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PALEONTOLOGY AND SIGNIFICANCE OF THE IMPERIAL FORMATION AT GARNET HILL, RIVERSIDE COUNTY, CALIFORNIA

by

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ABSTRACT

Mollusks in the Imperial Formation at Garnet Hill help define the paleogeography of the northern proto-Gulf of California during the late Miocene. Twenty-five invertebrate taxa, including 20 mollusks, four echinoids and a single arthropod are recognized from these deposits. Recovered fossils indicate an open-marine basin existed at, or near, the head of the proto-Gulf of California between about 8 and 6 Ma. Outcrops at Garnet Hill also extend the earliest occurrence of the bivalve *Pycnodonte? heermanni* (Conrad) from the early Pliocene to the late Miocene.

INTRODUCTION AND PREVIOUS WORK AT GARNET HILL

The Imperial Formation and its fauna are in a unique position to help resolve the early development, history, and paleogeography of the proto-Gulf of California in southern California and Baja California Norte. Unfortunately, most aspects of the Imperial Formation, from stratigraphy, to age, to paleoecology, are poorly understood making its relationship to other Neogene marine outcrops in the proto-Gulf of California difficult to interpret. Outcrops at Garnet Hill help to rectify this situation by constraining the age of local Imperial Formation outcrops and by beter defining the paleoenvironment of the northwestern portion of the proto-Gulf of California during the late Miocene. Other outcrops of the Imperial Formation in the northwestern part of the Salton Trough yield paleoecological information of the northern part of the basin during the late Miocene, while outcrops to the southeast represent the western portion of the basin and are younger in age.

An earlier informal division of the Imperial Formation (Powell, 1986, 1988) distinguished "northern" (Riverside County) and "southern" exposures (Imperial and San Diego Counties) (Fig. 1), based on differences in provenance of sediment, paleogeography in the proto-Gulf of California, age, and macrofauna. Outcrops from the "northern" exposures are considered Miocene in age (Powell, 1986, 1988; McDougall and others, 1994; Rymer and others, 1994) and include those at Cabazon (Lion Canyon area of Powell, 1985; 1986; 1988), Whitewater (Super Creek area of Powell, 1985; 1986; 1988), and Garnet Hill. Outcrops from the "southern" exposures are considered Pliocene in age (Mount, 1974; Johnson and others, 1983; Opdyke and others, 1977) and include those at Ocotillo Wells State Vehicle Recreation area [=San Felipe Hills of earlier reports (see Powell, 1993)], Supersitition Mountain, Fish Creek-Valecitos Wash area, southern Coyote Mountain, Yuha Buttes, and northern Cucupa Mountains, east of Mexicali, Mexico (Ingle, 1974). At least one exception to this north-south division is the Imperial Formation exposure at Willis Palms, where the fauna appear to be Pliocene (Powell, 1986).

Fossil were first reported from the Imperial Formation at Garnet Hill by Woodring (1931); recovered fossils included six bivalves and one echinoid from float along the south slope of the hill. He attributed the initial discovery to Richard Bramkamp (ca. 1935) who discussed the Imperial Formation in the San Gorgonio Pass - upper Coachella Valley area, but made only brief mention of outcrops at Garnet Hill. Proctor (1958, 1968) briefly mentioned the Imperial Formation at Garnet Hill in his study of the Desert Hot Springs quadrangle.

Rymer and others (1994) derived a lower limit for the age of the Imperial Formation at Garnet Hill by correlating an air-fall ash (reported by Proctor (1968) to be within the Imperial Formation, but now known to be below the Imperial Formation) with an ash bed exposed in the Ventura Basin. The ash bed in the Ventura Basin is dated by diatom biostratigraphy to between 8.0 and 7.6 Ma. This age determination is in general agreement with other radiometric age determinations (Peterson, 1975; Matti and others, 1985) and molluscan data (Powell, 1985;

