

J. Paleont., 70(1), 1996, pp. 63-73
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0022-3360/96/0070-0063\$03.00

LATE EOCENE CHEMOSYNTHETIC? BIVALVES FROM SUSPECT COLD SEEPS, WAGONWHEEL MOUNTAIN, CENTRAL CALIFORNIA

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ABSTRACT—An anomalous pair of small, isolated calcareous sandstone bodies in the middle member of the upper Eocene Wagonwheel Formation, Wagonwheel Mountain, of the San Joaquin Valley, California, contain numerous articulated specimens of soft-bottom-dwelling bivalves. The lucinid bivalve *Epilucina washingtoniana* (Clark, 1925) dominates the fauna, which also sparingly contains the thyasirid bivalve *Conchocele bisecta* (Conrad, 1849) and the vesicomylid bivalve *Vesicomya* (*Vesicomya*) aff. *V. (V.) tschudi* Olsson, 1931.

The fossils in the pair of calcareous sandstone bodies, which are surrounded by deep-water silty mudstone barren of megafossils, most likely represent cold-seep communities in the upper bathyal environment. These cold seeps apparently were formed by diffusive flow through coarse sand-fill material in submarine channels.

Epilucina washingtoniana was previously known only from upper Eocene rocks on the Olympic Peninsula, Washington, and in Santa Barbara County, southern California. This species, along with a late Eocene species from Colombia, South America, are the earliest representatives of *Epilucina*. The Wagonwheel Formation contains one of the earliest records of *Conchocele bisecta*, which is a widespread Cenozoic fossil and is extant in the north Pacific. The species of *Vesicomya* in the Wagonwheel Formation is the earliest record of *Vesicomya* s.s. and has close affinity to *Vesicomya* (*Vesicomya*) *tschudi* Olsson, 1931, from the upper Oligocene of northwestern Peru, South America. As in the case of *Conchocele bisecta*, *Vesicomya* s.s. has not been reported previously from the Eocene of California.

INTRODUCTION

THE PURPOSE of this paper is to describe the molluscan fauna in a pair of anomalous calcareous sandstone bodies rich in lucinid bivalves isolated in the middle part of the Wagonwheel Formation on the west side of Wagonwheel Mountain [=Hannah Hills of early workers], Devils Den district, west side of the San Joaquin Valley, northwest corner of Kern County, southern California (Figure 1). The taxonomic composition of this fauna received only cursory study by a few early workers, and there is little agreement as to species identification (Arnold and Johnson, 1910; Van Couvering and Allen, 1943; Smith, 1956). Only Smith (1956) offered paleoenvironmental comments about this fauna, and he concluded that it was of deep-water origin. An ancillary purpose of this present report is to offer comments about the depositional environment of the calcareous sandstone bodies.

Abbreviations used for catalog and/or locality numbers are: CSUN, California State University, Northridge; LACM, Natural History Museum of Los Angeles County, Malacology Section; LACMIP, Natural History Museum of Los Angeles County, Invertebrate Paleontology Section; MCZ, Harvard Museum of Comparative Zoology; PRI, Paleontological Research Institution, Ithaca, New York; SU, Stanford University (collections

now housed at the California Academy of Sciences, San Francisco); UCMP, University of California Museum of Paleontology (Berkeley); USNM, United States National Museum of Natural History, Washington, D.C.; UWBM, University of Washington (Seattle), Thomas Burke Memorial Washington State Museum (=UW in older literature). The specimens illustrated in this report have been deposited at LACMIP, and the other specimens used in this study are stored at CSUN.

Systematic arrangement of the subgenera and higher taxonomic categories used herein follows that of Coan et al. (in press).

STRATIGRAPHY

The areal extent of the Wagonwheel Formation, which was named by Johnson (1909), is limited. The entire area of outcrop is no more than 3.6 km long and 0.4 km wide. Smith (1956) divided the 143 m-thick formation into three members (Figure 2). The pair of isolated bodies of bivalve-rich calcareous sandstone that are the subject of this present paper are enclosed in silty mudstone in the lower part of the middle member and are about 20 m above the top of the lower member, which is a gray, nearly structureless, well-sorted medium sandstone. The pair of sandstone bodies are anomalous because they contain megafossils and are calcareous. Elsewhere on Wagonwheel Mountain, the silty mudstone in the middle member is barren of megafossils and is argillaceous. The small bodies of calcareous sand-

¹ Deceased.

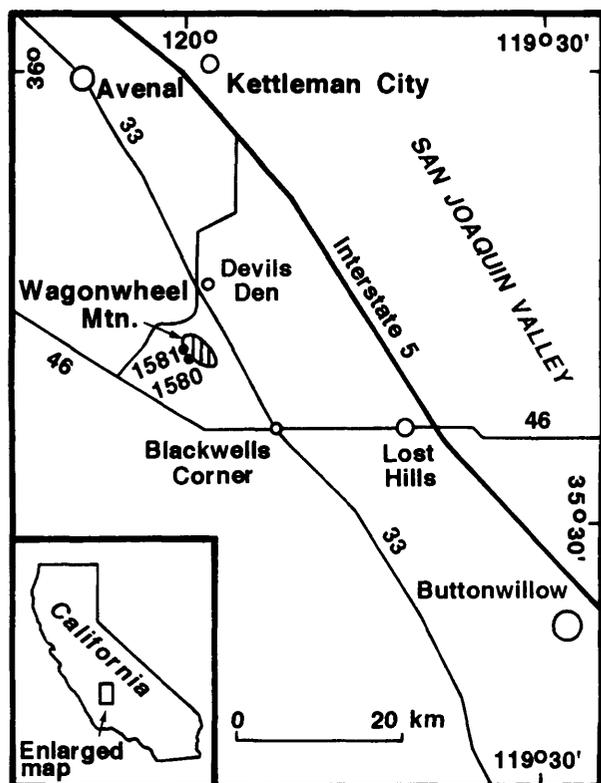


FIGURE 1—Index map to CSUN localities at Wagonwheel Mountain, central California.

stone crop out along the same stratigraphic horizon and are 200 m apart laterally, at CSUN locs. 1580 and 1581. Because of their resistance to weathering, they cap small hills, and the silty mudstone that underlies them is nearly all covered by slope wash. Between the calcareous sandstone bodies, there are three distinct beds of moderately resistant muddy siltstone that seem to be truncated near the calcareous sandstone bodies. Slope wash covers the areas where these three beds and the calcareous sandstone bodies are in contact. Just south of CSUN loc. 1580, there is another muddy siltstone bed that also seems to be truncated near the calcareous sandstone body.

