GOEDERT & CAMPBELL, 1995

THE VELIGER

The Veliger 38(1):22-29 (January 3, 1995)

An Early Oligocene Chemosynthetic Community from the Makah Formation, Northwestern Olympic Peninsula, Washington

by

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Abstract. A small, allochthonous, localized mass of limestone is present within deep-water strata of the early Oligocene part of the Makah Formation exposed at Shipwreck Point on the Olympic Peninsula, Washington State. This limestone is a methane-derived authigenic carbonate, as evidenced by faunal-sedimentologic associations and stable isotopes; it is enclosed in siltstone that is nearly barren of megafossils. Fossils from the limestone represent a diverse chemosynthetic community that includes more than 20 species. The fauna consists of eight bivalve genera (including *Calyptogena* and *Modiolus*), 13 gastropods (including *Provanna*), one scaphopod, one chiton, and vestimentiferan? worm tubes. We report the first fossil record for the genus *Provanna* and the first record for chitons at ancient cold-methane seeps.

INTRODUCTION

Fossil communities of chemosynthetically-supported mollusks similar to those now living near modern hydrothermal vents and cold-seeps have now been recognized in rocks around the world. Ancient cold-seeps have been described from marine sedimentary deposits in Europe (Gaillard et al., 1985; Clari et al., 1988); Japan (Niitsuma et al., 1989); the Canadian Arctic (Beauchamp et al., 1989); and the western United States (Howe & Kauffman, 1986; Campbell, 1989, 1992; Goedert & Squires, 1990; Campbell & Bottjer, 1993). Most of these reports discuss stratigraphic, petrographic, and isotopic data from suspected seep sites, with the faunas only briefly mentioned.

The purpose of this paper is to document a newly discovered Oligocene cold-seep fauna from localized limestone within deep-water sandstone and siltstone deposits in the Makah Formation at Shipwreck Point, northwestern Olympic Peninsula, Washington (Figure 1). All the taxa are illustrated except those recently described from other known ancient cold-seep faunas or too poorly preserved for identification. Some of the mollusks from this fauna are new species, and will be described by others. The acronym LACMIP designates catalog and locality numbers of the Natural History Museum of Los Angeles County, Invertebrate Paleontology Section, Los Angeles, California. Locality LACMIP 15911 is an isolated *in situ* limestone block (2.5 m long × 2.5 m wide × 0.75 m high), accessible only during low tides (Figure 1). Locality LACMIP 8233 represents float, erosional-lag materials, on the modern beach terrace. Rare limestone blocks up to 1 m across are present on the beach terrace. They are more weathered and easier to sample for fossils than the *in situ* block (LACMIP loc. 15911), and most of the specimens

illustrated were obtained from them. The loose, smaller blocks of limestone are identical to the *in situ* block, and all taxa found in the smaller blocks were also found in the *in situ* block. Approximately 200 kg of limestone were sampled for fossils.

DEPOSITIONAL ENVIRONMENT AND AGE

The Makah Formation was deposited in a deep-water, submarine-fan setting, and is late Eocene to late Oligocene in age (Snavely et al., 1980). It contains six named members: four are thick turbidite sandstones; a fifth (the Jansen Creek Member) is made up of olistostromal and deformed shallow-water strata; and a sixth unit is a thin tuff deposit. Thin-bedded sandstones and siltstones separate each member and represent basin-plain and outer fan-fringe deposits (Snavely et al., 1980). Limestones are isolated and rare both in the Makah Formation and in other Cenozoic, deep-water siliciclastic sequences throughout the Pacific Northwest.