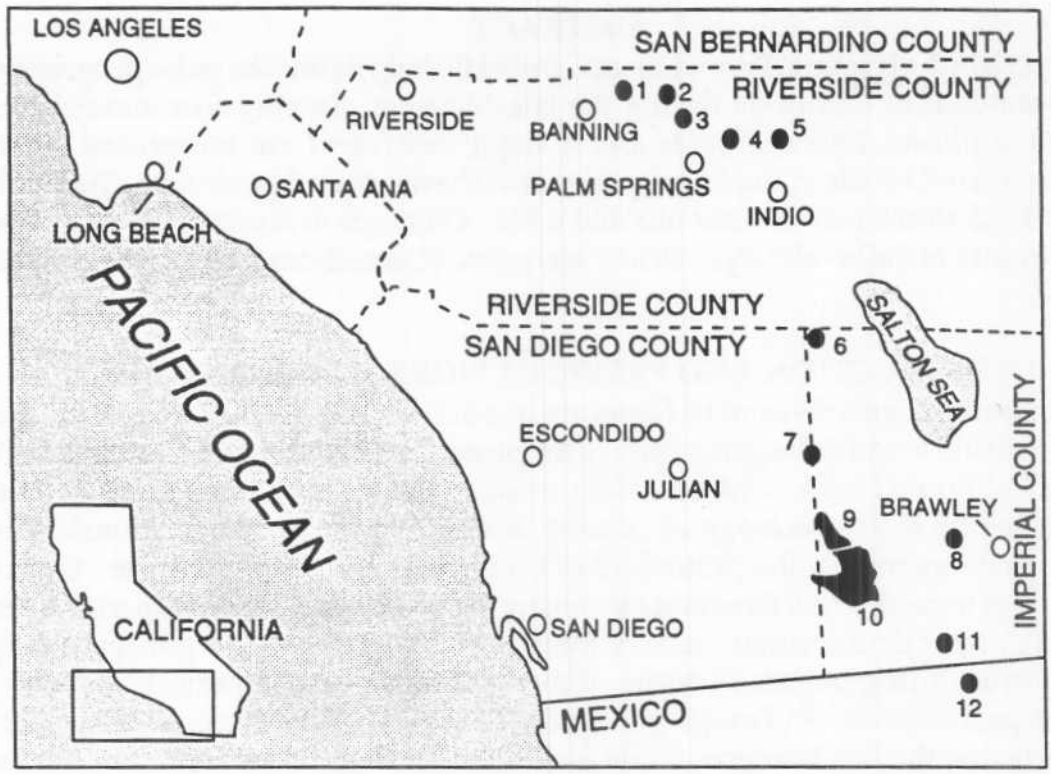

Figure 1.—Outcrops of Imperial Foramtion in southern California and Baja California Norte: 1-Cabazon; 2-Whitewater; 3-Garnet Hill; 4-Mt. Edom; 5-Willis Palm; 6-Travertine Point; 7-Ocotillo Wells State Vehicle Recreation area; 8-Supersitution Mountain; 9-Split Mountain-Vallecito Creek; 10-Coyote Mountain; 11-Yuha Buttes; 12-near Mexicali, Baja California Norte.

1986; 1988) for the Imperial Formation in Riverside County.

GEOLOGY AND STRATIGRAPHY OF THE IMPERIAL FORAMTION AT GARNET HILL

An understanding of the geology of Garnet Hill is hindered by limited exposures of the Imperial Formation and by abundant lag deposits that contaminate the few good exposures. In situ sediments of the Imperial Formation are preserved in two small sections with a maximum observable stratigraphic thickness of about 17 m (Powell, 1985, 1986), although a thicker section is presumably present under an extensive fanglomerate that overlies the Imperial Formation. Sediments of the Imperial Formation consist of white to light gray to very pale orange, moderately well cemented, poorly sorted, medium to fine grained sandstone with rounded- to well-rounded metamorphic pebbles to boulders (to 2 m). Some of these clasts contain lithopholad borings and/or attached oyster spats.