The calcareous sandstone bodies are each about 20 m in lateral extent and consist of closely spaced, triple-stacked discontinuous massive units separated by thin intervals of silty mudstone. At locality 1580, the lower and middle units are both 1.5 m thick, and the upper unit is 1 m thick. At locality 1581, the lower unit is 3.5 m thick, the middle unit is 3 m thick, and the upper unit is 4 m thick. The triple-stacked units are gray-white to orange-brown, calcitic, poorly sorted, subangular, fine to coarse sandstones with abundant bivalves. The amount of calcareous matrix is usually 10 to 15 percent of the rock, but it can be high enough as to locally constitute a sandy limestone. The amount of matrix can vary considerably within a single hand specimen. There are rare large pebbles of black quartzite, up to 2 cm in length. At a few places in the lower part of the calcareous sandstone body at CSUN loc. 1580, there are wavy-banded layers of cement and rip-up clasts (9 cm in length) of cross-bedded sandy limestone.

The calcareous sandstone at both localities is bioturbated, especially at CSUN loc. 1581, where distinct unlined straight and "Y"-shaped horizontal and oblique burrows are present.

The bioturbation seems to be related to the mottled coloration present throughout the calcareous sandstone at CSUN loc. 1581 and at the base of the calcareous sandstone at CSUN loc. 1580.

The calcareous sandstone bodies vary in the amount of fossils. The fossils are dominated by the lucinid bivalve *Epilucina washingtoniana* (Clark, 1925), but there are scattered specimens of the bivalves *Conchocele bisecta* (Conrad, 1849) and *Vesicomya* (*Vesicomya*) aff. *V. (V.) tschudi* Olsson, 1931. The richest concentration of bivalves is at CSUN loc. 1580 in the upper part of the calcareous sandstone body where dense patches of *E. washingtoniana* make up 30 percent of the rock and are closely packed in random orientation (Figure 3). Nearly all the specimens are articulated and many are large in size, up to about 6 cm in length. The specimens are not broken or abraded and are not covered by encrusting organisms. In the same rich concentration are specimens of *C. bisecta*, which are also nearly all articulated, randomly oriented, and mostly large in size (up to 6 cm in length). Specimens of the small-sized *Vesicomya* (*Vesicomya*) aff. *V. (V.) tschudi* are most abundant in dense patches where the lithology is a sandy limestone rather than a calcareous sandstone. These patches are in the uppermost part of the calcareous sandstone body at CSUN loc. 1580 and in the middle part of the calcareous sandstone body at CSUN loc. 1581, and the specimens were found at both places associated with juvenile specimens of *C. bisecta*.

Preservation of bivalves is mostly poor. The calcareous sandstone is so well indurated that much effort is required to obtain specimens, when pounding the rock, a petroliferous odor is usually noticeable. Some specimens of *Epilucina washingtoniana* show shell alteration with portions of the surface sculpture difficult to discern because of dissolution or chalkiness. Many of these specimens are casts.

The only other megafossils found in the calcareous sandstone bodies are two fragments of oyster, two internal molds of gastropods (a naticid and a buccinid?), and a few small clusters of vertical serpulid worm tubes; all were found at CSUN loc. 1581. The oysters were found in the lower part of this calcareous sandstone body.

AGE

Except for the calcareous sandstone bodies, the Wagonwheel Formation is barren in terms of megafossils. Microfossils, however, are abundant in the middle member, and starting about 14 m stratigraphically above the cold-seep communities there are calcareous nannofossils indicative of the uppermost Eocene CP15b Zone of Okada and Bukry (1980) and benthic foraminifers indicative of the upper Eocene Refugian Stage of Schenck and Kleinpell (1936) (A. A. Almgren, personal commun.) (Figure 2). Using benthic foraminifers, Smith (1956) and Tipton (1980) also placed the lower part of the middle siltstone member of the Wagonwheel Formation in the Refugian Stage. Bartow (1991) also assigned the Wagonwheel Formation to the Refugian Stage.

Epilucina washingtoniana is the only age-diagnostic member of the megafauna. As will be discussed below in the "Systematic Paleontology" section, it has been found before only in upper Eocene rocks in Washington and southern California.

The age of the calcareous sandstone bodies in the middle member of the Wagonwheel Formation is contemporaneous with the late Eocene Bear River and Menlo cold-seep communities in the Lincoln Creek Formation (or its temporal equivalents) in southwestern Washington (Goedert and Squires, 1990) and the late Eocene Vernonia-Timber Road cold-seep community in the Keasey Formation in northwestern Oregon (Campbell and Bottjer, 1993; Nesbitt et al., 1994).

DEPOSITIONAL ENVIRONMENT

The taxonomic composition and low diversity (almost monospecific) of the megafauna, as well as the dense concentration of articulated lucinid, thyasirid, and vesicomimid bivalves in isolated and anomalous carbonate-bearing deposits that have a petroliferous odor, are very similar to modern-day and Cenozoic examples of chemosynthetic communities associated with cool-fluid seepage (Callender and Powell, 1992; Campbell and Bottjer, 1993). Hickman (1994) listed literature concerning the discovery of chemosymbiosis in lucinid and thyasirid bivalves. Based on present knowledge, family Vesicomymidae is a rare taxon found in the deep sea, and the small number of known living species shelter chemosynthetic symbiotic bacteria in their thick and large gills (Turner, 1985).

Epilucina has not been reported from cold-seep environments, but the closely related genera *Lucina* and *Nymphalucina* are known from ancient cold seeps (Gaillard et al., 1992; Campbell and Bottjer, 1993). *Thyasira*, which is very closely related to *Conchocele*, and *Vesicomyma*, as well as vertical tubes of serpulid worms similar to those found in the calcareous sandstone bodies in the Wagonwheel Formation, are among the key indicators of both modern (Kennicutt et al., 1985; Mayer et al., 1988) and ancient (Goedert and Squires, 1990; Campbell and Bottjer, 1993) cold-seep environments.

The Wagonwheel Formation calcareous sandstone bodies also have the main taphonomic characteristics associated with autochthonous assemblages reported by Callender and Powell (1992) for modern cold seeps. These characteristics are the dominance of large individuals, presence of dense patches of fossils, random shell orientation, and shells that show little evidence of abrasion, fragmentation, or biological alteration. The high articulation frequency of the bivalves in the Wagonwheel Formation deposits and the absence of encrusting organisms indicate rapid burial and short residence times on the ocean floor.

Ancient cold-seep communities in the rock record of the western margin of North America range in age from latest Jurassic to middle Pliocene (Goedert and Squires, 1990; Campbell, 1992, 1995; Campbell et al., 1993; Campbell and Bottjer, 1993; Goedert and Squires, 1993; Goedert and Campbell, 1995), and the Tertiary examples are associated with "core taxa" that usually consist of one or more of the bivalves *Modiolus*, *Solemya* or *Acharax*, *Calyplogena*, *Thyasira*, and *Lucina* or *Lucinoma* (Goedert and Squires, 1990; Campbell and Bottjer, 1993; Campbell, 1995), abundant "worm" tubes, "archaeogastropods," and possibly the gastropod *Provanna* and chitons (Squires and Goedert, 1991; Squires, 1995a; Squires, 1995b).

