S. Nat. Mus. 498624. Locality 40.

10, 11. *Pratulum centifilosum* (Carpenter). Left valve. Length 24.9 mm., height 22.8 mm., diameter 8 mm. U. S. Nat. Mus. 498625. Locality 32a. Found also in Lomita marl and San Pedro sand.

12. *Mya truncata* Linné. Right valve. Length 50 mm., height 33.7 mm., diameter 10.7 mm. U. S. Nat. Mus. 498626. Locality 45.

13. *Panomya beringianus* Dall, small var. Left valve. Length 58.7 mm., height 42.8 mm., diameter 11.8 mm. Calif. Inst. Tech 3416. Calif. Inst. Tech. Locality 78, Timms Point.

14. *Panomya beringianus* Dall, small var. Left valve of sheared paired specimen. Length 47.5 mm., height 33.5 mm. U. S. Nat. Mus. 498627. Locality 44a.

15. *Thracia trapezoides* Conrad. Right valve of paired specimen. Length 57.8 mm., height 42.7 mm., diameter (both valves) 18.3 mm. Calif. Inst. Tech. 3415. Calif. Inst. Tech. locality 320, Timms Point. Found also in Lomita marl.

16, 17. *Pandora grandis* Dall. Right valve. Length (incomplete) 35.5 mm., height 32.8 mm., diameter 3 mm. U. S. Nat. Mus. 498628. Locality 44.

18. *Pandora grandis* Dall. Left valve of paired specimen. Length 33 mm., height 26.5 mm., diameter (both valves) 7.7 mm. Calif. Inst. Tech. 3412. Calif Inst. Tech. locality 77, Timms Point.

PLATE 34

[Species and varieties illustrated are still living unless otherwise specified]

FIGURES 1, 2. *Acmaea funiculata* (Carpenter). Small form. Length 6.3 mm., width 5.5 mm., height 3.7 mm. U. S. Nat. Mus 498629. Locality 30. Found also in Lomita marl and Timms Point silt.

3. *Pupillaria optabilis knechti* (Arnold). Length 8.3 mm., width 7.7 mm. U. S. Nat. Mus. 498630. Locality 47a. Found also in Palos Verdes sand. Recently reported to be living at Forrester Island, Alaska.

4. *Pupillaria optabilis knechti* (Arnold). Length 6.3 mm., width 6.2 mm. U. S. Nat. Mus. 498631. Locality 47a.

5. *Iselica fenestrata* (Carpenter). Length 8 mm., width 5.2 mm. U. S. Nat. Mus. 498632. Locality 47a. Found also in Lomita marl, deposits on second terrace, and Palos Verdes sand.

6. *Bittium armillatum* Carpenter. Length 12 mm., width 3.9 mm. U. S. Nat. Mus. 498633. Locality 47a. Found also in Lomita marl, Timms Point silt, in deposits on twelfth, ninth, sixth (identification doubtful), and fifth to second (inclusive) terraces, and in Palos Verdes sand. *B. armillatum* proper is not known to be living.

7. *Turritella pedroensis* Applin. Length (not quite complete) 56 mm., width 15.7 mm. U. S. Nat. Mus. 498634. Locality 30. Found also in Lomita marl, Timms Point silt, deposits on third terrace, and Palos Verdes sand. Not known to be living.

8. *Turritella cooperi* Carpenter. Length 46.8 mm., width 12.3 mm. U. S. Nat. Mus. 498635. Locality 30. Found also in Lomita marl, Timms Point silt, and Palos Verdes sand.

9. *Barbarofusus barbarensis* (Trask) of Arnold. Length 71.7 mm., width 25 mm. U. S. Nat. Mus. 498636. Locality 30. Found also in Lomita marl and Timms Point silt and reported from Palos Verdes sand.

10. *Barbarofusus arnoldi* (Cossmann). Neotype. Length 65.3 mm., width 27 mm. U. S. Nat. Mus. 498637. Locality 30. Found also in Timms Point silt (identification doubtful) and Palos Verdes sand.