Proctor (1968) described two rock types from the Imperial Formation at Garnet Hill: an unfossilerous, friable white sandstone and varicolored, red to green, mudstone that contains an ash bed, and an upper, generally massive, whitish, fossiliferous sandstone. Powell (1986) removed the lower rock types from the Imperial Formation because these beds are dissimilar to other Imperial Formation outcrops in southern California and because of their probable nonmarine origin. Microfossils commonly abundant in the Imperial Formation are absent in the lower rock types (E. Brouwers personal communication, 1989) which appear to represent lacustrine and fluvial deposition.

AGE AND CORRELATION OF THE IMPERIAL FORMATION AT GARNET HILL

Age control for exposures of the Imperial Formation at Garnet Hill comes from radiometric dating and tephrochronology. A K-Ar age of about 6 Ma (Matti and others, 1985; Matti and Morton, 1993; Figure 2) in the Painted Hill Formation above the Imperial Formation and another from the Coachella Fanglomerate below the Imperial Formation of about 10 Ma (Peterson, 1975; Figure 2) indicates a late Miocene age for the Imperial Formation at Whitewater. At Garnet Hill a tephra correlation suggests a age between 8.0 and 7.6 Ma for strata below the Imperial Formation (Rymer and others, 1994). Taken together the Imperial Formation in Riverside County appears to be between 8.0 Ma and 6.0 Ma (Rymer and others, 1994).

The occurrance of the bivalve mollusks *Chlamys corteziana* (Durham), *Flabellipecten* n. sp.?, and *Myrakeena angelica* (Rocheburne), record their oldest occurrence in the Miocene part of the Imperial Formation at Garnet Hill and Whitewater (Powell, 1986, 1988). *Dendostrea vespertina* (Conrad) has been reported elsewhere in California from late Miocene deposits (Addicott and Galehouse, 1973; Stanton, 1966) and also occurs at Garnet Hill and Whitewater. These taxa suggest a correlation between the Garnet Hill and Whitewater outcrops and support the late Miocene age. An interesting note is the occurrence of *Pycnodonte? heermanni* (Conrad) which records its oldest occurrence at Garnet Hill.

FAUNAL COMPOSITION AND PALEOECOLOGY

Faunal composition and preservation

On Garnet Hill eighty percent (20 taxa) of the fauna are mollusks, with 76% (19 taxa) bivalves and 4% (1 taxa) gastropods (Table 1), echinoderms make up about 16% (4 taxa) and arthropods about 4% (1 taxon). In comparison, mollusks compose 91% of the fauna at Travertine Point, Imperial County, with bivalves representing about 70%, gastropods 21%; echinoderms about 7% and corals about 2% (C. Powell, II, unpublished data) although the Travertine Point fauna is nearly half again as large (43 taxa).

Preservation of fossils from Garnet Hill is very poor. As is common in the Imperial Formation throughout southern California, pectinids, oysters and echinoderms show better preservation than other mollusks. This may be because their shells are composed mostly of calcite, as opposed to aragonite in most other mollusk taxa. Calcitic shells are commonly collected as float while other taxa are found as internal molds which are easily eroded.

Paleoecology

Water depth-*Myrakeen angelica* (Rocheburne) is the only taxa for which modern depth data is available and is reported from water depths of 1 to 5 m (Bernard, 1983). This taxon indicates intertidal to shallow subtidal water depths for the deposits at Garnet Hill. This depth determination is supported by the occurrence of oyster spats which commonly settle at or near the high-water mark and can be found in lines around boulders at Garnet Hill.

Substrate-Many of the taxa occur attached to rocks and/or other hard substrate (i.e., *Dendostrea? vespertina* (Conrad), *Spondylus* sp. and the Patellacean gastropod). Others commonly occur in sandy sediments (i.e., *Euvola* sp., *Turritella* sp., and *Clypeaster* sp.). Taken together with the geology of the outcrops at Garnet Hill it appears to represent a sandy beach to shallow subtidal environment with common well rounded rocks, an environment common to the Gulf of California today.