The *in situ* limestone (LACMIP loc. 15911) is positioned stratigraphically within the basin-plain and fan-fringe deposits of the Makah Formation. A 10 cm-thick turbidite sandstone bed is preserved 2.5 m stratigraphically below the limestone. The surrounding siltstone is barren of megafossils and contains scattered calcareous concretions, a few small blocks of sandstone, glauconitic siltstone horizons, and oblong concretionary blocks that are oriented randomly with respect to bedding. Based on the following evidence, we conclude that the limestone originally formed in a shelf/slope environment and subsequently slid or slumped into mid to lower bathyal parts of a basin. First, the Jansen Creek Member of the Makah Formation is located only about 30 m stratigraphically below the *in situ* limestone. The Jansen Creek Member is an olistostromal unit (200 m thick), derived from shallow- and deep-water sediments that slumped or slid off the Vancouver Island shelf/slope into a deep marginal basin (Snavely et al., 1980; Niem et al., 1989). Second, petrographic observations on micritic limestone from the *in situ* block yielded a probable nodosariid microfossil (A. G. Fischer, personal communication). Nodosariids are typically associated with outer shelf to bathyal water depths (Boersma, 1978); therefore, its presence within a limestone block surrounded by mid to lower bathyal strata may imply an allochthonous origin. Third, the contact between the limestone and the enclosing siltstone is sharp. Ancient cold-seep limestone mounds that formed *in situ*, due to concentrated fluid seepage, typically preserve nodular carbonate material trailing into the siliciclastic deposits around all the mound margins (Rolin et al., 1990).

The upper part of the Makah Formation in the vicinity of Shipwreck Point is early Oligocene in age (Snavely et al., 1980). This age assignment is based on benthic foraminifera; molluscan fossils are rare in the basin-plain deposits. This part of the Makah Formation also contains rare fossils of isopod crustaceans (Wieder & Feldmann, 1989), a few mollusks associated with cetacean skeletons and pieces of wood (Squires et al., 1991), and a few bivalves associated with turbidite deposits (Goedert & Squires, 1993). The limestone (LACMIP loc. 15911) at Shipwreck Point differs from the nearly barren surrounding siltstone in that it contains an abundance of fossil invertebrates, all randomly oriented and, in places, closely packed together. For this diverse, localized assemblage (Table 1) we apply the term "community" defined by Hickman (1984:1220) as "an association of organisms inferred to have lived together and interacted ecologically." Nearly identical Eocene-age localized carbonate deposits from southwest Washington contain faunas interpreted by Goedert & Squires (1990) as representing chemosynthetic communities formed near cold-seeps in deep water. Similar isolated limestones in deep-water siliciclastics have been recognized as additional cold-seep sites in various sedimentary sequences in the Pacific Northwest Cenozoic and California Mesozoic (Campbell, 1989, 1992; Campbell & Bottjer, 1993).

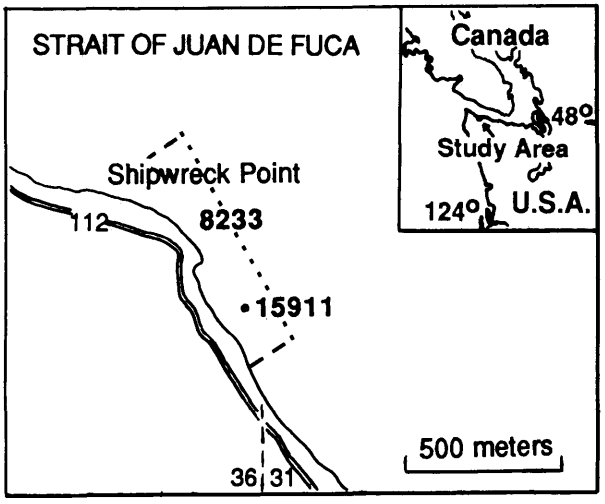


Figure 1

Index map of Shipwreck Point, Washington showing fossil localities.

PETROGRAPHY AND STABLE ISOTOPES

The petrographic and stable-isotopic signatures of several representative carbonates from the Shipwreck Point area reveal microenvironmental details of the seep-origin of the limestone. The *in situ* block (LACMIP loc. 15911) has both micritic and layered-calcite cement fabrics. The smaller blocks (LACMIP loc. 8233) show either micritic fabrics or layered-calcite cement fabrics. Fossils are rare to absent in the blocks composed of layered-calcite cements but are more common in the indurated micritic limestone. A similar association between micrite/calcite cement fabrics and faunal distributions has been observed for Jurassic and

Table 1

Megafossil assemblage from isolated limestone within the Makah Formation at Shipwreck Point, Washington (listed in order referred to in text).