11. *Barbarofusus arnoldi* (Cossmann). Length 42.2 mm., width 18 mm. U. S. Nat. Mus. 498638. Locality 30.

12. "*Nassa*" *mendica cooperi* Forbes. Length 15.5 mm., width 7.8 mm. U. S. Nat. Mus. 498639. Locality 30. Found also in Lomita marl, Timms Point silt, deposits on twelfth (identification doubtful) and sixth to second (inclusive) terraces, and in Palos Verdes sand.

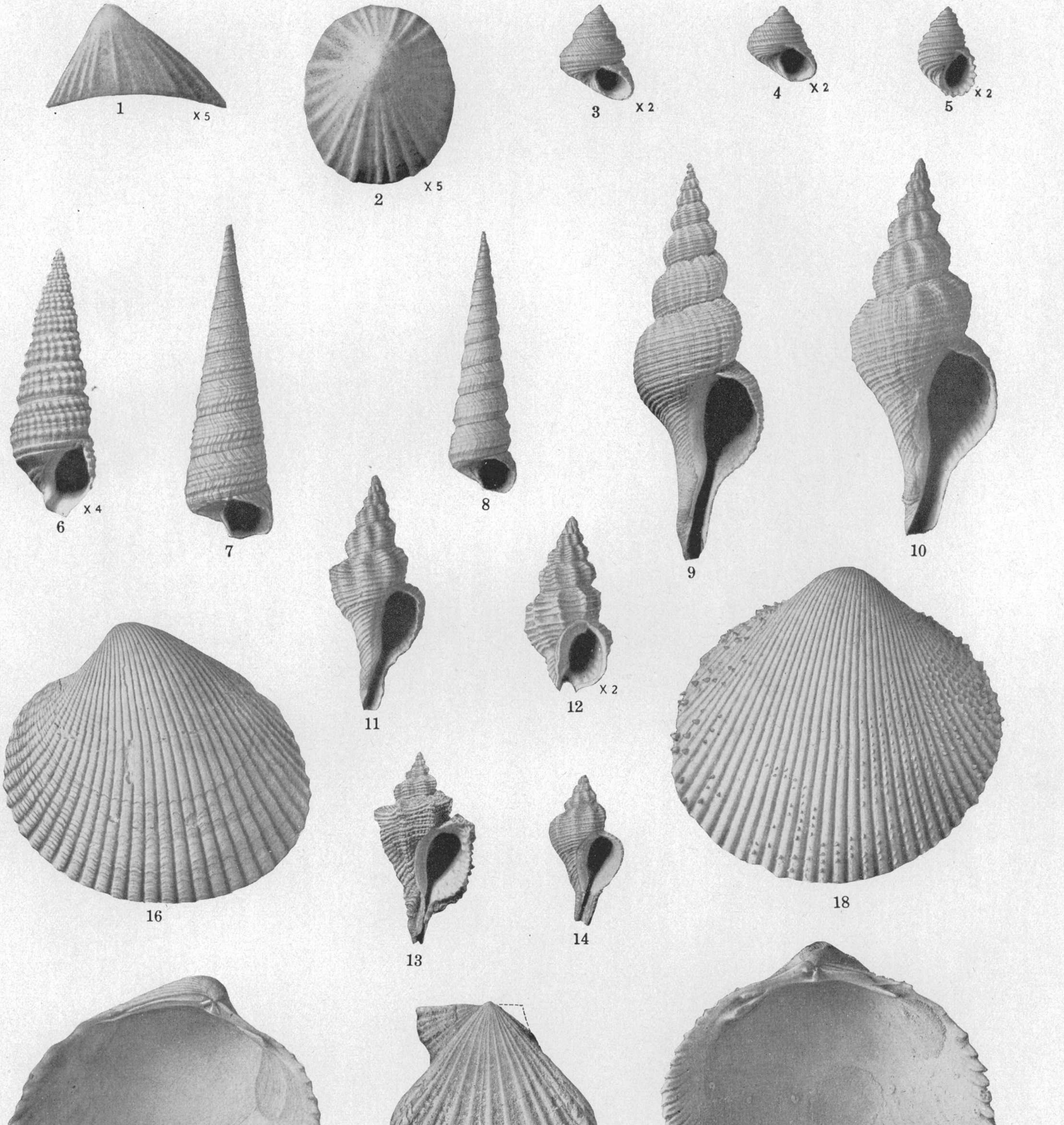
13. *Tritonalia squamulifera* (Carpenter). Length 34.6 mm., width 18 mm. U. S. Nat. Mus. 498640. Locality 30.

