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Additions to the Late Paleocene Molluscan Fauna from the Santa Monica Mountains, Los Angeles County, Southern California

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Abstract. Several previously unreported shallow-marine, warm-water gastropods and bivalves from the upper part of the Santa Susana Formation, east–central Santa Monica Mountains, Los Angeles County, southern California, are described and discussed. The gastropods are *Diodora* sp. nov.? (Fissurellidae) and *Terebralia* ***susana*** sp. nov. (Potamididae). The bivalves are *Solena* (*Eosolen*) *stantoni* (Weaver, 1905) (Solenidae), *Martesia* sp. (Pholadidae), and *Nototeredo*(?) sp. (Teredinidae). These mollusks are of late Paleocene (Thanetian Stage) age. For the Pacific Coast of North America, the specimens of *Diodora* and *Martesia* represent the earliest records, the specimens of *Terebralia* the first confirmed record, and the specimens of *Nototeredo*(?) the first record. The specimens of *Solena* (*Eosolen*) *stantoni* are the best preserved and largest of this species.

INTRODUCTION

The late Paleocene was a time of a large influx of migrant shallow-marine mollusks into the Pacific Coast region of North America via circum-global tropical circulation, and this influx continued on into the early Eocene (Zinsmeister, 1983a; Squires, 1988). Upper Paleocene marine rocks are uncommon on the Pacific Coast of North America but are well represented in the Palisades Highlands area in the east-central Santa Monica Mountains, southern California (Figure 1). Although natural outcrops are scarce due to extensive vegetative cover, shallow-marine mollusks have been found locally, particularly in new exposures temporarily uncovered by bulldozer activity during the construction of homesites. Most of the specimens of rare and previously unreported mollusks that are the focus of this paper were collected during the past 15 years by J. M. Alderson and W. L. Rader, who donated them to local museums. These mollusks are the gastropods *Diodora* sp. nov.? and *Terebralia* ***susana*** sp. nov., and the bivalves *Solena* (*Eosolen*) *stantoni* (Weaver, 1905), *Martesia* sp., and *Nototeredo*(?) sp.

The following institutional acronyms are used: CSUN, California State University, Department of Geological Sciences, Northridge; LACMIP, Natural History Museum of Los Angeles County, Section of Invertebrate Paleontology, Los Angeles; and UWBM, University of Washington, Thomas Burke Memorial Museum, Seattle.

STRATIGRAPHY

The mollusks discussed in this report were collected from the area east of Santa Ynez Canyon, in the tributaries of Quarry Canyon, Trailer Canyon, Pulga Canyon, and other unnamed tributaries (Figure 1). All the localities plot within the upper part of the Santa Susana Formation as mapped by Dibblee (1992). Colburn et al. (1988) and Colburn (1996) assigned the Paleocene rocks here to the Santa Susana Formation, in its broad sense, although other recent workers (e.g., Saul, 1983; Strathearn et al., 1988) referred to them as the Coal Canyon Formation of Yerkes & Campbell (1979).

The upper part of the Santa Susana Formation in the Santa Ynez Canyon area is a marine unit consisting mostly of olive to gray-green, fine-grained sandstone and siltstone, which are bluish gray when unweathered. Megafossils are either in thin lenses or scattered throughout the beds. Within the upper part of the formation there are outcrops of coralline-algal limestone, which are white and resistant. These might represent a single stratigraphic unit that is present in minor fault blocks and/or landslide blocks, or they might represent multiple units of similar lithology. Previous geologic studies in the area have failed to clarify the stratigraphic relationships. Colburn et al. (1988), in a study of the Santa Susana Formation in the Santa Monica Mountains, considered the algal limestone to make up a single 10 m-thick marker bed in the formation. Strathearn et al. (1988) reported several lenses of algal limestone. Mack (1993) reported that the algal limestones (10 to 30 m thick) apparently represent several stratigraphic levels. Strathearn et al. (1988) and Mack (1993), however, grouped all of the algal limestones into a single stratigraphic unit in their generalized stratigraphic columns.