Bivalves
Modiolus (*Modiolus*) *willapaensis* Squires & Goedert
Calyptogena (*Calyptogena*) *chinookensis* Squires & Goedert
Acharax sp.
Anodontia? (*Anodontia*?) *inflata* (Wagner & Schilling)
Lucinoma hannibali (Clark)
Unidentified lucinid
Nuculana sp.
Macoma? sp.
Vesicomya? sp.
Gastropods
Provanna n. sp.
"*Admete*" n. sp.
Margarites (*Pupillaria*) *columbiana* Squires & Goedert
Hyalogyrinids (2 spp.)
Limpet
Solariella? sp.
Aforia sp.
Naticids
Marginellids
Scaphandrids
Turrid
Buccinid
Polyplacophoran
Leptochiton sp.
Other
Scaphopod
Vestimentiferan? worm tubes
Shrimp, *Callianassa* sp.

Cretaceous seep limestones in California (Campbell, unpublished data).

Several representative thin-sections of carbonate were cut from the *in situ* block to be examined petrographically. It is composed predominantly of a dark gray-brown lime mudstone or micrite, containing abundant quartz and feldspar grains and woody debris. Relatively homogeneous regions of micrite are commonly disrupted by irregular intraclasts of micrite with diffuse boundaries, or by angular to rounded, brecciated micrite fragments. Fibrous cements and blocky, clear spar fill pore spaces between micrite fragments, but the micrite/cement ratio is high.

Pyrite-coated corrosion surfaces are prevalent in some of the micritic thin-sections and in places, pyrite is interlayered with micrite on a fine-scale. Some modiolid bivalves are also coated with a thin layer of pyrite, but the underlying calcareous shell layers remain unaffected by pyritization. Some of the woody debris has been replaced by pyrite. Pyrite coatings and corrosion surfaces reported from several ancient cold-seep settings probably represent phases of sulfide-rich fluid seepage in a locally geochemically reduced seep-microenvironment (Beauchamp & Savard, 1992; Campbell et al., 1993).

Two carbonate and two fossil shell samples from the *in situ* block (LACMIP loc. 15911) were examined isotopically (Table 2). Carbonate components were separated with a microdrill, weighed (150–400 μg); and roasted *in vacuo* at 375°C for one hour. CO_2(g) was devolved from the sample by reaction in orthophosphoric acid at 90°C. Weighed standards (Ultissima marble) were interspersed with samples and analyzed under the automated runs. Isotopic signatures of shell material can be compared to modern seawater values (~0‰ for $\delta^{13}C$ and $\delta^{18}O$, PDB [Hoefs, 1987]), with slight isotopic enrichment in carbon values and slight isotopic depletion in oxygen values for the sampled fossil solemyid. These results fall in the range of shell carbonate values reported from both littoral and vent/seep modern bivalves, albeit chemosynthetic taxa tend to show either more depleted (to −6‰) or more positive (to +4‰)$\delta^{13}C$ signatures (Rio et al., 1986, 1992). Fibrous cements are depleted in carbonate carbon (to −34‰), suggesting that methane was present in fluids that precipitated the cements (see Anderson & Arthur, 1983). It is unknown whether thermogenic or biogenic sources were tapped, or if mixing with other carbon reservoirs affected the isotopic signal. For example, typical carbon sources for most deep-sea settings include: total dissolved inorganic carbon in seawater (0‰); marine organic carbon, particulate and dissolved (~−20 to −25‰); terrestrial plant material (~−10 to −30‰); thermogenic methane (+ values to −40‰); and biogenic methane (~−50 to <−80‰) (Paull et al., 1985, and references therein). Oxygen isotopic signatures of the cement are consistent with seawater values and indicate that there was no significant change in ambient temperature of formation. Additional isotopic measurements are needed to more clearly elucidate these relationships and to ascertain the origin of the micrite.

PALEONTOLOGY

In the fossiliferous micritic limestone at Shipwreck Point, the most common faunal constituents are the bivalves *Modiolus* (*Modiolus*) *willapaensis* Squires & Goedert, 1991, from 4 to 27.9 mm in length, and *Calyptogena* (*Calyptogena*) *chinookensis* Squires & Goedert, 1991, up to 33 mm in length. Most specimens are articulated, in some cases in clusters of randomly oriented individuals. Both of these bivalves have been reported from cold-seep limestones in southwestern Washington. *Calyptogena* (*Calyptogena*) *chinookensis* has also been reported from cold-seep limestone of Oligocene age in the Pysht Formation about 50 km southeast of Shipwreck Point and in turbidites from below the Jansen Creek Member of the Makah Formation (Goedert & Squires, 1993).

