MOLLUSCAN PALEONTOLOGY AND BIOSTRATIGRAPHY OF THE LOWER MIOCENE UPPER PART OF THE LINCOLN CREEK FORMATION IN SOUTHWESTERN WASHINGTON

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ABSTRACT. The uppermost part of the Lincoln Creek Formation in the Knappton area of southwestern Washington is assigned to the lower Miocene upper part of the Juanian Molluscan Stage (=Saucesian Foraminiferal Stage) and the *Liracassis apta* Molluscan Zone. This part of the Lincoln Creek Formation is correlated with the upper part of the Pysht Formation of the Twin River Group in northwestern Washington.

Fossils, invertebrates and vertebrates, are preserved in concretions that erode out of landslides and accumulate as float along the Columbia River. The molluscan fauna of the upper part of the Lincoln Creek Formation consists of 33 species in 30 genera, including five newly described species in the genera "*Bathybembix,*" *Ancistrolepis, Musashia, Modiolus,* and *Acesta.* Eastern Pacific species in the genus *Musashia* are reviewed. The fauna lived at depths between 100 and 350 m, a bathymetric range substantiated by the inferred ranges of 16 associated phyla also preserved as fossils at Knappton. The nautiloid cephalopod *Aturia,* which is common in the collections, indicates that the water temperature may have been as high as 16°C at a depth of 100 m. The abundance of preserved organic material suggests that free oxygen was depleted in the sediment below the level of bioturbation.

INTRODUCTION

Fossiliferous concretions that have eroded out of landslide blocks from the upper part of the Lincoln Creek Formation occur as float along the Columbia River near the site of Knappton in southwestern Washington (Figs. 1, 2). The Lincoln Creek Formation in this area is part of a homocline, and the sequence dips eastward. The upper part consists of poorly bedded, locally laminated, bioturbated, concretionary dark-gray siltstone. The formation is unconformable upon the upper Eocene siltstones of Cliff Point unit (Wells, 1979).

The invertebrate fauna described in this report is from the uppermost part of the Lincoln Creek Formation (LAM Loc. 5842) and is early Miocene in age. The fauna is assigned to the upper part of the Juanian Mollusean Stage (=Saucesian Foraminiferal Stage) and the *Liracassis apta* [*Echinophoria apta*] Molluscan Zone. The Lincoln Creek Formation is overlain by the lower Miocene part of the Astoria Formation, assigned to the Pillarian Molluscan Stage and the *Vertipecten fucanus* Molluscan Zone (Fig. 3).

Although the fossiliferous concretions are collected as float on the bank of the Columbia River, an approximate stratigraphy is preserved in the landslides because wedge-shaped blocks move south toward the river bank parallel with the strike of the rocks. One locality, informally ealled the "glass sponge bed" (LAM Loc. 5852), and others below it, called the "decapod crustacean bed" (LAM Loc. 5843) and the "gooseneck barnacle bed" (LAM Loc. 5844), all lie stratigraphically below the major mollusk-bearing unit (the *Aturia* bed) described here (LAM Loc. 5842). Faunas in these four beds are segregated in the float in proper stratigraphic position. The lack of mixing is also characteristic of faunas typical of the overlying Astoria Formation (LAM Loc. 5863).

The geology in the area is complicated by landslides, faults, by few road cuts, and by vegetative cover (Figs. 4, 5). Generally, only sections 100 m or less can be measured in tidal exposures, and the relationship between exposures is often difficult to discern (Figs. 6, 7). Mapping by Wells (1979) portrays the complexities in the area.

Despite the poor exposures, some interpretations can be made. The concretions are continuously being reworked from the landslides and new accumulations appear with sufficient regularity to be collected every two weeks at low tide. The concretions therefore are randomly distributed throughout the unit.

Most of the concretions are spherical and composed of fine-grained siltstone with calcareous cement. A few are cemented by quartz in the central part and calcite at the rim. I believe that the concretions formed early in diagenesis, because the mollusks preserved in the concretions are almost always eomplete specimens that are neither broken nor

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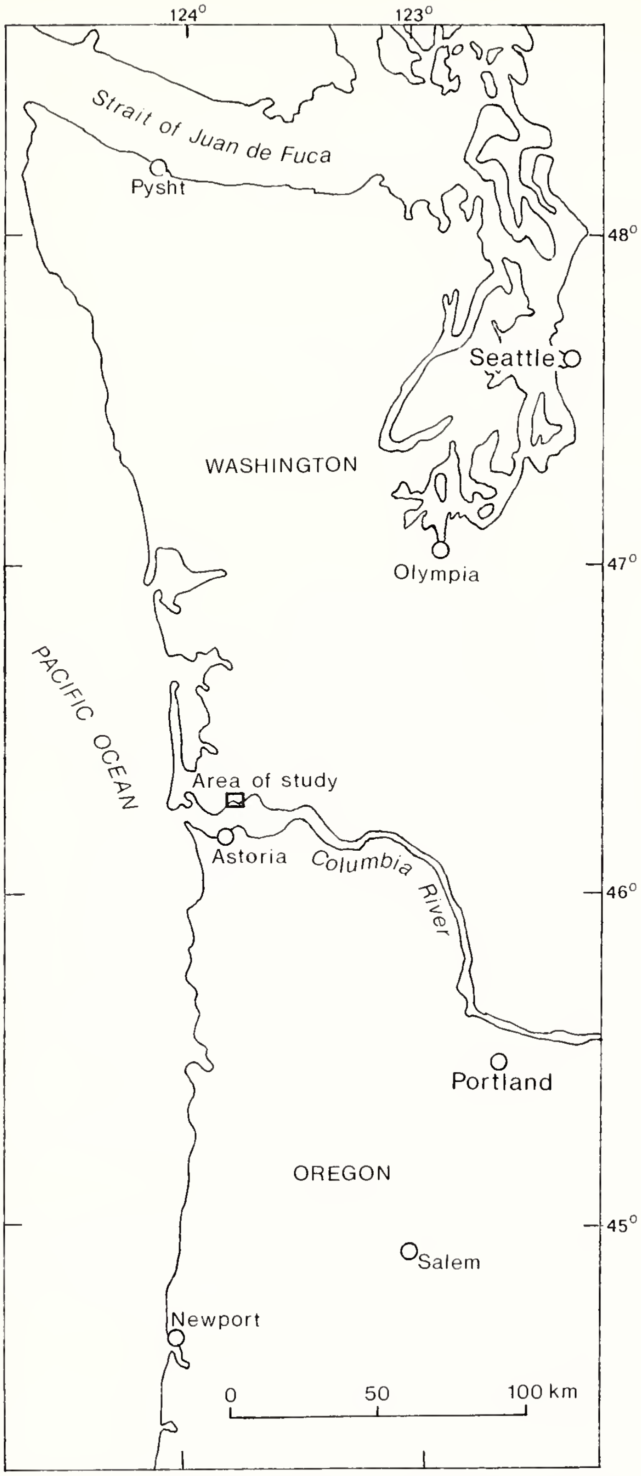


Figure 1. Index map of the Pacific coast showing localities mentioned in the text.

crushed. Delicate features of snails such as the long, narrow siphonal canal of *Priscofusus* and the T-shaped axial ribs of *Ancistrolepis* are preserved intact. Some of the concretions do not have any obvious organic center, but most contain fossils, many are bioturbated, and most contain fecal pellets.

Of particular interest as an aid to diagenetic interpretation is the preservation of complex sequences of laminated calcite, sparry calcite, barite, and quartz, precipitated in that order, within the phragmocone chambers of the cephalopod *Aturia.* This sequential mineralization is currently being studied, but it is obvious now that the laminated calcite was precipitated first followed by sparry calcite, barite, and quartz.

PREVIOUS WORK

James L. Goedert, in collaboration with Gail H. Goedert, began collecting fossils in the Knappton area in the late 1970's and donated the collections to the Natural History Museum of Los Angeles County. The first invertebrate collections were made over a relatively large area and assigned the locality number LAM 5787. Later observations led Goedert to realize that the concretions and other fossiliferous material on the terrace represented separate faunal zones. Thus he separated subsequent collections into three localities: the lowest (LAM Loc. 5844) contains abundant gooseneck barnacles (*Arcoscalpellum*) and the trace fossil *Tisoa;* the middle (LAM Loc. 5843) contains many decapod crustaceans; and the uppermost (LAM Loc. 5842) contains siliceous sponges, mollusks including large specimens of the cephalopod *Aturia,* and abundant marine vertebrates. Still later, he was able to separate the siliceous sponge-bearing locality (LAM Loc. 5852) from the other three localities. At that time, he divided the collecting area into four informal faunal units. Beginning at the base of the section these are: Unit I (LAM Loc. 5844), Unit II (LAM Loc. 5843), Unit III (LAM Loc. 5852), and Unit IV (LAM Loc. 5842) (Fig. 3).

Victor A. Zullo (1982) described the barnacles from Units I and IV. From Unit I, he described two species of gooseneck barnacles, *Arcoscalpellum knapptonensis* and *A. raricostatum,* and assigned the unit to the upper Eocene. From Unit IV, Zullo described the archaeobalinid *Solidobalanus* (*Hesperibalanus*) sp. aff. *S.* (*H.*) *sookensis* (Cornwall) and assigned the unit to the upper Oligocene.

J. Keith Rigby and David E. Jenkins (1983) described sponges from Units II, III, and IV. *Eurete goederti* was described from Unit III and *Aphrocallistes polytretos* was described from Units II, III, and IV. Rigby and Jenkins also identified *A. polytretos* in three other places: a limestone quarry in the Bear River area northwest of Knappton (LAM Loc. 5802) that is in the upper Eocene siltstones of Cliff Point unit (Wells, 1979); in the type area of the lower and middle Miocene Astoria Formation at Astoria, Oregon; and in the upper Oligocene and lower Miocene Yaquina Formation, south of Newport, Oregon. Thus *E. goederti* is early Miocene in age and the range of *A. polytretos* is late Eocene to middle Miocene.

J. Dale Nations, Northern Arizona University, is studying the decapod crustaceans from Units II and IV, Carole S. Hickman, University of California, is studying micromollusks from the section at Knappton, and Bruce J. Welton, Chevron Oil Field Research Company, the fish. Birds and marine mammals, collected throughout the section but most

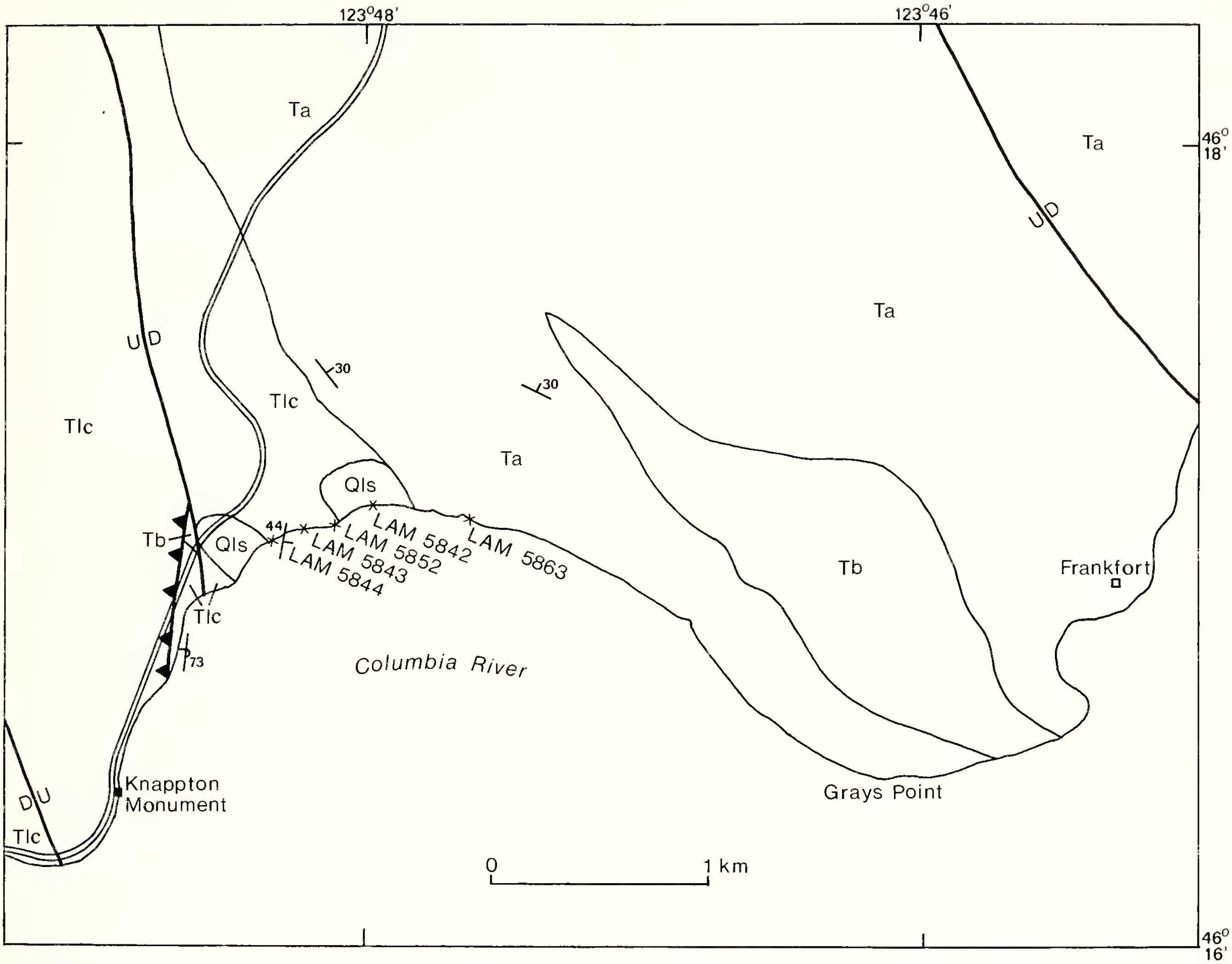


Figure 2. Geologic map of the Knappton area, Washington, modified from Wells (1979), showing fossil localities. Tlc = Lincoln Creek Formation, Ta = Astoria Formation, Tb = Tertiary basaltic sill, and Qls = Quarternary landslide material.

commonly from Unit IV, are in the vertebrate collections of the Natural History Museum of Los Angeles County.