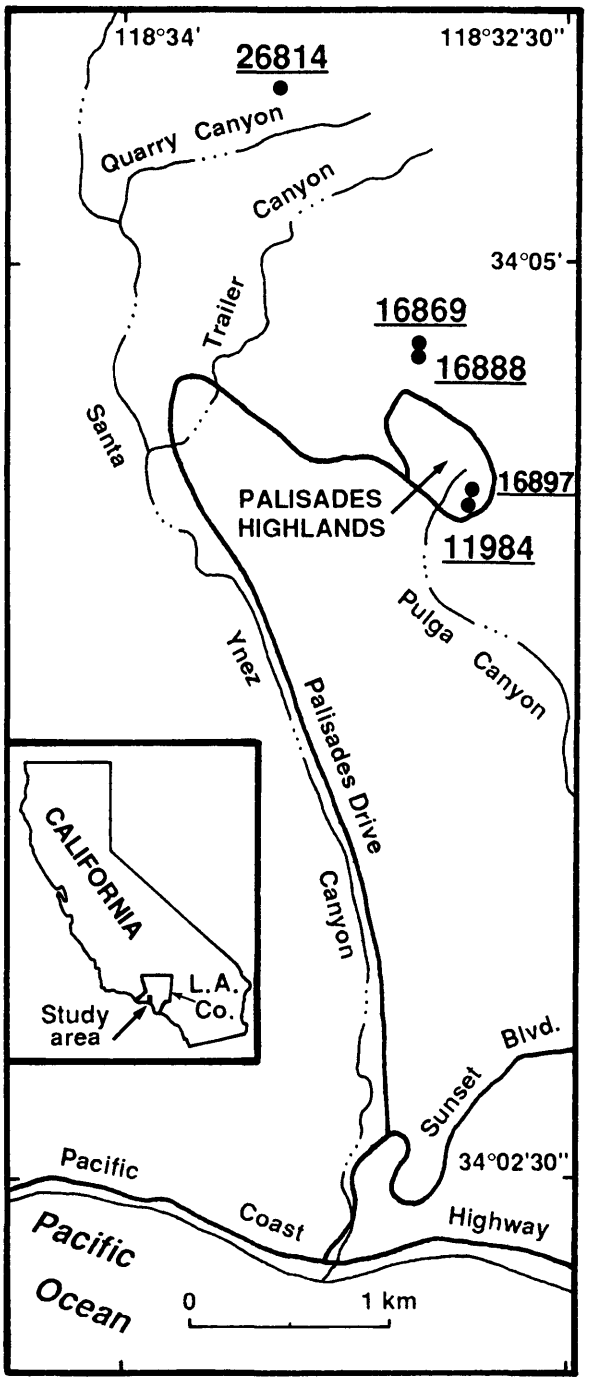


Figure 1

Index map showing LACMIP collecting localities in the upper Santa Susana Formation, Palisades Highlands and vicinity, east–central Santa Monica Mountains, Los Angeles County, southern California. Base map from Dibblee (1992).