Most of the micritic limestone contains angular, unworn fragments of the bivalve *Acharax* sp.; however, one poorly preserved, articulated specimen from a block of layered-calcite crusts is 75 mm long and 35 mm high. This block

also contained sparse specimens of *Modiolus* (*Modiolus*) *willapaensis*.

The limestone also contains poorly preserved bivalves that resemble *Thyasira*, but may be *Anodontia*? (*Anodontia*?) *inflata* (Wagner & Schilling, 1923), known previously only from Eocene rocks in California (Moore, 1988). The hinge is not exposed in any of the Shipwreck Point specimens, but some show faint irregular internal ribbing. They are found articulated and as single valves and are from 7.6 up to 48 mm in length.

Specimens of *Lucinoma hannibali* (Clark, 1925) are rare in the limestone; all are articulated and are from 7.8 to 31.9 mm in length. Fragments of another, unidentified lucinid bivalve were also found; if complete, its length would exceed 75 mm. Single and articulated valves of a rare, small species of *Nuculana* (up to 7 mm length) are also present. The shell of *Nuculana* sp. (Figure 2) has numerous well-defined concentric ribs on the posterior and mid-sections, but the anterior third is always smooth. Two specimens of *Macoma*? sp., length 14.5 to 18.5 mm, were also found; one was associated with numerous specimens of articulated and randomly oriented *Calyptogena* (*Calyptogena*) *chinookensis*.

A single valve of *Vesicomya*? sp. (Figure 3) was also found in the limestone. The hinge is not exposed, but the valve is referred to *Vesicomya* because of the strongly curved beak, smooth and extremely convex shell, lunule with a groove, slight depression posteriorly, and general outline of the shell.

Gastropods are abundant in the limestone that contains bivalves, but most of the gastropods are quite small. One new species, or possibly more, of the genus *Provanna* are present (Figures 4–7), ranging from about 2 to 7 mm in height (under study by R. L. Squires). Some have a smooth shell (Figure 4), somewhat like the modern *Provanna laevis* Warén & Ponder, 1991. A few specimens have spiral ribs (Figures 5, 6) and resemble some specimens of the modern *Provanna macleani* Warén & Bouchet, 1989, and some also have axial ridges (Figure 7). The apex is not present in any of the *Provanna* specimens, probably due to corrosion during life. *Provanna* has no previously documented fossil record, and almost all living species are thought to be from hydrocarbon seeps or hydrothermal vents (Warén & Bouchet, 1986, 1989; Warén & Ponder, 1991).

Another gastropod in the limestone is "*Admete*" n. sp. (Figure 8). Specimens are moderately common and range in height from 5 to 17 mm. "*Admete*" n. sp. resembles "*Admete*" *umbilicata* Hickman, 1980, from bathyal rocks in the late Eocene and early Oligocene Keasey Formation in northwest Oregon, but "*Admete*" n. sp. is more elongate with more steeply inclined whorls.

Five specimens of *Margarites* (*Pupillaria*) *columbiana* Squires & Goedert, 1991, were found and range from 5.1 to 9.6 mm in height. This species had previously been found in only one other cold-seep fauna in late Eocene rocks in southwestern Washington (Squires & Goedert, 1991).

Table 2

Carbon and oxygen isotope values from representative Shipwreck Point fossil shells and carbonate fabrics. See text for interpretation.

Material	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)
Solemyid shell, umbo, outer shell layer	2.06	−1.76
Solemyid shell, posterior, inner shell layer	2.46	−1.12
Fibrous cement	−26.20	−2.29
Fibrous cement	−34.47	−0.76

Delta (δ) values are given in per mil (‰), such that $\delta^{13}C = [(^{13}C/^{12}C)_{sample} \div (^{13}C/^{12}C)_{standard} - 1] \times 1000$ (‰), where standard = Pee Dee Formation belemnite (PDB). Same notation and form applicable to oxygen-isotope data. The precision of measurements is better than 0.1‰.