14. *Trophonopsis lasia* (Dall). Length (almost complete) 27.2 mm., width 14 mm. U. S. Nat Mus. 498641. Locality 48. Reported from Timms Point silt and Palos Verdes sand.

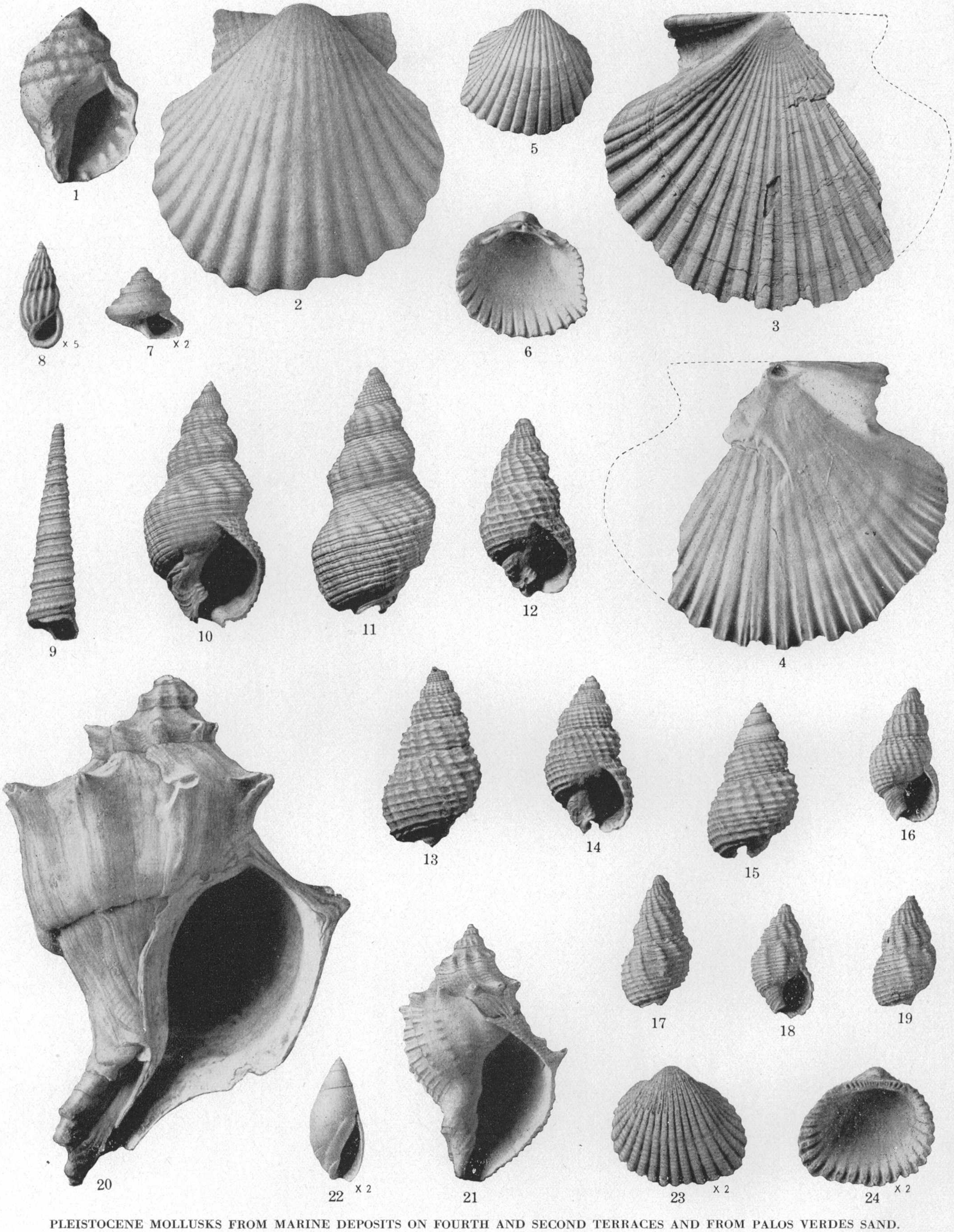
15. *Chlamys anapleus* Woodring, n. sp. Type, incomplete left valve. Length 23.2 mm., height 19.5 mm., diameter 4 mm. U. S. Nat. Mus. 498642. Locality 30. Found also in Lomita marl. Not known to be living.