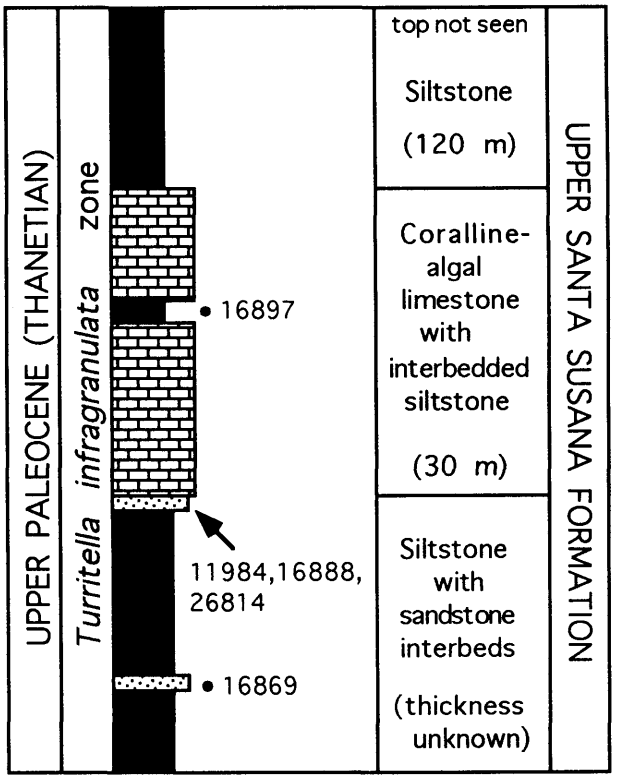


Figure 2

Generalized columnar section showing relative stratigraphic positions of the cited megafossil localities in the upper Santa Susana Formation in the Palisades Highlands and vicinity, east-central part of the Santa Monica Mountains, southern California.

Recent reconnaissance work by the senior author to resolve the algal-limestone problem in the immediate study area was uninformative because all of the outcrops had been obliterated by extensive housing-tract development. Pending future information, it seems best to refer to the algal limestone(s) as the "algal-limestone interval." Although the exact stratigraphic position of this interval is not known because structural complications make it impossible to identify the upper contact of the Santa Susana Formation, the interval is approximately 120 m below the stratigraphically highest outcrops of the Santa Susana Formation in the area (Mack, 1993).

The mollusks described in this report were collected from rocks stratigraphically near or within the algal-limestone interval, and their positions are shown in Figure 2. The pholadid bivalve *Martesia* sp. and the teredinid bivalve *Nototeredo*(?) sp. are from a richly fossiliferous lens within the gray-green very fine-grained sandstone at LACMIP loc. 16869 (Figures 1,2). This lens is approximately 20 m below the algal-limestone interval. The fauna at this locality is much more diverse than those from other units and yielded numerous specimens of the bi-

valves *Cucullaea mathewsonii* Gabb, 1864, *Crassatella unioides* (Stanton, 1896), *Saulella undulifera* (Gabb, 1869), and *Pholadomya* (*P.*) *nasuta* Gabb, 1864, and the gastropods *Turritella infragranulata* Gabb, 1864, and various species of naticids. A few small specimens of the solenid bivalve *Solena* (*Eosolen*) *stantoni* were also present.

The two gastropods treated herein are from fine-grained sandstone immediately subjacent to the algal limestone and are from slightly higher in the stratigraphic section than where *Martesia* and *Nototeredo* were found. Most of the specimens of the fissurellid gastropod *Diodora* sp. nov.? were found at LACMIP loc. 16888. One other specimen of *Diodora* sp. nov.? was found at LACMIP loc. 11984, and a single specimen of the potamidid gastropod *Terebralia* ***susana*** sp. nov. was found at LACMIP loc. 26814 in the Quarry Canyon area and below an algal limestone that Dibblee (1992) mapped as the only algal limestone in that area. This specimen of *Terebralia* ***susana*** is somewhat worn.

The largest and best preserved specimens of the solenid bivalve *Solena* (*Eosolen*) *stantoni* are from gray-green muddy silstone in the upper Pulga Canyon area at LACMIP loc. 16897. This siltstone appears to be a major interbed within the algal-limestone interval and, if so, would be slightly higher stratigraphically than the other discussed mollusks. Unfortunately, there have been no detailed stratigraphic sections in the critical area of upper Pulga Canyon where Dibblee's (1992) geologic map shows four vertically stacked lenses of algal limestone with intervening, mostly fine-grained siliciclastic units that dip consistently to the southwest. This is the only area where there are more than two vertically stacked outcrops of algal limestone, and this is the area where there has been extensive housing-tract construction since about 1988. The homes now make up the Summit and Enclave communities of Palisades Highlands in the city of Los Angeles. The siltstone at LACMIP loc. 16897 might represent a landslide or fault block and is from the same stratigraphic level as LACMIP loc. 16869. The siltstone at locality 16987, however, is muddier and has yielded a less diverse megafauna. In this paper, the siltstone at locality 16897, where the large *S.* (*E.*) *stantoni* specimens were found, will be considered tentatively as being within the algal-limestone interval.