CHRONOSTRATIGRAPHY

Molluscan stages were proposed for the Pacific northwest Tertiary section by Addicott (1976e) and by Armentrout (1975, 1977), and molluscan zones by Durham (1944), with revisions and additions by both Addicott (1976c) and Armentrout (1977). Subsequent work (Allison, 1978; Marincovich, 1979; Moore, 1984) has demonstrated the usefulness of these stages and zones (Fig. 3).

Stratigraphic sections representing the major Oligocene part of the Juanian Molluscan Stage have been extensively studied and their molluscan faunas described and illustrated (Tegland, 1933; Weaver, 1942; Durham, 1944; Armentrout, 1973; Addicott, 1976a, 1976b).

The upper part of the Lincoln Creek Formation is assigned to the upper part of the Juanian Molluscan Stage, equivalent to the upper part of the *Liracassis apta* Molluscan Zone (Fig. 3). The upper part of the formation is of early Miocene age and equivalent in age to the earliest part of the Saucesian Foraminiferal Stage.

The upper part of the Lincoln Creek Formation in southwestern Washington, assigned to the part of the Juanian that is of late Oligocene age, contains a molluscan fauna that remained essentially the same in species composition throughout the late Oligocene. The strata exposed near Knappton, which represent the highest exposed part of the Lincoln Creek Formation and the part of the Juanian Molluscan Stage that is of earliest Miocene age, contains five new species, representing about 15% of the molluscan fauna in the unit. I interpret this as indicating that this part of the section is rarely preserved and that the fauna is transitional between the well-known part (upper Oligocene) of the Juanian and the Pillarian (lower Miocene). The fauna has more

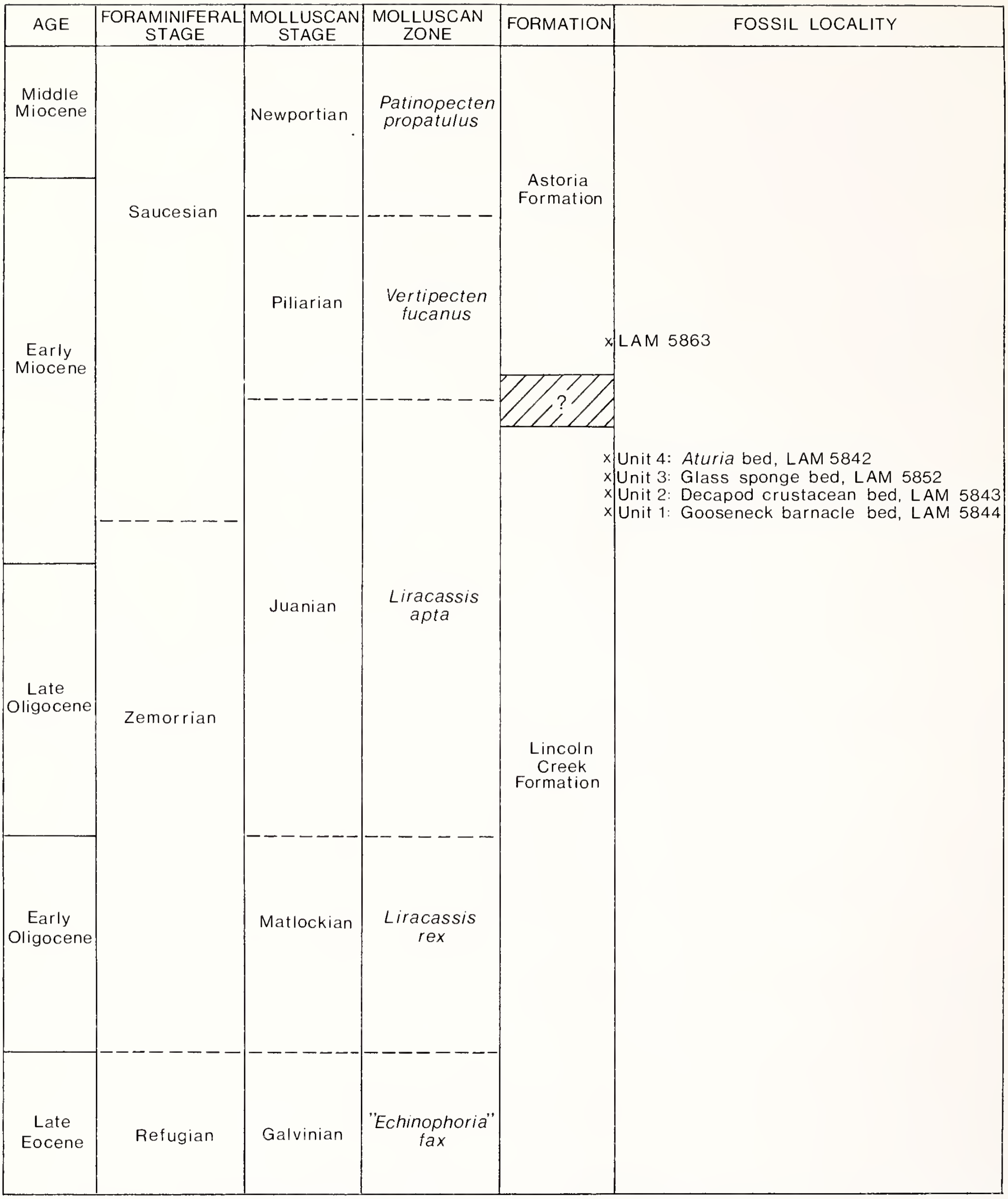


Figure 3. Stratigraphic position of fossil localities in the Lincoln Creek Formation and adjacent formations in southwestern Washington.

species in common with the Juanian than with the Pillarian, which may indicate that it is closer in age to the Juanian or lived at depths more commonly represented in the Juanian.

The mollusks from the upper part of the Lincoln Creek Formation are similar enough to the molluscan fauna from the upper part of the Pysht Formation of the Twin River Group, exposed along the Strait of Juan de Fuca, to suggest a partial correlation of those formations. Addicott (1976b:

Figure 4. View looking southwest toward Knappton monument at upper left and past fossil localities along the coast at the right. [m = monument; f = fossil localities.]

442) considered the molluscan fauna in the upper part of the Pysht Formation to belong to the *Liracassis apta* Molluscan Zone. Although *L. apta* was not collected from the Pysht Formation, Addicott believed that this was due to that unit's relatively shallow-water depositional environment rather than to the organism's extinction. On the basis of foraminiferal evidence, Addicott assigned the upper part of the Pysht Formation to the Saucesian. "*Bathybembix*" *hickmanae* n. sp., *Bruclarkia yaquinana,* and *Megasurcula* sp. cf. *M. wynoocheensis* suggest correlation of the upper part of the Lincoln Creek Formation with the upper part of the Pysht Formation.

Musashia (*Nipponomelon*) *shikamai* n. sp. and *Bruclarkia yaquinana,* from the upper part of the Lincoln Creek Formation at Knappton, were previously reported from strata

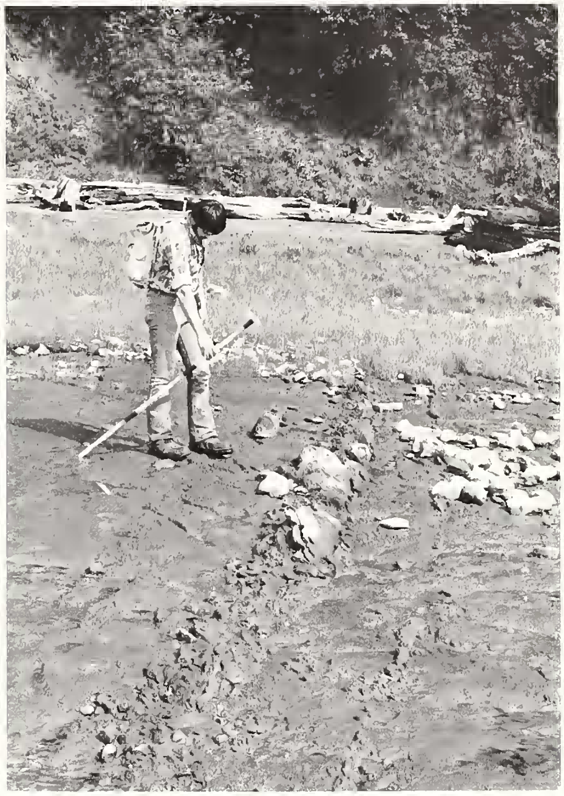


Figure 6. Tidal exposure of upper part of the Lincoln Creek Formation on the Columbia River terrace.

no older than the Clallam Formation (Addicott, 1976c:14–15) of early Miocene age, equivalent to the Pillarian Molluscan Stage. The occurrence of these species in the upper part of the Lincoln Creek Formation extends their range

Figure 5. Landslide exposure of upper part of the Lincoln Creek Formation along the Columbia River.

Figure 7. Concretionary layer in upper part of the Lincoln Creek Formation exposed in a landslide block along the Columbia River.

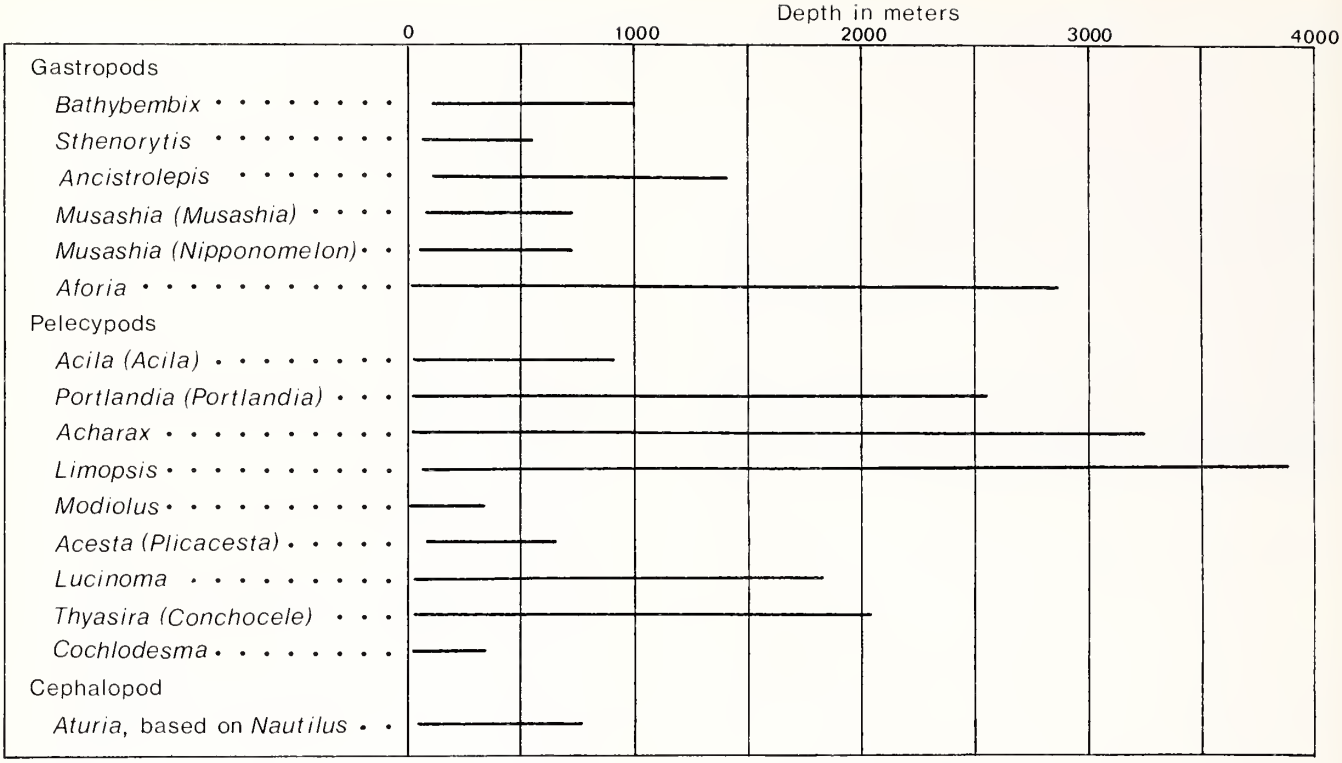


Figure 8. Depth range of living species of genera of fossils found in concretions in the *Aturia* bed near the top of the Lincoln Creek Formation, at Knappton, Washington. The overlapping ranges indicate a depth for the assemblage of about 100 to 350 meters, equivalent to the outer continental shelf or the upper continental slope.

downward into the upper part of the Juanian Molluscan Stage. This further refines the Juanian Molluscan Stage and indicates an interval in the earliest part of the Saucesian when a single molluscan province may have extended from southwestern to northwestern Washington.

