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OF THE PALOS VERDES HILLS, CALIFORNIA

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LATE PLEISTOCENE MOLLUSCAN FAUNAS FROM UPPER TERRACES OF THE PALOS VERDES HILLS, CALIFORNIA¹

By LOUIE MARINCOVICH²

ABSTRACT: The Palos Verdes Hills of southern California bear a sequence of thirteen Pleistocene marine terraces that locally contain abundant molluscan remains. Study of faunas from several upper terraces—five, seven, nine, and twelve—shows them to have essentially the same character as the better-known lower terraces (terrace levels one to four). The entire terrace sequence at the Palos Verdes Hills is considered to be of late Pleistocene age. The mollusks are inferred to have lived mainly in rocky shore habitats in water depths no greater than about 30 metres, and in a marine hydroclimate cooler than the one along the modern Palos Verdes coastline. The large number of southern rocky shore species required a local site of warmer water or the periodic introduction of southern species by warm counter-currents. Forty-seven species of mollusks found in the Pleistocene deposits of the Palos Verdes Hills were not previously reported.

INTRODUCTION

The Palos Verdes Hills, near Los Angeles, California (Fig. 1), bear a sequence of 13 emergent Pleistocene marine terraces that locally contain abundant molluscan faunas. Study of these terrace deposits by Woodring, Bramlette, and Kew (1946) established their general age and nature, but was based mainly on deposits of the four lowest terraces (here referred to collectively as the lower terraces). Although these workers considered all of the terraces to be of late Pleistocene age, others believed that the upper terraces could be of early Pleistocene or even late Pliocene age (Bandy, *in* Bandy and others 1964; Wahrhaftig and Birman 1965). In addition to uncertainties about age, there was relatively little information on the paleoecology of the upper terrace faunas, owing to insufficient collecting. For example, the southern rocky shore faunal element common on the lower terraces had never been found above the fifth terrace level, and its presence on higher terraces would influence interpretations of regional marine hydroclimate during the Pleistocene. Most of the upper terraces (terrace levels five to thirteen) apparently had never been searched for the extinct rocky shore molluscan assemblage, characterized by the gastropod *Calicantharus fortis* (Carpenter), commonly found in higher terrace deposits of the southern California islands. The presence of this faunal element in the higher terraces of the Palos Verdes Hills would provide a possible first means of correlation with the higher terraces of the islands.

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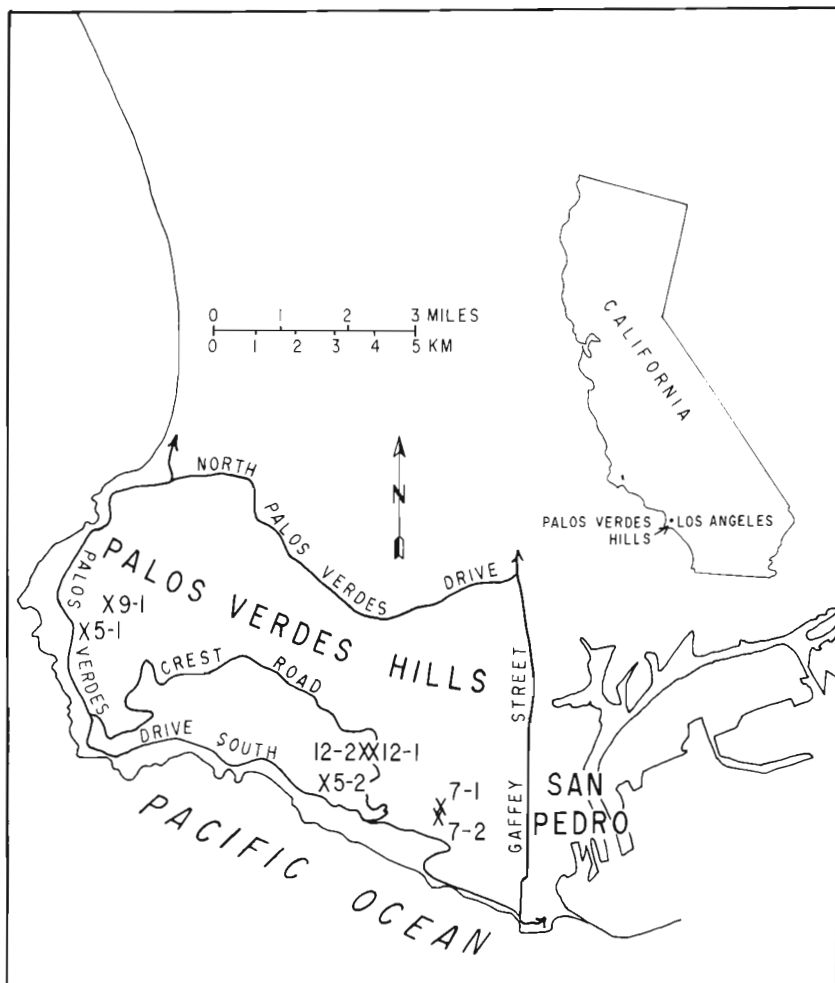


FIGURE 1. Index map of Palos Verdes Hills, showing Pleistocene fossil localities. First part of each locality number indicates terrace level on which locality is situated.

Search of the Palos Verdes Hills for all exposures of Pleistocene marine deposits above the fourth terrace level resulted in seven collections from terrace levels five, seven, nine, and twelve. Only one of these localities, locality 12-1, had been found by earlier workers (Woodring and others 1946); the new exposures presumably were not available to Woodring and earlier workers because few artificial cuts existed on the higher terraces prior to World War II. Part of the fossil material in these collections was made available by William H. Easton, University of Southern California. All specimens have been deposited in the Invertebrate Paleontology

Section, Natural History Museum of Los Angeles County. James H. McLean of the Museum aided in the identification of several species and made available his unpublished notes on Pacific Coast mollusks. Spencer Thorpe, El Cerrito, California, identified the chiton remains. I thank Warren O. Addicott and John G. Vedder, U.S. Geological Survey, and James W. Valentine, University of California at Davis, for making helpful comments on this study.

LATE PLEISTOCENE MOLLUSCAN FAUNAS

PREVIOUS STUDIES

The geology and paleontology of the Palos Verdes Hills has attracted many workers, beginning with Trask (1855), who gave a brief general description of the rock types in the San Pedro area and mentioned the presence of fossil marine mollusks "upon the summits of the cliffs among the fine alluvium and soil," probably the earliest reference to Pleistocene terrace deposits of this area. This work was followed by numerous others, many of which included descriptions and discussions of the Pleistocene mollusks in and around San Pedro. These works and many others dealing only indirectly with the Pleistocene deposits are listed chronologically by Woodring and others (1946). Kennedy (1975) brought this compilation up to date, annotated it, and included it in a review of paleontologic records of this area.

Gabb (1869) gave the earliest large list of Pleistocene fossils from the San Pedro area, including 86 species of mollusks, but did not specify the localities from which the fossils had come; it was left for Arnold (1903) to describe the formations comprehensively. His monographic work on the San Pedro Pleistocene strata listed nearly 400 species of mollusks, many of them new, and stimulated further work on these deposits. Numerous systematic papers and reports on new finds of early and late Pleistocene molluscan assemblages followed Arnold's work. Grant and Gale (1931) included records of Pleistocene mollusks from the Palos Verdes Hills in their monumental catalog, but speculated only incidentally on paleoecology. With the exception of Berry's (1922) treatment of the chitons, the next comprehensive work was the areal report on the Palos Verdes Hills by Woodring and others (1946). Their report, the most complete account to date of the geology and paleontology of the Palos Verdes Hills, describes with varying completeness the fossil assemblages from 142 localities, of which 114 were in Pleistocene deposits. The detailed composition of the molluscan faunas in the lower and upper Pleistocene formations is presented in this work, along with a discussion of the environments represented by the faunas. The presentation is most complete for the lower Pleistocene units and for the marine deposits on the lowest emergent terrace. The molluscan faunas of the upper terraces were only generally outlined, probably owing to a paucity of well-preserved material, and the only complete faunal list was for a single locality on the twelfth terrace. Kennedy (1975) discussed Pleistocene faunas of the San Pedro area but presented no new faunal lists from Palos Verdes Hills Pleistocene localities.

The most recent papers on the upper terrace deposits are Valentine's (1961, 1962) interpretations of some paleoecological aspects of the molluscan faunas neglected

by earlier workers and a note on the present study by Marinovich (1971). The earlier of Valentine's papers deals briefly with the upper terraces; the more recent paper is concerned mainly with terrace levels four, five, and six.

STRATIGRAPHY

The greater part of the Palos Verdes Hills is made up of moderately deformed middle and upper Miocene marine sedimentary rocks, at least 1,200 metres thick, consisting of mudstone and diatomaceous, cherty and phosphatic shales that form part of the Monterey Formation. Relatively rare molluscan and fish remains are known from these strata (Woodring and others 1946). Microfossils indicate deposition in bathyal and abyssal depths (Ingle 1967).

Lower Pliocene deposits of the Fernando Formation consist of as much as 45 metres of soft, bluish-gray siltstone in the Hills, but thicken northward to as much as 1,500 metres in the Los Angeles Basin. Foraminiferal and molluscan evidence (Woodring and others 1946; Ingle 1967) suggests deposition at bathyal or abyssal depths. The deposits crop out discontinuously along the northern flank of the Palos Verdes Hills, where they rest disconformably upon Miocene rocks. These deposits lie disconformably below lower Pleistocene deposits and are truncated in places by upper Pleistocene terrace deposits.