Campbell (1995), in her comprehensive review of ancient cold seeps in the rock record of this region, reported that there is a continuum of chemosynthetic-related deposits that contain "core" taxa. This continuum ranges from active fluid-flow seeps to diffusive ("leaky") fluid-flow seeps to reduced-sediment (non-seep) deposits. The Wagonwheel Formation calcareous sandstone bodies, with their "core" taxa of potential chemosynthetic bivalves, seem to fit the parameters of cold seeps associated with diffusive fluid flow. The studied bodies are small sandstone lenses with moderate amounts of carbonate. They are not like the active fluid-flow seeps that have positive-relief calcareous mounds, large-scale structural conduits (e.g., faults, veins, diapirs, shear zones), small-scale fluid-flow conduits (e.g., chimneys, pipes, doughnuts), and extensive vuggy, laminated, or brecciated fabrics. Furthermore, the study area bodies are not like reduced-sediment deposits that have no carbonates. A stable-carbon isotope study of the Wagonwheel Formation calcareous sandstone bodies could confirm an authigenic methane influence during the sedimentation of the bodies. In order for

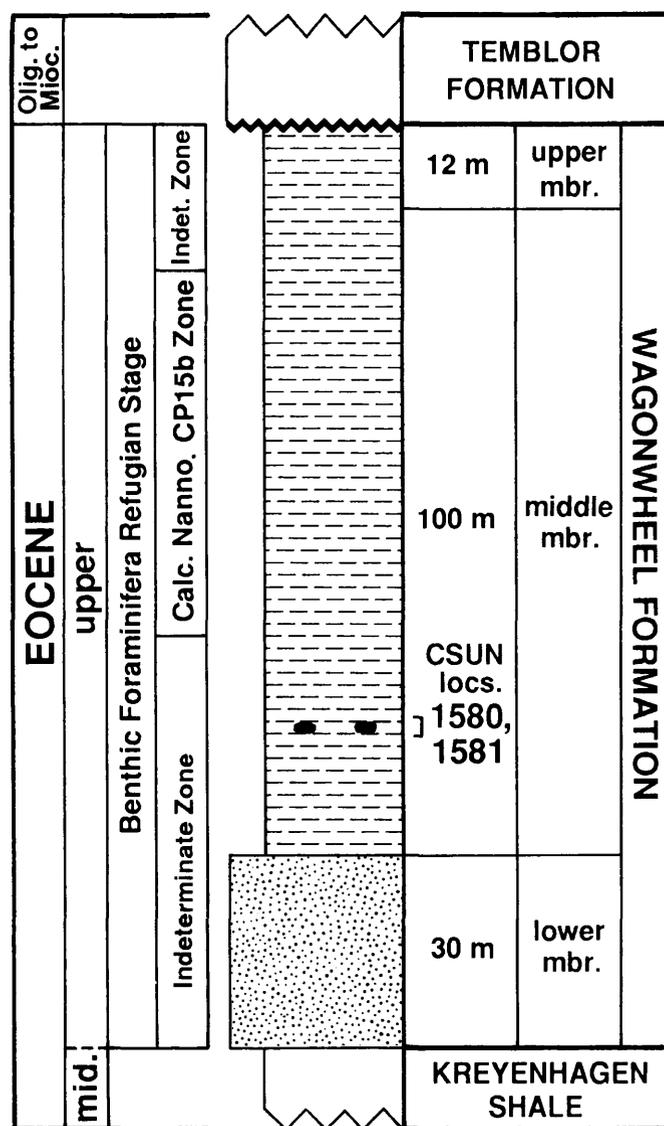


FIGURE 2—Stratigraphic section of the Wagonwheel Formation, Wagonwheel Mountain. Lithologies indicated by standard symbols.

the carbon-isotope signature to be unaffected by weathering, it will be necessary to obtain fresh rock samples by means of coring. Pending future detailed geochemical and sedimentologic studies, it seems most reasonable to infer that the pair of calcareous sandstone bodies in the Wagonwheel Formation are "suspect cold seeps" that formed by diffusive fluid flow.

Based on a detailed study of benthic foraminifers, Smith (1956) reported that the middle siltstone member of the Wagonwheel Formation formed in depths that fluctuated near the line of demarcation between the continental shelf and slope (the upper reaches of the bathyal environment). Also on the basis of benthic foraminifers, A. A. Almgren (personal commun.) assigned the entire Wagonwheel Formation to the middle bathyal environment. The abrupt change in lithology along strike from silty mudstone to calcareous sandstone, twice over a lateral distance of 200 m, and apparent truncation of the underlying and laterally adjacent silty mudstone suggest that the calcareous sandstone bodies are submarine-channel deposits that filled channels approximately 20 m wide and 4 to 10 m deep that were cut into



FIGURE 3—Outcrop of a portion of the Wagonwheel Formation cold-seep community at CSUN loc. 1580 showing the abundance of articulated and randomly oriented specimens of *Epilucina washingtoniana*. View is from the side. Hammer is 32.6 cm in length.

the underlying muddy deposits. The scattered pebbles, rip-clasts, and oyster fragments in the lower part of the calcareous sandstone body at CSUN loc. 1580 represent coarse, transported, fill material along the axis of one of the submarine channels. In keeping with the benthic foraminiferal data, the location of the submarine channels was at the shelf-break, between neritic and bathyal environments. These submarine channels could have served as conduits for the movement of organic-rich connate waters compacted out of the surrounding muds and silts. The opportunistic chemosynthetic bivalves could have penecontemporaneously established soft-bottom communities in the localized sandy areas where the porosity was highest and fluid flow strongest. Campbell (1992) recognized a diffuse (“leaky”) fluid flow associated with middle Pliocene cold seeps in the Quinault Formation, western Washington.

The lucinid *Nymphalucina occidentalis* (Morton, 1842), which is the dominant megafossil in cold-seep massive limestone bodies (“teepee buttes”) described by Howe and Kauffman (1986), closely resembles *Epilucina washingtoniana* in morphology. Gaillard et al. (1992, figure 7b) illustrated a specimen of *N. occidentalis* from the “teepee buttes,” which he referred to as “pseudobioherms.” The Wagonwheel Formation cold-seep communities also strongly resemble the limestone “teepee buttes” in terms of dimensions, stacking of the highly fossiliferous deposits, enclosure in monotonous fine-grained strata barren of megafossils, and high content of articulated and closely spaced infaunal lucinid bivalves. The Wagonwheel Formation cold seeps differ from the “teepee buttes” in the presence of sand and the absence of an extensive vuggy texture filled or partially filled with fibrous cement linings, and the absence of vertically elongated pipes.