The generic composition of the Knappton fauna ("*Bathybembix*," *Liracassis, Ancistrolepis,* and *Musashia*) is similar to other assemblages of mollusks collected from the Lincoln Creek Formation and its correlative units, and the conditions of deposition seem also to be similar.

Musashia (*Nipponomelon*) *weaveri* survived throughout the entire Oligocene. *Musashia* (*N.*) *shikamai* n. sp., also present in the Clallam Formation (Addicott, 1976c, pl. 3, fig. 27) and in the upper part of the Poul Creek Formation, replaced *M. weaveri* in the upper part of the Lincoln Creek Formation.

Liracassis durhami Kanno, which occurs with *Liracassis apta* at Knappton (Moore, 1984), was present during the upper part of the Juanian Stage, then became locally extinct, but survived through the Pillarian Stage in the upper part of the Poul Creek Formation in the Gulf of Alaska. Although common in the collections from Knappton, *L. durhami* is rare in other exposures of the Lincoln Creek Formation.

Ancistrolepis clarki teglandae occurs in the Oligocene part of the Juanian Stage and was preceded by *A. clarki clarki* in the Matlockian Stage. *Ancistrolepis jimgoederti* n. sp. occurs in the upper part of the Lincoln Creek at Knappton, in the lower Miocene part of the Juanian Stage.

The uppermost part of the Lincoln Creek Formation at Knappton is assigned to the earliest Miocene on the basis of its molluscan fauna. Two fossil localities of Goedert, units 3 and 4 are of early Miocene age; units 1 and 2 may be of late Oligocene age. The upper part of the Lincoln Creek Formation at Knappton is correlative with the upper part (lower Miocene) of the Pysht Formation. The placement of the upper part of the Lincoln Creek Formation in the lower Miocene corroborates the assignment of the upper part of the Juanian Stage to the lower Miocene (Addicott, 1976b:442).

PALEOECOLOGY

The Lincoln Creek Formation in southwestern Washington represents the accumulation of sediment in a relatively stable basin environment that shallowed to the southeast. The molluscan fauna of the lowermost Miocene part of the Lincoln Creek Formation at Knappton lived at dephs between 100 and 350 m (Fig. 8).

The mollusk-bearing concretions are highly bioturbated with numerous burrows. Preserved fecal pellets occur as small spherical ooids within the body chambers of gastropods, elongate pelloids within the septal chambers of the cephalopod *Aturia* (Figs. 156, 157), and both types scattered throughout the concretions. Seventeen phyla are represented in the fauna, and they indicate a healthy community of organisms living in water of normal salinity. The abundance of *Aturia* suggests that the water temperature may have been as high as 16°C with shallow embayments nearby with temperatures as high as 24°C for egg laying (Cochram, Rye, and Landman, 1981:477). The abundance of preserved organic material suggests that the sediment below the level of bioturbation was dysaerobic, reduced in oxygen (0.1–0.5 ml/liter), and that regular sedimentation gradually buried the organic material without destroying it or the organisms that lived there.

Zullo (1982 and written commun., 1982) described *Solidobalanus* (*Hesperibalanus*) aff. *S.* (*H.*) *sookensis* (Cornwall) from the upper part of the Lincoln Creek Formation at Knappton. Although this archeobalanid barnacle is representative of a sessile-benthic group usually found at subtidal to inner-shelf depths, the basal plates of the Knappton specimens suggest attachment to shells or wood, which could have been transported to the site of deposition.

Rigby and Jenkins (1983) described and assigned sponges from the upper part of the Lincoln Creek Formation to the genera *Aphrocallistes* and *Eurete;* the distribution of living species of both genera suggests that they lived at a depth of approximately 300 to 350 m.

The foraminifers in the upper part of the Lincoln Creek Formation in the Grays River quadrangle, just east of Knappton, indicate water depths of 300 to 900 m (Rau *in* Wolfe and McKee, 1972:42).

James C. Ingle, Jr. (written commun., 1982) examined thin sections made from the centers of mollusk-bearing concretions. He concluded: "All of the evidence in your thin sections suggests deposition occurred on a continental slope or marginal basin associated with impingement of the oxygen minimum layer producing anaerobic or dysaerobic conditions . . . . The core of this oxygen depleted water mass commonly occurs at a depth between 200 and 600 m off California today and the foraminifera identified in your thin sections support this depth range (*Globulimina, Epistominella, Bolivina, Uvigerina*). There is evidence of redeposition of some of the material from shallower environments with neritic-littoral echinoderm spines and thick walled porcelaneous foraminifera present in several samples. In addition, the rare glauconite fragments were likely redeposited from the adjacent shelf-edge or outer neritic area."

A sample of sediment from the head of the active landslide at the west end of the major fossil-bearing concretion locality (LAM 5842) and samples from a measured section stratigraphically below have yielded Zemmorian age foraminiferal assemblages and suggest, as a conservative estimate, that the water depth was midslope, 1000 m or possibly deeper (Kristin McDougall, written commun., 1982; James C. Ingle, Jr., written commun., 1983).

Bruce J. Welton, studying the fish remains from Knappton, has found bones, scales, and teeth to be abundant at all the localities and bony-fish otoliths to be common in almost all samples. Preliminary identifications show that the fish include seven genera of sharks representing six families, and one family of bony fish, in addition to numerous unidentified otoliths and isolated bones. According to Welton (written commun., 1982),

> Ecologically, the sharks are represented by two epipelagic genera (*Cetorhinus* and *Eugomphodus*) and five genera (*Centrophorus, Chlamydoselachus, Notorynchus, Scymnodon,* and *Pristiophorus*) with closely related living species which are predominantly benthic and deep water forms. Several taxa are broad ranging bathymetrically (*Notorhynchus* and *Pristiophorus*) but collectively the assemblage is taxonomically right for deep water. A precise depth would be difficult to substantiate but all forms would be expected to occur together at a depth of 600 to 1500 ft [180 to 460 m].
>
> Silicified otoliths are usually poorly preserved, however, the majority (98%) are of mesopelagic lanternfishes (Family Myctophidae). Many compare favorably to the genus *Diaphus.* The extant *D. theta* occurs today in the N. Pacific from N. Baja California to the Gulf of Alaska and Japan, at depths from surface (over deep water) to 2600 ft [790 m].
>
> If one considers only the present day bathymetric distribution of the genera of sharks and bony fishes known to occur at Knappton, the assemblage from all four localities would have to be characterized as a mix of epipelagic and deep water benthic sharks and mesopelagic teleosts. A bottom depth of 600 to 1500 ft [180 to 460 m] would not be unreasonable.
>
> Although the sample is small, the absence of other selachian taxa (e.g. *Heterodontus, Squatina, Squalus, Triakis, Mustelus, Galeorhinus,* and assorted skates and rays) strongly dictates against both a shallow water (shelf) origin of the fauna or resedimentation of a shallow water assemblage into deeper water by turbidites or related processes.

From LAM Vertebrate Locality 4510 (=LAM Invertebrate Locality 5842) Welton has identified *Scymnodon* sp., cf. *Diaphus* sp., and Myctophidae with a combined modern bathymetric distribution of 300 to 800 m.

Because *Aturia* is 20 times as abundant as any other mollusk in the fauna, particular attention should be paid to its inferred ecologic requirements. *Nautilus,* the structurally similar closest living relative of *Aturia,* implodes at a water depth of 785 m (Kanie et al., 1980), which presumably sets a maximum living depth for *Aturia* and the associated megafauna and microfauna. *Nautilus* eggs are probably laid in shallow water, 100 m or less. After hatching, the young descend to 250 to 350 m (Hamada, Obata, and Okutani, 1980: 47). The first seven septa in *Nautilus* have shown low $\delta^{18}O$ values, indicating *Nautilus* hatched in warm, shallow water, about 24°C (Cochram, Rye, and Landman, 1981:477). The eighth and later septa have higher $\delta^{18}O$ values, suggesting that the juvenile *Nautilus* subsequently migrates to deeper, colder water, about 16°C. Indirect evidence for the need of shallow warm water for egg laying and hatching of *Aturia* lies in the present distribution of *Nautilus* in the south Pacific

Other authors:	This report:
Musashia (*Musashia*) n. sp. Armentrout in MS (1973)	*Musashia* (*Musashia*) n. sp. a
Musashia (*Musashia*) sp. of Allison and Marincovich (1981, pl. 3, figs. 8, 14)	*Musashia* (*Musashia*?) sp. b
Musashia (*Musashia*) sp. of Allison and Marincovich (1981, pl. 3, figs. 12, 13)	*Musashia* (*Musashia*?) n. sp. c
Musashia (*Musashia*) sp. of Allison and Marincovich (1981, pl. 3, figs. 16, 17)	*Musashia* (*Nipponomelon*?) n. sp.?
Miopleiona sp. A Durham (1944:178; UCMP 35421, 35422)	*Musashia* (*Musashia*) n. sp. a
Miopleiona sp. B Durham (1944:178; UCMP 35423)	*Musashia* sp.
Miopleiona weaveri Tegland (1933:127–128, pl. 11, figs. 1–5)	*Musashia* (*Nipponomelon*) *weaveri* (Tegland)
Miopleiona scowensis Durham (1944:177–178, pl. 17, fig. 15)	*Musashia* (*Nipponomelon*) *weaveri* (Tegland)
Psephaea (*Miopleiona*) cf. *P.* (*M.*) *weaveri* (Tegland) of Addicott (1970, pl. 13, figs. 15, 19)	*Musashia* (*Nipponomelon*) *weaveri* (Tegland)
Psephaea (*Miopleiona*) *indurata* (Conrad) of Moore (1963:43–44, pl. 7, figs. 1, 2, 3–9, 11; pl. 8, figs. 1–4, 5)	*Musashia* (*Miopleiona*) *indurata* (Conrad)
Miopleiona oregonensis Dall (1909:35–36, pl. 18, figs. 3, 7)	*Musashia* (*Nipponomelon*) *oregonensis* (Dall)
Miopleiona sp. Clark (1918, pl. 23, fig. 13; UCMP 11244	*Musashia* (*Nipponomelon*?) sp.
Psephaea (*Miopleiona*) *weaveri* (Tegland) of Addicott (1970, pl. 13, fig. 17)	*Musashia* (*Nipponomelon*) *weaveri* (Tegland)
Miopleiona indurata (Conrad) of Clark (1918:185; UCMP 12030)	*Musashia* (*Nipponomelon*?) sp. cf. *M.* (*N.*) *weaveri* (Tegland)
Psephaea corrugata Clark (1932:831, pl. 21, figs. 5, 11)	*Musashia* (*Neopsephaea*) *corrugata* (Clark)
Miopleiona sp. Loel and Corey (1932:241; UCMP 12136)	*Musashia* (*Nipponomelon*) *shikamai* n. sp.
Psephaea (*Miopleiona*) cf. *P.* (*M.*) *indurata* (Conrad) of Addicott (1970, pl. 13, figs. 6, 8)	*Musashia* (*Nipponomelon*) *shikamai* n. sp.
Musashia indurata (Conrad) of Addicott (1976c, pl. 3, fig. 27)	*Musashia* (*Nipponomelon*) *shikamai* n. sp.
Musashia n. sp. of Addicott (1976a, pl. 4, fig. 18)	*Musashia* (*Nipponomelon*) n. sp.?
Rostellaria indurata Conrad (1849:727–728, pl. 19, fig. 12)	*Musashia* (*Miopleiona*) *indurata* (Conrad)
Miopleiona indurata (Conrad) of Weaver (1942:491, pl. 94, figs. 5, 8, 13)	*Musashia* (*Miopleiona*) *indurata* (Conrad)

Figure 9. Allocation of Eastern Pacific Tertiary volutids assigned to the genus *Musashia.*

and in the fact that *Aturia* became extinct in the eastern Pacific at the close of the early Miocene. A combination of cooling and marine regression may have eliminated suitable sites for reproduction. *Aturia* also probably inhabited a shelf or slope environment where it could have come into shallow warm water for nocturnal feeding and reproduction and easily returned to deeper water for resting and escape from predators.

A depth between 100 and 350 m for the organisms preserved in the concretions is indicated on the basis of all the mollusks including the most abundant element of the fauna, *Aturia.* Foraminifers from nearby sediment at the modern landslide at Knappton indicate a greater depth (about 1000 m). If the difference is real, a possible explanation is that an early Miocene submarine landslide transported the *Aturia*-bearing sediment into deeper water before lithification.

Other fossil remains present in the biota but not yet studied in detail include radiolarians, coelenterates, echinoderms, bryozoans, brachiopods, decapods, polychaetes, trace fossils, marine mammals (cetaceans), birds, seeds, and wood.

The pelecypods are mostly infaunal at shallow subbottom depths; the spantagoid echinoids and marine worms also are infaunal, perhaps to depths as much as 6 cm. The gastropods are mostly epifaunal, although the cassids may have plowed through the sediment in search of their echinoid prey. The sponges, coral, and crabs were also mostly epifaunal.