The lower Pleistocene rocks consist of marine sandstone, siltstone and marl present along the eastern and northern margins of the hills. These deposits form the San Pedro Formation, which is divided into three members (Poland and Piper 1956), in ascending order: the Lomita Marl Member, Timms Point Silt Member, and an unnamed sand member. The unnamed sand member has been referred to by some workers (Woodring and others 1946; Valentine 1961) as the San Pedro Sand, but this name would conflict with the formational name according to the Code of Stratigraphic Nomenclature. The maximum thickness of the San Pedro Formation in outcrop is not over 105 metres; the maximum subsurface thickness is thought to be about 180 metres (Woodring and others 1946). The three members intergrade or are unconformable wherever their contacts are exposed, and the lowest part of the Lomita is thought to be slightly older than the rest of the San Pedro Formation. Molluscan faunal trends suggest shoaling upsection within sublittoral depths for the Lomita and the unnamed sand member (Valentine 1961). Outer sublittoral mollusks from these strata may have been reworked into the upper Pleistocene beds during terrace cutting.

Upper Pleistocene marine strata in the Palos Verdes Hills are preserved on remnants of the 13 recognized major terraces (numbered 1 to 13 in ascending order by Woodring and others 1946). The shoreline angle of the highest terrace is at an elevation of 356 metres, the lowest at 2 metres. Possibly four to six submarine terrace levels of late Pleistocene age lie adjacent to the southern and west coasts of the Palos Verdes Peninsula to depths of about 90 metres (Emery 1958, 1960). The marine terrace deposits of the Palos Verdes Hills constitute the Palos Verdes Sand (Marinovich 1970; Kennedy 1975), which ranges from fine silty sand to coarse-grained sand and gravel up to about 5 metres thick that locally contains abun-

dant and well-preserved molluscan remains. Fossil assemblages from the lowest terrace contain a few northern and many southern extra-limital mollusk species (Woodring and others 1946; Valentine 1961). This distinctive array of molluscan communities has lent itself to the naming of the late Pleistocene Verdean faunal province by Valentine (1961).

Deposits on the Pleistocene marine terraces vary in thickness from nearly 5 metres at the seaward edges of the terraces to a few centimetres at the landward edges. However, marine sediments do not always occur on each terrace level, and marine deposits more than 1 to 1.5 metres thick are the exception. Although Woodring and others (1946) list 67 Pleistocene fossil localities on the terraces, the deposits are discontinuous, generally occurring as laterally restricted pods or lenses and not as extensive beds. This spotty occurrence of fossiliferous sediments is due in part to the concealment by the extensive nonmarine cover, but possibly also to primary deposition in slight depressions or pockets worn into the Miocene platform surface. As Addicott (1966) has pointed out, this could possibly protect such deposits from further reworking and help insure their preservation.

FAUNAL COMPOSITION

The Pleistocene terrace fauna of the Palos Verdes Hills includes at least 700 species of larger invertebrates. Mollusks are the dominant faunal element, followed in order of species abundance by foraminifers, bryozoans, echinoids, barnacles, and corals. Arnold (1903) recorded nearly 400 molluscan species from the lowest terrace at San Pedro, and subsequent workers listed 348 additional mollusks from the terrace above the lowest one (including species in this report). One hundred and seventy-four molluscan species were identified for this report (Table 6), including 47 taxa not previously recorded from marine terraces of the Palos Verdes Hills (Table 1). A detailed survey of the non-molluscan terrace fossils has never been made.

The presence of *Collisella edmitchelli* (Lipps) on terraces seven and twelve marks the first occurrence of this species on the mainland, as it had been found only on San Nicolas Island at localities ranging in elevation from less than 120 metres to more than 240 metres (Lipps 1963). Although Lipps considered *C. edmitchelli* to be most closely related to *C. limatula* (Carpenter) on the basis of shell sculpture, *C. edmitchelli* in the present collections intergrades completely with specimens of *C. scabra* (Gould), one of the most widespread limpets in Pleistocene terrace deposits throughout southern California. The sculptural features of *C. limatula* and *C. edmitchelli* do not intergrade in specimens from the Palos Verdes Hills, contrary to findings for San Nicolas Island Pleistocene specimens (Lipps 1963).

The minute bivalves *Lasaea cistula* Keen and *Lasaea subviridus* Dall intergrade in the present collections, a condition noted by Valentine (1962) for these species at a locality on terrace five. It is impossible to separate the species of *Cerithiopsis*, of which there are undoubtedly several, because their worn condition does not permit examination of sculptural features.

TABLE I

Pleistocene mollusks not previously reported from terraces (terrace levels 1 to 13) in the Palos Verdes Hills.

BIVALVES	
<i>Milneria</i> cf. <i>M. minima</i> Dall	<i>Maxwellia gemma</i> (Sowerby)
<i>Nettastomella rostrata</i> (Valenciennes)	<i>Megathura crenulata</i> (Sowerby)
<i>Parapholas</i> cf. <i>P. californica</i> Conrad	<i>Metaxia convexa</i> (Carpenter)
<i>Pristes oblonga</i> (Carpenter)	<i>Mitromorpha intermedia</i> Arnold
<i>Saxidomus nuttalli</i> Conrad	<i>Odostomia aepynota</i> Dall & Bartsch
<i>Semele incongrua</i> Carpenter	<i>Odostomia</i> cf. <i>O. helga</i> Dall & Bartsch
<i>Semele rupicola</i> Dall	<i>Odostomia</i> aff. <i>O. hemphilli</i>
<i>Ventricolaria fordii</i> (Yates)	Dall & Bartsch
	<i>Odostomia</i> cf. <i>O. lucca</i> Dall & Bartsch
	<i>Odostomia navisa</i> Dall & Bartsch
	<i>Odostomia</i> cf. <i>O. trachis</i> Dall & Bartsch
GASTROPODS	<i>Palia montereyensis</i> (Dall)
<i>Acteocina culcitella</i> (Gould)	<i>Parviturbo acuticostata</i> (Carpenter)
<i>Acteocina</i> cf. <i>A. harpa</i> (Dall)	<i>Petalococonchus</i> cf. <i>P. macrophragma</i>
<i>Alvinia aequisculpta</i> Keep	Carpenter
<i>Alvinia cosmia</i> (Bartsch)	<i>Petalococonchus montereyensis</i> Dall
<i>Balcis</i> cf. <i>B. thersites</i> (Carpenter)	<i>Rissoina dalli</i> Bartsch
<i>Barleieia</i> cf. <i>B. subtenuis</i> Carpenter	<i>Volvarina taeniolata</i> Mörch
<i>Bitium purpureum</i> (Carpenter)	
<i>Clathromangilia interfossa</i> (Carpenter)	CHITONS
<i>Clathromangilia variegata</i> Carpenter	<i>Callistoichiton decoratus</i> Pilsbry
<i>Collisella edmitchelli</i> (Lipps)	<i>Lepidochitona keepiana</i> Berry
<i>Cymatium</i> sp.	<i>Mopalia</i> cf. <i>M. lowei</i> Pilsbry
<i>Diodora arnoldi</i> McLean	<i>Mopalia wossnessenski</i> Middendorff
<i>Haliotis rufescens</i> Swainson	<i>Nuttallina californica</i> (Reeve) or
<i>Homalopoma fenestrata</i> (Dall)	<i>N. fluxa</i> (Carpenter)
<i>Lirularia</i> cf. <i>L. acuticostata</i> (Carpenter)	<i>Stenoplax heathiana</i> Berry or
<i>Lirularia succincta</i> (Carpenter)	<i>S. fallax</i> Carpenter
<i>Lucapinella callomarginata</i> (Carpenter)	

A large and complete specimen of the red abalone, *Haliotis rufescens* Swainson, is reported here for the first time from terraces of the Palos Verdes Hills. Absence of this species in previous collections was probably due to the incompleteness of specimens found, for fragments would most likely be mistaken for the common *Haliotis cracherodii* Leach, the only other abalone known from the terraces.

The addition of seven species of *Odostomia* to the terrace fauna is more indicative of fortuitous preservation than of basic changes in the marine environment. Four of the seven species are from localities 7-2 and 12-2, which appear to have been situated farther offshore than most of the upper terrace localities. *Odostomia* cf. *O. trachis* Dall and Bartsch is of further interest because it is restricted in its known modern range to San Pedro Bay (Dall and Bartsch 1909), while the present record from terrace seven is the first known fossil occurrence of this species. If the Pleistocene and Holocene records are accurate, this species has maintained a very restricted geographic range throughout much of the Pleistocene while profound thermal changes were taking place in the marine hydroclimate.

The occurrence of the minute bivalve *Bernardina bakeri* Dall on terrace seven is only the fourth fossil record of this species (Valentine 1962; Valentine and Lipps 1963; Vedder and Norris 1963), and the equally small bivalve *Pristes oblonga* (Carpenter) on terrace nine has apparently never before been reported as a fossil. The only extinct species in the present collection is *Rissoina pleistocena* Bartsch, known only from upper Pleistocene deposits of southern California.