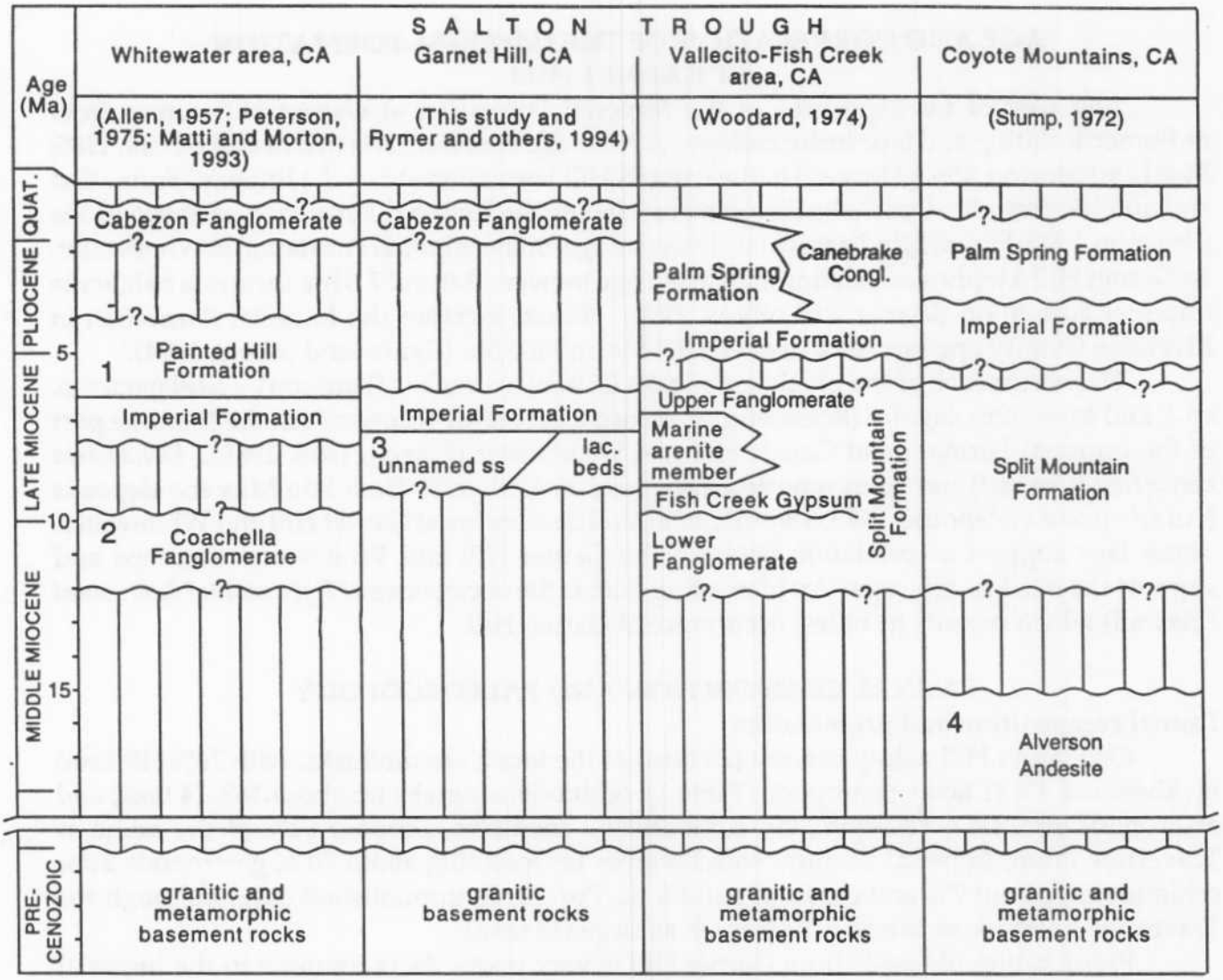

Figure 2.—Correlation chart of the Imperial and related formations at selected sites in the Salton Trough. This charts shows the age difference between the "northern" and "southern" outcrops of the Imperial Formation. Large numbers indicate age determinations: 1- about 6 Ma (Matti and others, 1985); 2-about 10 Ma (Peterson, 1975); 3- between 8 Ma and 7.6 Ma (Rymer and others, 1994); 4- between 24.8 Ma and about 15 Ma (Ruisaard, 1979).