The fossils in the muddy siltstone at LACMIP loc. 16897 are in poorly defined lentils containing bivalves and some gastropods. Three specimens of *S.* (*E.*) *stantoni* were found. Their valves are open and positioned next to each other in parallel fashion, with the anterior and posterior ends matching each other ("butterflied"). The specimens also lie parallel to the original bedding. Other bivalves here include *Nuculana* sp., a thin-shelled *Ostrea* sp., and *Venericardia* sp. Some of these bivalves are complete and are partially to completely closed, whereas others are unbroken single valves. Gastropods are represented by a few large specimens of *Turritella infragranulata* Gabb, 1864, (very near to *T. i. pachecoensis* Stanton, 1896, fide L. R. Saul, personal communication) and some small specimens of *Tornatellaea pinguis* (Gabb, 1864).

DEPOSITIONAL ENVIRONMENT

Colburn et al. (1988) and Colburn (1996) concluded that the upper part of the Santa Susana Formation in the Santa Ynez Canyon area was deposited in a low-energy protected bay, no deeper than 40 m, with the bay situated behind a barrier bar. They based their conclusion on the following: condition of the megafossils, fine grain size of the deposits, presence of well-developed horizontal laminae within the deposits, and lack of sedimentary structures associated with strong wave or current action. Their megafossil evidence consists of articulated bivalve shells, both adult and juvenile specimens of the same species, and absence of both preferred orientation and current-size sorting of the shells. They also concluded that branching calcareous algae developed shoals on the bay floor.

Strathearn et al. (1988) concluded that the upper part of the Santa Susana Formation in the Santa Ynez Canyon area accumulated in an unrestricted, muddy, middle-shelf environment near or below storm-wave base and no deeper than 70 m. They based their conclusions on the taxonomic composition of the dinoflagellates and benthic foraminifera in the deposits, as well as on the predominantly non-transported condition of the megafossils. They also concluded the algal limestones, which formed when there was interruption of the deposition of the terrigenous siliciclastics, represent *in situ* buildups in subtropical to tropical waters of about 20 m depth.

A relatively low-energy depositional environment is in keeping with the presence of complete and unabraded bivalves found associated with the bivalves treated herein. This is especially true for the "butterflied" condition of most of the specimens of *Solena* (*Eosolen*) *stantoni* found in siltstone at LACMIP loc. 16897 within the algal-limestone interval. Although "butterflied" specimens of bivalves can be transported, the distance of post-mortem transport cannot be great and the water cannot be too agitated; otherwise the valves will break apart. Modern solenids have a mostly tropical distribution and live from the intertidal zone to depths of 60–110 m; most species are found just below the low-water mark in the lower part of the intertidal zone or in shallow inner sublittoral depths (20–30 m) on the shelf. Some species live in coralline-algal sediment, whereas others live around mangroves (Von Cosel, 1990).

The other bivalves treated herein are not all that useful in paleoenvironmental studies. *Martesia* and *Nototeredo* are wood borers that live today in tropical to temperate seas (Turner, 1966; Cvancara, 1966, 1970). Their presence does not necessarily indicate proximity to land because drift wood can disperse widely in oceanic settings.

The two gastropods treated herein, and which were found immediately subjacent to algal limestone, belong to genera that one might expect to have lived in tropical to subtropical shallow-marine waters in the vicinity of algal-carbonate buildups. *Diodora*, a herbivorous gastropod that requires a hard substrate, is widespread today, ranging from cool-temperate to tropical waters. Along the Pacific Coast of North America only *D. aspera* (Rathke, 1833) lives north of California, and it is usually found intertidally on wave-swept rocky habitats. In California, *D. aspera* and *D. arnoldi* McLean, 1966, live subtidally (McLean, 1978). Species of *Diodora* show a greater diversity in the warmer waters of the Gulf of California to Peru, where they usually live in shallow subtidal settings (Keen, 1971). The specimens of *Diodora* found in the Santa Susana Formation are complete and do not show any signs of abrasion due to post-mortem transport.