MODE OF FORMATION

All of the localities visited during this study contain abundant broken and abraded shell debris in a poorly sorted matrix, attesting to some degree of transportation before final deposition. However, localities 12-2, 9-1, 7-2, and 5-2 contain some fairly well-sorted sediments which have well-preserved fossils in them that appear not to have been transported far. Specimens of *Haliotis cracherodii* Leach and *H. rufescens* Swainson from localities 12-1 and 12-2 are commonly unworn and some retain their delicate shell margins intact. Complete specimens of *Astraea undosa* (Wood) and *Cypraea spadicea* Swainson, rarely found in terrace deposits, provide more evidence for lack of post-mortem transport at locality 12-2. The large number of well-preserved minute species at localities 12-2, 9-1, and 7-2 also suggests that there has not been significant post-mortem transport. Broken and abraded specimens are to be expected in deposits representing high-energy marine environments, such as those of the Palos Verdes terraces, but easily destroyed minute specimens may be preserved by lodging in the interstices between larger shell fragments and coarse rock debris. Larger gastropod shells are commonly used as portable shelters by hermit crabs and thereby exposed to a longer period of abrasion than if they were immediately incorporated into the substrate. The most convincing evidence for an undisturbed deposit is at locality 9-1, where large numbers of the bivalve *Epilucina californica* (Conrad) were found with their valves intact. The interiors of the shells are filled with sand, but remnants of the ligaments are preserved in some individuals. Oriented infaunal bivalves such as observed by Addicott (1966) in Pleistocene sediments of central California are compelling evidence for undisturbed deposition, but were not found in the terrace deposits of the Palos Verdes Hills.

Besides possibly being transported and abraded during their addition to the substrate, the terrace fossils could have been reworked by wave action during retreat of the sea (uplift of the land), and later during subaerial formation of the non-marine terrace cover. Retreat of the high-energy breaker zone from its position at highest sea stand on a given terrace level would cause erosion of the previously formed terrace deposits. Depth of effective wave abrasion extends to about 10 metres (Dietz and Menard 1951; Bradley 1958) and length of exposure of the terrace deposits to wave erosion depends on the rate at which the sea retreated from the land. This, in turn, is a resultant of the differential rates of movement of the tectonically unstable Palos Verdes block and a rising or sinking sea level.

At numerous fossil localities in the Palos Verdes Hills worn and broken fragments of a few species are the only molluscan fossils found; these deposits have

undoubtedly been extensively reworked during deposition or afterward. Withdrawal of the sea from the maximum shoreline attained during cutting of a given terrace would have subjected deposits on that terrace platform to a vigorous abrasion (Addicott 1966) and might have similarly affected terrace deposits formed previously at a lower elevation. Destruction of fossils would also occur if sea level again rose enough to erode deposits formed during an earlier cycle of marine inundation.

The preservation of relatively undisturbed fossil deposits on several terraces might indicate rapid retreat of the sea from its points of greatest inundation. As Addicott (1966) has noted, gradual retreat of the high-energy breaker zone probably would destroy all traces of inner sublittoral deposits and possibly admix littoral invertebrates. Since a common inner sublittoral and a small but persistent outer sublittoral molluscan element are present in all of the thoroughly studied Palos Verdes terrace deposits, it is possible that retreat of the Pleistocene seas was a relatively rapid event after cutting of each terrace platform.

Additional abrasion and chemical weathering of the terrace fossils occurs during subaerial formation of the nonmarine terrace cover. Commonly throughout the Palos Verdes Hills, the alluvial cover lies upon the terrace platform cut into Miocene rocks, without intervening Pleistocene deposits. This complete absence of Pleistocene sediments and fossils most probably resulted from formation of the nonmarine terrace cover, as even vigorous erosion by the retreating sea would probably leave some evidence of its former presence. The lack of cobbles and other large debris is still puzzling. Scattered Pleistocene mollusks, usually in poor condition, commonly occur in the nonmarine terrace cover. They were probably derived from two sources: Indian kitchen middens, very common in the Palos Verdes Hills, and marine terrace deposits reworked during formation of the nonmarine alluvium. Once buried in kitchen middens, the shells became scattered throughout the nonmarine deposits by natural processes of erosion, including burrowing animals, and by agricultural, construction, and earthmoving activities. In most cases it is impossible to determine the source of scattered mollusks in the nonmarine terrace cover.

RELATIVE SIZE OF THE UPPER TERRACE FAUNAS

The largest assemblages of Pleistocene mollusks on the west coast of North America are those from Newport Bay, California (Kanakoff and Emerson 1959), and Magdalena Bay, Baja California, Mexico (Jordan 1936), each of which contains more than 400 species of mollusks and numerous other invertebrates. Such large faunas are made up of species representing more than one biotope and are not directly comparable with the Palos Verdes Hills upper terrace faunas, which almost exclusively contain species restricted to rocky open coastlines.

Faunas of the Palos Verdes Hills upper terraces include 348 taxa of mollusks reported in the literature (including those herein), by far the largest assemblage of Pleistocene rocky shore invertebrates along the California coast. The present collection contains 174 species of mollusks, of which 47 are new to the Palos Verdes

Hills terrace deposits (Table 1). Faunas of about 100 to 150 species of mollusks are known from terraces on Anacapa Island (Valentine and Lipps 1963), San Nicolas Island (Vedder and Norris 1963), Santa Barbara Island (Lipps and others 1968), and Point Loma (Valentine and Meade 1961) in southern California. Pleistocene faunas of similar size are recorded from Cayucos (Valentine 1958) and near Santa Cruz (Addicott 1966) in central California, and from Punta China, Baja California (Emerson 1956). Vedder and Norris (1963) report more than 275 taxa from the lowest emergent terrace in the Laguna Beach-Dana Point area of southern California. Valentine (1962) reported 94 molluscan taxa from the fourth terrace of the Palos Verdes Hills, and Woodring and others (1946) reported, but never fully recorded, a collection of 109 species from the second terrace. The largest assemblage from a single terrace in the present collection is 88 species from terrace twelve. Numerous other Pleistocene terrace localities with smaller assemblages of mollusks are known along the coasts of California and Baja California.

The large size of Pleistocene molluscan assemblages facilitates study of their paleoecology. But even these large faunas may not provide an accurate picture of what the ancient faunas were like. Valentine (1967) records 1,222 species of shelled benthic mollusks from the modern Californian molluscan province [as defined by Valentine (1966), and Durham (1967)] notes that the recorded Pleistocene invertebrate fauna of California is only about two-thirds as large as the living preservable fauna of the same region. Because of the original high-energy depositional environment of terrace fossils and the erosion and weathering to which they have been exposed, the faunas of the Palos Verdes upper terraces probably represent less than two-thirds of the original Pleistocene molluscan fauna that inhabited the coastline.

BATHYMETRY

The upper terrace faunas were deposited in depths ranging from the intertidal zone to about 30 metres. Most upper terrace mollusks are restricted to their present bathymetric ranges to the intertidal zone or to inner sublittoral depths (0 to 100 metres; Hedgpeth 1957). Only 11 species in the present collection are restricted exclusively to sublittoral depths (Table 2), and of these only five have the greater part of their ranges in the deeper part of the inner sublittoral zone. The deepest-ranging species in the present collection is *Fusinus arnoldi* (Cossmann), which is known to range from 30 to 216 metres (Burch 1945) but seems to be most common at about 200 metres (J. H. McLean, *oral communication*).

The majority of the species restricted to the inner sublittoral zone (Table 2) have their upper depth limits between 20 and 40 metres, suggesting that most of the sublittoral elements in the terrace faunas came from no shallower. This is considerably below the commonly accepted 10-metre limit of effective wave-produced submarine erosion (Dietz and Menard 1951; Bradley 1958), but is still apparently well within the zone susceptible to active, if irregular, sand transport (D. S. Grosline, *personal communication*). It is thus possible that mollusks in this depth range could have been transported inshore to the sites of the present terrace deposits. The

TABLE 2

Species with exclusively sublittoral bathymetric ranges, showing their occurrence at upper terrace localities and modern habitat data. F = fragment

	TERRACE LOCALITIES							HABITAT (Burch 1945, 1946)
	5-1	5-2	7-1	7-2	9-1	12-1	12-2	
BIVALVES								
<i>Semele incongrua</i> Carpenter	1F	...	...	30-5m, nestling or in sand
<i>Ventricolaria fordii</i> (Yates)	3,1F	...	...	...	...	under kelp on gravel bottom
<i>Ventricolaria</i> cf. <i>V.</i> <i>fordii</i> (Yates)	1F	...	...	...	same as above
GASTROPODS								
<i>Acteon traski</i> Stearns	1F	...	...	...	...	60-100m on sand
<i>Fusinus</i> cf. <i>F. arnoldi</i> (Cossman)	2F	...	...	...	...	30-216m near Palos Verdes
<i>Caecum</i> cf. <i>C. crebricinctum</i> (Carpenter)	2	...	...	...	...	20-70m under kelp, mainly on sand, gravel
<i>Mitrella tuberosa</i> (Carpenter)	3	...	...	...	14-70m on gravel
<i>Mitromorpha gracilior</i> (Tryon)	1	...	40-50m, on gravel under kelp
<i>Ocenebra foveolata</i> (Hinds)	...	2,1F	...	...	...	...	...	40-80m, on gravel under kelp
<i>Rissoina kelseyi</i> Dall & Bartsch	3	...	2	14,2F	20-50m, sand & gravel
<i>Turbonilla</i> cf. <i>T. asser</i> Dall & Bartsch	4,2F	...	...	30-150m
<i>Turbonilla</i> cf. <i>T.</i> <i>moerchi</i> Dall & Bartsch	1,3F	28-100m

lack of abrasion of some of the sublittoral fossils suggests that they have not been transported very far, and their presence in the terrace sediments may be due to upwelling conditions that prevailed along the exposed Pleistocene coastline. It may be that both wave transport and upwelling contributed the deeper sublittoral species to the upper terrace faunas.