Olsson (1931) reported an isolated exposure (concretionary-like in form) of cherty limestone of Oligocene? age in the Lomitos Formation, northwestern Peru, South America, where abundant specimens of thyasirids were found associated with

lucinids, vesicomyids, and solemyids, as well as a few other mollusks. The taxonomic composition of the megafauna, the abundance of bivalves, and their localization in a concretionary like limestone suggests that the Lomitos Formation locality may be another ancient chemosynthetic community. The vesicomyid specimens in the Wagonwheel Formation have close affinity to *Vesicozyma* (*Vesicomya*) cf. *V. (V.) tshudi* Olsson, 1931, one of the species in the Lomitos Formation locality. Olsson (1931) also reported that the isolated exposure of the above-mentioned cherty limestone might actually belong in the Talara Formation. Marsaglia and Carozzi (1990) assigned the Talara Formation to the middle Eocene.

Honda (1989) reported two localities in the lower upper Oligocene Omagari Formation in Japan where abundant specimens of *Conchocele bisecta* are present in closely packed groups in very fine-grained sandstone. No other mollusks were found. Kanno (1971a) reported that specimens of *C. bisecta* from the upper Eocene or lower Oligocene Poronai Formation in Japan are associated with a vesicomyid bivalve in a biohermal deposit; both types of bivalves are present in closely packed patches of articulated specimens representing all growth stages. The density of the bivalves and their taxonomic composition imply that both of these occurrences may be related to ancient chemosynthetic communities.

No definite cause-and-effect relations can be established, but it could be that regional tectonic activity was related somehow to the development of the suspect cold seeps in the Wagonwheel Formation. The development of these suspect cold-seeps coincided with a possible change reported by Bartow (1991) from an oblique to a normal angle of subduction along the west side of San Joaquin Valley near the end of the Eocene. Also possibly associated with this change in subduction angle was the emplacement of the Franciscan wedge under the San Joaquin Valley, and this emplacement might also be related to cold-seep activity.

SYSTEMATIC PALEONTOLOGY

Class BIVALVIA Linné, 1758

Order VENEROIDA H. Adams and A. Adams, 1856

Family LUCINIDAE Fleming, 1828

Subfamily LUCININAE Fleming, 1828

Genus EPILUCINA Dall, 1901

Type species.—*Lucina californica* Conrad, 1837, by original designation, Recent, California.

Epilucina washingtoniana (Clark, 1925)

Figure 4.1–4.4

Phacoides n. sp. aff. *californica* Conrad. ARNOLD AND JOHNSON, 1910, p. 41. *Corbis washingtoniana* CLARK, 1925, p. 90, pl. 20, figs. 1–4, Pl. 21, figs. 1, 2; WEAVER, 1942 [1943], p. 152–153, pl. 37, figs. 1, 3; DURHAM, 1944, p. 144. WEAVER AND KLEINPELL, 1963, p. 201, pl. 33, figs. 10, 11.

Lucina inflata Wagner & Schilling. VAN COUVERING AND ALLEN, 1943, fig. 211.

Lucina aff. *L. diegoensis* Dickerson. SMITH, 1956, p. 77.

Lucina (*Myrtea*) aff. *L. diegoensis* Dickerson. WEAVER AND KLEINPELL, 1963, p. 200–201, pl. 33, fig. 6 [not 8].

Codakia (*Epilucina*) *washingtoniana* (Clark). SQUIRES, 1990, p. 553–554.

Discussion.—At both localities (CSUN 1580 and 1581), specimens are almost always articulated and range from 3 to 5 cm in height and 3 to 6 cm in length.

Specimens of *Epilucina washingtoniana* from the Wagonwheel Formation show some variation in the outline of the posterior end, which can be moderately truncate to abruptly truncate. Although the lunule is not observable on most spec-