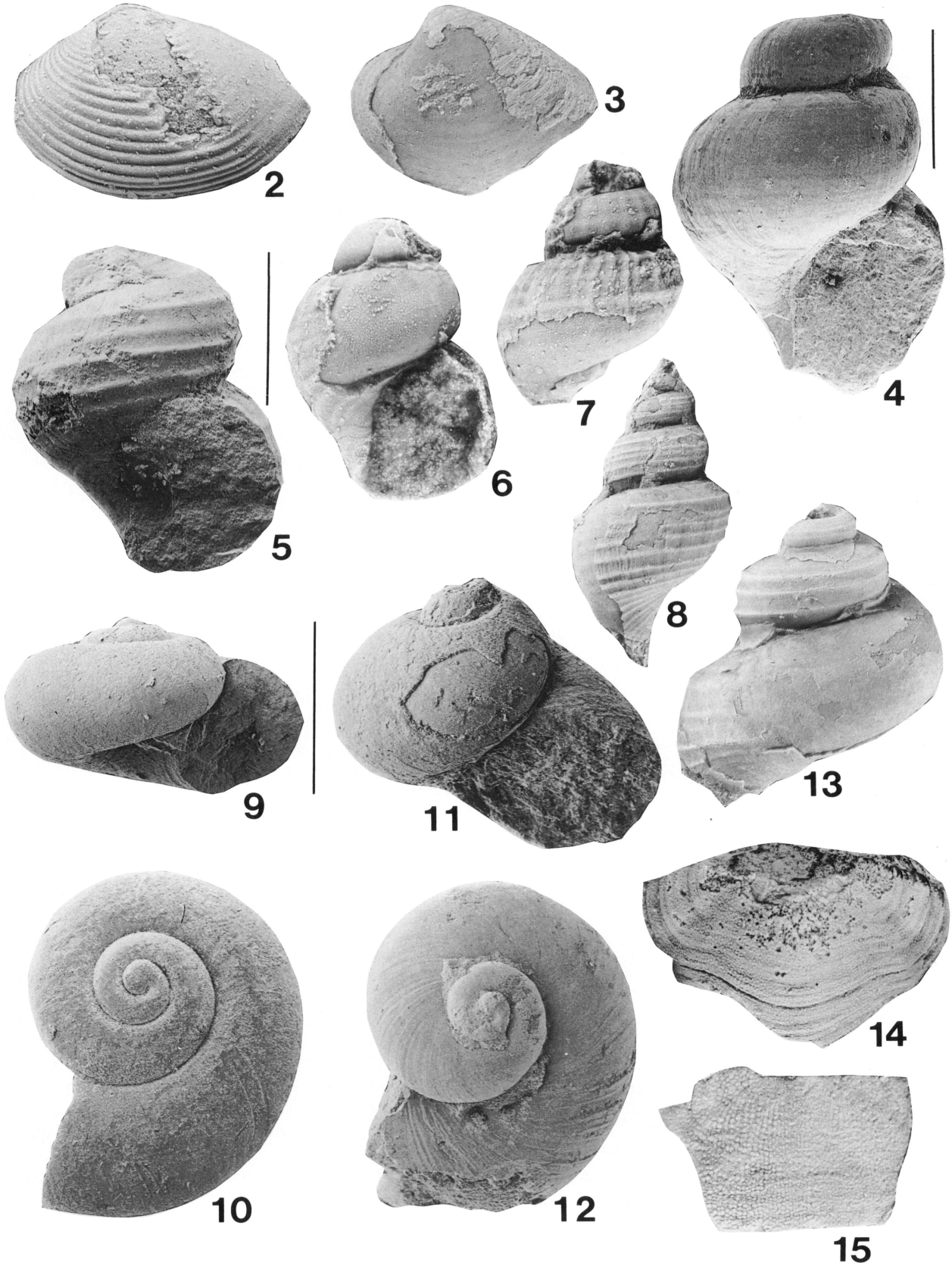
The limestone contains numerous specimens of unidentified, minute gastropods (Figures 9–12), which are probably species belonging to the family Hyalogyrinidae Warén & Bouchet, 1993. One species is about 1 to 2 mm in diameter, and some specimens have the larval shell intact (Figures 9, 10). Another species has a higher spire, more fragile shell, and is 2 to 4 mm in height (Figures 11, 12). Living hyalogyrinids are usually found in deep water, associated with sunken organic debris or hydrothermal vents (Marshall, 1988; Warén et al., 1993).