The shallow-water character of the molluscan faunas corresponds to the low relief of the Palos Verdes terrace platforms. Where nonmarine cover is thin or deposits are exposed by excavations, the tectonically undeformed Pleistocene terrace surfaces are seen to dip gently seaward. Although the difference between the seaward edge of a given terrace and its apparent shoreline angle can be more than 35 metres, it is commonly only about 20 metres. The range of elevation of a terrace platform is usually impossible to determine because of nonmarine cover, at least 30 metres thick in places (Woodring and others 1946).

SUBSTRATE

A rocky substrate was necessary to support most of the gastropods and the epifaunal bivalves of the Palos Verdes terraces. Most of the bivalves from the upper terraces have living descendants in the coarse sand and gravel of nearby tide pools. However, gastropods such as *Acteocina culcitella* (Gould), *Alabina tenuisculpta* (Carpenter), *Assiminea californica* (Tryon), and *Sinum scopulosum* (Conrad) are evidence for at least the transitory presence of protected or semi-protected habitats with soft substrates. *Assiminea californica* (Tryon) is especially common at locality 5-1, and the small bivalve *Transenella tantilla* (Gould), common on silt and sand bottoms, was found on all of the upper terraces sampled. The limpet *Notacmaea insessa* (Hinds), found at all terrace localities but 9-1 and 12-2, lives exclusively on the brown alga *Egregia* (Burch 1945). The mollusks of the upper terraces suggest a variety of substrates during the Pleistocene similar to that found along the Palos Verdes coastline today.

LOCAL MARINE HYDROCLIMATE

Molluscan faunas of the upper terraces are generally similar to the fauna of the modern Californian province. Only four of the Pleistocene species have modern ranges that do not extend as far north as the Palos Verdes Hills (Table 3) and no northern extra-limital species are present. However, five species have their known ranges mainly to the north of the fossil localities (Table 4), whereas 25 species are presently known mainly to the south (Table 5). The upper terrace faunas are notable for their small number of extra-limital forms and their large number of predominantly southern rocky shore mollusks. All of the southern extra-limital forms are restricted to the seventh terrace; the predominantly northern and southern species are more evenly distributed among the upper terraces.

The presence of four southern extra-limital species on terrace seven, the lack of comparable northern forms, and the large number of predominantly southern exposed-shore species on most higher terraces suggests the conclusion that upper terrace faunas have a warm-water aspect, but such is not the case. Valentine and Meade (1961) noted that isotopic evidence indicates southern species in exposed-

Species in the upper terrace faunas whose modern geographic ranges do not extend as far north as the Palos Verdes Hills.

	TERRACE LOCALITIES		RANGE IN DEGREES OF NORTH LATITUDE (P. V. Hills = 33°40'N)
	7-1	7-2	
BIVALVES			
<i>Bernardina bakeri</i> Dall	18	...	33-25
<i>Chione picta</i> Willett	...	1	25-8
GASTROPODS			
<i>Acteon</i> cf. <i>A. traski</i> Stearns	1F	...	33-8
<i>Trivia solandri</i> Gray	1	...	33-25

TABLE 4

Species in the upper terrace faunas whose modern geographic ranges lie mainly to the north of the Palos Verdes Hills. F = fragment

	TERRACE LOCALITIES					RANGE IN DEGREES OF NORTH LATITUDE (P. V. Hills = 33°40'N)
	5-1	5-2	7-1	7-2	12-2	
BIVALVES						
<i>Nettastomella rostrata</i> (Valenciennes)	1	...	48-33
<i>Parapholas</i> cf. <i>P.</i> <i>californica</i> Conrad	10F	...	...	43-33
GASTROPODS						
<i>Acanthina spirata</i> (Blainville)	2,2F	2,1F	1	...	...	48-33
<i>Mitromorpha intermedia</i> Arnold	1	37-34
<i>Opalia montereyensis</i> Dall	1F	...	...	37-34

shore facies do not represent waters as warm as their present distributions suggest, but record isotopic paleo-temperatures fully as cool as those from associated frigidophilic species. The likelihood is that although southern exposed-shore species lived most of their lifespans at cool-water sites, they required relatively warm water at a critical stage of their early development (Valentine and Meade 1961). Such southern species may be evidence for a nearby warm-water area, perhaps a shallow coastal indentation removed from the effects of upwelling. The presence of southern extralimital mollusks on the seventh terrace only may indicate that the local warm-water area was better developed there than on the other upper terraces, or that these localities were closer to a warm-water area than those from other terraces.

Another possible explanation for the anomalous southern species in the Palos Verdes upper terrace deposits is that the pelagic larvae of subtropical Mexican species occasionally are transported northward to southern California by warm countercurrents (Woodring and others 1946; Vedder and Norris 1963; Zinsmeister 1974). Zinsmeister gave examples of modern tropical and subtropical mollusks and other invertebrates occurring far north of their known ranges, and correlated these occurrences with years when the southern countercurrent significantly raised marine temperatures along the southern California coastline. Under such conditions southern species are able to survive but not successfully reproduce in the cooler hydroclimate into which they have been transported. This could account for scattered tropical species in otherwise temperate faunas but would not account for large populations of tropical species in temperate latitudes year after year. The sparse occurrence of tropical mollusks in the upper terraces fits this hypothesis quite well. Bandy (*in* Bandy and others 1964) stated that the highest Palos Verdes terraces have a warmer water foraminiferal fauna than the lower terraces, but he did not document this.

TABLE 5

Species in the upper terrace faunas whose modern geographic ranges lie mainly to the south of the Palos Verdes Hills. F = fragment

	TERRACE LOCALITIES							RANGE IN DEGREES OF NORTH LATITUDE (P. V. Hills = 33°40'N)	
	5-1	5-2	7-1	7-2	9-1	12-1	12-2		
BIVALVES									
<i>Pristes</i> cf. <i>P. oblonga</i> (Carpenter)	4	...	...	34-33	34-30
<i>Semele</i> cf. <i>S. decisa</i> Conrad	6F	...	...	...	...
GASTROPODS									
<i>Alabina tenuisculpta</i> (Carpenter)	1	...	34-25	34-31
<i>Alvinia cosmia</i> Bartsch	8	...	...	...	34-33	34-33
<i>Alvinia oldroydae</i> Bartsch	2	34-28	34-28
<i>Astraea undosa</i> (Wood)	1,1F	...	...	...	...	34-31	34-28
<i>Bititium armillatum</i> Carpenter	2,2F	...	...	...	...	...	...	34-28	34-28
<i>Caecum dalli</i> Bartsch	13,7F	...	...	...	34-28	34-28
<i>Caecum</i> cf. <i>C. dalli</i> Bartsch	1	34-25	34-25
<i>Ceratostoma nuttalli</i> (Conrad)	1,1F	...	...	1	...	34-28	34-28
<i>Cerithium sculptum</i> Sowerby	56,10F	12,12F	...	...	...	...	...	34-5	34-28
<i>Crepidula coei</i> Berry	2	...	...	...	...	...	...	34-23	34-27
<i>Cypraea spadicea</i> Swainson	3,2F	...	...	2F	...	34-22	34-23
<i>Fartulum orcutti</i> (Dall)	11	34-27	34-22
<i>Maxwellia gemma</i> (Sowerby)	1	...	...	1	...		
<i>Metaxia convexa</i> (Carpenter)	1F	...		
<i>Odostomia aepynota</i> Dall & Bartsch	1	...	...	...	34-23	34-23
<i>Odostomia</i> cf. <i>O. aepynota</i> Dall & Bartsch	1		

The five species on the upper terraces that have predominantly northern modern ranges were found on terraces five, seven, and twelve, supporting the general cool-water aspect of the upper terrace faunas. The dominant cool-water aspect of the upper terrace faunas, with the presence of a small southern element, agrees well with the thermal environment of the southern California Pleistocene as reconstructed by Valentine (1961) and others.

The faunas of upper terraces described here are similar in most respects to the faunas of the lower terraces. The fauna on the lowest subaerial terrace, which has been thoroughly studied, is an association of warm-water mollusks representing deposition at protected sites and cool-water mollusks representing exposed rocky and sandy habitats. Woodring and others (1946) noted that the upper terraces seemed to have a fairly uniform faunal facies made up of mollusks known from tide pools and shallow subtidal habitats and designated this the "rock-cliff and tide-pool facies." This facies was observed to be dominant above the fourth terrace and prevalent at lower elevations, where a few mollusks from protected and semi-protected habitats were known. From terraces four, five, and six, Valentine (1962) recognized essentially the same molluscan associations as had Woodring and his coworkers (1946), with a small number of additional species representative of a sandy substrate in near proximity to an exposed rocky shore. The 47 species added to the Palos Verdes Hills terraces in this report more firmly establish the predominance of the "rock-cliff and tide-pool facies" in the upper terrace deposits, since all of these added species are found living in the intertidal or shallow subtidal zones of exposed shores or in closely adjacent habitats. The specimens of *Bernardina bakeri* Dall, *Chione picta* Willett, *Acteon* cf. *A. traski* Stearns, and *Trivia solandri* Gray from terrace seven (Table 3) extend the known range of the southern rocky shore element slightly backward in time, as this element had previously been known only as high as terrace five (Valentine 1962).

The upper terrace deposits represent a hydroclimate similar to that of the lowest terrace beds (the "Palos Verdes Sand" of most earlier workers) and other lower terrace deposits, but a narrower range of environments. The broader terrace platforms and more extensive coastlines developed on the lower terraces were probably responsible for the more diverse molluscan communities that occurred there.