Temperature data obtained from living or closely related molluscan species are somewhat ambiguous. Whereas mollusks such as *Ancistrolepis, Aforia, Portlandia, Acharax, Acesta* (*Plicacesta*), *Acesta* (*Acesta*), and *Lucinoma* suggest temperatures between 5 and 8°C, *Aturia* may have required a temperature of at least 16°C.

MOLLUSCAN PALEONTOLOGY

The molluscan fauna consists of 33 taxa and many of these have been treated by Tegland (1931, 1933), Durham (1944), and Addicott (1970, 1976b, 1976c). Taxonomic notes rather than formal systematic descriptions are used for all but new species to avoid redundancy. Newly described species are treated more formally.

The following taxa are included, and, unless otherwise indicated, all are from LAM Locality 5842 (Unit IV) and are illustrated at natural size.

Gastropods:
- "*Bathybembix*" *hickmanae* n. sp.
- *Epitonium* (*Nitidiscala*?) sp.
- *Sthenorytis* sp.
- Unidentified naticids
- *Liracassis durhami* Kanno
- *Liracassis apta* (Tegland)
- Buccinid?
- *Bruclarkia yaquinana* (Anderson and Martin)
- *Ancistrolepis jimgoederti* n. sp.

Priscofusus? sp. cf. *P. geniculus* (Conrad)
Musashia (*Musashia*) n. sp.
Musashia (*Nipponomelon*) *shikamai* n. sp.
Musashia (*Miopleiona*) n. sp.
Aforia wardi (Tegland)
Turricula? sp.
Megasurcula? sp. cf. *M. wynoocheensis* (Weaver)
Microglyphus n. sp.?

Pelecypods:
Acila (*Acila*) *gettysburgensis* (Reagan)
Portlandia (*Portlandia*) *chehalisensis* (Arnold)
Acharax dalli (Clark)
Limopsis nitens (Conrad)
Modiolus addicotti n. sp.
Acesta (*Acesta*) *twinensis* (Durham)
Acesta (*Plicacesta*) *wilsoni* n. sp.
Crassostrea? sp.
Lucinoma hannibali (Clark)
Thyasira (*Conchocele*) *disjuncta* (Gabb)
Nemocardium? sp. cf. *N. lorenzanum* (Arnold)
Macoma sp. cf. *M. twinensis* Clark
Cochlodesma bainbridgensis Clark
Teredinid

Scaphopod:
Dentalium (*Fissidentalium*?) sp. cf. *D. porterensis* Weaver

Cephalopods:
Aturia angustatata (Conrad)
Sepiid?

ABBREVIATIONS

CAS: California Academy of Sciences, San Francisco.
LACMIP: Natural History Museum of Los Angeles County, Invertebrate Paleontology Section, California.
LACMP: Natural History Museum of Los Angeles County, Invertebrate Paleontology Section, California.
LAM: Natural History Museum of Los Angeles County, California.
CAS/SU: Stanford University, Stanford, California. (The Stanford University collections are now housed at the California Academy of Sciences.)
SU: Stanford University, Stanford, California.
UC: University of California, Berkeley.
UCMP: University of California, Museum of Paleontology, Berkeley.
USGS: U.S. Geological Survey, Washington, D.C., Cenozoic locality register.
USGS M: U.S. Geological Survey, Menlo Park, California, Cenozoic locality register.
USNM: National Museum of Natural History, Washington, D.C.
UW: University of Washington, Seattle, Washington.

GASTROPODS

Trochidae

The genus *Bathybembix* is used here in a broad sense following Hickman (1980:16) who is currently undertaking a detailed revision of the large tuberculate trochid gastropods allied to *Bathybembix.* The Pacific Northwest fossil species, *Turcicula columbiana* Dall (1909:99–100, pl. 3, figs. 2, 11) and *T. washingtoniana* Dall (1909:99–100, pl. 17, figs. 1, 2; pl. 18, fig. 4) were considered by Rehder (1955:225) to "belong to *Bathybembix,* or are more closely related to that genus than to any other." Noda (1975:60) believed that "*Turcicula*" *columbiana* and "*T.*" *washingtoniana* differ sufficiently to warrant a new subgeneric name. Certainly "*T.*" *washingtoniana* needs more careful scrutiny in terms of generic or subgeneric allocation. Other Pacific coast fossil species that have been assigned to *Turcicula* or to *Bathybembix* are: *Turcicula arnoldi* Durham (1944:153–154, pl. 15, fig. 10), *Turcicula sanctacruzana* Arnold (1908:373, pl. 33, fig. 4), *Turcicula turbonata* Clark (1932:826, pl. 20, fig. 11), and *Bathybembix nitor* Hickman (1980:17–18, pl. 2, figs. 1, 2). In addition, Armentrout (1973), in his study of the Lincoln Creek Formation in Washington, recognized three new species which he assigned to *Bathybembix.*

***"Bathybembix" hickmanae* n. sp.**

Figures 10–12, 18

Bathybembix aff. *B. arnoldi* (Durham). Addicott, 1976b, figs. 6u, w.

"*Bathybembix*" *hickmanae* is a thin-shelled, moderately large trochid with five whorls. The body whorl is characterized by two spiral cords separated by an almost vertical angulation. The whorls of the spire also have two spiral cords, one at the suture separated from the cord above by the same type of vertical angulation. The outer shell layer is preserved only in small patches, but the spirals may have been keeled and tuberculate on the shoulder of the body whorl and the spire whorls; the rest of the shell may have been smooth. The available specimens are poorly preserved and no nacreous shell material is apparent on any of shell patches preserved, whereas nacreous shell material is commonly preserved on both "*Bathybembix*" *columbiana* and "*Bathybembix*" *washingtoniana.*

HOLOTYPE. LACMIP 6623, height 42 mm, width 35 mm; paratypes LACMIP 6621, height 41 mm, width 35 mm; LAM 6622, height 28 mm.

TYPE LOCALITY. LAM 5842.

"*Bathybembix*" *hickmanae* somewhat resembles "*B.*" *arnoldi* (Durham) and "*B.*" *sanctacruzana* (Arnold) in outline but differs in having both a steeper and longer slope between the spirals and the suture on the body whorl. In addition, "*B.*" *hickmanae* has the anterior spiral on the spire whorls at the suture, whereas "*B.*" *arnoldi* and "*B.*" *sanctacruzana* have a space between the anterior spiral and the suture. The vertical angulation between spirals on the body whorl and the higher spire in proportion to width separate "*B.*" *hickmanae* from "*B.*" *washingtoniana* (Dall). In addition, "*B.*" *washingtoniana* has a strong keel on the periphery of the body whorl. The vertical angulation between spirals on the body whorl distinguishes "*B.*" *hickmanae* from "*B.*" *turbonata* (Clark). "*Bathybembix*" *columbiana* (Dall, 1909:100, pl. 3, figs. 2, 11) has a higher spire and larger nodes than

"*B.*" *hickmanae.* "*Bathybembix*" *hickmanae* differs from "*Bathybembix*" *nitor* (Hickman) in having a quadrate rather than an ovate aperture.

Traditionally, the species assigned to *Bathybembix* have been assumed to indicate deep, often bathyal depths. The bathymetric distribution of living species in Japan, assigned to *Turcicula, Bathybembix, Ginebis,* and *Convexia,* is 100 to 1000 m (Noda, 1975:58, fig. 3).

This species is named in honor of Carole S. Hickman.

Epitoniidae

Epitonium (*Nitidiscala*?) sp.

Figures 13, 14, 16

A latex impression of the mold of a specimen preserved in a concretion is illustrated along with the original external and internal molds. It is a thick-shelled epitoniid with seven whorls preserved each of which probably bore 14 or 15 thick axial ribs (seven are exposed). No spiral sculpture is preserved.

The rounded whorls, deep sutures, slim high spire, and lack of spiral sculpture between the axial ribs suggest *Nitidiscala.*

This species somewhat resembles *Epitonium* (*Cirsotrema*) *saundersi* Tegland (1933:133, pl. 13, figs. 7–9; Durham, 1937: 491–492, pl. 57, fig. 21) which occurs in the *Liracassis rex* Molluscan Zone (Durham, 1944:158). *Epitonium saundersi,* however, has spiral sculpture and less rounded but wider whorls than *E.* (*N.*?) sp.

Sthenorytis sp.

Figures 15, 19, 20

Sthenorytis sp. may have had five, or possibly more, rapidly enlarging well-rounded whorls, including a very large body whorl set off from the axis at an angle of about 40°, as is typical of *Sthenorytis.* The suture presumably is deep, and the body whorl may have had 16 varices. The varices are rather evenly spaced, triangular in cross section, sharp edged, and project about 4 mm beyond the shell.

The only described species resembling *S.* sp. is *Sthenorytis ventricosum* (Clark, 1918:164, pl. 23, fig. 14) from the San Ramon Sandstone, California. It has a smaller body whorl (31 mm wide) than *S.* sp. (36 mm wide) and is 45 mm high compared to about 55 mm for *S.* sp. The varices number about 12 and are rounded on *S. ventricosum; S.* sp. has about 16 varices that are triangular and sharp-edged.

Three Pacific coast Tertiary species are assigned to *Sthenorytis: S.*? *crescentense* (Durham, 1937), *S. ventricosum* (Clark, 1918), and *S. stearnsi* (Dall, 1892). The geologic range of these species is Eocene to Pliocene and the geographic range is northwestern Washington to southern California.

Sthenorytis lives today no farther north than the Gulf of California and Cape San Lucas; it lives in warm water in the Pacific and the Atlantic and is usually found on sandy bottoms (Durham, 1937:499). Woodring (1959:184) reported *S. pernobilis* (Fischer and Bernardi) from Cape Hatteras to the Lesser Antilles at depths of 134 to 220 m, Keen (1971:434, 436) recorded *S. dianae* (Hinds) from Baja California Sur in 82 to 145 m and *S. turbinum* (Dall) from the Gulf of California to the Galapagos Islands in 82 to 550 m, and Clench and Turner (1950:225–226) recorded *S. pernobilis* (Fischer and Bernardi) from North Carolina to the Lesser Antilles at 134 to 284 m.

Naticidae

Unidentified naticid

Figure 17

Naticids that may represent *Polinices* (*Euspira*) are represented by three specimens, none with the umbilical area well enough preserved for positive identifications.

Cassididae

Two species of *Liracassis, L. durhami* and *L. apta,* were found in the upper part of the Lincoln Creek Formation.

Liracassis durhami Kanno

Figures 21–23, 25, 26

Liracassis durhami Kanno, 1971:112–113, pl. 13, figs. 14a–b.

Liracassis durhami Kanno has nodes on the shoulder that usually form oblique ridges to the suture (Figs. 21–23, 25), but may be separated from the suture by a narrow unsculptured band or confined to two spiral straps. Secondary spirals are absent on the body whorl except for one specimen which

Figures 10–23. "*Bathybembix*" *hickmanae* n. sp., *Epitonium* (*Nitidiscala*?) sp., *Sthenorytis* sp., unidentified naticid, and *Liracassis durhami* Kanno.

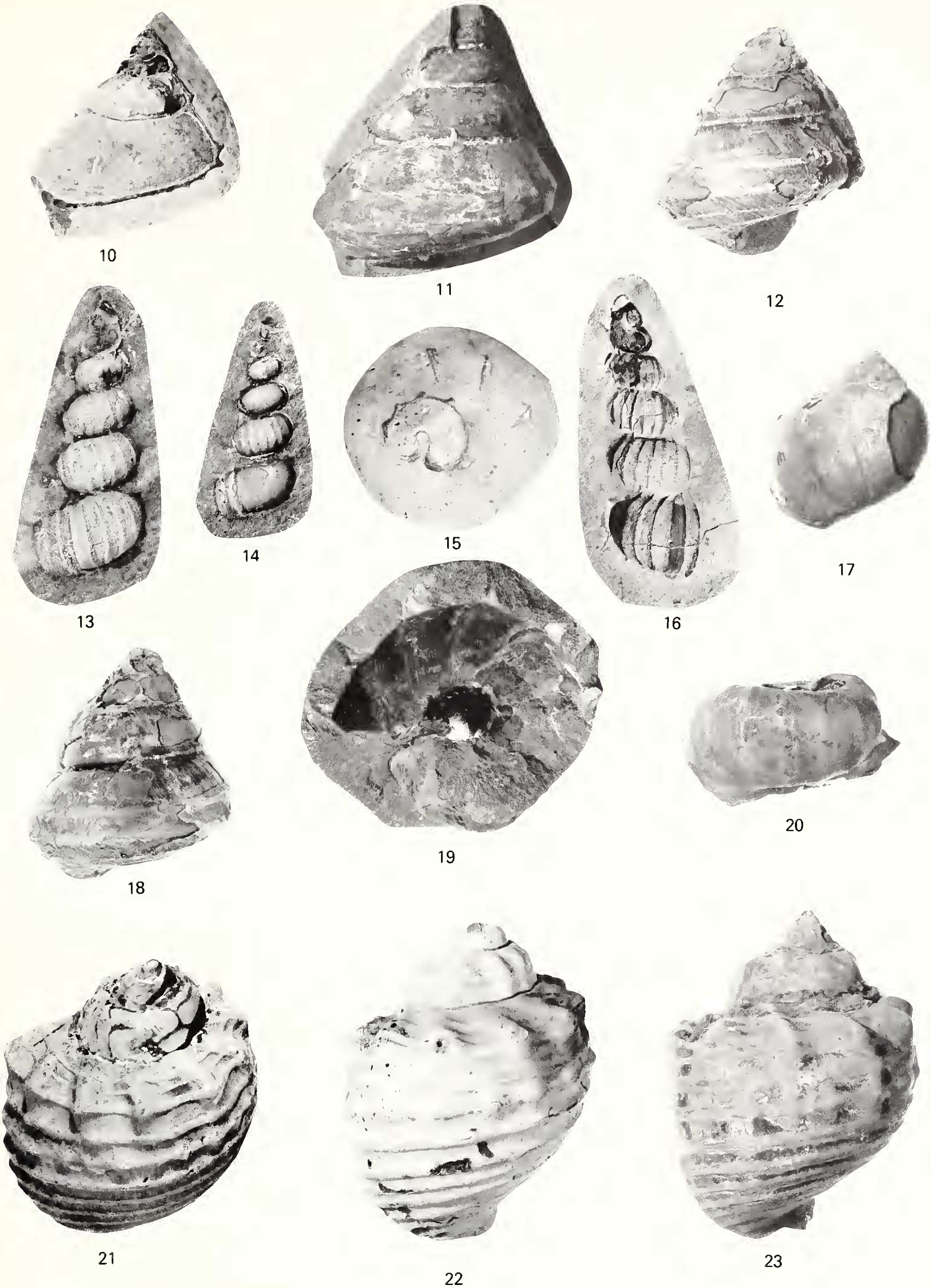
Figures 10–12, 18. "*Bathybembix*" *hickmanae* n. sp. **10.** Paratype LACMIP 6621, height 41 mm, width 35 mm. Showing cross section of spiral cords. **11.** Paratype LACMIP 6622, height 28 mm. Showing nodes on shoulders of spire and body whorl, ×1.5. **12, 18.** Holotype LACMIP 6623, height 42 mm, width 35 mm. Showing patches of preserved shell.

