[AMERICAN JOURNAL OF SCIENCE, Vol. 250, June 1952, Pp. 401-410]

American Journal of Science

JUNE 1952

PLIOCENE-PLEISTOCENE BOUNDARY IN CALIFORNIA COAST RANGES *

W. P. WOODRING

ABSTRACT. The Pliocene-Pleistocene boundary in the Cenozoic marine section of California is drawn at a marked faunal discontinuity, at the base of the Santa Barbara formation of the Ventura basin and at the base of the Lomita marl and Timms Point silt of the Los Angeles basin. The boundary so drawn is not opposed by meager evidence based on fossil vertebrates, nor is it known to violate the recommendation of the Eighteenth International Geological Congress.

A period of deformation and erosion is assigned—somewhat arbitrarily as to duration—to the middle third of the Pleistocene. Marine terrace deposits, which locally reach an altitude of at least 1200 feet, are considered of late Pleistocene age.

INTRODUCTION

THE Pliocene-Pleistocene boundary in the Cenozoic marine section of the California Coast Ranges has been a subject of discussion for many years and there still is disagreement concerning it. In the western part of the Ventura basin, in southern California, where 20,000 feet of Pliocene and Pleistocene marine strata are exposed, the boundary has been placed during recent years at three horizons, the lowest and highest of which represent a stratigraphic range of 3,000 feet.

The relations of the marine formations of presumed Pleistocene age to glacial deposits cannot be directly determined. Eaton (1928, pp. 138-139, fig. 3; 1941), indeed, considered the early Pleistocene of California to be preglacial and the late Pleistocene to be late glacial. No unequivocal evidence is now apparent to prove or disprove his opinion that the early Pleistocene is preglacial. There is general agreement that the late Pleistocene is chronologically late glacial. Despite assignments to glacial and interglacial divisions of the Pleistocene by some paleontologists, the age relations of the marine Pleistocene formations to those divisions appear to be indeterminable at the present time by usual stratigraphic

* Publication authorized by the Director, United States Geological Survey.

and paleontologic procedures. According to present estimates, the formations of late Pleistocene age are close to the maximum age limit of radiocarbon dating, some results of which were recently recorded in this JOURNAL (Flint and Deevey, 1951). The youngest, or even perhaps all, of the late Pleistocene formations, however, presumably are within the limit, and they contain suitable material for use of that method of dating.

In view of the uncertainty concerning the age relations of the marine formations to glacial chronology, the Pliocene-Pleistocene boundary is drawn on the basis of the progressive modernization of the local marine faunas, that is, on the basis of the Lyellian principle (but not strictly on Lyellian percentages) of percentage of modern genera and species. That basis, however, has led to different results when applied to the formations under discussion, depending on whether emphasis is placed on faunas as a whole or on the occurrence of particular species that are held to be reliable indicators of age—a fruitful source of dissension among paleontologists.

PLEISTOCENE MARINE FORMATIONS

The age and correlation of the marine formations referred to the late Pliocene and Pleistocene in the present discussion are shown in figure 1. Not all areas of marine late Pliocene are shown in figure 1, and in some of the areas shown part, or all, of the Pleistocene is nonmarine. No exposed marine deposits in California are referred to the middle Pleistocene. Marine deposits of that age, however, are doubtless buried in the deep parts of the Ventura and Los Angeles basins. According to the classification adopted, the middle Pleistocene is represented, at least in the exposed formations of southern California, by a hiatus corresponding to a period of deformation and later deep erosion. The importance of those events was recognized many years ago by Lawson (1893, pp. 157-160; 1894, pp. 269-271), who thought they marked the end of the Tertiary period. The dating now accepted was first pointed out by Eaton (1928, pp. 131-132, fig. 3) and later by other geologists, notably H. Rodney Gale (in Grant and Gale, 1931, pp. 37-38, 44-45, 60-63), Reed (1933, pp. 255-256, 262-263), and Bailey (1935, p. 491; 1943). Bracketing of the deformation and erosion with the middle third of the Pleistocene is, of course, arbitrary in the light of the present knowledge