16, 17. *Cerastoderma nuttallii* (Conrad). Left valve. Length 56.5 mm., height 50.5 mm., diameter 17 mm. U. S. Nat Mus. 498643. Locality 30. Found also in Lomita marl, Timms Point silt, and Palos Verdes sand.

18, 19. *Trachycardium quadragenarium* (Conrad). Small right valve. Length 62 mm., height 57 mm., diameter 21 mm. U.S. Nat. Mus. 498644. Locality 30. Found also in Lomita marl, Timms Point silt, deposits on third and second terraces, and Palos Verdes sand.



PLEISTOCENE MOLLUSKS FROM SAN PEDRO SAND.



PLEISTOCENE MOLLUSKS FROM MARINE DEPOSITS ON FOURTH AND SECOND TERRACES AND FROM PALOS VERDES SAND.

PLATE 35

[Species and varieties illustrated are still living unless otherwise specified]

FIGURE 1. *Acanthina lugubris* (Sowerby). Length 34 mm., width 23.5 mm. U. S. Nat. Mus. 498645. Locality 82, fourth terrace. Found also in deposits on second terrace.

2. *Pecten vogdesi* Arnold. Worn broken right valve. Length 59.5 mm., height 56.5 mm., diameter 20 mm. U. S. Nat. Nat. Mus. 498646. Locality 105, second terrace. Reported from Palos Verdes sand.

3, 4. *Pecten vogdesi* Arnold. Broken left valve. Length (incomplete) 53.5 mm., height 55.5 mm. diameter 6.5 mm. U. S. Nat. Mus. 498647. Locality 105, second terrace.

5, 6. *Trigoniocardia biangulata* (Sowerby). Right valve of medium size. Length 26.4 mm., height 24.3 mm., diameter 9.5 mm. U. S. Nat. Mus. 498648. Locality 105, second terrace.

7. *Calliostoma eximium* (Reeve). Length 7.6 mm., width 8 mm. U. S. Nat. Mus. 498649. Locality 121, Palos Verdes sand.

8. *Rissoina pleistocena* Bartsch. Length 4 mm., width 1.8 mm. U. S. Nat. Mus. 498650. Locality 140, Palos Verdes sand. Found also in deposits on second terrace. Not known to be living.

9. *Turritella cooperi* Carpenter. Length (incomplete) 41.7 mm., width 10.5 mm. U. S. Nat. Mus. 498651. Locality 112, Palos Verdes sand. Found also in Lomita marl, Timms Point silt, and San Pedro sand.

10, 11. "*Nassa*" *fossata coilotera* Woodring, n. var. Type. Length (almost complete) 48 mm., width 25 mm. U. S. Nat. Mus. 498652. Locality 108, Palos Verdes sand. Not known to be living.

12, 13. "*Nassa*" *delosi* Woodring, n. sp. Type. Length (incomplete) 34 mm., width 19 mm. U. S. Nat. Mus. 498653. Locality 113, Palos Verdes sand. Not known to be living.

14, 15. "*Nassa*" *delosi* Woodring, n. sp. Length (almost complete) 30.7 mm., width 17.7 mm. U. S. Nat. Mus. 498654. Locality 120, Palos Verdes sand.

16, 17. "*Nassa*" *cerritensis* Arnold. Length (almost complete) 25.6 mm., width 13.6 mm. U. S. Nat. Mus. 498655. Locality 120, Palos Verdes sand.