Figures 13, 14, 16. *Epitonium* (*Nitidiscala*?) sp. **13.** Latex impression of specimen shown in Figure 16, ×1.5. **14.** Internal mold, height 25 mm, width 10 mm. LACMIP 6624a. **16.** External mold from which latex impression was taken shown in Figure 13, ×2.0; height 26 mm, width 10 mm. LACMIP 6624.

Figures 15, 19, 20. *Sthenorytis* sp. **15.** View looking down upon spire, ×1.5; height 55 mm. LACMIP 6625a. **19.** View of base of same specimen in Figure 15 showing triangular cross section of varices, ×1.5. LACMIP 6625b. **20.** Portion of body whorl of specimen shown in Figure 19, width 37 mm.

Figure 17. Unidentified naticid, ×1.5; height 23 mm, width 20 mm. LACMIP 6626.

Figures 21–23. *Liracassis durhami* Kanno. **21.** Showing one secondary rib in interspace, ×1.5; width 46 mm. LACMIP 6627. **22.** Showing ridges on shoulder of body whorl; height 57 mm, width 46 mm. LACMIP 6628. **23.** Showing spire; height 63 mm, width 48 mm. LACMIP 6493.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has a single intercalary in one interspace (Fig. 26). *Liracassis durhami* always has a rounded body whorl without nodes below the shoulder; this character distinguishes it from *Liracassis rex* (Tegland, 1931:413–415, pl. 60, fig. 12; pl. 61, figs. 1–4; pl. 62, figs. 1–6), depicted in Figure 32 and the tabulate form of *L. apta* (Figs. 27, 31, 33, 39, 42). From the round form of *L. apta* (Figs. 24, 28, 30, 47), *L. durhami* is distinguished by its more concave body-whorl shoulder, ridgelike nodes on the shoulder, and the absence of intercalaries on the body whorl. *Liracassis durhami* always has nodes on the shoulder of the body whorl, whereas the round form of *L. apta* may not. *Liracassis petrosa* (Moore, 1963, pl. 10, figs, 7, 17) differs from *L. durhami* in having intercalaries between primary spirals on the body whorl and nodes that are more fluted on the periphery of the body-whorl shoulder, forming less oblique and generally smaller ridges on the shoulder.

Liracassis durhami ranges from the northeastern Gulf of Alaska to southwestern Washington; it occurs in the upper part of the Poul Creek Formation and the lower part of the Yakataga Formation, Alaska, as well as in the upper part of the Lincoln Creek Formation, Washington. In the lower part of the Yakataga Formation in Alaska, *L. durhami* is associated with Pillarian mollusks (Scott McCoy, pers. commun., 1980). In Washington, *L. durhami* ranges from the upper Galvinian Stage through the Juanian Stage. The infrequent occurrence of *L. durhami* compared to *L. apta* in the upper part of the Lincoln Creek Formation may indicate that southwestern Washington was at the southern limit of its range. *Liracassis apta* is restricted to the Juanian, but has a greater geographic range than *L. durhami,* having been found as far south as California (Ham, 1952:8).

Liracassis apta (Tegland)

Figures 24, 27–31, 33, 39, 42, 46, 47

Galeodea apta Tegland, 1931:415–417, pl. 63, figs. 1–10.

Liracassis apta is common in the upper part of the Lincoln Creek Formation. The largest specimens of *L. apta* usually have round shoulders (Figs. 28, 30), but it is not uncommon to find large specimens with tabulate shoulders nor is it unusual to find small specimens with round shoulders. The largest specimens of the round-shouldered form almost never have nodes on either the shoulder or the rest of the body whorl. The tabulate form always has nodes on the shoulder of the body whorl and may have them on spiral cords anterior to the shoulder. Of the *Liracassis* species studied (Moore, 1984), *L. apta* is the only one showing the wide range of variation first noted by Tegland (1931:401, 406), who distinguished three varieties. Tegland's varieties 1 and 2 fit into the tabulate form and variety 3 into the round-shouldered form. *Liracassis apta* has intercalaries in the interspaces between primary spiral cords (Fig. 24) as do *L. rex,* from the type section of the Blakeley Formation of Weaver (1912), Washington, and *L. petrosa,* from the Astoria Formation, Oregon, but *L. durhami* is distinguished by having smooth spaces between the primary spirals. *Liracassis rex* always has nodes on the eoncave shoulder of its body whorl; these nodes are not confined to the shoulder but continue adapically as ridges to the suture, whereas in *L. apta* the nodes, if present, are confined to the shoulder periphery. *Liracassis rex* always has at least one, and commonly more than one, row of nodes below the shoulder; *L. apta* never has more than one row and commonly has none at all. The nodes on the periphery of the shoulder of *L. petrosa* are fluted, whereas they are rounded in *L. apta. Liracassis apta* is restricted to the Juanian Stage, and its geographic range is from California to the western Gulf of Alaska.

Studies of living cassids have shown that these carnivores eat only echinoids, and that different species within each cassid genus prefer certain distantly related genera of echinoids. That different echinoids can serve as food for closely related cassids makes clear how two different species of *Liracassis,* such as *L. durhami* and *L. apta,* could live in the same biologic community, but in different niches.

Buccinidae?

Unidentified buccinid

Figure 36

A single specimen of a poorly preserved gastropod may be a buccinid. Although many gastropod families can be eliminated from consideration on the basis of outline, sculpture, suture, aperture, or siphonal canal, the specimen is not identified with complete confidence as a buccinid. The evenly rounded whorls, slightly impressed suture, elongate-oval aperture, seeming lack of columellar plaits, a probably short, straight siphonal canal, and cancellate sculpture suggest buccinid genera such as *Cymatophos* or *Antillophos.*

Neptuneidae

Bruclarkia yaquinana (Anderson and Martin)

Figures 41, 44

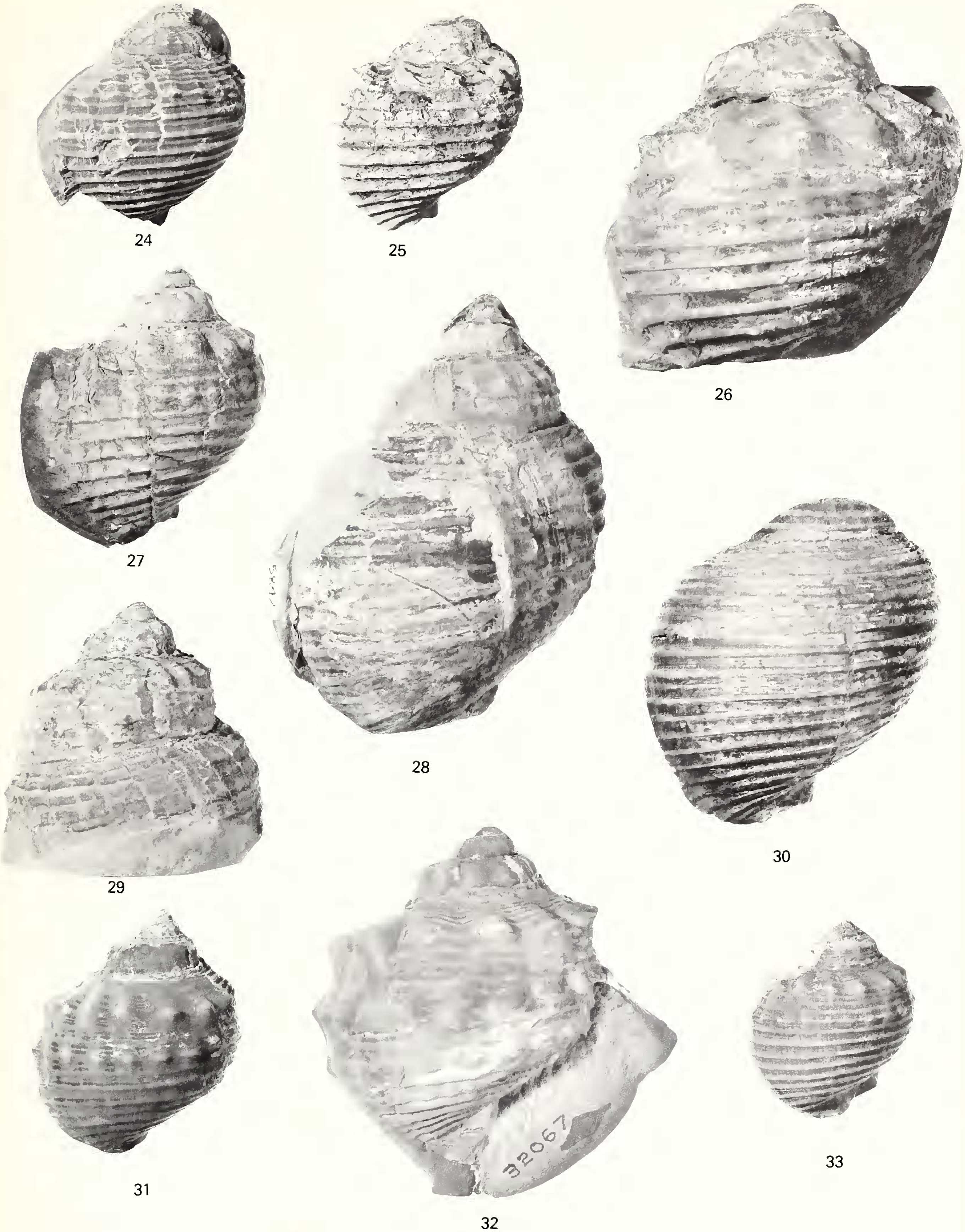
Agasoma yaquinana Anderson and Martin, 1914:75, pl. 4, figs. 5a–b.

Figures 24-33. *Liracassis apta* (Tegland), *Liracassis durhami* Kanno, and *Liracassis rex* (Tegland).

Figures 24, 27-31, 33. *Liracassis apta* (Tegland). **24.** Round form without body-whorl nodes; height 44 mm, width 37 mm. LACMIP 6495. **27.** Tabulate form; height 55 mm. LACMIP 6629. **28.** Round form; height 85 mm, width 62 mm. LACMIP 6630. **29.** Showing round body whorl and tabulate spire; height 63 mm, width 49 mm. LACMIP 6631. **30.** Round form; height 63 mm. LACMIP 6632. **31.** Tabulate form with nodes on body whorl; height 47 mm, width 42 mm. LACMIP 6633. **33.** Tabulate form with beads on body whorl; height 40 mm, width 33 mm. LACMIP 6634.

Figures 25, 26. *Liracassis durhami* Kanno. **25.** Showing smooth interspaces and ridges on shoulder; height 43 mm, width 39 mm. LACMIP 6496. **26.** Showing straplike spiral cords; height 70 mm, width 66 mm. LACMIP 6494.

Figure 32. *Liracassis rex* (Tegland). Showing nodes on body whorl of holotype UCMP 32067; height 75 mm, width 64 mm. Blakeley Formation, Restoration Point, Seattle, Washington.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Bruclarkia yaquinana is represented by a single incompletely preserved specimen (Figs. 41, 44). As noted by Addicott (1970:90–91; 1976c:23), *B. yaquinana* is characterized by four or five coarsely noded spiral cords on the body whorl. *Bruclarkia oregonensis* (Conrad, 1848:433, fig. 13; Moore, 1963: pl. 3, figs. 2, 3, 8, 11, 13) has finer spiral sculpture and is a larger, more rounded species. In the San Joaquin Valley, California, the stratigraphic occurrence of *B. yaquinana* (basal part of the Jewett Sand) and *B. oregonensis* (Olcese Sand) is mutually exclusive (Addicott, 1970:91). In the Clallam Formation of northwestern Washington, *B. oregonensis* occurs almost exclusively at the top of the formation, and *B. yaquinana* at and near the base (Addicott, 1976c:23–24).