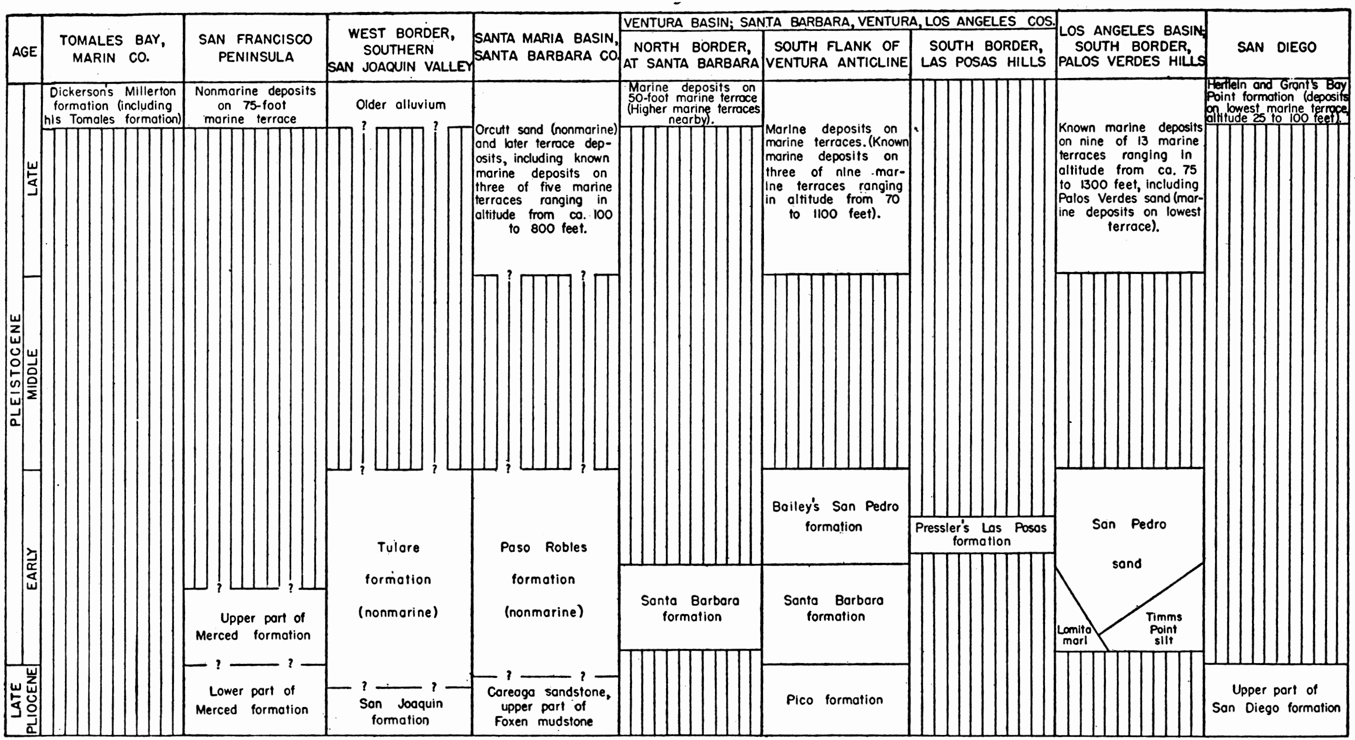

Fig. 1. Age and correlation of marine late Pliocene and Pleistocene formations of California. Vertical ruling represents hiatus.

concerning the time required for those events and the duration of the Pleistocene epoch itself. Some of the formations of both early and late Pleistocene age may extend into the middle Pleistocene.

Paleontologists agree concerning the age of most of the formations shown as Pleistocene in figure 1. The only disagreement lies in the Pliocene-Pleistocene boundary in the Los Angeles and Ventura basins. In the central part of both basins marine Pleistocene deposits overlie marine Pliocene without discontinuity no matter where the boundary is placed, unless it is placed so high that it would be unacceptable to any paleontologist who has considered the matter during recent years. The boundary shown in figure 1 is drawn to correspond to the most marked faunal discontinuity. The formations of late Pliocene and Pleistocene age shown in figure 1 contain the genera and subgenera, listed in table 1, that are not known to be living, or are not known to be living along the coast of California and farther north in the eastern Pacific. So far as known these genera and subgenera are extinct or locally extinct.