Three minute limpets found in the limestone have smooth shells, 1 to 2 mm in diameter, and are identical to the limpet reported (Goedert & Squires, 1990:1184, fig. 2b, c) from the cold-seep community in the middle to upper Eocene Humptulips Formation in southwest Washington. This limpet has also now been collected in the upper Eocene Bear River cold-seep limestone in Pacific County, Washington (Goedert, unpublished data).

At least seven other gastropod species are present in the limestone but are poorly preserved. A single, incomplete specimen of *Solariella*? sp. (Figure 13), one specimen of a small *Aforia* sp., five specimens of an unidentified naticid, three specimens of a marginellid, one scaphandrid, and one turrid gastropod were found. Four specimens of a buccinid up to 23.5 mm in height were also found.

Chiton plates (Figures 14, 15) are common in the limestone. They are small and represent a species of *Leptochiton* Gray, 1847. Some modern species of *Leptochiton* are found in deep water (Ferreira, 1981). Unidentified chitons have been reported associated with authigenic carbonates in shelf/slope environments off the Oregon coast (Kulm & Suess, 1990).

Other invertebrates found in the limestone are poorly preserved. Echinoid spines are commonly visible in thin-sections. A single unidentifiable scaphopod was found. Individual tubes of vestimentiferan? worms are thin-walled and up to 2.9 mm in diameter. Fragments of crustaceans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probably represent a species of the shrimp *Callianassa* (R. B. Manning, personal communication).

Small fragments of woody detritus are sparse throughout the limestone. A single fossil seed was found (Florida Museum of Natural History UF12745) and identified as *Cruciptera* sp. (S. R. Manchester, personal communication). This genus has been identified in terrestrial deposits of Eocene and Oligocene age in Oregon, Washington, and Wyoming, and middle Eocene rocks in England and Germany (Manchester, 1991).

DISCUSSION

The fossil mollusks contained within the Shipwreck Point limestone are typical of taxa described from modern and ancient hydrothermal vent and cold-seep settings, both in terms of abundance and dominant genera. The limestone contains numerous macroinvertebrates whereas the surrounding basin-plain deposits are nearly barren. Modern deep-sea vent/seep communities owe their extraordinary population densities to the geochemical food base exploited by chemoautotrophic bacteria (free-living and endosymbiotic) which rely on localized, reduced fluid seepage. Moreover, the dominant fossil genera collected from the limestone include *Modiolus, Calyptogena,* and *Provanna*; and all have species known today to be chemosynthetic. Other vent/seep taxa are also well represented; solemyid and lucinid bivalves, the gastropod genus *Margarites,* hyalogyrinid gastropods, limpets, and tubes of vestimentiferan? worms. Overall, the macroinvertebrate fossil assemblage from Shipwreck Point represents a relatively diverse chemosynthetic community. This is a significant finding because, by contrast, most reported chemosynthetic communities (modern and ancient) show relatively low species richness; however, most have been poorly sampled.

The association of vent/seep-type taxa with anomalous, isolated carbonates that have peculiar sedimentologic and isotopic characteristics is typical for modern and ancient cold-seep environments thus far recognized. This faunal-sedimentologic association allows for prediction of new sites, both in modern settings and in the geologic record, and enables identification of the local geochemical conditions necessary for chemosynthetic taxa to flourish. For example, studies of modern and ancient seep-carbonates show that they are derived from the oxidation of methane, mixed to varying degrees with seawater (Ritger et al., 1987; Han & Suess, 1989; Campbell, 1992). Depleted $\delta^{13}C$ signatures from two cement samples from Shipwreck Point also suggest that methane was present during carbonate formation. Modiolids, present in abundance in the limestone, rely today on methane for chemosynthesis. Furthermore, pyrite-coated corrosion surfaces in the micrites attest to the presence of sulfide-rich fluids in the depositional environment, a necessary component to chemosynthesis for the solemyids, vesicomyids, and vestimentiferan worms.