AGE AND CORRELATION

The precise age of the terrace deposits in the Palos Verdes Hills is still in doubt. The deposits on the lowest emergent terrace are of undoubted late Pleistocene age (Woodring and others 1946; Valentine 1961), but uncertainty as to age assignment increases for progressively higher terraces. Woodring and others (1946) considered all of the present Palos Verdes terraces to have been cut during the late Pleistocene. However, they also thought that lower Pleistocene terrace deposits had once been formed and subsequently removed during formation of the present terrace deposits, and that the time interval between deposition of the lower Pleistocene formations in San Pedro and the terrace deposits was approximately equal to the middle third of the Pleistocene. Some later workers have considered the terrace deposits to be

of slightly greater age. Wahrhaftig and Birman (1965) noted that the water depths suggested by the molluscan facies of the lower Pleistocene formations around the base of the hills made it possible for some of the highest terraces to be contemporaneous with these units, but Poland and Piper (1956) considered the 12 upper terraces to be only partly correlative with unnamed upper Pleistocene deposits in the Long Beach-Santa Ana area. Bandy (*in* Bandy and others 1964) considered the highest Palos Verdes terraces to be of early Pleistocene or late Pliocene age because they exhibited a warmer water foraminiferal fauna than the lower terraces, although this was not documented. Only two extinct molluscan taxa are known from the higher terraces, whereas 49 are found in the nearby lower Pleistocene beds in San Pedro.

More precise age estimates for the terraces have been attempted by several workers, usually based on detailed analysis of the temperature facies shown by molluscan fossils. Late Pleistocene deposits at Newport Bay were correlated with the fauna of the lowest Palos Verdes terrace by Kanakoff and Emerson (1959) and referred to a time interval later than early Pleistocene and prior to the Wisconsin Glaciation. An Illinoian age has been suggested for lower terrace deposits throughout southern California and Baja California (Hubbs 1960). The modern aspect of the mollusks in the beds of the lowest Palos Verdes terrace and the relatively late occurrence of these deposits in the sequence of Pleistocene events of the Los Angeles Basin suggested an early Wisconsin age to Valentine (1961). Noting the lack of southern mollusks on terraces above the fourth, however, Valentine admitted that such higher terraces could represent earliest Wisconsin or even late Sangamon time. The discovery of four extra-limital southern species on terrace seven during this study does not modify Valentine's suggested age, as these four species are of the rocky shore southern facies, which has been shown to yield isotopic paleotemperatures fully as low as strictly northern mollusks (Valentine and Meade 1961), and a warmer hydroclimate is not required to explain their presence.

The terrace mollusks at Punta China, Baja California, are thought to be of late Pleistocene age on faunal and stratigraphic grounds and are similar to the terrace faunas above the first terrace at Palos Verdes (Emerson 1956). Terrace faunas on the southern California islands are much like those of the Palos Verdes Hills. Their ages and suggested correlations with the mainland deposits are divisible into two groups: terraces at about 30 metres elevation and lower have molluscan faunas virtually identical to those of upper Pleistocene mainland deposits; terrace faunas at higher levels seem to be older (Valentine and Lipps 1967). These higher terraces contain a well-defined extinct element of mollusk species such as *Calicantharus fortis* (Carpenter), *Crepidula princeps* Conrad, *Arca sisquocensis* Reinhart, and *Humiliaria perlaminosa* (Conrad), and the echinoid *Dendraster venturaensis* Kew. Island terraces bearing these extinct species range in elevation from about 45 metres to 270 metres. These species suggest that the upper island terraces are older than the upper Pleistocene deposits of the mainland, though they are insufficient evidence to support a definite older age for these terraces (Valentine and Lipps 1967). Vedder and Norris (1963) attributed the presence of these taxa to the survival of a relict fauna on the islands, not to an early Pleistocene age. No such

extinct element occurs on the Palos Verdes or other mainland terraces, which suggests either that the marine hydroclimate between the two regions was different, or that the islands were tectonically uplifted before the mainland coast. Since the southern Channel Islands are clearly within the late Pleistocene Verdean molluscan province (Valentine and Lipps 1967), it would be reasonable to expect the mainland and islands to have shared the same Pleistocene fauna. However, differences between the islands and mainland are known for the modern molluscan faunas (Strong 1923), including the presence of the islands of both northern and southern species that are absent on the mainland (Lipps 1967), and this situation might have prevailed during much or all of the Pleistocene. Even though the Palos Verdes Hills formed an island during the Pleistocene, it was only about 10-15 miles (16-24 kilometres) from the mainland, but at least 50 miles (82 kilometres) from the other islands that now have fossiliferous Pleistocene deposits. Molluscan faunal differences between the Palos Verdes island and the other Pleistocene islands were certainly possible. As differences in the tectonic histories of the Channel Islands and the present mainland are still not known with certainty, faunal differences between the upper terraces of the islands and the mainland cannot yet be definitely attributed to either environmental or tectonic causes. If the differences are environmental, the groups of mainland and island terraces cannot be correlated. If they are tectonic, all of the Palos Verdes terraces are younger than the higher island terraces and doubtless of late Pleistocene age.

A number of radiometric dates are available from southern California Pleistocene terrace deposits (Kulp and others 1952; Fanale and Schaeffer 1965; Szabo and Rosholt 1969; Szabo and Vedder 1971), primarily on the mainland. They do not clarify the terrace chronology based on faunal evidence. There is wide discordance among such dates and they will remain in doubt until more reliable methods of dating mollusk shells are developed. In general, however, radiometric ages for the lowest Palos Verdes Hills terrace range from about 70,000 to 130,000 years, whereas those for terrace twelve indicate an age greater than about 360,000 years.

The Palos Verdes Hills upper terraces are considered here to be of late Pleistocene age. The modern character of the faunas and absence of the extinct faunal element present on the higher terraces of the southern California islands suggests faunal equivalence of the entire Palos Verdes terrace sequence with the lower island terraces. It seems to exclude a Pliocene or early Pleistocene age for any of the Palos Verdes Hills terraces. The inferred cool-water character of the upper terrace molluscan faunas also does not support a Pliocene age for the upper terrace deposits.

SUMMARY

The molluscan faunas of the Palos Verdes Hills upper terraces are similar in many ways to the more extensively studied faunas of the lower terraces. They represent the same range of environments as the lower terrace faunas, but contain mainly species from an exposed rocky shore habitat. Very few species from protected or semiprotected habitats occur in the upper terrace deposits, suggesting that such

habitats were quite restricted or perhaps transitory. In this respect, the Palos Verdes island of Pleistocene time might have been like the present southern California islands, where semiprotected coves with sandy or silty bottoms indent rugged coastlines. The shallowness of the sites of deposition is indicated by the gentle seaward slope of the terrace platforms and by the molluscan faunas. Numerous intertidal species occur in the terrace deposits, and the greatest modern depth limits of most of the shallow inner sublittoral mollusks occur between 20 and 40 metres. It is likely that most of the terrace deposits were laid down within a depth range of 0 to 30 metres, although depositional sites on the margin of a rising landmass would naturally contain organic remains from several depth zones. The sites of deposition might have been somewhat deeper than indicated by analogy with modern depth limits of the fossil mollusks if there was upslope migration due to the cooler Pleistocene hydroclimate.

The upper terrace molluscan faunas suggest a greater range of water temperatures than prevails today along the Palos Verdes Hills coastline, and a generally lower sea surface temperature. The rocky shore species that predominate in the terrace deposits, whether of northern or southern affinity, suggest cool water. Valentine and Meade (1961) showed with oxygen isotope studies that both southern and northern rocky shore mollusks yield low isotopic paleotemperatures. A few species present in the terrace deposits live today only in tropical waters to the south. These lived in protected warm-water sites or were introduced occasionally by warm southern countercurrents.

The entire terrace sequence is considered to be of late Pleistocene age as suggested by the modern aspect of the mollusks. There is only one extinct species, the gastropod *Rissoina pleistocena* Bartsch, found on terrace nine. The upper terrace faunas are virtually identical to the lower terrace faunas of accepted late Pleistocene age. Several extinct species of mollusks and an extinct echinoid of late Pliocene and early Pleistocene age present on the upper terraces of the southern California islands are absent in the Palos Verdes Hills. Although molluscan evidence for a pre-late Pleistocene age for the Palos Verdes Hills terrace sequence is lacking, faunal grounds are often unreliable for accurate age estimates within an epoch as brief as the Pleistocene. Precise age determinations must await more reliable radiometric measurements.