It is quite evident from the list of table 1 that the faunal discontinuity at the Pliocene-Pleistocene boundary shown in figure 1 is a marked discontinuity at generic and subgeneric levels. Moreover, *Anadara* s.s., represented in the late Pliocene by *A. trilineata*, is conspicuous in almost all districts in California where marine formations of late Pliocene age are found. *Lyropecten* s.s., represented in the late Pliocene by *L. cerrosensis*, also is conspicuous, but is less widespread. The faunal discontinuity is fairly well marked at the specific level in some genera found in both late Pliocene and early Pleistocene formations. *Opalia varicostata*, *"Nassa" moraniana* (which, like *Anadara trilineata*, occurs in practically all the late Pliocene of central and southern California), *Strioterebrum martini*, *Mytilus coalingensis*, *Patinopecten healeyi*, *Patinopecten dilleri*, *Ostrea erici*, *Clinocardium meekianum*, and *Platyodon colobus* are well-defined extinct species, not closely related to Recent species, that occur in the late Pliocene but not in the Pleistocene. There are very few such species in the Pleistocene but not also in the late Pliocene. In fact, aside from the three early Pleistocene species representing the genera *Mistostigma*, *Elassum*, and *Adontorhina* (listed in table 1), the early and late Pleistocene *Turritella pedroensis* is the only

Table 1

Extinct and locally extinct genera and subgenera in late Pliocene and Pleistocene formations of California

Genus or subgenus	Family	Occurrence	
		Late Pliocene	Pleistocene
EXTINCT			
Echinoid:			
Merriamaster	Scutellidae	San Joaquin formation, Foxen mudstone, San Diego formation.	
Gastropods:			
Mistostigma[1]	Rissoidae(?)		Santa Barbara formation, Lomita marl.
Elassum[1]	Cerithiidae		Lomita marl, Timms Point silt, San Pedro sand.
Apparently unnamed genus or subgenus represented by *"Gyrineum" mediocre*	Cymatiidae	Careaga sandstone, Foxen mudstone, San Diego formation.	
Apparently unnamed genus or subgenus represented by *"Gyrineum" elsmerense*	Cymatiidae	Foxen mudstone.	
Calicantharus	Neptuneidae	Lower part of Merced formation, San Joaquin formation, Careaga sandstone, Foxen mudstone, Pico formation, San Diego formation.	Santa Barbara formation, Bailey's San Pedro formation, Lomita marl, Timms Point silt, San Pedro sand, Palos Verdes sand, Hertlein and Grant's Bay Point formation.
Apparently unnamed genus or subgenus represented by *"Cancellaria" tritonidea*	Cancellariidae	San Joaquin formation, Careaga sandstone, Pico formation.	Bailey's San Pedro formation, San Pedro sand, Palos Verdes sand.
Apparently unnamed genus or subgenus represented by *"Cancellaria" arnoldi*	Cancellariidae	Careaga sandstone, Foxen mudstone, San Diego formation.	
Apparently unnamed genus or subgenus represented by *"Cancellaria" hemphilli*	Cancellariidae	Careaga sandstone, Pico formation, San Diego formation.	
Apparently unnamed genus or subgenus represented by *"Drillia" graciosana*	Turridae	Lower part of Merced formation, Careaga sandstone.	
Pelecypods:			
Lyropecten s.s. (subgenus of *Lyropecten*)	Pectinidae	Careaga sandstone, Pico formation, San Diego formation.	
Adontorhina[1]	Thyasiridae(?)		Lomita marl.
LOCALLY EXTINCT, SURVIVING SOUTH OF CALIFORNIA			
Gastropods:			
Trochita	Calyptraeidae	Careaga sandstone, Foxen mudstone, Pico formation.	
Cheilea	Calyptraeidae	Pico formation in Los Angeles.	
Architectonica	Architectonicidae	Careaga sandstone, San Diego formation.	
Pyruclia (subgenus of *Cancellaria*)	Cancellariidae	Careaga sandstone, San Diego formation.	
Pelecypods:			
Arca	Arcidae	Careaga sandstone, Foxen mudstone.	Santa Barbara formation, Lomita marl.
Anadara s.s. (subgenus of *Anadara*)	Arcidae	Lower part of Merced formation, San Joaquin formation, Careaga sandstone, Foxen mudstone, Pico formation, San Diego formation.	
Cunearca (subgenus of *Anadara*)	Arcidae		Palos Verdes sand.
Dosinia	Veneridae	Careaga sandstone, Pico formation, San Diego formation.	Palos Verdes sand, Hertlein and Grant's Bay Point formation.
Apparently unnamed subgenus of *Chione* represented by *Chione picta*[2]	Veneridae		Marine deposits on second terrace in Palos Verdes Hills, Palos Verdes sand.
Lirophora	Veneridae	Careaga sandstone.	
Mexicardia (subgenus of *Trachycardium*)	Cardiidae		Palos Verdes sand, Hertlein and Grant's Bay Point formation.
Varicorbula (subgenus of *Corbula*)	Myacidae	San Joaquin formation, Pico formation.	
LOCALLY EXTINCT, SURVIVING IN NORTHWESTERN PACIFIC			
Gastropod:			
Fulgoraria (*Miopleiona* or *Psephaea* of California literature)	Volutidae	Careaga sandstone, Foxen mudstone, San Diego formation.	
Pelecypods:			
Swiftopecten (subgenus of *Chlamys*)	Pectinidae	San Joaquin formation, Careaga sandstone, Foxen mudstone, Pico formation, San Diego formation.	
Pseudocardium	Mactridae	Careaga sandstone.	