Ancistrolepis jimgoederti n. sp.

Figures 34, 35, 37, 38, 40, 43, 45, 56, 58, 59

The shell of *Ancistrolepis jimgoederti* is large and thin with eight or nine subtabulate whorls that bear T-shaped spiral cords that are strongly undercut and, on the holotype (Figs. 35, 37, 38), preserve three secondary spiral cords. The interspaces on the body whorl bear secondary spiral cords and one specimen has four moderately prominent and three very fine secondary cords preserved in one interspace. On this same specimen, fine vertical striations are preserved in one interspace, perhaps reflecting the periostracum. The specimen with the most whorls preserved (eight) is 68 mm in height (incomplete), and the specimen with the largest body whorl has a maximum width of 36 mm. The largest T-shaped spiral cord preserved projects 3.2 mm beyond the shell body. The T-shaped spirals are preserved only in concretionary matrix (Fig. 58) from which they were subsequently exposed by preparation (Figs. 34, 35, 37, 38, 40). The body of the shell is so thin that the spiral cords exfoliate easily from the shell, leaving preserved a completely erroneous shell outline (Figs. 43, 45). The T-shaped spirals are now replaced by sparry calcite, but do not seem to have been hollow folds of the shell, as in the genus *Ecphora* from the Miocene of the eastern United States (Vokes, 1957, pl. 25, fig. 2).

HOLOTYPE. LACMIP 6636, height 55 mm, width 35 mm; paratypes LACMIP 6635, height 40 mm, width 29 mm; LACMIP 6637, height 67 mm, width 35 mm; LACMIP 6638, height 65 mm, width 35 mm; LACMIP 6646, width 35 mm; and LACMIP 6647, height 70 mm.

TYPE LOCALITY. LAM 5842.

Species, such as *Ancistrolepis clarki* (Tegland, 1933:131–132, pl. 12, fig. 14), *A. landesi* (Tegland, 1933:132–133, pl. 13, figs. 1–4), and *A. clarki teglandae* (Durham, 1944:177, pl. 17, fig. 2), may also have had T-shaped spirals that were removed by exfoliation. The concretionary fragments remaining with the holotype of *A. clarki teglandae*, and the specimen itself (Figs. 52, 54), show no indication of T-shaped spirals, but some specimens of *A. jimgoederti* also show no indication of these spirals (Fig. 43).

Grant and Gale (1931:657) noted the similarity in spiral sculpture between *Ancistrolepis* and *Beringius* and suggested that perhaps *Ancistrolepis* should be considered a section or synonym of *Beringius* (Dall, 1887:304; type species *Chrysodomus crebicostatus* Dall). Clifford M. Nelson, U.S. Geological Survey, kindly called my attention to the fact that the whorl proportions, aperture, and fasciole of *A. jimgoederti* do not fit *Neptunea* in the strict sense, and that the species is more closely related to *Ancistrolepis*. Species from the eastern Pacific Tertiary that have been assigned to *Ancistrolepis* are: *Ancistrolepis rearensis* (Clark, 1932), *Ancistrolepis macneili* Kanno (1971), *Ancistrolepis clarki clarki* Tegland (1933), *Ancistrolepis clarki teglandae* Durham (1944), *Ancistrolepis landesi* Tegland (1933), and *Ancistrolepis packardi* Durham (1944).

The spiral ribs on the penultimate whorl of *Ancistrolepis rearensis* (Clark, 1932:831, pl. 20, figs. 14, 15) are described as having a fairly prominent collar and thus would resemble those on *A. jimgoederti*. *Ancistrolepis rearensis* has convex whorls rather than subtabulate ones and lacks the concavity just below the suture, present on *A. jimgoederti*. Kanno (1971:118) placed *A. clarki teglandae* into synonymy with *A. rearensis* without discussion, and Addicott (1976c:23) cited it as a junior synonym. *Ancistrolepis clarki teglandae* (Figs. 52, 54) has a round body whorl and a shorter, wider spire than *A. jimgoederti*. *Ancistrolepis macneili* Kanno (1971:119, pl. 14, fig. 7) is much more inflated and has a shorter spire in proportion to the body whorl than does *A. jimgoederti*. The body whorl of *A. clarki clarki* is evenly rounded to the suture; the body whorl of *A. jimgoederti* is deeply concave between the suture and the first spiral cord and the whorls of the spire are more tabulate. *Ancistrolepis clarki clarki* is also wider and has fewer whorls (six or seven) than *A. jimgoederti*. *Ancistrolepis landesi* has a high spire, similar to *A. jimgoederti*, but the body whorl is convex to the suture rather than concave just below the suture. In addition, the primary spiral cords on the body whorl of *A. landesi* are grouped together

Figures 34–47. *Ancistrolepis jimgoederti* n. sp., unidentified buccinid, *Liracassis apta* (Tegland), and *Bruclarkia yaquinana* (Anderson and Martin).

Figures 34, 35, 37, 38, 40, 43, 45. *Ancistrolepis jimgoederti* n. sp. **34.** Paratype LACMIP 6635. Showing secondary spirals, ×1.5; height 40 mm, width 29 mm. **35, 37, 38.** Holotype LACMIP 6636; height 55 mm, width 35 mm. Figures 35 and 37 show primary spirals sculptured by secondaries. Figure 38 is the same specimen tipped to display undercut spiral cords. **40.** Same specimen as Figure 34. Showing angular spiral cord, ×1.5. **43.** Paratype LACMIP 6637. Showing cast from which shell has exfoliated; height 67 mm, width 35 mm. **45.** Showing spiral cords in concretion; height 65 mm, width 35 mm. Paratype LACMIP 6638.

Figure 36. Unidentified buccinid, ×2.0; height 28 mm, width 13 mm. USGS Loc. M 7891, USNM 363986.

Figures 39, 42, 46, 47. *Liracassis apta* (Tegland). **39.** Tabulate form with body whorl nodes; height 45 mm, width 35 mm. LACMIP 6497. **42.** Tabulate form showing nodes and intercalaries; height 49 mm. LACMIP 6639. **46, 47.** Rear and apertural view of round form; height 68 mm, width 45 mm. LACMIP 6640.

Figures 41, 44. *Bruclarkia yaquinana* (Anderson and Martin). Views of aperture and side showing configuration and sculpture, ×1.5; height 30 mm, width 22 mm. LACMIP 6641.


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on the middle of the body whorl whereas they are equally spaced from the suture on *A. jimgoederti.* The entire shell of *A. landesi* bears fine, evenly spaced secondary spiral sculpture. The one specimen of *A. jimgoederti* that has the secondary spiral sculpture preserved (Figs. 34, 37, 40) shows the spirals to be of unequal strength and spacing. The living species *Ancistrolepis grammatus* (Dall, 1907:158; 1925:3, pl. 30, fig. 8) has T-shaped spiral cords on a thin shell with subtabulate whorls. The body whorl, however, has nine T-shaped spirals of almost equal width compared to five on *A. jimgoederti* and the spire whorls have five rather than three or four spirals. The siphonal canal of *A. jimgoederti* is probably slightly longer and more strongly recurved than on *A. grammatus* and also bears finer spiral sculpture.

Weaver (1942:427) assigned *Ancistrolepis clarki clarki* to *Neptunea,* and renamed it *N. teglandae,* as *N. clarki* was a homonym of *Neptunea clarki* (Meek). The reassignment of *A. clarki clarki* to *Ancistrolepis* makes this action by Weaver no longer necessary.

Ancistrolepis landesi and *A. clarki clarki* occur in the type Blakeley Formation in the *Liracassis rex* Molluscan Zone. *Ancistrolepis clarki teglandae* occurs in the upper part of the Pysht Formation of the Twin River Group in the *Liracassis apta* Molluscan Zone. *Ancistrolepis rearensis* was originally collected from the upper part of the Poul Creek Formation in the *Liracassis apta* Molluscan Zone and the geographic and stratigraphic ranges were subsequently extended by Addicott (1976c:23) to the Clallam Formation, Washington, in the *Vertipecten fucanus* Molluscan Zone. *Ancistrolepis jimgoederti* was collected from the upper part of the Lincoln Creek Formation, in the upper (Saucesian) part of the *Liracassis apta* Molluscan Zone.

Chrysodomus eucosimium Dall (1891:187–188), the genotype of *Ancistrolepis,* was collected off the coast of Unalaska in the Bering Sea. *Ancistrolepis grammatus* was collected from Tsugaru Strait, Japan, at a depth of 550 m where the surface temperature averages about 18°C.

This species is named in honor of James L. Goedert.

Fusinidae

Priscofusus? sp. cf. *P. geniculus* (Conrad)

Figures 50, 53, 55, 60, 61

Priscofusus? sp. cf. *P. geniculus* (Conrad) is represented by three specimens; two free of matrix (Figs. 50, 53, 55, 61) and the third preserved in a concretion with the shell missing on most of the specimen, but replaced by sparry calcite where still embedded (Fig. 60). *Priscofusus geniculus* (Conrad, 1849: 728, pl. 20, fig. 3) has been described and illustrated by Moore (1963:40–41, pl. 6, figs. 13, 15–18) and by Addicott (1970: 101–102, pl. 12, figs. 21, 22, 26, 28–30) and occurs in the Astoria Formation, Oregon, and the Jewett Sand, California. The *Priscofusus* reported from the Clallam Formation (Addicott, 1976c:24, pl. 2, fig. 12) and the Nye Mudstone (Moore, 1963:41, pl. 6, figs. 12, 19) may represent a new species.

Volutidae

Neogene volutids of the eastern Pacific Tertiary have in recent years commonly been assigned to the genus *Musashia* (Hayashi, 1960) and the subgenus *Musashia* or *Miopleiona* (Dall, 1907). A new species of *Miopleiona* from the Eugene Formation in Oregon (Howe, 1922) extends the geologic range of that subgenus into the late Eocene or early Oligocene.

Nipponomelon (Shikama, 1967), a subgenus previously reported from the Miocene to Holocene in Japan, is used here for most of the northeastern Pacific volutids, thus extending the geographic range of the subgenus across the Pacific and the geologic range into the Oligocene.

Musashia (*Musashia*) has a smooth shell or only thin axial ribs; axial ribs, if present, may be only on the posterior portion of the whorls (Fig. 70); the suture is slightly impressed. *Musashia* (*Nipponomelon*) has thin axial ribs, a slightly impressed suture, and only rarely a sutural collar (Figs. 66, 68). *Musashia* (*Miopleiona*) has very thick keel-like ribs markedly curved near the suture, which is deeply impressed and channeled (Figs. 51, 57, 64, 67). Shikama (1967) thought that *Miopleiona* was intermediate between the subgenera *Musashia* and *Nipponomelon* and was uncertain as to its proper assignment, although he placed it in the genus *Musashia.* On the basis of the suture and the thick axial ribs, *Miopleiona* could perhaps be elevated to generic rank. The type species of *Miopleiona* is *Musashia* (*Miopleiona*) *indurata* (Conrad, 1849). The markedly curved axial ribs and deeply channeled suture of *M.* (*M.*) *indurata* set it apart from all other described species of volutids, but the undescribed new species from the Eugene Formation, Oregon (Howe, 1922), also has a deeply channeled suture (Fig. 48) and is here assigned to *Miopleiona.* The suture is so deeply channeled on *Miopleiona* that even internal molds can be identified as belonging in the subgenus.

Figures 48–61. *Musashia* (*Miopleiona*) n. sp., *Musashia* (*Nipponomelon*) *shikamai* n. sp., *Priscofusus*? sp. cf. *P. geniculus* (Conrad), *Musashia* (*Nipponomelon*) *indurata* (Conrad), *Ancistrolepis clarki teglandae* Durham, and *Ancistrolepis jimgoederti* n. sp.

Figure 48. *Musashia* (*Miopleiona*) n. sp. Plaster cast of a specimen from the Eugene Formation, Oregon; height 95 mm. CAS/SU 2358.