TABLE 6

Mollusks from upper terraces of the Palos Verdes Hills, showing number of specimens or valves from each locality. F= fragment

	TERRACE LOCALITIES						
	5-1	5-2	7-1	7-2	9-1	12-1	12-2
BIVALVES							
<i>Mytilus</i> sp.	...	...	...	1F	1F	...	2
<i>Septifer bifurcatus</i> (Conrad)	...	...	1,1F	2	2,5F	14,27F	6,7F
<i>Modiolus</i> sp.	2F	1	...	8F	...	...	...
<i>Lithophaga</i> sp.	...	...	3	...	5	...	...
<i>Osrea</i> cf. <i>O. lurida</i> Carpenter	...	...	1	...	1F	...	...
<i>Osrea</i> sp.	...	...	...	...	...	...	...
<i>Hinnites multirugosus</i> (Gale)	...	...	2,2F	...	...	...	...
<i>Pecten</i> sp.	...	...	...	1F	...	...	...
<i>Pododesmus macroschismus</i> (Deshayes)	...	...	1	...	...	...	...
<i>Chama pellucida</i> Broderip	...	...	7,2F	2	1	...	1
<i>Glans subquadrata</i> (Carpenter)	1,2F	2	1	11,3F	62	16	32
<i>Milneria kelseyi</i> Dall	1	...	...	...	...	...	...
<i>Milneria</i> cf. <i>M. minima</i> Dall	...	...	1	1	...	...	...
<i>Bernardina bakeri</i> Dall	...	...	18	...	...	...	...
<i>Lasaea cistula</i> Keen	...	...	1	...	...	...	...
<i>Lasaea subviridus</i> Dall	12	...	...	7	3	...	1
<i>Lasaea</i> cf. <i>L. subviridus</i> Dall	...	...	...	...	4	...	...
<i>Pristes oblonga</i> (Carpenter)	...	...	...	...	...	...	...
<i>Epilucina californica</i> (Conrad)	18,5F	3	8,2F	2F	437,143F	19,10F	3,1F
<i>Lucinoma annulata</i> Reeve	1F	...	...	...	...	...	...
<i>Diplodonta</i> cf. <i>D. sericata</i> (Reeve)	...	...	1	...	...	...	...
<i>Chione picta</i> Willett	...	...	...	1	...	...	...
<i>Chione</i> sp.	1F	...	...	...	...	...	...
<i>Cumingia californica</i> Conrad	...	...	...	1F	...	...	...
<i>Cumingia</i> cf. <i>C. californica</i> Conrad	...	...	...	...	1F	...	...
<i>Cumingia lamellosa</i> Sowerby	...	...	1	...	...	...	...
<i>Semele</i> cf. <i>S. decisa</i> (Conrad)	...	...	6F	...	...	...	...
<i>Semele incongrua</i> Carpenter	...	...	...	...	1F	...	...

TABLE 6 (cont'd)

Mollusks from upper terraces of the Palos Verdes Hills, showing number of specimens or valves from each locality. F = fragment.

	TERRACE LOCALITIES						
	5-1	5-2	7-1	7-2	9-1	12-1	12-2
BIVALVES (cont'd)							
<i>Semele rupicola</i> Dall	...	...	1F	...	...	...	...
<i>Semele</i> sp.	...	...	...	...	...	...	1F
<i>Corbula luteola</i> Carpenter	...	...	1	...	...	...	...
<i>Ventricolaria fordii</i> (Yates)	...	...	3,1F	1F	...	...	...
<i>Tranzenella tantilla</i> (Gould)	20	1	6	16	1	...	2
<i>Saxidomus nuttalli</i> Conrad	...	...	2,3F	...	...	...	...
<i>Penitella</i> sp.?	...	...	...	1F	...	...	...
<i>Parapholas</i> cf. <i>P. californica</i> Conrad	...	...	10F	...	...	...	...
<i>Neitastomella rostrata</i> (Valenciennes)	...	...	...	1	...	...	...
GASTROPODS							
<i>Haliotis cracherodii</i> Leach	...	...	...	...	...	13,131F	4F
<i>Haliotis rufescens</i> Swainson	...	...	...	...	...	1	...
<i>Haliotis</i> sp.	11F	...	...	...	19F	...	4F
<i>Diodora arnoldi</i> McLean	...	...	...	...	...	1	3
<i>Megathura crenulata</i> (Sowerby)	...	...	1	...	...	...	3,1F
<i>Megatebennus bimaculatus</i> (Dall)	...	...	...	...	...	...	...
<i>Lucapinella callomarginata</i> (Dall)	...	...	...	...	...	1F	...
<i>Fissurella volcano</i> Reeve	...	...	16,1F	12,2F	4	19,30F	17,14F
<i>Acmaea mitra</i> Eschscholtz	2	...	...	...	...	...	...
<i>Acmaea</i> cf. <i>A. mitra</i> Eschscholtz	...	...	...	...	...	...	1
<i>Collisella edmitchelli</i> (Lipps)	...	...	...	3	...	13,5F	5
<i>Collisella</i> cf. <i>C. edmitchelli</i> (Lipps)	...	...	...	...	...	...	4
<i>Collisella limatula</i> (Carpenter)	19,12F	...	17,7F	8	...	20	3
<i>Collisella</i> cf. <i>C. limatula</i> (Carpenter)	...	...	...	...	1,1F	...	...
<i>Collisella pelta</i> (Rathke)	5	1	...	...	...	...	...
<i>Collisella</i> cf. <i>C. pelta</i> (Rathke)	4	...	...	...	...	1,1F	...
<i>Collisella scabra</i> (Gould)	4	1	9,1F	4,3F	9,3F	26,8F	44,4F

TABLE 6 (cont'd)

Mollusks from upper terraces of the Palos Verdes Hills, showing number of specimens or valves from each locality. F = fragment	TERRACE LOCALITIES						
	5-1	5-2	7-1	7-2	9-1	12-1	12-2
GASTROPODS (cont'd)							
<i>Rissoina kelseyi</i> Dall & Bartsch	...	...	...	3	...	2	14,2F
<i>Rissoina pleistocena</i> Bartsch	...	...	...	...	4,4F	...	...
<i>Assimineia californica</i> (Tryon)	22	...	...	...	...	3	...
<i>Tetinostoma supravallata</i> (Carpenter)	...	...	...	59	167	2	121
<i>Caecum californicum</i> Dall	...	...	...	47,10F	9,1F	...	...
<i>Caecum</i> cf. <i>C. crebricinctum</i> Carpenter	...	...	2	13,7F	...	...	...
<i>Caecum</i> cf. <i>C. dalli</i> Bartsch	...	...	...	3,2F	...	...	1
<i>Caecum</i> sp.	...	...	...	2	42	...	20,1F
<i>Fartulum occidentale</i> Bartsch	...	...	...	...	...	...	1
<i>Fartulum</i> cf. <i>F. occidentale</i> Bartsch	...	...	46F	...	...	41F	2F
<i>Fartulum orcutti</i> (Dall)	...	...	...	1F	...	...	7F
<i>Serpulorbis squamigerus</i> Carpenter	...	...	...	...	...	...	...
<i>Petalocochnus macrophragma</i> Carpenter	...	...	...	...	...	...	...
<i>Petalocochnus montereyensis</i> Dall	3F	1F	...	2F	4F	...	...
<i>Petalocochnus</i> cf. <i>P. montereyensis</i> Dall	...	...	...	...	...	...	...
<i>Cerithium sculptum</i> Sowerby	68,10F	9,12F	...	...	...	1	...
<i>Alabina tenuisculpta</i> (Carpenter)	...	...	...	...	...	...	1
<i>Alabina</i> cf. <i>A. tenuisculpta</i> (Carpenter)	...	...	...	...	...	...	...
<i>Bitium armillatum</i> Carpenter	2,2F	...	...	...	...	...	...
<i>Bitium</i> cf. <i>B. armillatum</i> Carpenter	2	...	...	...	...	...	23
<i>Bitium</i> cf. <i>B. attenuatum</i> Carpenter	2	...	...	2	...	...	1
<i>Bitium purpureum</i> (Carpenter)	1	...	...	...	...	...	...
<i>Bitium</i> aff. <i>B. purpureum</i> (Carpenter)	...	...	...	...	...	...	3
<i>Cerithiopsis</i> sp.	2,2F	...	3	10	1	50	41
<i>Metaxia convexa</i> Carpenter	...	...	...	1	...	1F	3,1F
<i>Metaxia</i> sp.	...	...	...	...	...	...	2
<i>Seila montereyensis</i> Bartsch	...	...	...	1	2	2	4,2F

<i>Triphora pedroana</i> Bartsch	...	1F	1,2F	...	1,6F	4,4F
<i>Triphora</i> cf. <i>T. pedroana</i> Bartsch	...	...	...	...	...	4,4F
<i>Epitonium</i> sp.	...	...	3	...	...	1F
<i>Opalia montereyensis</i> (Dall)	...	1F	...	...	1F	...
<i>Opalia</i> sp.	...	...	...	...	...	...
<i>Balcis micans</i> (Carpenter)	...	...	1	...	...	...
<i>Balcis</i> cf. <i>B. theristes</i> (Carpenter)	...	...	1F	...	...	2
<i>Balcis</i> sp.	...	1	...	...	...	1
<i>Hipponix antiquatus</i> (Linnaeus)	16,3F	2	59	8,1F	131,5F	16
<i>Hipponix tumens</i> Carpenter	...	...	14	26	16,5F	56
<i>Crepidula adunca</i> Sowerby	1F	...	...	...	...	...
<i>Crepidula</i> cf. <i>C. adunca</i> Sowerby	1	...	...	...	...	...
<i>Crepidula coei</i> Berry	2	...	...	...	...	...
<i>Crepidula</i> cf. <i>C. coei</i> Berry	...	...	3	...	...	...
<i>Crepidula nummaria</i> Gould	...	...	3,2F	1	1	...
<i>Crepidula onyx</i> Sowerby	...	...	1	...	2	...
<i>Crepidula</i> cf. <i>C. onyx</i> Sowerby	3	...	...	...	...	...
<i>Crepidula</i> sp.	...	...	...	1	...	36
<i>Crepidatella lingulata</i> (Gould)	...	...	5,1F	...	5,2F	4
<i>Sinum scopulosum</i> (Conrad)	...	...	...	...	...	1F
<i>Trivia solandri</i> (Sowerby)	...	...	1	...	...	...
<i>Cypraea spadicea</i> Swainson	...	...	3,2F	...	2F	...
<i>Cymatium</i> sp.	1F	...	...	...	...	...
<i>Ceratostoma nuttalli</i> (Conrad)	...	...	1,1F	...	1	...
<i>Ocenebra foveolata</i> (Hinds)	...	2,1F	...	...	...	...
<i>Ocenebra interfossa</i> (Carpenter)	2	...	...	3	...	...
<i>Ocenebra lurida</i> (Middendorff)	1	...	...	...	1	...
<i>Maxwellia gemma</i> (Sowerby)	...	...	1	...	...	...
<i>Acanthina spirata</i> (Blainville)	2,2F	2,1F	1	...	...	...
<i>Macron lividus</i> (A. Adams)	1	...	2	...	7F	1,3F
<i>Amphissa versicolor</i> Dall	...	...	2,2F	3,2F	...	...
<i>Amphissa</i> cf. <i>A. versicolor</i> Dall	...	...	...	...	...	...
<i>Mitrella carinata</i> (Hinds)	13,3F	6,1F	1	6,1F	1F	...
<i>Mitrella tuberosa</i> (Carpenter)	...	...	...	3	...	...
<i>Nassarina penicillata</i> (Carpenter)	...	...	...	8	...	...