[1] These minute genera may be found to be living when the modern fauna at depths of 25 to 100 fathoms is better known.

[2] *Chione picta* was referred to the subgenus *Nioche* by Hertlein and Strong (New York Zool. Soc., Zoologica, vol. 33, pt. 4, p. 187, 1948), but its small size, elongate outline, and interior brown band indicate that it is subgenerically removed from *Nioche*.

species of that class. To be sure, the typical form of the early and late Pleistocene *Calicantharus fortis* and of the early and late Pleistocene *"Cancellaria" tritonidea* are not certainly known to occur in the late Pliocene, but both have close allies of late Pliocene age that may not be of more than subspecific rank.

Paleontologists who place the Pliocene-Pleistocene boundary at a higher level, so as to include in the late Pliocene all, or the lower part, of the Santa Barbara formation of the Ventura basin and the Lomita marl and Timms Point silt of the Los Angeles basin, emphasize the occurrence, in one or more of those formations, of the following species: *Terebratalia hemphilli, Crepidula princeps, Pecten bellus, Pecten stearnsii,* and *Chlamys opuntia,* all of which these paleontologists hold to be reliable indicators of Pliocene age (Bailey, 1935, p. 494; 1943, p. 1562; Grant and Hertlein, 1941; Keen and Bentson, 1944, pp. 11-15). *Arca sisquocensis* and *Ostrea megodon cerrosensis,* both of which are found in the Lomita marl, may be added to that list of species. It is a matter of preference whether these species are to be considered as early Pleistocene survivors or are to be considered as outweighing the faunal discontinuity just described.

Meager evidence based on fragmentary remains of a few fossil land mammals is not opposed to the Pliocene-Pleistocene boundary of figure 1. Teeth identified as *Equus* have been found in the Santa Barbara formation (Bailey, 1943, p. 1562), *Equus* cf. *occidentalis* in Bailey's San Pedro formation of the Ventura basin (Bailey, 1943, p. 1559), and in Pressler's Las Posas formation (Pressler, 1929, pp. 340-341); and teeth identified in the field by Stock as *Equus* cf. *occidentalis* are reported to have been found in the thick section of San Pedro sand on the north flank of the Gaffey anticline at the south border of the Los Angeles basin—strata that evidently include the equivalent of the thick section of Lomita marl on the south flank of the anticline (Woodring, Bramlette, and Kew, 1946, pp. 52, 86).[3]

Practically all paleontologists, invertebrate and vertebrate,

[3] Professor Stock did not carry out his intention of borrowing and studying these fossils. I remember that when he examined them during a trip to the Palos Verdes Hills in 1943 he was disturbed to find, apparently in the early Pleistocene, teeth so similar to those of *Equus occidentalis* (as identified by Merriam) of the late Pleistocene Rancho La Brea asphalt deposits.

agree that the late Pleistocene of figure 1 is indeed to be referred to the late Pleistocene. Remains of land mammals are more numerous in deposits on the youngest late Pleistocene marine coastal terrace, both in marine deposits and in the overlying nonmarine terrace cover, than in the early Pleistocene formations.

The early Pleistocene formations of figure 1 are transgressive and rest with marked unconformity on Miocene or Oligocene formations at the west end of the north and south borders of the Ventura basin, and on early Pliocene or Miocene along the south border of the Los Angeles basin. The marginal deformation and overlap are irrelevant in choosing the series boundary. Their effects, however, have a practical advantage, inasmuch as they agree with the boundary as determined by faunal discontinuity.