CONCLUSIONS

Fossils and outcrops of the Imperial Formation at Garnet Hill help to develop a better understanding of the age, paleogeography, and paleoecology of the proto-Gulf of California in southern California. First, the dated ash bed below the Imperial Formation helps to refine the lower age limit of the formation in Riverside County to between 8 and 6 Ma. Second, sediments show that the Imperial Formation represents a sandy beach environment with scattered rocks and open marine conditions. This is an environment not previously recognized from the Imperial Formation in Riverside County and only questionably reported from Imperial County. Lastly, the occurrence of *Pycnodonte? heermanni* (Conrad) at Garnet Hill extends its lower stratigraphic datum from early Pliocene to late Miocene.

TABLE 1.—Garnet Hill faunal list. Taxa cited by Woodring (1931) are listed in the last column and most have been confirmed in collection from the California Institute of Technology (CIT 196) now at the Los Angeles County Museum of Natural History.

TAXA/LOCALITY	M9016	M9018	M9857	M9858	M9859	M9860	WOODRING 1932 CIT 196
MOLLUSCA							
BIVALVIA							
Argopecten? sp. indet. -	x	-	-	-	-	x	probably as *"Pecten" purpuratus mendenhalli* Arnold?
Cardiidae indet.	-	-	-	-	x	-	-
Chlamys? corteziana Durham?	-	-	-	-	-	-	as *"Pecten"* cf. *sanctiludovici* Anderson and Martin
Dendostrea? vespertina (Conrad)	-	-	-	-	x	x	-
Euvola ? sp. indet. and/or *Flabellipecten*? sp. indet.	-	-	?	?	-	-	-
Flabellipecten n. sp.?	x	-	-	-	x	x	probably as *Pecten carrizoensis* Arnold
Lima sp. indet.	-	-	-	x	-	-	-
Lithophaginae indet.	x	x	-	-	-	-	-
Lucinidae indet.	-	-	-	-	?	-	-
Lyropecten? sp. indet.	x	-	x	-	-	x	-
Myrakeena angelica (Rocheburne)	-	-	x	x	x	-	-
Mytilidae indet.	-	-	-	-	x	-	-
"Oyster" indet.	-	-	x	-	x	x	-
Pectinidae indet.	-	-	x	2 forms	x	x	x
Pinnidae indet.-	-	-	-	x	-	-	-
Pycnodonte? heermanni (Conrad)	x	x	x	-	x	x	-
Spondylus sp. indet.	x	-	x	-	-	x	x
Ungulinidae indet.	-	-	-	-	x	-	-
indet. bivalves	-	-	-	x	x	-	-
GASTROPODA							
Patellacea indet.	-	-	-	-	x	-	-
ARTHROPODA							
Balanus? sp.	-	-	-	-	-	x	-
ECHINOIDERMATA							
ECHINOIDEA							
Clypeaster sp. indet.	-	-	-	-	-	-	x
Eucidaris cf. *E. thousarsii* (Valenciennes)	-	-	-	x	x	-	-
indet test fragment	-	-	-	-	-	-	x
indet. sand dollar	-	-	-	-	-	-	x

TAXONOMY

Phylum: Mollusca

Class: Bivalvia

Mytilidae

A single, poorly preserved, interior mold is referred to this family as its shape resembles the genus *Mytilus*.

Lithophaginae

The occurrence of this family is based on the long, tear-drop shaped borings found in limestone clasts. Lithophaginae borings are distinguished from pholadid borings by their much more elongate shape (G. Kennedy, 1985, personal communication).

Pinnidae

This family is reported from a single poorly-preserved internal mold which has an outline similar to both *Atrina* and *Pinna*. Distinguishing features that differentiate the two genera are not present on the available specimen.

Pectinidae

Woodring (1931) reported *Pecten carrizoensis* Arnold, *"Pecten" purpuratus mendenhalli* Arnold?, *"Pecten"* cf. *sanctiludovici* Anderson and Martin, and indeterminate *"Pecten"* from Garnet Hill. During the present study five distinct Pectinid taxa were recovered at Garnet Hill, although most specimens are fragmentary and cannot be identified with precision.