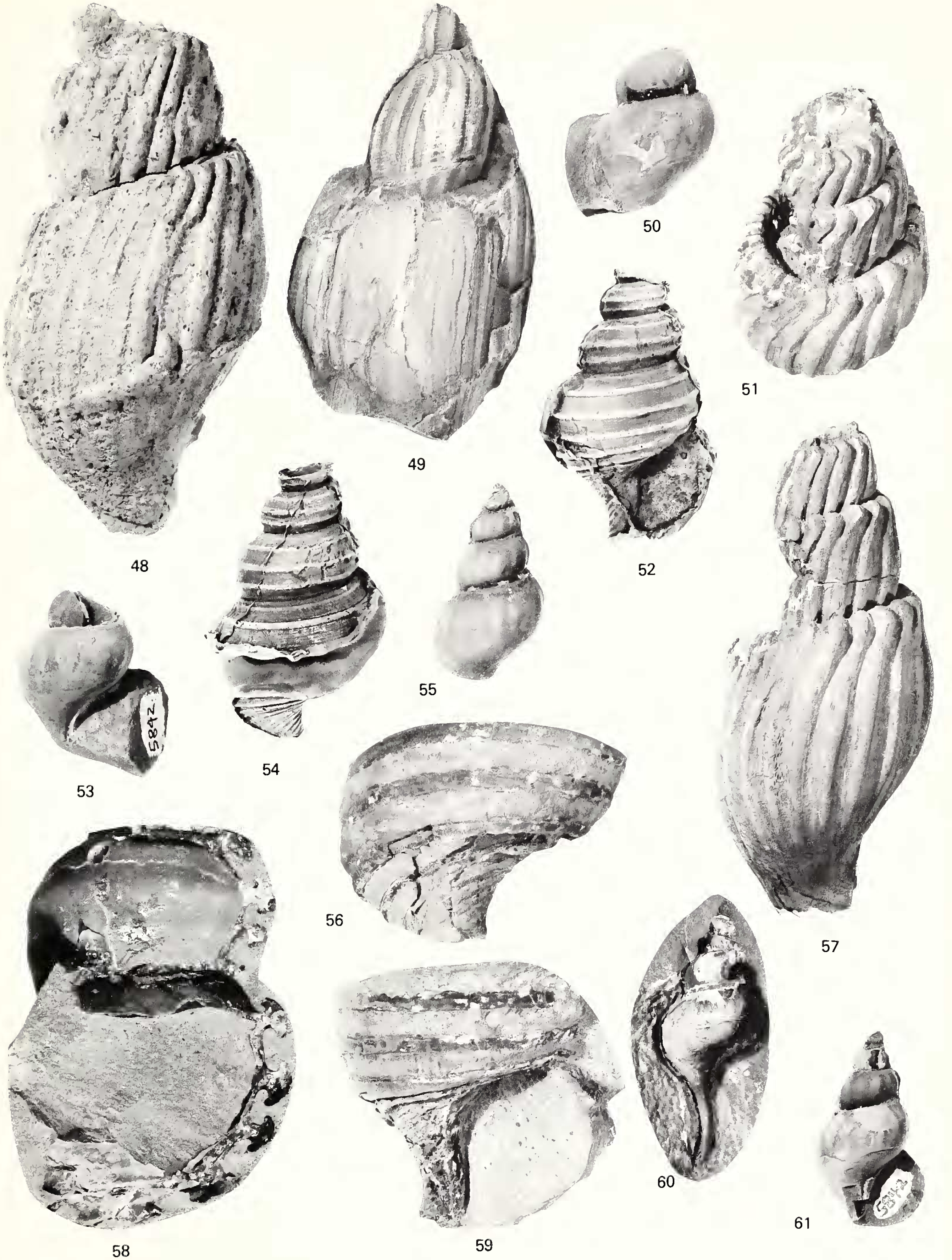
Figure 49. *Musashia* (*Nipponomelon*) *shikamai* n. sp. Paratype. Latex impression showing fine spiral sculpture, height 82 mm. LACMIP 6642.

Figures 50, 53, 55, 60, 61. *Priscofusus*? sp. cf. *P. geniculus* (Conrad). **50, 53.** Internal mold showing traces of axial ribs, ×1.5; height 21 mm, width 18 mm. LACMIP 6643. **55, 61.** Almost complete internal mold showing spire outline and axial ribs; height 26 mm, width 15 mm. LACMIP 6644. **60.** Showing siphonal canal; height 51 mm, width 18 mm. LACMP 6645.

Figures 51, 57. *Musashia* (*Nipponomelon*) *indurata* (Conrad). Showing twisted axial ribs and deeply impressed suture, ×0.8; height 125 mm, width 59 mm. From the Astoria Formation, Lincoln County, Oregon. CAS 037058.

Figures 52, 54. *Ancistrolepis clarki teglandae* Durham. Latex impression of holotype external molds, UCMP 35417, showing spiral sculpture; height 48 mm.

Figures 56, 58, 59. *Ancistrolepis jimgoederti* n. sp. **56, 59.** Paratype LACMIP 6646. Showing siphonal canal, ×1.5; width 35 mm. **58.** Paratype LACMP 6647. Showing T-shaped cross section of spiral ribs preserved in concretion, ×2.0; height 70 mm.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Armentrout (1973) reported an undescribed species of volutid from the Lincoln Creek Formation and assigned it to *Musashia* (*Musashia*), an assignment with which I concur. Although several species of *Musashia* (*Musashia*) have been described from the Cenozoic of Japan, Armentrout's material documents the oceurrence of the subgenus in western North America. It has a smooth shell, a slightly impressed suture that is markedly inclined, and a spire that is short in relation to the length of the body whorl (Figs. 62, 65, 76, 80, 87).

Subgeneric characters used by Shikama (1967) to differentiate volutids, such as the character of the protoconch and the number of initial and last columellar plaits, are useful for the allocation of living species, but are difficult to use with incompletely preserved fossils. The character of the suture and axial ribs serve best to distinguish fossil forms both subgenerically and specifically. On the basis of thin axial ribs and a slightly impressed suture, I assign most of the eastern Pacific Tertiary volutids to the subgenus *Nipponomelon* (Fig. 68). My allocation of eastern Pacific Tertiary species is shown in Figure 9.

Hayashi (1960:2) in his description of the genus *Musashia* noted that sexual dimorphism is very pronounced and that the large convex shells may be female. It is well to bear this in mind when looking at closely related eastern Pacific Tertiary species. In the Knappton fauna, however, slim forms are more common that convex forms, which would lead to the presumably false conclusion that males were more abundant than females.

The oldest recorded occurrence I have found for *Musashia* is *Musashia* (*Nipponomelon*?) *caucasica* (Korobkov, 1949: 694–695, text figs. 1, 2; 1955:205–206, pl. 4, figs. 6, 6a) from the middle Eocene in the Caucasus of the U.S.S.R. The oldest record of *Miopleiona* is *Musashia* (*Miopleiona*) n. sp. from the Eugene Formation, Oregon, of late Eocene to middle Oligocene age. The oldest record of *Nipponomelon* in the eastern Pacific is in the lower Oligocene part of the Lincoln Creek Formation, Washington. *Musashia* and *Nipponomelon* may have originated in the western Pacific; *Miopleiona* is indigenous to Alaska, Washington, Oregon, and California, and did not invade the western Pacific.

Musashia (*Musashia*) n. sp.

Figures 62, 65, 76, 80, 87

Miopleiona sp. A Durham, 1944:178.

Musashia (*Musashia*) *evelynae* Armentrout, 1973, in MS: 338–339, pl. 5, figs. 25, 27.

Musashia (*Musashia*) n. sp. has a slim shell with a very low spire compared to the body-whorl height. The suture is very slightly impressed and markedly inclined. The shell is smooth, without axial ribs, and only growth lines are preserved. The aperture is elongate oval, the siphonal fasciole probably straight and with a rather thick posterior callus and with two columellar plaits, the anteriormost one bladelike.

Musashia (*Musashia*) n. sp. is the only species assigned to this subenus in the eastern Pacific. The type species of *Musashia* is *M.* (*M.*) *hirasei* (Sowerby) (Figs. 69, 70). The only other described species at all similar to *M.* n. sp. is *Musashia* (*Musashia*?) *nagaoi* Shikama (1967:111–112, pl. 13, figs. 9–12) from the late Oligocene and early Miocene in Japan. Shikama (1967:112) considered *M. nagaoi* to be unique among Japanese fulgorids because it lacks axial ribs and radial striations; this is equally true for *M.* n. sp. in the eastern Pacific. *Musashia nagaoi* has a much more inflated body whorl than *M.* n. sp. and the suture of *M. nagaoi* is not as steeply inclined. *Musashia* (*Musashia*) n. sp. is being described by J. M. Armentrout.

Musashia (*Nipponomelon*) *shikamai* n. sp.

Figures 49, 63, 72, 74, 75, 77, 78, 82, 83, 88, 89

Psephaea (*Miopleiona*) cf. *P.* (*M.*) *indurata* (Conrad). Addicott, 1970:105, pl. 13, fig. 8; not pl. 13, fig. 6 (=*M. indurata*).

Musashia indurata (Conrad, 1849). Addieott, 1976c:25, pl. 3, fig. 27. Not *Rostellaria indurata* Conrad, 1849.

Musashia (*Nipponomelon*) *shikamai* is large, slender, and high spired with about nine whorls. The shell bears narrow axial ribs that are closely spaced and usually twisted near the suture. On large specimens the axial ribs disappear toward the anterior end. Narrow axial folds between the ribs presumably represent growth lines; the entire shell is sculptured by closely spaced subrounded spiral cords. The suture is slightly impressed and no subsutural band is preserved. The number of axial ribs ranges from 16 to 19, with 18 or 19 being the most common. The protoconch is not preserved. The aperture is assumed to be elongate oval. The siphonal fasciole is not preserved but may have been straight and long.

HOLOTYPE. LACMIP 6652, height 135 mm, width 52 mm; paratypes LACMIP 6642, height 87 mm; LACMIP 6648, height 73 mm, width 32 mm; LACMIP 6649, height 41 mm, width 20 mm; LACMIP 6650, height 90 mm, width 34 mm; LACMIP 6654, height 67 mm, width 25 mm; LAC-

Figures 62–70. *Musashia* (*Musashia*) n. sp., *Musashia* (*Nipponomelon*) *shikamai* n. sp., *Musashia* (*Miopleiona*) *indurata* (Conrad), *Musashia* (*Nipponomelon*) *prevostiana magna* (Kuroda and Habe), and *Musashia* (*Musashia*) *hirasei* (Sowerby).

Figures 62, 65. *Musashia* (*Musashia*) n. sp. U W 16444a; height 57 mm, width 25 mm. **62.** Showing smooth shell. **65.** Showing columnar plaits.

Figure 63. *Musashia* (*Nipponomelon*) *shikamai* n. sp. Paratype LACMIP 6648. Showing narrow axial ribs; height 73 mm, width 32 mm.

Figures 64, 67. *Musashia* (*Miopleiona*) *indurata* (Conrad). Showing wide axial ribs and deeply impressed suture; height 66 mm, width 35 mm. USNM 363987.

Figures 66, 68. *Musashia* (*Nipponomelon*) *prevostiana magna* (Kuroda and Habe). CAS 028423; height 170 mm, width 60 mm. **66.** Looking down on apex to show suture. **68.** View of aperture.

Figures 69, 70. *Musashia* (*Musashia*) *hirasei* (Sowerby). CAS 028422; height 165 mm, width 56 mm. **69.** Looking down on apex to show suture. **70.** View of aperture.


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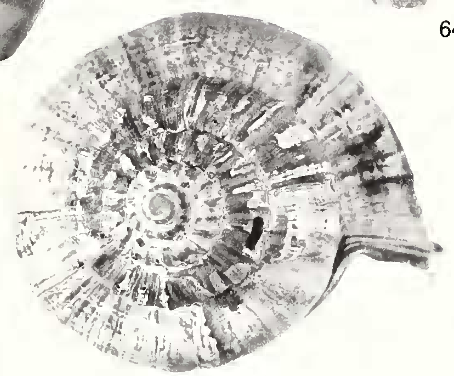
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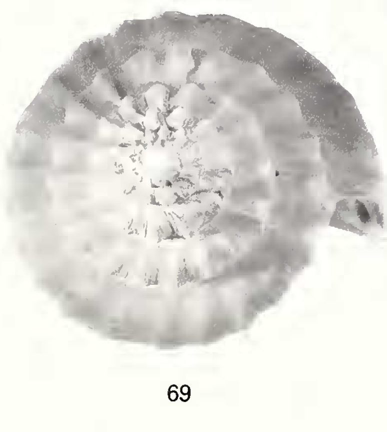
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MIP 6655, height 104 mm, width 36 mm; and LACMIP 6651, height 67 mm, width 26 mm.

TYPE LOCALITY. LAM 5842.

The species closely similar to *M.* (*N.*) *shikamai* are *M.* (*N.*) *weaveri* (Tegland, 1933) and *M.* (*N.*) *miensis* (Araki, 1960). *Musashia weaveri* (Figs. 71, 81, 94) has a slimmer shell with fewer (11 to 14) and wider axial ribs and a slightly angulated shoulder rather than a smoothly rounded one as in *M. shikamai. Musashia miensis* is slimmer and more elongate in outline, the axial ribs are not twisted near the suture, and the preserved radial sculpture is not as well developed as in *M. shikamai.*

Musashia n. sp. of Addicott (1976a:108, pl. 4, fig. 18) is similar to *M. shikamai* but has a few more axial ribs and a concave area below the suture. The latter character, however, could reflect sexual dimorphism.

Musashia (*Miopleiona*) *indurata* (Conrad, 1849) is distinguished from *M. shikamai* by its deeply impressed, channeled suture and by its strongly twisted keel-like axial ribs.

Musashia indurata (Conrad) of Addicott (1976c:25, pl. 3, fig. 27) does not have the deeply impressed, channeled suture and wide, keel-like axial ribs of *M.* (*Mioleiona*) *indurata* and is here assigned to *M. shikamai.*

On the basis of the incomplete holotype of *Miopleiona scowensis* Durham (1944:177–178, pl. 17, fig. 15), I am unable to find any characters to distinguish it from *M. weaveri* and believe it should be synonymized with that species.