TABLE 6 (cont'd)

Mollusks from upper terraces of the Palos Verdes Hills, showing number of specimens or valves from each locality. F = fragment

	TERRACE LOCALITIES							
	5-1	5-2	7-1	7-2	9-1	12-1	12-2	
GASTROPODS (cont'd)								
<i>Nassarius fossatus</i> (Gould)	3,2F	2	...	1	...	...	...	...
<i>Nassarius mendicus</i> (Gould)	...	...	2F	...	...	1	...	...
<i>Fusinus</i> cf. <i>F. arnoldi</i> (Cossman)	...	...	...	...	...	...	2	...
<i>Mitra</i> cf. <i>M. idae</i> Melvill	...	...	...	...	...	1	...	...
<i>Volvarina taeniolata</i> Mörch	...	...	...	...	...	...	...	...
<i>Granula subrigona</i> (Carpenter)	1	...	...	9	2,1F	1	...	...
<i>Granulina margaritula</i> (Carpenter)	...	...	...	5	3	1	...	5,1F
<i>Olivella</i> cf. <i>O. baetica</i> Carpenter	...	...	...	1F	...	...	...	...
<i>Olivella biplicata</i> (Sowerby)	14,2F	2	8,1F	...	...	...	...	...
<i>Conus californicus</i> Hinds	...	...	69,17F	5,3F	2F	9,12F	3,3F	1F
<i>Mitromorpha aspera</i> (Carpenter)	...	...	...	...	...	1	...	...
<i>Mitromorpha gracilior</i> (Tryon)	...	...	...	...	...	...	...	...
<i>Mitromorpha intermedia</i> Arnold	...	...	...	...	...	...	1	...
<i>Clathromangilia interfossa</i> (Carpenter)	1	...	...	...	...	...	4,1F	...
<i>Clathromangilia</i> cf. <i>C. interfossa</i> (Carpenter)	1	1	...	...	...	...	...	1F
<i>Clathromangilia variegata</i> Carpenter	...	...	...	...	...	...	...	...
<i>Clathromangilia</i> cf. <i>C. variegata</i> (Carpenter)	...	...	...	1,1F	...	...	...	...
<i>Clathromangilia</i> aff. <i>C. variegata</i> (Carpenter)	...	...	1	...	...	1	...	...
<i>Clathromangilia</i> sp.	2	...	1F	...	...	...	1	...
<i>Acteon traski</i> Stearns	...	...	...	...	...	...	...	...
<i>Acteocina culcitella</i> (Gould)	1	...	...	...	...	...	...	...
<i>Acteocina</i> sp.?	...	...	...	...	...	...	1F	...
<i>Acteocina</i> cf. <i>A. harpa</i> (Dall)	...	...	...	1,2F	...	...	...	...
<i>Odostomia aepynota</i> Dall & Bartsch	...	...	...	1	...	...	...	...
<i>Odostomia</i> cf. <i>O. aepynota</i> Dall & Bartsch	...	...	...	...	...	...	...	1
<i>Odostomia</i> cf. <i>O. helga</i> Dall & Bartsch	...	...	...	...	1	...	...	...
<i>Odostomia</i> aff. <i>O. hemphilli</i> Dall & Bartsch	...	...	...	...	2	...	...	...
<i>Odostomia</i> cf. <i>O. lucca</i> Dall & Bartsch	...	...	...	...	4	...	...	...

<i>Odostomia navisa</i> Dall & Bartsch	...	...	...	4	...	...	...
<i>Odostomia</i> cf. <i>O. trachis</i> Dall & Bartsch	...	...	...	9	...	...	...
<i>Odostomia turricula</i> Dall & Bartsch	1	...	...	1	1	...	2
<i>Odostomia</i> sp.	...	...	...	...	1	...	1
<i>Turbonilla</i> cf. <i>T. asser</i> Dall & Bartsch	...	...	...	...	4,2F	...	1
<i>Turbonilla</i> cf. <i>T. moerchi</i> Dall & Bartsch	...	...	...	...	...	...	1,3F
<i>Turbonilla</i> sp.	...	...	...	3,1F	...	...	4
<i>Trimusculus reticulatus</i> (Sowerby)	...	...	...	...	...	1	2
CHITONS							
<i>Lepidochitona keptiana</i> Berry	...	...	1	...	1	...	...
<i>Nutallina californica</i> (Reeve) or <i>N. fluxa</i> Carpenter	...	...	...	...	6	23	...
<i>Nutallina</i> sp.	...	...	...	1	5	5	...
<i>Chaetopleura gemma</i> Carpenter	...	...	1	1	...	1	1
<i>Mopalia</i> aff. <i>M. ciliata</i> (Sowerby)	1	...	1	...	...	...	...
<i>Mopalia</i> cf. <i>M. lowei</i> Pilsbry	...	...	...	2	...	...	...
<i>Mopalia muscosa</i> (Gould)	3	2	2	1	...	...	...
<i>Mopalia wosnessenski</i> Middendorff	...	...	...	...	...	1	...
<i>Mopalia</i> cf. <i>M. wosnessenski</i> Middendorff	1	1	...	...	...	...	...
<i>Mopalia wosnessenski</i> Middendorff or <i>M. hindsi</i> (Sowerby)	1	...	...	...	...	...	...
<i>Mopalia</i> sp.	...	...	...	...	...	...	1
<i>Placiphorella velata</i> Carpenter	...	...	1	...	...	...	...
<i>Callistochiton crassicosiatus</i> Pilsbry	...	...	1	8	...	10	27
<i>Callistochiton decoratus</i> Pilsbry	...	...	2	3	...	2	2
<i>Callistochiton palmulatus</i> Carpenter	...	...	1	3	...	4	...
<i>Callistochiton</i> sp.	...	...	...	...	...	2	...
<i>Stenoplax heathiana</i> Berry	1	1	...	...	...	1	2
<i>Stenoplax heathiana</i> Berry or <i>S. fallax</i> Carpenter	1	...	...	...	...	...	...
<i>Stenoplax</i> cf. <i>S. magdalenensis</i> (Hinds)	...	...	8	4	6	...	...
<i>Stenoplax</i> sp.	1	...	...	...	...	...	...

REGISTER OF LOCALITIES

LACMIP = Natural History Museum of Los Angeles County, Invertebrate Paleontology Section, where collections made for this study are housed.

Loc. 5-1 (LACMIP loc. 1309). Terrace five. Road cut on east side of Via Buena, opposite a fire hydrant about 60 metres north of the intersection with Via Victoria. Lies 480 metres (1,600 feet) N. 16° E. from bench mark 273. Elevation 123 metres (410 feet). Collected by W. H. Easton and L. Marincovich.

Loc. 5-2 (LACMIP loc. 1310). Terrace five. Road cut at the intersection of Dauntless Drive and Conqueror Drive. Lies 474 metres (1,580 feet) N. 89° E. from bench mark 320. Elevation 146 metres (485 feet). Collected by W. H. Easton and L. Marincovich.

Loc. 7-1 (LACMIP loc. 1307). Terrace seven. Building excavation 582 metres (1,940 feet) N. 4° W. from bench mark 382. Elevation 192 metres (640 feet). Collected by W. H. Easton and L. Marincovich.

Loc. 7-2 (LACMIP loc. 1308). Terrace seven. Same building excavation as locality 7-1, but 30 metres farther south along the excavation cut from the Pleistocene sea cliff. Lies 550 metres (1,850 feet) N. 8° W. from bench mark 382. Elevation 192 metres (640 feet). Collected by W. H. Easton and L. Marincovich.

Loc. 9-1 (LACMIP loc. 1306). Terrace nine. Building excavation 1,470 metres (4,900 feet) N. 69° E. from bench mark 273. Elevation 254 metres (847 feet). Collected by W. H. Easton and L. Marincovich.

Loc. 12-1 (LACMIP loc. 1304). Terrace twelve. Road cut on north side of Crest Road, 525 metres (1,750 feet) S. 60° E. from triangulation station on San Pedro Hill. Equivalent to locality 75 of Woodring and others (1946). Elevation 365 metres (1,215 feet). Collected by W. H. Easton.