Woodring's citation of *Pecten carrizoensis* Arnold is equated here to *Euvola?* sp., *Flabellipecten?* sp., and *Flabellipecten* n. sp.? *Flabellipecten carrizoensis* (Arnold) (=*Pecten carrizoensis* Arnold) is similar to *F.* n. sp.? but is easily distinguished in having only 18 to 19 ribs on the right valve which are commonly medially sulcate, while *F.* n. sp.? has 23 to 26 ribs which are seldom medially sulcate. Specimens referred to *Euvola?* sp. and *Flabellipecten?* sp. in this study are flat, left valves which are so fragmentary that they cannot be identified with certainty. Left valves of both genera are so similar they can only be differentiated with well-preserved material. Specimens of *Flabellipecten* n. sp.? occur at both Whitewater and Garnet Hill, and are very similar to *Flabellipecten bosei* (Hanna and Hertlein). *Flabellipecten* n. sp.? has 22 to 25 ribs on the right valve and an apical angle of between 95° and 105°, which is similar to the 24 to 25 ribs and apical angle of 100° reported for *F. bosei* (Hanna and Hertlein). The major distinction between the two taxa comes in the left valve: *F.* n. sp.? from Whitewater have 17 to 19 radial ribs counted on the exterior of the left valve, specimens from Garnet Hill have 15 to 17 counted on the interior of the valve (due to presentation of the valve in the rock) while specimens of *F. bosei* (Hanna and Hertlein) have 24 to 25 radial ribs on the left valve. *Flabellipecten* n. sp.? is thereby distinguished from *F. bosei* (Hanna and Hertlein) by the greater number of ribs on the left valve. A problem arises in that no articulate specimens were collected at Garnet Hill and it is possible that the left valves collected are from a species different from *F.* n. sp.? This seems unlikely, however, because of the large number of both valves collected with no other forms present.

Woodring also reported *Argopecten mendenhalli* (Arnold) (=*"Pecten" purpuratus mendenhalli* Arnold of Woodring, 1931) and *Chlamys corteziana* Durham (=*"Pecten"* cf. *P. sanctiludovici* Anderson and Martin of Woodring, 1931) from Garnet Hill. No specimens referable to *Argopecten mendenhalli* (Arnold) were collected during the present study and Woodring's specimens could not be located. Specimens referable to *Argopecten*? sp. recovered during the present study consists of very small fragments which are distinguished from other Pectinid taxa in having "tent"-shaped ribs with narrow interspaces. These specimens are suggestive of *Argopecten mendenhalli* (Arnold) which was questionably reported from the nearby Whitewater section (Powell, 1986, 1988). *Chlamys? corteziana* Durham is questionably reported from Garnet Hill on the basis of valve fragments which have fine beading that is lacking on other similar taxa.

In addition to the species reported by Woodring, two distinct taxa were recovered: one is questionably assigned to the genus *Lyropecten*, the other is distinct but no genus could be found that matches the fragmentary material available. The genus *Lyropecten?* is represented by a number of fragments, including auricles, which show distinct, large ribs with three to nine riblets and very fine, concentric wavy ridges making a distinct microsculpture. One right auricle is preserved which shows four distinct radial ribs with about equal interspaces, followed by an interspace twice the width of the ribs and again followed by 2 radial ribs and interspaces as before. The last Pectinid is represented by one shell fragment and several

internal molds some of which have shell material attached which show the interior of the valves. This species is moderately thick, large (possibly up to 6 cm height) with very narrow radial ribs that number more than 20 with interspaces that are twice the width of the ribs.

Gryphaeidae

Pycnodonte? heermanni (Conrad) is a common constituent of the Garnet Hill fauna and was reported by Woodring (1931). It occurs as valves and fragments which are eroded from the Imperial Formation on the south slope of the hill. It is easily recognized by its large, thick shell with variable plications and a broad, well-developed hinge. Its presence at Garnet Hill records the oldest occurrence of this taxa. Other occurrences are from the Pliocene portion of the Salton Trough in southern California and Baja California Norte.