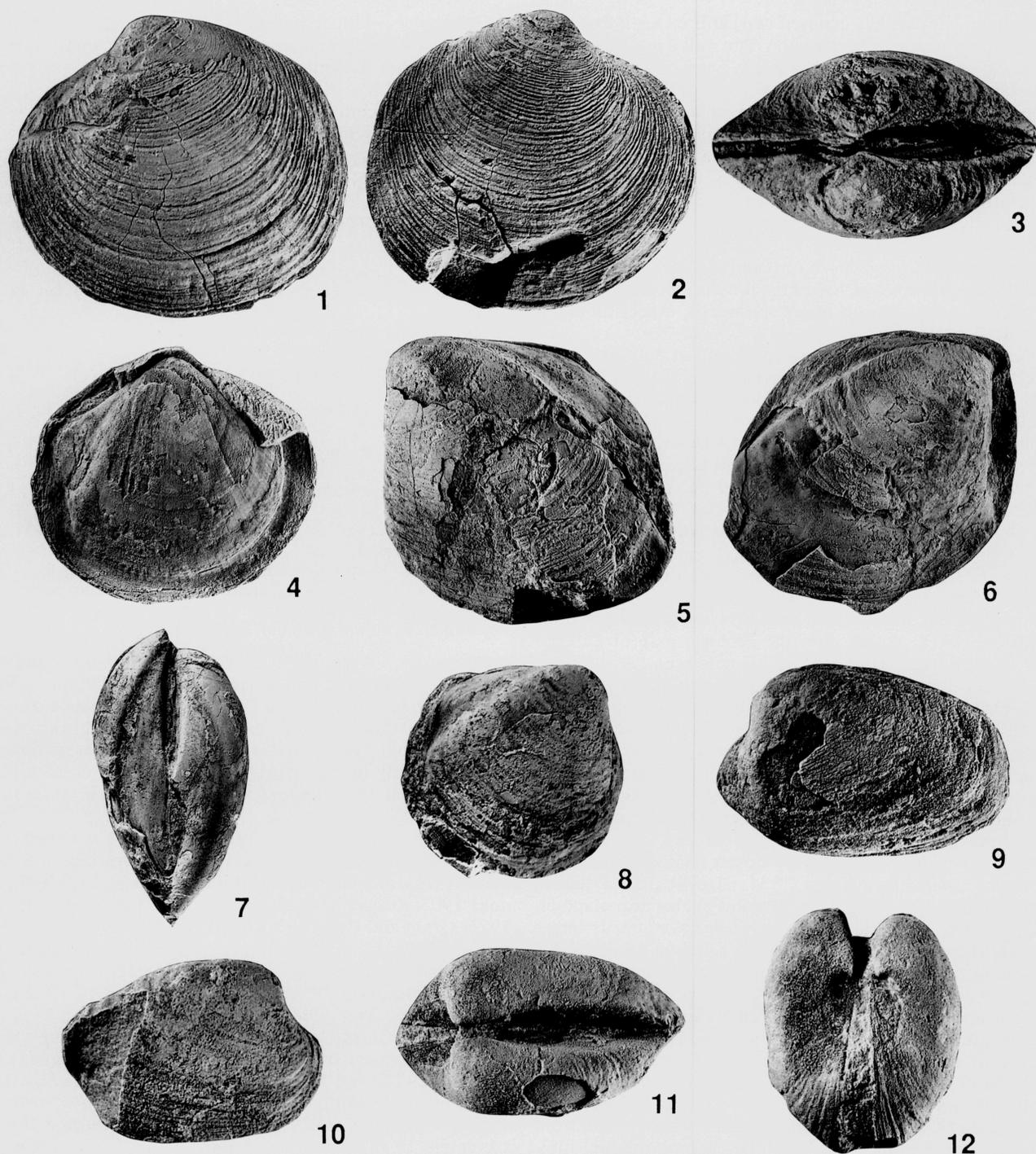


FIGURE 4—All specimens coated with ammonium chloride. All specimens from CSUN loc. 1580, unless otherwise noted. 1–4, *Epilucina washingtoniana* (Clark, 1925); 1–2, hypotype LACMIP 12354, height 52.5 mm, $\times 0.8$. Figure 1, left valve; 2, right valve; 3, hypotype LACMIP 12355, hinge-line (anterior to the left), thickness 20.2 mm, $\times 1.5$; 4, hypotype LACMIP 12356, cast of interior of right valve, height 37.5 mm, $\times 1.1$; 5–8, *Conchocele bisecta* (Conrad, 1849); 5, hypotype LACMIP 12357, cast of left valve, height 58.4 mm, $\times 0.8$; 6, hypotype LACMIP 12358, cast of right valve, height 51 mm, $\times 0.8$; 7, hypotype LACMIP 12357, posterior view, thickness 36.8 mm, $\times 0.7$; 8, hypotype LACMIP 12359, CSUN loc. 1581, cast of right valve of a juvenile, height 17.5 mm, $\times 2$; 9–12, *Vesicomya* (*Vesicomya*) aff. *V. (V.) tschudi* Olsson, 1931; 9, hypotype LACMIP 12360, left valve, height 18.4 mm, $\times 1.7$; 10, hypotype LACMIP 12361, right valve, height 18.3 mm, $\times 1.5$; 11–12, hypotype LACMIP 12362; 11, hinge-line (anterior to the left), thickness 16.1 mm, $\times 1.7$; 12, anterior view, $\times 2$.

imens, due to adherence of extremely hard rock matrix, the lunule is well preserved on a few specimens. It is situated entirely in the right valve and fits into a corresponding depression in the left valve. This type of asymmetric lunule is a diagnostic

feature of *Epilucina*. The dentition is very hard to observe because of the high number of articulated specimens, but on one specimen (LACMIP 12356), a part of the dentition is observable between the articulated valves. Alteration on the left valve of

this specimen has partially exposed two cardinal teeth, but they cannot be photographed because the right valve interferes with lighting. On one other specimen, which is a cast of a right? valve, a large lateral tooth is present. *Epilucina washingtoniana* has an internal radial structure that is observable only on rare internal molds with surfaces that are unaffected by dissolution or extensive weathering (Figure 4). These specimens show evidence of radial ribs on the medial part of the valves and along the ventral edge. The presence of radial ribs is not a characteristic that is usually listed by workers as a feature of *Epilucina*. Examination of two lots (LACM 151265 and 151266) of modern specimens of *Epilucina californica* (Conrad, 1837) from southern California, however, revealed the presence of weak but distinct internal radial ribs on many specimens, especially along their ventral edges.

Epilucina washingtoniana has been found at only two other places besides at Wagonwheel Mountain. One place is the type locality of the species in the upper Eocene Marrowstone Shale, Olympic Peninsula, Jefferson County, Washington (Clark, 1925; Durham, 1944; Squires, 1990). At this locality, Clark (1925) reported *E. washingtoniana* in sandy shale and associated with *Conchocele bisecta*, mytilid bivalves, and an epitioid gastropod. The second place is a single locality (UCMP loc. B-7027) in the upper part of the Gaviota Sandstone, southwestern Santa Ynez Mountains, Santa Barbara County, southern California (Weaver and Kleinpell, 1963). At this locality, Weaver and Kleinpell (1963) reported *E. washingtoniana* to be the only megafossil present. This locality, which is in a gray concretionary siltstone when plotted onto the geologic map of Dibblee (1988), is most likely associated with a cold seep.

Epilucina washingtoniana superficially resembles *Anodontia?* (*Anodontia?*) *inflata* (Wagner and Schilling, 1923, page 254, plate 45, figures 3, 4) from the "black shale" of the San Emigdio Formation, San Emigdio Mountains, Kern County, California. DeLise (1967) assigned this "black shale" to the upper Eocene Refugian Stage. Examination of the holotype of this species revealed it to have an apparently symmetric lunule and coarser commarginal ribbing than *E. washingtoniana*.

Epilucina washingtoniana is very closely related to *Phacoides* (*Lucinoma*) *zapotalensis* Olsson (1931, page 49, plate 5, figures 2-5) from the middle Oligocene Mambri shales near Zapotal, Ecuador, South America. *Epilucina washingtoniana* is larger and has coarser concentric ribs than does Olsson's species. Although poor preservation of the lunule area prevents determination of whether or not Olsson's species has an asymmetric lunule, we also assign his species to genus *Epilucina* because of the remarkable similarity to *Epilucina washingtoniana*.

According to Bretsky (1976, figure 7), *Epilucina* probably evolved from *Myrtucina* during the Eocene. *Epilucina washingtoniana* is one of the earliest species of the genus. Clark (1946, page 60, plate 12, figure 6) described *Epilucina gabrielensis* from an upper Eocene shallow-marine [non-chemosynthetic] molluscan assemblage in Colombia, South America. *Epilucina washingtoniana* has much coarser and more widely spaced concentric ribbing. In addition to *E. washingtoniana*, the only other known Cenozoic species of *Epilucina* from the Pacific coast of North America is the type species, *E. californica* (Conrad, 1837, page 255, plate 20, figure 1), the geologic range of which is late Miocene to Recent and with a geographic range from Crescent City, northern California to Rocas Alijos, Baja California Sur, Mexico (Coan et al., in press). *Epilucina washingtoniana* is larger, has coarser concentric ribs, and has a more truncated posterior end than *E. californica*.