Modern species of *Terebralia* are restricted to circumtropical regions that extend from eastern Africa to the western Pacific Ocean. They usually live in great numbers on fine substrate in brackish water on coastal mudflats in mangrove regions. Some specimens live on the roots of mangroves, and others live on intertidal sand and rocky habitats throughout the salt-marsh environment. Specimens can also be found in tidal channels, where they appear to have been washed in from adjacent environments (Houbrick, 1991). *Terebralia sulcata* Born, 1778, from throughout the western Pacific, is a hardy generalist and able to tolerate a wide range of substrate types and diet, with algae being one of its food sources. It can live in protected bays from which mangroves are absent (Houbrick, 1991). The single specimen of *Terebralia* found in the Santa Susana Formation is somewhat worn, indicating some post-mortem transport.

Another habitat-distinctive gastropod found just below algal limestone in the study area is *Campanile greenellum* Hanna & Hertlein, 1939, reported from the Santa Ynez Canyon area (i.e., Quarry Canyon and Trailer Canyon) by Squires (1993). *Campanile* is a primarily Old World Tethyan genus that is indicative of warm waters and very shallow depths.

AGE

Biostratigraphic age assignments for the Santa Susana Formation in the Santa Ynez Canyon area have previously relied upon mollusks, even though the megafauna is incompletely known. Early collections of mollusks were assigned to the Eocene (*sensu lato*) by Hoots (1931), but that was before the Paleocene Epoch was a formally recognized time interval. These "Eocene" mollusks are now widely regarded as mostly late Paleocene in age (e.g., Saul, 1983; Strathearn et al., 1988; Colburn et al., 1988; Dibblee, 1992). Saul (1983:fig. 8) restricted the algal limestones in the Coal Canyon Formation [= the Santa Susana Formation of herein] to the upper Paleocene *Turritella infragranulata* Zone, which is correlative to the European Thanetian Stage. The *T. infragranulata* Zone also corresponds to the Standard Planktonic Foraminferal Zone P4 (Saul, 1983) and to the upper part of the provincial "Martinez Stage" (Saul, 1983).

Our work also supports a late Paleocene age for the upper part of the Santa Susana Formation in the Santa Ynez Canyon area. The most useful locality in the study area for geologic age control is LACMIP loc. 16869, approximately 20 m downsection from the algal limestone (Figure 2). In addition to *Turritella infragranulata*, other age-diagnostic mollusks found at this locality include the gastropods *Prisoficus caudatus* (Gabb, 1869) and *Fulgoraria* (*Psephaea*) *zinsmeisteri* Mount, 1976, as well as the bivalves *Cucullaea mathewsonii, Crassatella unioides, Saulella undulifera,* and *Pholadomya* (*P.*) *nasuta*. These species are among the most characteristic species found in upper Paleocene rocks along the Pacific Coast of North America (Dickerson, 1914; Mount, 1976; Zinsmeister, 1983a; and Saul, 1983).

Most of the specimens of *Diodora* sp. nov.? were found at LACMIP loc. 16888, immediately below the algal limestone. The gastropod *Campanile greenellum* was also found at this locality, and it is confined to upper Paleocene rocks elsewhere in California (Squires, 1993).

At LACMIP loc. 11984, where a specimen of *Diodora* sp. nov.? was found immediately below the algal limestone, a fragmentary specimen of either a late form of *Turritella infragranulata pachecoensis* or an early form of *Turritella infragranulata* sensu stricto was found. At LACMIP loc. 16897, where specimens of *Solena* (*Eosolen*) *stantoni* were found in the middle of the algal-limestone interval (Figure 2), this same turritellid is also present. This turritellid indicates a late Paleocene (middle Thanetian) age (L. R. Saul, personal communication). The bivalve *Solena* (*Eosolen*) *stantoni* also indicates this age, as it is found elsewhere in California in rocks of late Paleocene age (Weaver, 1905; Dickerson, 1914; Zinsmeister, 1983a). This present study, therefore, shows that all the available megafossil evidence indicates that mollusks found near and immediately associated with algal limestones are late Paleocene in age.