TEMPERATURE FACIES OF PLEISTOCENE MARINE FAUNAS

The temperature facies of the late Pliocene and Pleistocene marine faunas has been converted directly into data for estimating isotherm shifts from the time of James Perrin Smith's well-known analysis (Smith, 1919, pp. 134-155) until a recent discussion by Durham (1950, pp. 1257-1260). These faunas cannot properly be used for that purpose unless they have a common denominator of identical, or practically identical, inferred environment. They do not have such a common denominator, if the present environment of species that are still living, or are closely related to species still living, can be trusted as a close guide. In the Palos Verdes Hills (at the south border of the Los Angeles basin), the Lomita marl, Timms Point silt, San Pedro sand, and Palos Verdes sand contain 150 to 350 species of mollusks, a total of about 500 species. The faunal facies of these formations, which have been assigned to glacial and interglacial subdivisions (Gale, in Grant and Gale, 1931, pp. 68-76), has been recently documented and discussed (Woodring, Bramlette, and Kew, 1946, pp. 86-103). The early Pleistocene Lomita marl and San Pedro sand, and particularly the Timms Point silt, contain cool-water species. They are found, however, in associations inferred to represent different depths ranging from 25 to 100 fathoms. No shallow-water northern fauna is known to occur in the Los Angeles or Ventura basin.

The late Pleistocene Palos Verdes sand (the marine deposits on the lowest terrace) has a shallow-water fauna of 250 species, about 20 of which are north of their present range, some species hundreds of miles. The marine deposits on the next older terrace contain seven such species out of a total of 110; those on the fourth terrace (in upward sequence) one southern species out of 90. Other terrace deposits in the Palos Verdes Hills have so far yielded only a relatively meager rock-cliff and tide-pool association that is indistinguishable no matter on what terrace it is found, except that the fourth terrace has yielded a southern species in an association of that character. Though the fossils from at least the lowest terraces may be interglacial or interstadial, they do not represent a Lower California fauna. Morover, the southern species are found in terrace deposits from San Diego northward to Santa Monica, but not in apparently contemporaneous terrace deposits in the Ventura basin and farther north. These relations indicate that the western end of the Santa Monica Mountains marked the boundary between two well-defined late Pleistocene faunal provinces that are unrecognizable at the present time.

At localities in Santa Barbara County north of the Ventura basin terrace deposits contain a fauna like the modern fauna at the same latitude. Contrary to expectation, Dickerson's Millerton formation (Dickerson, 1922, pp. 559-570; Mason, 1934, pp. 85-87, 104-105; Weaver, 1949, pp. 99-104), immediately north of San Francisco Bay, contains 40 species, 14 of which are somewhat north of their present range. As suggested by Dickerson, that formation may be interglacial, or interstadial. According to Mason (1934, pp. 99-106), however, the associated flora has a northern aspect.

RECOMMENDATION OF EIGHTEENTH INTERNATIONAL GEOLOGICAL CONGRESS

The Council of the Eighteenth International Geological Congress unanimously accepted a recommendation, presented by a Temporary Commission, that "the lower Pleistocene should include as its basal member in the type area [Italy] the Calabrian formation (marine) together with its terrestrial (continental) equivalent the Villafranchian" (Anonymous, 1950). Moore (1949) interpreted this recommendation to mean that the San Joaquin formation,[4] shown in figure 1, is early Pleistocene, on the grounds that it contains a vertebrate fauna of vertebrate paleontologists' Blancan stage and that the Blancan is correlated with the Villafranchian. The meager vertebrate fauna of the San Joaquin formation is considered by vertebrate paleontologists of Blancan age on the basis of the occurrence of teeth described by Merriam as *Pliohippus proversus*, a species now referred to *Plesippus* or *Equus*. There is no agreement, however, among vertebrate paleontologists that the Blancan is to be correlated with the Villafranchian. The Blancan has, in fact, been correlated with the Villafranchian (McGrew, 1944, pp. 42-48; Schultz and Stout, 1948, p. 571), and it has been claimed that the Blanco formation and correlated deposits are late Nebraskan and early Aftonian (Frye, Swineford, and Leonard, 1948, pp. 519-521, fig. 3). The Blancan, however, has also been correlated with the Astian of Italy (Wood and others, 1941, plate 1), which underlies the Villafranchian, and with both Astian and Villafranchian (Simpson, 1947, p. 623).

Until there is agreement that the Blancan is of Villafranchian age, California geologists need not be concerned that they are flouting international agreement by continuing to refer the San Joaquin formation to the late Pliocene. It is doubtful whether any paleontologist familiar with the succession of Cenozoic marine molluscan faunas of western North America would accept the San Joaquin and correlated formations as Pleistocene for any reason other than to encourage international agreement.