Material.—Specimens very abundant at both localities (CSUN loc. 1580 and 1581). Holotype SU 35, UW loc. 705, upper Eocene, Olympic Peninsula, Washington.

Occurrence.—Upper Eocene: Olympic Peninsula, Washington; Wagonwheel Mountain, central California; and southwestern Santa Ynez Mountains, southern California.

Family THYASIRIDAE Dall, 1901
Genus CONCHOCELE Gabb, 1866

Type species.—*Conchocele disjuncta* Gabb, 1866, by monotypy, Miocene, California.

Conchocele bisecta (Conrad, 1849)
Figure 4.5-4.8

Venus bisecta CONRAD, 1849, p. 724, pl. 17, figs. 10, 10a.

Conchocele disjuncta GABB, 1866, p. 28; 1869, p. 99, pl. 7, figs. 48, 48a, 48b.

Thyasira bisecta var. *nipponica* YABE AND NOMURA, 1925, p. 84, pl. 23, fig. 3, pl. 24, figs. 2-4.

Thyasira quadrata YABE AND NOMURA, 1925, p. 92-93, pl. 23, figs. 1a, 1b.

Thyasira (*Conchocele*) *bisectoides* KURODA, 1931, p. 50, pl. 12, figs. 95, 96.

Thyasira bisecta var. *humila* KRISHTOFOVICH, 1936, p. 24-28, pl. 2, figs. 1, 1a.

Thyasira bisecta var. *alta* KRISHTOFOVICH, 1936, p. 29-32, pl. 1, figs. 3, 4.

Thyasira disjuncta var. *ochotica* KRISHTOFOVICH, 1936, p. 35-38, pl. 3, fig. 2, pl. 4, figs. 1, 2, pl. 5, figs. 1-3.

Thyasira clarki KRISHTOFOVICH, 1936, p. 39-40, pl. 2, fig. 2.

Thyasira folgeri Wagner and Schilling. VAN COUVERING AND ALLEN, 1943, fig. 211 [misidentified].

Thyasira cf. *T. disjuncta* (Gabb). SMITH, 1956, p. 77.

Discussion.—At locality CSUN 1580, nearly all of the specimens are articulated and range from 1.8 to 5.9 cm in height and 1.85 to 6.2 cm in length. The largest specimen is shown in Figure 4.5. At locality 1581, all of the specimens are articulated juveniles about 2 cm in height. Juvenile specimens do not elongate posteriorly in the ventral region until they reach a height of about 2.4 cm. A juvenile specimen 1.65 cm in height is shown in Figure 4.8.

There has been much confusion concerning whether or not *Conchocele bisecta* is conspecific with *Conchocele disjuncta*. Some authors regarded them as a single species (e.g., Dall, 1895; Arnold, 1903; Reagan, 1909; Yokoyama, 1924; Yabe and Nomura, 1925; Grant and Gale, 1931; Makiyama, 1934; Kanno, 1971a; Abbott, 1974; Coan et al., in press), but others regarded them as two distinct species (e.g., Tegland, 1928; Stewart, 1930; Clark, 1932; Krishtofovich, 1936; Kamada, 1962; Bernard, 1972; Yoon, 1976; Moore, 1984, 1988; Honda, 1989).

The main morphological basis used for separating the two species has been the shape of the anterior surface. Tegland (1928), Bernard (1972), and Moore (1984) reported that *C. bisecta* has a concave outline of the anterior surface and *C. disjuncta* has a straight outline. Kanno (1971a), however, reported that the specimens of *C. bisecta* are extremely variable in shape, with the greatest amount of variation in the apical angle. Based on this observation, as well as on the observations by Makiyama (1934) that the varietal forms of *C. bisecta* and their intermediates commonly occur in the same outcrop, Kanno (1971a) concluded that *C. disjuncta* is a synonym of *C. bisecta*. Most subsequent workers would have most likely accepted Kanno's conclusion, except Bernard (1972), who reported *C. bisecta* and *C. disjuncta* to be anatomically distinct. Recently, however, Coan et al. (in press) reported that the "anatomical differences do not seem of great significance and cannot be confirmed in any available material, including the specimens Bernard evidently examined."

Based on the preceding discussion, we consider *C. bisecta* and *C. disjuncta* to be the same species. We list all the junior syn-

onyms of *C. bisecta*, but we did not attempt to list the voluminous literature citations of *C. bisecta* and its synonyms. The latest lengthy synonymy of *C. bisecta* is given by Honda (1989), but he considered *C. disjuncta*, as well as the Japanese fossils *Conchocele nipponica* (Yabe and Nomura, 1925) [=originally considered to be a variety of *Conchocele bisecta*] and *C. bisecta omaruri* (Oyama and Mizuno, 1958), to be distinct taxa. A useful synonymy of *C. disjuncta* is given in Moore (1988), and a useful abbreviated synonymy of *C. bisecta* is given in Coan et al. (in press).

Smith (1956) commented that *Thyasira folgeri* Wagner & Schilling, 1923, seems to be based on small specimens of the *T. cf. T. disjuncta* that they collected from the middle member of the Wagonwheel Formation. Jenkins (1931) also suspected that *T. folgeri* was a juvenile form but thought it should be referred to *T. bisecta*.

Weaver (1942 [1943], plate 34, figures 5, 6) and Moore (1963, plate 23, figure 8, not plate 7, figures 23, 24 = a paratype) figured the holotype (USNM 3518) of *C. bisecta* (Conrad).

Van Winkle (1919) described *Thyasira adoccasa* Van Winkle (1919, pages 25–26, plate 3, figures 15, 16) from the middle? Tertiary of Trinidad in the southeastern Caribbean Sea. She noted that although *Thyasira adoccasa*, a large species with specimens to 12 cm length, resembles *Conchocele bisecta* (Conrad), the latter species does not reach such large size. Coan et al. (in press), however, have reported specimens of *T. bisecta* to 11 cm length. Intermediate stages of the two species are similar, but *Conchocele bisecta* differs from *T. adoccasa* by retaining the prominent fold that extends from the beaks to the posterior margin and by not becoming ovate in shape in the late adult specimens.

Olsson (1931) reported that *Thyasira peruviana* Olsson (1931, pages 148–149, plate 6, figures 3, 5, 7, 8, 9, 12) resembles *Conchocele bisecta*. The stratigraphic position and geologic age of *T. peruviana* are uncertain. The specimens are known only from an isolated exposure, and Olsson (1931) reported that, based on field relations, this exposure seems to belong to the Talara Formation. Marsaglia and Carozzi (1990) considered this formation to be of middle Eocene age. Olsson, however, tentatively assigned *T. peruviana* in the isolated exposure to the Oligocene because some of the molluscan species in the rock resembled Oligocene species. Examination of the type specimens of *T. peruviana* revealed that this species belongs to genus *Conchocele* because the anterior margin is straight, which is a diagnostic feature of this genus (Coan et al., in press). *Conchocele peruviana* is similar to *Conchocele bisecta* but differs in being smaller in size and in having a much wider and more sharply delineated ligamental area.