Benthic foraminiferal, dinoflagellate, and pollen studies of the Santa Susana Formation in the study area have yielded conflicting geochronologic results. Mack (1993) reported benthic foraminifers that indicated the entire algal-limestone interval to be upper Paleocene, although the overlying rocks in the Santa Susana Formation might also range into the lower Eocene. Mack (1993) and Mack & Colburn (1993) reported also that benthic foraminifers indicate the Paleocene/Eocene boundary to be within the algal-limestone interval but did not discuss their reasoning.

Strathearn et al. (1988), based on dinoflagellate and pollen studies, suggested that the Paleocene-Eocene boundary might be several meters below the algal-lime-

stone interval, but this determination was based on a single genus of fungal spore, whose geologic range is somewhat open to question and primarily based on specimens in nonmarine outcrops in the continental interior. If Strathearn et al. (1988), Mack (1993), and Mack & Colburn (1993) are correct, then the molluscan fauna in the algal limestone and younger parts of the Santa Susana Formation in the Santa Ynez Canyon area should contain species found in the provincial molluscan "Meganos Stage" that overlies the upper Paleocene "Martinez Stage." There is no molluscan evidence to support this conclusion. The molluscan fauna associated with the algal limestones in the Santa Ynez Canyon area is unlike that from "Meganos Stage" strata in the upper part of the Santa Susana Formation on both the north and south sides of Simi Valley, 27 km northwest of the Santa Monica Mountains (Squires, 1991).

Strathearn et al. (1988:table 3) also reported the gastropod *Mesalia clarki* (Dickerson, 1914) in rocks they considered to be within the lower Eocene part of the Santa Susana Formation in the Trailer Canyon area (Figure 1). A study of the collections at LACMIP revealed this species to be in strata immediately below, and possibly within, the single algal-limestone exposure mapped in this area by Dibblee (1992). *Mesalia clarki* was known previously only from its type locality in the upper Paleocene Martinez Formation on the north side of Mount Diablo, northern California.

In summary, the age of the molluscan fauna discussed herein is considered to be late Paleocene (Thanetian). There is no molluscan evidence, nor is there any compelling microfossil evidence, to support a younger, early Eocene age for the Santa Susana Formation in the eastern Santa Monica Mountains.

SYSTEMATIC PALEONTOLOGY

Class GASTROPODA Cuvier, 1797

Order VETIGASTROPODA Salvini-Plawén, 1980

Family FISSURELLIDAE Fleming, 1822

Genus *Diodora* Gray, 1821

Type species: *Patella apertura* Montagu, 1803 [= *Patella graeca* Linnaeus, 1758], by original designation; Recent, British Isles.

Diodora sp. nov.?

(Figures 3–5)

Description: Shell medium in size (up to 3.4 cm in length and 5 mm in height), profile low, height about one-sixth of length, base flat, aperture oval. Apex situated slightly anterior to middle of shell. Anterior slope slightly steeper than posterior slope. Perforation moderately large, just anterior of apex, anterior end of perforation rounded, posterior end narrower. Interior apertural callus truncate posteriorly. Sculpture shown on internal mold consists of numerous closely spaced, equal strength primary radial ribs originating at apex; ribs slightly stronger near ventral margin. Stronger radial ribs alternate with slightly weaker ones on posterior slope. Concentric ornamentation weak, imparting a minute cancellate pattern on shell.

Distribution: Upper part of Santa Susana Formation, Pulga Canyon area, east-central Santa Monica Mountains (LACMIP locs. 11984 and 16888).

Geologic age: Late Paleocene (Thanetian).