Loc. 12-2 (LACMIP loc. 1305). Terrace twelve. Road cut on north side of Crest Road, 405 metres (1,356 feet) S. 14° E. from triangulation station on San Pedro Hill. The first road cut downhill along Crest Road from locality 12-1. Elevation 360 metres (1,200 feet). Collected by W. H. Easton and L. Marincovich.

LITERATURE CITED

- ADDICOTT, W. O. 1966. Late Pleistocene marine paleoecology and zoogeography in central California: U.S. Geol. Survey Prof. Paper 523-C:1-21, pls. 1-4, text-figs. 1-6.
- ARNOLD, R. 1903. The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, California: California Acad. Sci. Mem. 3:1-420, pls. 1-37.
- BANDY, O. L., J. C. INGLE AND J. M. RESIG. 1964. Facies trends, San Pedro Bay, California: Geol. Soc. America Bull. 75(5):403-424, text-figs. 1-10.
- BERRY, S. S. 1922. Fossil chitons from western North America: California Acad. Sci. Proc., ser. 4, 11(18):399-526, pls. 1-16, text-figs. 1-11.
- BRADLEY, W. C. 1958. Submarine abrasion and wave-cut platforms: Geol. Soc. America Bull. 69(8):967-974, text-figs. 1-6.
- BURCH, J. Q. 1944-1946. Distributional list of west American marine mollusks from San Diego, California, to the Polar Sea: Southern California Conchol. Club Minutes, nos. 33-63, pagination by issue, 3 pls.

- DALL, W. H. AND P. BARTSCH. 1909. A monograph of west American pyramidellid mollusks: U.S. Natl. Mus. Bull. 68:1-258, pls. 1-30.
- DIETZ, R. S. AND H. W. MENARD. 1951. Origin of abrupt change in slope at continental shelf margin: Am. Assoc. Petroleum Geologists Bull. 35(9):1994-2016, 1 pl., text-figs. 1-12.
- DURHAM, J. W. 1967. The incompleteness of our knowledge of the fossil record: Jour. Paleontology 41(3):559-565.
- EMERSON, W. K. 1956. Pleistocene invertebrates from Punta China, Baja California, Mexico, with remarks on the composition of the Pacific Coast Quaternary faunas: Am. Mus. Nat. History Bull. 111(4):315-342, text-fig. 1.
- EMERY, K. O. 1958. Shallow submerged marine terraces of southern California: Geol. Soc. America Bull. 69(1):39-60, 1 pl., text-figs. 1-13.
- . 1960. The sea off southern California: Wiley and Sons, New York, 366 p.
- FANALE, F. P. AND O. A. SCHAEFFER. 1965. Helium-uranium ratios for Pleistocene and Tertiary fossil aragonite: Science 149:312-317.
- GABB, W. M. 1869. Synopsis of the Tertiary invertebrate fossils of California: California Geol. Survey, Paleontology, v. 2, sec. 1, pt. 3, p. 65-124.
- GRANT, U.S., IV AND H. R. GALE. 1931. Catalogue of the marine Pliocene and Pleistocene Mollusca of California and adjacent regions: San Diego Soc. Nat. History Mem. 1:1-1036, pls. 1-32, text-figs. 1-15.
- HEDGPETH, J. W. 1957. Classification of marine environments, in Hedgpeth, J. W., ed., Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, v. 1:17-27, text-figs. 1-5.
- HUBBS, C. L. 1960. Quaternary paleoclimatology of the Pacific Coast of North America: California Coop. Fish. Inv. Repts. 7:105-112.
- INGLE, J. C., JR. 1967. Foraminiferal biofacies and the Miocene-Pliocene boundary in southern California: Bull. Amer. Paleo. 52:217-394, pls. 1-43, text-figs. 1-43.
- JORDAN, E. K. 1936. The Pleistocene fauna of Magdalena Bay, Lower California: Stanford Univ. Dept. Geology Contr. 1(4):1-173, pls. 1-3.
- KANAKOFF, G. P. AND W. K. EMERSON. 1959. Late Pleistocene invertebrates of the Newport Bay area, California: Los Angeles County Mus. Contr. Sci. 31:1-47, text-figs. 1-5.
- KENNEDY, G. L. 1975. Paleontologic record of areas adjacent to the Los Angeles and Long Beach harbors, Los Angeles County, California, in Soule, D. F., and Oguri, M., Marine studies of San Pedro Bay, California, pt. 9, Paleontology: Allan Hancock Foundation, Univ. Southern California, p. 1-119.
- KULP, J. L., L. E. TRYON, W. R. ECKLEMAN AND W. A. SNELL. 1952. Lamont natural radio-carbon measurements, II: Science 116:409-414.
- LIPPS, J. H. 1963. A new species of *Acmaea* (Archaeogastropoda) from the Pleistocene of San Nicolas Island, California: Los Angeles County Mus. Contr. Sci. 75:1-15, text-figs. 1-6.
- . 1967. Age and environment of a marine terrace fauna, San Clemente Island, California: Veliger 9(4):388-398, text-figs. 1-4.
- LIPPS, J. H., J. W. VALENTINE AND E. MITCHELL. 1968. Pleistocene paleoecology and biostratigraphy, Santa Barbara Island, California: Jour. Paleontology 42(2):291-307, text-figs. 1-7.
- MARINCOVICH, L. N., JR. 1970. Pleistocene molluscan faunas from upper terrace deposits of the Palos Verdes Hills, California: Univ. Southern California, Los Angeles, Dept. Geol. Sci., Unpub. MS thesis, 133 p.
- . 1971. Late Pleistocene mollusks from upper terrace deposits of the Palos Verdes Hills, California: Second Natl. Coastal Shallow Water Res. Conf., Abstract Vol., p. 149.
- POLAND, J. F. AND A. M. PIPER. 1956. Groundwater geology of the coastal zone, Long Beach-Santa Ana area, California: U.S. Geol. Survey Water Supply Paper 1109:1-161, text-figs. 1-2.

- STEVENSON, R. E., R. B. TIBBY AND D. S. GORSLINE. 1956. The oceanography of Santa Monica Bay, California: Univ. Southern California, Allan Hancock Found. Rept., p. 1-139, text-figs. 1-71.
- STRONG, A. M. 1923. Partial list of the molluscan fauna of Catalina Island: *Nautilus* 37(2):37-43.
- SVERDRUP, H. U., M. W. JOHNSON AND R. H. FLEMING. 1942. The oceans, their physics, chemistry and general biology: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1060 p.
- SZABO, B. J. AND J. N. ROSHOLT. 1969. Uranium-series dating of Pleistocene molluscan shells from southern California—an open system model: *Jour. Geophys. Research* 74(12): 3253-3260, fig. 1.
- SZABO, B. J. AND J. G. VEDDER. 1971. Uranium-series dating of some Pleistocene marine deposits in southern California: *Earth Planetary Sci. Letters* 11(4):283-290.
- TRASK, J. B. 1855. Report on the geology of the coast mountains: California Legislature, Assembly Jour. Appendix, 6th sess., State Doc. 14:1-95.
- VALENTINE, J. W. 1958. Late Pleistocene megafauna of Cayucos, California, and its zoogeographic significance: *Jour. Paleontology* 32(4):687-696, text-figs. 1-2.
- . 1961. Paleoecologic molluscan geography of the Californian Pleistocene: *Univ. California Pubs. Geol. Sci.* 34(7):309-442, text-figs. 1-16.
- . 1962. Older terrace faunas from Palos Verdes Hills, California: *Jour. Geology* 70(1):92-101, text-figs. 1-2.
- . 1966. Numerical analysis of marine molluscan ranges on the extratropical north-eastern Pacific shelf. *Limnology and Oceanography* 11(2):198-211, text-figs. 1-7.
- . 1967. The influence of climatic fluctuations on species diversity within the Tethyan provincial system, *in* Adams, C. G., and Ager, D. V., eds., *Aspects of Tethyan biogeography*: Systematics Assoc. Pub. 7:153-166, text-figs. 1-3.
- VALENTINE, J. W. AND J. H. LIPPS. 1963. Late Cenozoic rocky-shore assemblages from Anacapa Island, California: *Jour. Paleontology* 37(6):1292-1302, text-figs. 1-3.
- . 1967. Late Cenozoic history of the southern California islands, *in* Proc. Symposium on Biol. California Ids.: Santa Barbara Botanic Garden, p. 21-35, text-figs. 1-4.
- VALENTINE, J. W. AND R. F. MEADE. 1961. Californian Pleistocene paleotemperatures: *Univ. California Pubs. Geol. Sci.* 40(1):1-46, text-figs. 1-4.
- VEDDER, J. G. AND R. M. NORRIS. 1963. Geology of San Nicolas Island, California: U.S. Geol. Survey Prof. Paper 369:1-65, text-figs. 1-19.
- WAHRHAFTIG, C. AND J. H. BIRMAN. 1965. The Quaternary of the Pacific mountain system California, *in* Wright, H. E., Jr., and Grey, D. G., eds., *The Quaternary of the United States*, p. 299-340, text-figs. 1-12.
- WOODRING, W. P., M. N. BRAMLETTE AND W. S. W. KEW. 1946. Geology and paleontology of Palos Verdes Hills, California: U.S. Geol. Survey Prof. Paper 207:1-145, pls. 1-37, text-figs. 1-16.
- ZINSMEISTER, W. J. 1974. A new interpretation of thermally anomalous molluscan assemblages of the California Pleistocene: *Jour. Paleontology* 48(1):84-94, text-figs. 1-3.