18, 19. "*Nassa*" *cerritensis* Arnold. Length (almost complete) 21.5 mm., width 12 mm. U. S. Nat. Mus. 498656. Locality 120, Palos Verdes sand.

20. *Forreria belcheri* (Hinds). Length (incomplete) 103.5 mm., width (not including spines) about 63 mm. U. S. Nat. Mus. 498657. Locality 123, Palos Verdes sand.

21. "*Cancellaria*" *tritonidea* Gabb. Length (almost complete) 49 mm., width (not including nodes) about 30 mm. U. S. Nat. Mus. 498658. Locality 120, Palos Verdes sand. Found also in San Pedro sand and in deposits on third terrace (identification doubtful). Not known to be living.

22. *Olivella pedroana* (Conrad). Neotype. Length 12 mm., width 5.7 mm. U. S. Nat. Mus. 498659. Locality 113, Palos Verdes sand. Found also in San Pedro sand.

23, 24. *Anadara perlabiata* (Grant and Gale). Small left valve. Length 12.9 mm., height 11.7 mm., diameter 5.3 mm. U. S. Nat. Mus. 498660. Locality 124, Palos Verdes sand.

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PLATE 36

[Species illustrated are still living unless otherwise specified]

FIGURES 1–4. *Crassinella branneri* (Arnold). U. S. Nat. Mus. 498661. Locality 120. Found also in deposits on fourth terrace.
1. Right valve. Length 9.8 mm., height 8.3 mm., diameter 2 mm.
2. Right valve. Length 8.9 mm., height 8.4 mm., diameter 2 mm.
3. Right valve. Length 8.8 mm., height 7.7 mm., diameter 2.6 mm.
4. Left valve. Length 8.8 mm., height 8.2 mm., diameter 2 mm.

5, 6. *Crassinella branneri* (Arnold). U. S. Nat. Mus. 498662. Locality 124.
5. Right valve. Length 8.7 mm., height 7.9 mm., diameter 2 mm.
6. Left valve. Length 8.6 mm., height 7.2 mm., diameter 1.8 mm.

7, 8. *Crassinella nuculiformis* (Berry.) Right valve. Length 4.5 mm., height 4 mm., diameter 1.1 mm. U. S. Nat. Mus. 498663. Locality 124. Found also in deposits on second terrace.

9, 10. *Crassinella nuculiformis* (Berry.) Left valve. Length 5 mm., height 4.6 mm., diameter 1.1 mm. U. S. Nat. Mus. 498664. Locality 124.

11–14. *Diplodonta sericata* (Reeve). U. S. Nat. Mus. 498665. Locality 135. Found also in deposits on second terrace.
11, 12. Right valve. Length 13.7 mm., height 13 mm., diameter 3 mm.
13, 14. Left valve. Length 10.8 mm., height 10.3 mm., diameter 2.5 mm.

15, 16. *Dosinia ponderosa* (Gray). Broken right valve. Length (incomplete) 113 mm., height (incomplete) 97 mm., diameter 30 mm. U. S. Nat. Mus. 498666. Locality 135.

PLATE 37

[Species illustrated still living unless otherwise specified]

FIGURES 1, 2. *Chione gnidia* (Broderip and Sowerby). Left valve. Length (almost complete) 55 mm., height (almost complete) 47 mm., diameter 17 mm. U. S. Nat. Mus. 498667. Locality 135.

3, 4. "*Chione*" *picta* Dall. Left valve. Length 9.4 mm., height 7 mm., diameter 2.6 mm. U. S. Nat. Mus. 498670. Locality 121. Reported from deposits on second terrace.

5, 6. *Trachycardium procerum* (Sowerby). Right valve. Length 75 mm., height 79 mm., diameter 33 mm. U. S. Nat. Mus. 498668. Locality 121. Reported from San Pedro sand.

7, 8. *Trachycardium procerum* (Sowerby). Left valve. Length 55 mm., height 55 mm., diameter 23 mm. U. S. Nat. Mus. 498669. Locality 112.

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