The tectonostratigraphic conditions that allowed formation of the Shipwreck Point cold-seep deposit included: (1) generation and migration of reduced fluids (methane and hydrogen sulfide) to the sea-floor owing to convergent margin tectonism; (2) carbonate formation contemporaneous with seep community development around seep effluent area; and (3) slumping/sliding of this outer shelf or slope-derived limestone into mid to lower bathyal depths where the Makah Formation accumulated. The allochthonous nature of the Shipwreck Point limestone block is peculiar to this locality; most other reported ancient seep-carbonate deposits from western North America are preserved in place, in outer shelf to slope paleoenvironments (Campbell & Bottjer, 1993).

ACKNOWLEDGMENTS

We thank Richard L. Squires (California State University, Northridge) and Alicia Thompson (USC, Center for Electron Microscopy and Microanalysis) for assistance with photography of specimens for this study and Robert B. Manning (U.S. National Museum), William A. Newman (Scripps Institution of Oceanography), and Steven R. Manchester (Florida Museum of Natural History) for help in identifying fossils. For comments on the manuscript we thank Ellen J. Moore, Barry Roth, Richard L. Squires, and an anonymous reviewer. Thomas E. Angelos read the manuscript. Gail H. Goedert and William R. Buchanan

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Explanation of Figures 2–15

All specimens from limestone blocks at LACMIP loc. 8233 unless otherwise noted. Scale line for SEM photos is 1 mm. Figure 2. *Nuculana* sp., LACMIP 12310, right valve, ×7.4. Figure 3. *Vesicomya*? sp., LACMIP 12311, Loc. LACM 15911, right valve (convexity 4.8 mm), ×3.3. Figures 4–7, *Provanna* (one, or possibly more n. sp.). Figure 4. LACMIP 12312, apertural view, SEM. Figure 5. LACMIP 12313, apertural view, SEM. Figure 6. LACMIP 12314, apertural view, ×10.5. Figure 7. LACMIP 12315, back view, ×7. Figure 8. "*Admete*" n. sp. LACMIP 12316, back view, ×3.3. Figures 9, 10. Hyalogyrinid, LACMIP 12317, SEM. Figure 9. Apertural view, Figure 10. Dorsal view. Figures 11, 12. Hyalogyrinids, SEM (same scale as Figure 9). Figure 11. LACMIP 12318, oblique-apertural view, Figure 12. LACMIP 12319, dorsal view. Figure 13. *Solariella*? sp., LACMIP 12320, LACMIP loc. 15911, back view, ×3.7. Figures 14, 15. *Leptochiton*? sp. Figure 14. Intermediate valve (anterior end toward bottom of page), LACMIP 12322, dorsal view, ×7.6. Figure 15. Fragment of intermediate valve, LACMIP 12321, dorsal view, ×9.25.

fig. 9 = 12317
fig. 10 = 12323

helped at various times with fieldwork. Fieldwork by James L. Goedert was supported by a National Geographic Society grant (4439-90) to the Natural History Museum of Los Angeles County Foundation, for research on fossil cetacea on the Olympic Peninsula, Washington. Isotopic analyses were performed with the assistance of Ashish Sinha in the laboratory of Lowell D. Stott, University of Southern California. Research by Kathleen A. Campbell was supported by the donors of the Petroleum Research Fund, administered by the American Chemical Society.

LOCALITIES CITED

LACMIP loc. 8233. Float eroded from bedrock exposed on modern beach terrace at Shipwreck Point, SE¼ NE¼ sec. 36, T. 33 N, R. 14 W, (U.S. Geological Survey, 7.5-minute, Sekiu River, Washington quadrangle, provisional edition 1984) Clallam County, Washington. Upper part of Makah Formation. Age: Early Oligocene.

LACMIP loc. 15911. *In situ* isolated limestone block within thin-bedded sandstone and siltstone deposits, about 30 m stratigraphically above top of Jansen Creek Member, block measures 1.5 m (N-S) by 2.5 m (E-W), and is weathered out 0.75 m higher than surrounding siltstone; accessible only at low tide. Block is approximately 175 m southeast of tip of Shipwreck Point, SE¼ NE¼ sec. 36, T. 33 N, R. 14 W, (U.S. Geological Survey, 7.5-minute, Sekiu River, Washington quadrangle, provisional edition 1984) Clallam County, Washington. Upper part of Makah Formation. Age: Early Oligocene.

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