Ostreidae

Two oysters are reported from Garnet Hill, the most common and best identified is *Myrakeena angelica* (Rocheburne). *Myrakeena angelica* (Rocheburne) is distinguished from *Dendostrea? vespertina* (Conrad), which questionably occurs at Garnet Hill, by its larger size, more rounded outline, numerous shallow plication, smaller attachment area and short, small ridges which occur on the interior valve margin perpendicular to the margin.

Spondylidae

Fragments attributed to *Spondylus* sp. indet. are moderately common as float on the south slope of Garnet Hill. These specimens show sculpture similar to *S. victoriae* Sowerby fide Durham (1950) which occurs at Whitewater. They are not assigned to that species because of their fragmentary nature.

Limiodae

One internal mold and a few shell fragments are questionably assigned to the genus *Lima*. This is based on the general outline and size of the internal mold which is nearly identical to specimens of *Lima* sp. cf. *L. caribaea* (d'Orbigny) collected at Whitewater.

Lucinidae

A poorly preserved internal mold is questionably referred to this family based on its round outline and regular, fine concentric sculpture.

Ungulinidae

Several internal molds are questionably referred to this family based on their rounded outline and strongly inflated valves. These molds are similar in size and shape to *Timothynus* n. sp. reported from the Whitewater area (Powell, 1986).

Cardiidae

A few small internal molds are questionably assigned to this family based on their shape and strong radial sculpture. These specimens are very small and rounded in outline. They are somewhat similar to *Americardium* spp. reported from Whitewater (Powell, 1986) and Travertine Point (Powell, unpublished data) outcrops.

Class: Gastropoda

Patellacea

An internal mold of a single limpet was found during the present study, but cannot be assigned to family as it lacks shell structure. The general outline is similar to *Discurria insessa* (Hinds) which occurs in the Pliocene to Holocene of coastal Baja California north to Alaska. But it is unlikely to be that species because Lindberg (1988, 1991) suggests that the patellogastropod taxon Scurriini (which contains the genus *Discurria*) migrated from the southern hemisphere sometime during the Pliocene.

Phylum: Arthropoda
Class: Crustacea

Three small barnacles, tentatively assigned to *Balanus?* sp. are preserved from the surface of a *Flabellipecten* valve.

Phylum: Echinodermata
Class: Echinodea

Several fragments of a large test of *Clypeaster,* collected as float from Garnet Hill (Bramkamp, ca. 1935; Woodring, 1931), are to fragmentary to assign to species. The genus is common elsewhere in the Imperial Formation with three known species. A small test fragment easily distinguished from *Clypeaster* by its pore arrangement also was collected from Garnet Hill. Finally the regular echinoid, *Eucidaris* cf. *E. thousarsii* (Valenciennes) is represented by several large spines (to about 2 cm long) collected both in situ and as float.

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APPENDIX - LOCALITES

USGS Cenozoic Localities, Menlo Park register

M9016 (Field No.: IH027A) (=M9859) - In situ outcrop of the Imperial Formation at about 210 m elevation in second small canyon east of road which transverses Garnet Hill from the northwest to the southeast, Riverside County, California. Collected by M. Rymer.

M9018 (No field number) (=M9857) - Float collected from south-southwest slope of Garnet Hill, Riverside County, California. Collected by M. Rymer.

M9857 (Field No.: CP42194A) (=M9018) - Float collected on the south slope of Garnet Hill, Riverside County, California. Collected by Charles Powell, II, Mike Rymer and Louie Marincovich, Jr., April, 1994.

M9858 (Field No.: CP42194B) - Float collected on the south-southwest slope of Garnet Hill, Riverside County, California. Collected by Charles Powell, II, Mike Rymer and Louie Marincovich, Jr., April, 1994.

M9859 (Field Nos.: CP42194C, CP42294C) (=M9016) - In situ outcrop of the Imperial Formation at about 210 m elevation in second small canyon east of road which transverses Garnet Hill from the northwest to the southeast, Garnet Hill, Riverside County, California. Collected by Charles Powell, II, Mike Rymer and Louie Marincovich, Jr., April, 1994.