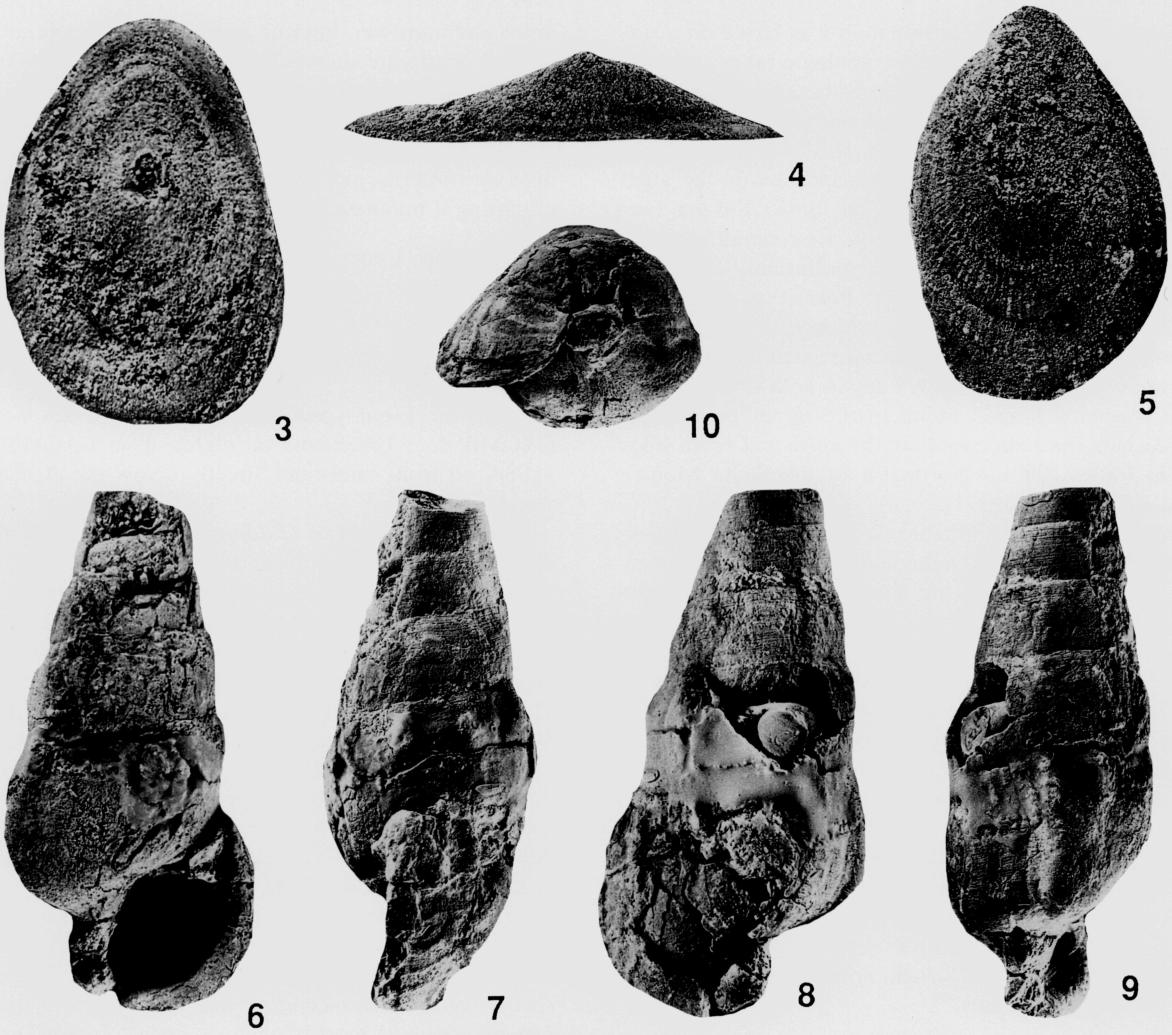
Discussion: Eight specimens were found, seven from LACMIP loc. 16888 and an eighth from LACMIP loc. 11984, all from sandstone directly below the algal limestone.

