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

RICHARD L. SQUIRES AND MICHAEL P. GRING[1]
Department of Geological Sciences, California State University, Northridge 91330-8266

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 vesicomyid 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 *Vescicomya* (*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.

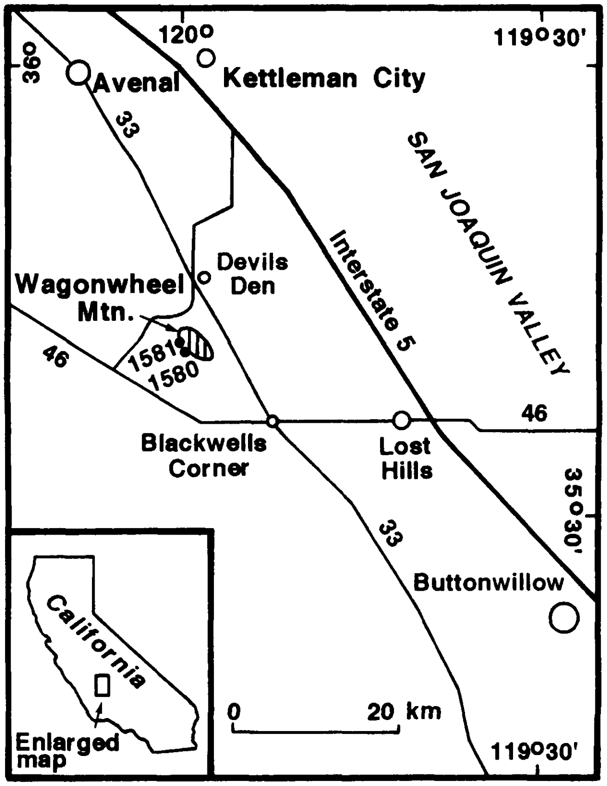

FIGURE 1—Index map to CSUN localities at Wagonwheel Mountain, central California.

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 vesicomyid 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 Vesicomyidae 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 *Vesicomya,* 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 authochthonous 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, Calyptogena, 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 (nonseep) 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 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.

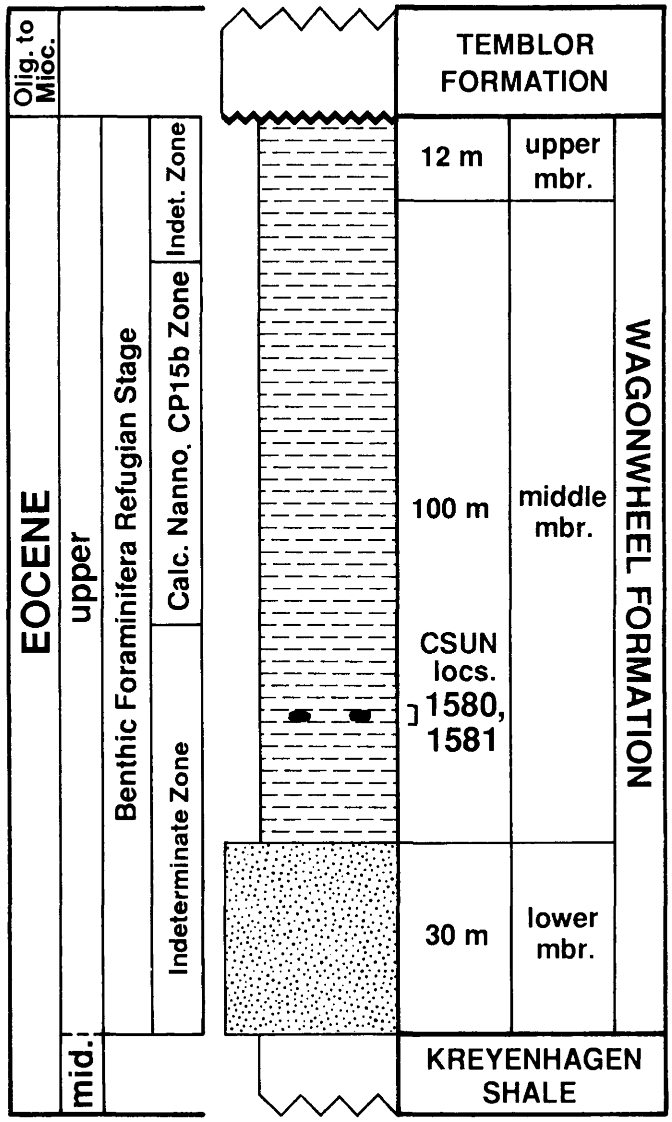

FIGURE 2—Stratigraphic section of the Wagonwheel Formation, Wagonwheel Mountain. Lithologies indicated by standard symbols.

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-up 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 *Vesicoyma* (*Vesicomya*) cf. *V.* (*V.*) *tschudi* 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-