Goedert et al. (in press) reported a possible occurrence of *Thyasira peruviana* associated with a whale-fall (chemosynthetic) habitat in the Oligocene part of the Pysht Formation, Washington.

The earliest occurrences of *Conchocele bisecta* on the Pacific coast of North America are in the upper Eocene Keasey Formation, northwest Oregon (Campbell and Bottjer, 1993), the upper Eocene Marrowstone Shale, Olympic Peninsula, Washington (Clark, 1925), and the uppermost Eocene middle member of the Wagonwheel Formation, Wagonwheel Mountain (herein).

Elsewhere in the fossil record on the Pacific coast of North America, *C. bisecta* has been found in the lower Oligocene part of the Poul Creek Formation, Gulf of Alaska (Clark, 1932; Addicott et al., 1971; Kanno, 1971b); the upper Oligocene uppermost part of the Lincoln Creek Formation, Knappton, southwestern Washington (Moore, 1984, see discussion of age in Squires and Goedert, 1994); the lower Miocene Clallam Formation, northern Olympic Peninsula, Washington (Addicott,

1976); the middle Miocene Astoria Formation, Astoria, northwestern Oregon (Weaver, 1942 [1943]; Moore, 1963); the Miocene to Pliocene Yakataga Formation, Gulf of Alaska (Kanno, 1971b); the Pliocene Pico Formation, southern California (Waterfall, 1929); the Pliocene Wildcat Group, northern California (Ogle, 1953); the Pleistocene Timms Point Silt, southern California (Arnold, 1903; Woodring et al., 1946); and the Pleistocene San Pedro Sand, southern California (Gabb, 1866). In all of these formations, *Conchocele bisecta* was originally identified as *C. disjuncta* or *Thyasira disjuncta*, except for the Astoria Formation (Weaver, 1942 [1943]; Moore, 1963), the Poul Creek Formation (Clark, 1932), and the Timms Point Silt (Arnold, 1903), where it was originally identified as *T. bisecta*.

Tentative reports of *Conchocele bisecta* (originally identified as *Thyasira cf. T. disjuncta*) in the fossil record on the Pacific coast of North America are: the Oligocene Kultieth Formation [formerly referred to as the Katella Formation (Louie Marinovich, personal comm.)], Katella district, southeastern Gulf of Alaska (Miller, 1975); the upper Oligocene Blakeley Formation, Olympic Peninsula, Washington (Tegland, 1933; Durham, 1944); the upper Oligocene to lower Miocene Pysht Formation (formerly referred to as the upper member of the Twin River Formation, see Snively et al., 1977), Olympic Peninsula, Washington (Durham, 1944); the Oligocene? to Miocene Redwood Formation, Katella district, southeastern Gulf of Alaska (Miller, 1975); and the upper lower to lower middle Miocene Topsy Formation, Lituya district, southeastern Gulf of Alaska (Marinovich, 1979).

The earliest records of *Conchocele bisecta* on the Pacific coast of North America are synchronous with the earliest occurrence of this species in Japan. The first appearance of *C. bisecta* in Japan is in late Eocene to early Oligocene Poronai Formation (Kanno, 1971a). Various authors have reported *C. bisecta* from the Eocene Tighil Series on the west coast of Kamchatka and use Krishtofovich (1936) as their source, but she assigned the Tighil Series (= lower part of the Whitish series) to the middle Miocene.

Material.—Seven adult and 10 juvenile specimens at CSUN loc. 1580; nineteen juvenile specimens at CSUN loc. 1581. Of *bisecta*: holotype USNM 3518, Miocene, Astoria, Oregon. Of *disjuncta*: lectotype MCZ 15017, selected by Stewart (1930), Pleistocene, Deadman's Island [now destroyed], San Pedro, Los Angeles County, southern California.

Occurrence.—Upper Eocene to Recent. Fossil: Alaska, Washington, Oregon, and central and southern California, western Kamchatka, Sakhalin, Japan (all discussed herein), Korea (Yoon, 1976), and Spitzbergen (Durham and MacNeil, 1967). Living: Pribilof Island, Bering Sea (57°N) to northern California (40.8°N); Sea of Okhotsk to Sea of Japan (Coan et al., in press), and Gulf of Darian, Colombia, Caribbean Sea (Boss, 1967).

Family VESICOMYIDAE Dall & Simpson, 1901
Genus VESICOMYA Dall, 1886

Type species.—*Callocardia atlantica* Smith, 1885, by original designation, Recent, northeastern Atlantic.

Subgenus VESICOMYA s.s.

Vesicomya (Vesicomya) aff. V. (V.) tschudi Olsson, 1931
Figure 4.9–4.12

Petricola n. sp. ARNOLD AND JOHNSON, 1910, p. 41.
Petricola (?) sp. SMITH, 1956, p. 77.

Discussion.—At locality CSUN 1580, nearly all of the specimens are articulated and range from 1.1 to 2.15 cm in height and 2.1 to 3.2 cm in length. At locality CSUN 1581, most of

the specimens are articulated and range from 1 to 2 cm in height and 1.7 to 2.8 cm in length.

The only sculpture on the valves is strongly defined growth lines. There are well-defined and steep, strongly curved umbones and the dorsal anterior area adjacent to the umbones is steep for a distance before it projects anteriorly. Dentition is not observable. The escutcheon is beveled and deep. The lunule is distinct, heart-shaped, and circumscribed by an impressed isocardioform line (Figure 4.12). The presence of a lunule is important in assigning the specimens to *Vesicomya* (*Vesicomya*) rather than to the *Vesicomya* (*Calyptogena*) Dall, 1891. *Calyptogena* does not have a lunule (Coan et al., in press).

The specimens show very close affinity to *Vesicomya* (*Vesicomya*) *tschudi* (Olsson, 1931, pages 150–151, plate 4, figures 6, 8) from the upper Oligocene Heath Formation, northwestern Peru, South America. The Wagonwheel Formation specimens are smaller and have (except for rare specimens) lower umbones than *V. (V.) tschudi*. Although poor preservation prevents the determination of whether or not the lunule of *V. (V.) tschudi* is circumscribed by an impressed isocardioform line, we assign the Peruvian species to *Vesicomya* s.s. because of the morphologic similarity to the material from the Wagonwheel Formation.