[4] Moore's representation, in his figure 1, of the Etchegoin, San Joaquin, and Tulare formations is misleading. At no place where the three formations are exposed is the San Joaquin formation neatly separated from the Etchegoin by a discontinuity, except a minor scour discontinuity similar to numerous discontinuities in both formations. Nor is the Tulare formation neatly separated from the San Joaquin by a discontinuity. In the Kettleman Hills the lower part of the Tulare formation, shown as late early Pleistocene in Moore's diagram, contains an extensive fauna of nonmarine mollusks unlike any known Pleistocene fauna. It is quite certainly not later than late Pliocene (Woodring, Stewart, and Richards, 1941, pp. 103-104).

REFERENCES

Anonymous, 1950. Recommendations of Commission appointed to advise on the definition of the Pliocene-Pleistocene boundary: International Geol. Congress, Rept. 18th Session, part 9, p. 6.

Bailey, T. L., 1935. Lateral change of fauna in the lower Pleistocene: Geol. Soc. America Bull., vol. 46, pp. 489-502.

———, 1943. Late Pleistocene Coast Range orogenesis in southern California: Geol. Soc. America Bull., vol. 54, pp. 1549-1568.

Dickerson, R. E., 1922. Tertiary and Quaternary history of the Petaluma, Point Reyes and Santa Rosa quadrangles: California Acad. Sci. Proc., 4th ser., vol. 11, pp. 527-601.

Durham, J. W., 1950. Cenozoic marine climates of the Pacific coast: Geol. Soc. America Bull., vol. 61, pp. 1243-1263.

Eaton, J. E., 1928. Divisions and duration of the Pleistocene in southern California: Am. Assoc. Petroleum Geologists Bull., vol. 12, no. 2, pp. 111-141.

———, 1941. The Pleistocene in California: California Div. Mines Bull. 118, part 2, pp. 203-207.

Flint, R. F., and Deevey, E. S., Jr., 1951. Radiocarbon dating of late-Pleistocene events: AM. JOUR. SCI., vol. 249, pp. 257-300.

Frye, J. C., Swineford, Ada, and Leonard, A. B., 1948. Correlation of Pleistocene deposits of the central Great Plains with the glacial section: Jour. Geology, vol. 56, pp. 501-525.

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

Grant, U. S., IV, and Hertlein, L. G., 1941. Pliocene correlation chart: California Div. Mines Bull. 118, part 2, pp. 201-202.

Keen, A. M., and Bentson, Herdis, 1944. Check list of California Tertiary marine Mollusca: Geol. Soc. America. Special Paper 56.

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

———, 1894. The geomorphogeny of the coast of northern California: California Univ., Dept. Geol. Bull., vol. 1, pp. 241-271.

McGrew, P. O., 1944. An early Pleistocene (Blancan) fauna from Nebraska: Field Mus. Nat. History Pub., Geol. ser., vol. 9, pp. 33-62.

Mason, H. L., 1934. Pleistocene floras of the Tomales formation: Carnegie Inst. Washington Pub. 415, pp. 81-179.

Moore, R. C., 1949. The Pliocene-Pleistocene boundary: Am. Assoc. Petroleum Geologists Bull., vol. 33, no. 7, pp. 1276-1280.

Pressler, E. D., 1929. The Fernando group in the Las Posas-South Mountain district, Ventura County, California: California Univ., Dept. Geol. Sci., Bull., vol. 18, pp. 325-345.

Reed, R. D., 1933. Geology of California, Am. Assoc. Petroleum Geologists, Tulsa.

Schultz, C. B., and Stout, T. M., 1948. Pleistocene mammals and terraces in the Great Plains: Geol. Soc. America Bull., vol. 59, pp. 553-588.

Simpson, G. G., 1947. Holarctic mammalian faunas and continental relationships during the Cenozoic: Geol. Soc. America Bull., vol. 58, pp. 613-687.

Smith, J. P., 1919. Climatic relations of the Tertiary and Quaternary faunas of the California region: California Acad. Sci. Proc., 4th ser., vol. 9, pp. 123-173.

Weaver, C. E., 1949. Geology of the Coast Ranges immediately north of the San Francisco Bay region, California: Geol. Soc. America Mem. 35.

Wood, H. E., 2nd, and others, 1941. Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., vol. 52, pp. 1-48.

Woodring, W. P., Bramlette, M. N., and Kew, W. S. W., 1946. Geology and paleontology of Palos Verdes Hills, California: U. S. Geol. Survey Prof. Paper 207.

Woodring, W. P., Stewart, Ralph, and Richards, R. W., 1940 (1941). Geology of the Kettleman Hills oil field, California; stratigraphy, paleontology, and structure: U. S. Geol. Survey Prof. Paper 195.

U. S. Geological Survey
Washington, D. C.