All the specimens of *Diodora* sp. nov.? are essentially internal molds of complete individuals, but they have taken on the impression of external ornamentation, and thus are functional casts. Although the specimens probably represent a new species, their poor preservation prevents confirmation of such. Only one specimen (Figure 3) shows evidence of the truncate internal callus that is diagnostic of *Diodora*.

The specimens of *Diodora* sp. nov.? from the upper Santa Susana Formation represent the earliest known specimens of *Diodora* from the Pacific Coast of North America. The genus has been reported from Paleocene and Eocene rocks in the eastern and southeastern United States (Palmer & Brann, 1966). Wenz (1938) and Keen (1960) reported the geologic range of *Diodora* to be Late Cretaceous to Recent. Sohl (1992) noted that Cretaceous species of so-called *Diodora* are very rare and that the generic status of most of them is open to question. Two of the earliest known species that can be assigned positively to *Diodora* are from Upper Cretaceous (Maastrichtian Stage) strata, from Puerto Rico and Jamaica (Sohl, 1992).

The Santa Susana Formation specimens most closely resemble specimens of *Diodora* sp. aff. *D. stillwaterensis* (Weaver & Palmer, 1922) of Squires & Deméré (1991: figs. 3A, B) from the middle Eocene ("Transition Stage") Friars Formation in San Diego County, southern California, but differs in having fewer primary radial ribs and in having secondary radial ribs on the posterior slope.

Only two Paleogene species of *Diodora* have been described from the Pacific Coast of North America. One is *Diodora stillwaterensis* (Weaver & Palmer, 1922:27, pl. 11, figs. 3, 6; Weaver, 1942 [1943]:284, pl. 63, fig. 20; pl. 64, figs. 4, 7, 12), from the Cowlitz Formation of Lewis and Cowlitz Counties in western Washington, which Nesbitt (1995) has assigned to the upper middle Eocene. The Santa Susana Formation specimens differ from *D. stillwaterensis* by having a larger shell, a lower profile, secondary radial ribs confined to the posterior re-



Explanation of Figures 3 to 10

All specimens coated with ammonium chloride. Figures 3–5. *Diodora* sp. nov.?, LACMIP loc. 16888. Figures 3–4. LACMIP hypotype 7940, length 33.2 mm, height 5 mm. Figure 3. dorsal view of internal mold, ×1.6. Figure 4. left-lateral view of internal mold, ×1.7. Figure 5. LACMIP hypotype 7941, length 26.9 mm, dorsal view of internal mold, ×1.9. Figures 6–10. *Terebralia* ***susana*** Squires & Kennedy, sp. nov., LACMIP holotype 7942, LACMIP loc. 26814, length 65 mm (incomplete), width 31.7 mm, ×1.1, low-level lighting used to show subdued sculpture. Figure 6. apertural view. Figure 7. right-lateral view. Figure 8. apertural view. Figure 9. left-lateral view. Figure 10. anterior view.

gion, and lack of tertiary radial ribs. Comparison with the holotype (UWBM 194) of *D. stillwaterensis* is not possible because the specimen is missing (R. C. Eng, personal communication).

The second Paleogene *Diodora* is *D. batequensis* Squires & Demetrion (1994:127, 129, figs. 3–6) from the middle lower Eocene ("Capay Stage") part of the Bateque Formation in the eastern Laguna San Ignacio area of Baja California Sur, Mexico (Squires & Demetrion, 1994). The Santa Susana Formation specimens differ from *D. batequensis* by having a larger shell, a lower profile, many fewer and much weaker primary radial ribs, secondary ribs confined to posterior region, a lack of tertiary radial ribs, and weaker concentric sculpture.

Squires & Goedert (1994a: 15, fig. 28) reported poorly preserved internal molds of *Diodora* sp. indet. from sandstone interbedded with basalt flows in the middle lower Eocene ("Capay Stage") part of the upper Crescent Formation in the Little River area, southwestern Washington. Similarly poorly preserved specimens of *Diodora* sp. indet. are also present in coralline algae-rich sandstone interbedded with basalt flows at CSUN loc. 1563 in the upper Crescent Formation at Larch Mountain, Black