We are reluctant to assign the Wagonwheel Formation specimens to a new species because the specimens are not that well preserved, show no interior features, and the differences they show when compared to the Peruvian species might be due only to growth stage.

Olsson (1931) also reported "*Vesicomya? tschudi*" from an isolated cherty limestone exposure of Oligocene? age in the Lomitos Formation, northwestern Peru, but he did not figure the bivalve. He also reported that the exposure might belong in the Talara Formation, which Marsaglia and Carozzi (1990) assigned to the middle Eocene.

There is some confusion regarding the spelling of *tschudi* by Olsson. In the description of the species, he used the name *tschudi*, but in the caption to the illustrated figures and in the text of his paper he used the name *tscludi*. Utilizing the "Principle of the First Reviewer" (Article 24c of Ride et al., 1985), we formally choose the spelling *tschudi* because that is the name used by Olsson in his systematic section.

Vesicomya (*Vesicomya*) *tschudi* is similar to *Vesicomya* (*Vesicomya*) *ramondi* Olsson (1931, pages 151–152, plate 4, figure 3), which is also from the upper Oligocene Heath Formation, northwestern Peru, South America. *Vesicomya* (*Vesicomya*) *tschudi* differs by having a less elongate shell.

The geologic history of *Vesicomya* s.s. is inadequately known, mainly due to the few reports of specimens in the fossil record. In addition, there are difficulties in the systematics of vesicomysids (Boss and Turner, 1980), and it is likely that *Vesicomya* s.s. has been assigned to other genera.

The earliest record of *Vesicomya* is *Vesicomya* s.s. of the Wagonwheel Formation. It was previously known from rocks only as old as late Oligocene (Olsson, 1931; Beets, 1943), although Goedert and Campbell (1995) reported a single valve of *Vesicomya* (?) from an early Oligocene cold-seep limestone in the Makah Formation, Olympic Peninsula.

The only other lower Tertiary species of *Vesicomya* s.s. that we know of is *V. (V.) alberdine* Beets, 1943, from the upper Oligocene of Celebes, Indonesia. Boss (1968) believed it to be closely related, if not a synonym, of the modern *V. (V.) ticaonica* Dall, 1908, from the Philippine Islands. The Wagonwheel Formation specimens differ from *V. (V.) alberdine* in having less inflated valves and umbones located much less anteriorly.

Presently, *V. (V.) lepta* (Dall, 1896, page 17; 1908, page 416, plate 18, figures 13, 14) and *V. (V.) sternsii* (Dall, 1895, page

693, figures 1a, 1b) are the only two species of *Vesicomya* s.s. living off the west coast of the United States (Coan et al., in press). Both have a convex rather than a straight dorsal anterior area adjacent to the umbones in comparison to the species from the Wagonwheel Formation. In addition, *V. (V.) sternsii* has a shallower escutcheon.

Material.—Twenty specimens at locality CSUN 1580; 28 specimens at locality CSUN 1581.

Occurrence.—Upper Eocene: Wagonwheel Mountain, central California.

ACKNOWLEDGMENTS

We thank A. A. Almgren (Bakersfield, California) for taking us to the study area and showing us the calcareous sandstone bodies. He also provided us with unpublished information by M. V. Filewicz and H. L. Heitman (both of Unocal Corporation, Houston, Texas) on the calcareous nanofossils and benthic foraminifers, respectively, of the Wagonwheel Formation. Both J. L. Goedert (Gig Harbor, Washington) and K. A. Campbell (Department of Geological Sciences, University of Southern California) kindly shared their extensive knowledge about ancient cold seeps, and both read an early draft of the manuscript and made valuable suggestions for improvement of the manuscript. K. A. Campbell also provided the senior author with a draft copy of part of her dissertation. E. Coan (Palo Alto, California) allowed the senior author to utilize up-to-date taxonomic information on *Epilucina*, *Conchocele bisecta*, and *Vesicomya* contained in a preprint of Coan et al. (in press). L. T. Groves (LACMP) provided access to the Recent collections for comparative study and access to the Malacology Section library. E. Coan, L. Marincovich (U.S. Geological Survey, Menlo Park, California), and L. T. Groves made available rare literature. W. D. Allmon (PRI) and K. Wetmore (UCMP) loaned comparative type material. The manuscript benefited from reviews by E. Coan and W. P. Elder (U. S. Geological Survey, Menlo Park).

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ACCEPTED 14 MARCH 1995

APPENDIX

LOCALITIES

CSUN 1580. At elevation of 760 ft at north end of top of small hill, latitude 35°42'13"N, longitude 119°59'30"W, 152 m (500 ft) N, and 69 m (225 ft) W of the SE corner of section 35, T25N, R18E, U. S. Geological Survey, 7.5-minute, Emigrant Hill Quadrangle, 1953 (photorevised, 1973), northwest Kern County, central California. Middle siltstone member of the Wagonwheel Formation. Age: Latest Eocene. Collectors: R. L. Squires and M. P. Gring, June, 1994. = LACMIP loc. 16886

CSUN 1581. At elevation of 730 ft at top of small hill, latitude 35°42'N, longitude 119°59'W, 312 m (1,025 ft) N, and 168 m (550 ft) W of the SE corner of section 35, T25N, R18E, U. S. Geological Survey, 7.5-minute, Emigrant Hill Quadrangle, 1953 (photorevised, 1973), northwest Kern County, central California. Middle member of the Wagonwheel Formation. Age: Latest Eocene. Collectors: R. L. Squires and M. P. Gring, June, 1994. = LACMIP loc. 16887

UCMP 3195. From small hogback which joins cliff S of Devil's Kitchen and N of locality, SE corner of section 31, T10N, R21W, U. S. Geological Survey, 7.5-minute, Eagle Rest Peak Quadrangle, 1942, Kern

County, southern California. Middle mudstone member of the San Emigdio Formation. Age: Late Eocene. Collectors: C. M. Wagner and K. H. Schilling, *circa* 1920.

UCMP B-7027. In a gray siltstone in Coyote Canyon, approximately 549 m (1,800 ft) S, and 610 m (2,000 ft) E of the SW corner of section 23, T5N, R33W, U. S. Geological Survey, 7.5-minute, Sacate Quadrangle, 1953, Santa Barbara County, southern California. Upper part

of Gaviota Sandstone. Age: Late Eocene. Collector: D. R. Forbes, June, 1948 (Weaver and Kleinpell, 1963:226, figure 6).

UWBM 705. On S shore of Mystery Bay on Marrowstone Island, NE side of Olympic Peninsula, section 32, T30N, R1E, U. S. Geological Survey, 7.5-minute Norland Quadrangle, 1953 (photorevised, 1973), Jefferson County, Washington. Marrowstone Shale. Age: Late Eocene. Collector: H. Hannibal, *circa* 1915.