Musashia (*Neopsephaea*) *corrugata* (Clark, 1932:831–832, pl. 21, figs. 4, 5, 11; Addicott et al., 1971, figs. 2y, aa–bb), from the Poul Creek Formation, Alaska (Figs. 73, 90, 92, 93, 95) is slimmer than *M. shikamai* and has a more sharply inclined suture and fewer axial ribs that are thicker and more widely spaced than in *M. shikamai.*

Musashia (*Musashia*) sp. of Allison and Marincovich (1981, pl. 3, figs. 12, 13; not pl. 3, figs. 8, 14, 16, 17) has a much wider body whorl in proportion to spire height and fewer (about 14) axial ribs than *M. shikamai.* The specimen figured by Allison and Marincovich (1981, pl. 3, figs. 8, 14), although poorly preserved, probably belongs in the subgenus *Musashia.*

Figures 71–77. *Musashia* (*Nipponomelon*) *weaveri* (Tegland), *Musashia* (*Nipponomelon*) *shikamai* n. sp., *Musashia* (*Neopsephaea*) *corrugata* (Clark), and *Musashia* (*Musashia*) n. sp.

Figures 71. *Musashia* (*Nipponomelon*) *weaveri* (Tegland). Showing spacing of axial ribs and spiral sculpture; height 125 mm, width 40 mm. UC locality A1806, Blakeley Formation of Weaver (1912), Bainbridge Island, Washington. UCMP 35420.

Figures 72, 74, 75, 77. *Musashia* (*Nipponomelon*) *shikamai* n. sp. **72.** Showing inflation of body whorl ×0.8; height 135 mm, width 52 mm. Holotype LACMIP 6652. **74.** Showing spiral sculpture ×2.0; height 41 mm, width 20 mm. Paratype LACMIP 6649. **75.** Showing deflection of ribs near suture; height 90 mm, width 34 mm. Paratype LACMP 6650. **77.** Showing spacing of ribs and spiral sculpture. Paratype LACMIP 6651.

Figure 73. *Musashia* (*Neopsephaea*) *corrugata* (Clark). Showing inclined suture and sculpture; height 120 mm, width 33 mm. Upper part of the Poul Creek Formation, Yakataga Reef, Alaska. USNM 363988.

Figure 76. *Musashia* (*Musashia*) n. sp. Showing outline of shell and inclined suture ×1.5; height 52 mm, width 20 mm. LAM Loc. 5843; LACMIP 6653.

Figures 78–86. *Musashia* (*Nipponomelon*) *shikamai* n. sp., *Musashia*? sp., *Musashia* (*Musashia*) n. sp., *Musashia* (*Nipponomelon*) *weaveri* (Tegland), and *Musashia* (*Nipponomelon*) *prevostiana magna* (Kuroda and Habe).

Figures 78, 82, 83. *Musashia* (*Nipponomelon*) *shikamai* n. sp. **78.** Paratype LACMIP 6654. Showing inclined suture ×1.5; height 67 mm, width 25 mm. **82.** Showing narrow, closely spaced axial ribs; height 73 mm, width 32 mm. Paratype LACMIP 6648, shown in Figure 63. **83.** Paratype LACMIP 6655. Showing siphonal canal and spiral sculpture; height 104 mm, width 36 mm.

Figure 79. *Musashia*? sp. Immature? specimen ×1.5; height 24 mm, width 10 mm. LACMIP 6656.

Figure 80. *Musashia* (*Musashia*) n. sp. Showing smooth shell and inclined suture; height 57 mm, width 22 mm. UW 16444.

Figures 81, 84, 86. *Musashia* (*Nipponomelon*) *weaveri* (Tegland). **81.** Showing widely spaced axial ribs and spiral sculpture ×1.5; height 40 mm, width 23 mm. USNM 363989. **84, 86.** From the basal part of the Jewett Sand, California. USNM 650185; height 73 mm, width 30 mm.

Figure 85. *Musashia* (*Nipponomelon*) *prevostiana magna* (Kuroda and Habe). Rear view showing narrow, closely spaced axial ribs and suture; height 170 mm, width 60 mm. CAS 028423.

Figures 87–95. *Musashia* (*Musashia*) n. sp., *Musashia* (*Nipponomelon*) *shikamai* n. sp., *Musashia* (*Neopsephaea*) *corrugata* (Clark), and *Musashia* (*Nipponomelon*) *weaveri* (Tegland).

Figure 87. *Musashia* (*Musashia*) n. sp. Showing smooth shell and inelined suture ×1.5; height 62 mm, width 19 mm. USNM 363992. USGS Loc. 25764, Lincoln Creek Formation, Grisdale Quadrangle, Washington.

Figure 88, 89. *Musashia* (*Nipponomelon*) *shikamai* n. sp. **88.** USGS Loc. M4050, Clallam Formation, Washington. Hypotype (Addicott, 1976c, pl. 3, fig. 27) USNM 216000; height 74 mm, width 34 mm. **89.** UCMP Loc. 3229, Monterey Group of Wagner and Schilling (1923). Hypotype (Addicott, 1970, pl. 13, fig. 6) UCMP 12136, a latex impression ×1.5; height 52 mm, width 21 mm.

Figures 90, 92, 93, 95. *Musashia* (*Neopsephaea*) *corrugata* (Clark). **90.** Paratype UCMP 12399; height 55 mm, width 30 mm. Poul Creek Formation, Alaska. **92, 95.** Holotype UCMP 12399; height 85 mm, width 29 mm. Poul Creek Formation, Alaska. **93.** Showing spire and aperture of specimen from Yakataga Reef, Alaska; height 120 mm, width 33 mm. USNM 363988. Same specimen shown in Figure 73.

Figures 91, 94. *Musashia* (*Nipponomelon*) *weaveri* (Tegland). **91.** View looking down on apex showing suture, ×1.5; height 40 mm, width 23 mm. Same specimen shown in Figure 81. USGS Loc. 4093, USNM 363989. **94.** Showing outline, axial ribs, and spiral sculpture; height 125 mm, width 40 mm. Same specimen shown in Figure 71. UCMP Locality A1806, Blakeley Formation of Weaver (1912), Bainbridge Island, Washington. UCMP 35420.

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Musashia (*Musashia*) n. sp., described above, differs from *M. shikamai* by having a smooth shell without axial ribs or radial threads, a much larger body whorl in proportion to height, and a strongly inclined suture.

In outline and axial sculpture, *M. shikamai* resembles *Musashia* (*Nipponomelon*) *elegantula* Shikama (1967) from the early Pliocene, Japan, but differs from that species by not having a subsutural band.

The early whorls of a few specimens of *M. shikamai* from the upper part of the Lincoln Creek Formation at Knappton, Washington, are filled with barite.

OCCURRENCE ELSEWHERE. Upper part of the Poul Creek Formation, Alaska, upper part of the Pysht Formation of the Twin River Group and the Clallam Formation, northwestern Washington, the Nye Mudstone, Oregon (Howe, 1922:138, pl. 10, fig. 3 as *Miopleiona clatsopensis* Howe, n. sp.), and the Freeman-Jewett Silt of Matthews (1955) and the Vaqueros Formation, southern California.

***Musashia* (*Miopleiona*) n. sp.**

Figure 48

Miopleiona n. sp. Howe, 1922:137.

Musashia (*Miopleiona*) n. sp., collected from the Eugene Formation in Oregon, is a large volutid with a thick shell that bears perhaps as many as 30 narrow, keel-like axial ribs. The suture is deeply impressed, channeled, and inclined. The species is represented by a single plaster cast of a specimen consisting of half of two whorls. The preserved portion is identical in all characters to *Musashia* (*Miopleiona*) *indurata* except that the axial ribs are half as wide and twice as closely spaced as on *M.* (*M.*) n. sp.

There is no doubt in my mind that *M.* (*M.*) n. sp. was collected from the Eugene Formation on the University of Oregon campus. The record is based on a specimen, now missing and presumed lost, collected by Professor Earl L. Packard, a paleontologist of note, and I have no reason to suspect the locality data. The specimen was first mentioned by Howe (1922:137) as "*Miopleiona* n. sp., (very large), lower Oligocene, Eugene," and later by Schenck (1928:11) as *Miopleiona* n. sp. from the Eugene Formation, Oregon. A plaster cast was made of the specimen for Schenck and deposited in the Stanford University collection, now housed at the California Academy of Sciences. Hickman (1969) did not describe any volutids from the Eugene Formation. Presumably the plaster cast was not seen at that time, or the locality description was considered suspect.

Musashia (*Miopleiona*) n. sp. is the oldest known species of *Miopleiona,* as the subgenus is used here. Its occurrence in the Eugene Formation extends its geologic range from the Miocene into the early Oligocene or late Eocene.

The Eugene Formation has been extensively collected, in part because it is exposed in almost all excavations made for buildings on the University of Oregon campus. The single, incomplete specimen of *M.* (*M.*) n. sp. indicates its rareness. Hickman (1969:22) suggested that the Eugene molluscan fauna lived at a depth of 55 m. The molluscan fauna of the upper part of the Lincoln Creek Formation at Knappton probably lived at a depth no shallower than 100 m and the related *Musashia* (*Nipponomelon*) is common in that part of the unit. *Musashia* (*Miopleiona*) *indurata* is usually found in the finer-grained, deeper-water facies of the Astoria Formation. I suggest that the molluscan fauna in the Eugene Formation lived in shallower water than was common for *Miopleiona.*

Turridae

Aforia wardi (Tegland)

Figure 99

Leucosyrinx clallamensis wardi Tegland, 1933:124, pl. 10, figs. 5–8.

Aforia wardi is of medium size and pagodaform, with nine strongly angulated whorls and a U-shaped sinus on the shoulder (Fig. 99). The shell is smooth above the angulations but sculptured by fine spiral threads below, and these spirals extend down the siphonal canal on the body whorl. *Aforia campbelli* (Durham, 1944:183, pl. 14, fig. 4) differs in having the whorl angulation closer to the suture, and the angulation is rounded rather than bladelike. Javidpour (1973) discussed the phylogeny of eastern Pacific Tertiary species of *Aforia.* The correlation diagram (Javidpour, 1973:198, fig. 17) is misleading in that *Aforia campbelli* is shown in the upper Oligocene part of the Lincoln Creek Formation, whereas it should have been placed in the middle Oligocene part of the unit as stated in the text (Javidpour, 1973:196, 199–200). *Aforia* was placed in the subfamily Turriculinae by McLean (1971:119), following Powell (1942).

Living species of *Aforia* in the eastern Pacific have been recorded from depths of 6 to 2870 m (Abbott, 1974:265) and in the western Pacific from depths of 55 to 90 m (Kira, 1962: 102). Powell (1969:411–414) said that *Aforia* prefers cold water ranging from −0.6° to +5.4°C and is bipolar, going deeper under equatorial waters.

Based on the illustrations by Powell (1969:411, pl. 322, figs. 1–4; 414, pl. 323, figs. 1–3) of the type species of *Aforia, Pleurotoma circinata* Dall, characters such as apical angle and position of whorl angulation are not useful in distinguishing species. If larger collections of well-preserved specimens of *Aforia* become available, future workers may see fit to synonymize some of the species proposed for eastern Pacific Tertiary *Aforia.*

OCCURRENCE ELSEWHERE. Lower part of the Blakeley Formation in the *Liracassis rex* Molluscan Zone, Washington.

Turricula? sp.

Figure 97

Turricula? sp. is represented by one incompletely preserved specimen on which the siphonal canal is not exposed. The sinus is U-shaped and confined to the shoulder slope. The shell is sculptured by moderately strong spiral cords that are not noded. *Turricula washingtonensis* (Weaver, 1912:78, pl.

3, fig. 31; 1942:533, pl. 98, figs. 16, 17, 22) differs from *Turricula*? sp. in having nodes.

Megasurcula? sp. cf. *M. wynoocheensis* (Weaver)

Figure 96

Megasurcula? sp. cf. *M. wynoocheensis* (Weaver) is represented by a single poorly preserved and somewhat erushed specimen. *Megasurcula wynoocheensis* (Weaver, 1912:70–71, pl. 11, figs. 87–89, 94) is a middle Miocene and possibly early Mioeene species (Addicott, 1976c:27, pl. 3, figs. 16, 17).

Actenoidae

***Microglyphus*? n. sp.?**

Figure 98

Microglyphus? n. sp.? has three or possibly four whorls and a body whorl that is very inflated with the maximum width at the middle of the whorl. The spiral cords, bounded by incised grooves, are not equidimensional. The single specimen is very small (2.1 mm high, 1.9 mm wide) and, although it may be an immature individual, the number of whorls indicates that it probably is a very small species. In addition to its small size, *Microglyphus*? n. sp.? differs from other described Tertiary actenoids in having a more globose body whorl with the maximum inflation at the middle of the whorl.

PELECYPODS

Nuculidae

Acila (*Acila*) *gettysburgensis* (Reagan)

Figures 100–102, 105

Nucula (*Acila*) *gettysburgensis* Reagan, 1909:171, 175, 177, pl. 1, fig. 3.

Acila (*Acila*) *gettysburgensis* is represented by five specimens. *Acila* (*A.*) *gettysburgensis* ranges from the Matlockian through the Pillarian Molluscan Stages.

Nuculanidae

Portlandia (*Portlandia*) *chehalisensis* (Arnold)

Figures 103, 104, 106, 107

Malletia chehalisensis Arnold, 1908:365, pl. 33, fig. 9.

Portlandia (*Portlandia*) *chehalisensis* is represented by seven specimens, some well preserved (Fig. 107) and one double-valved (Figs. 103, 104). One incomplete specimen has concentric *Saccella*-like ridges on the midportion of the shell near the ventral margin (Fig. 106). One single valve is 31.8 mm long, 18.5 mm high, and 7.0 mm thick; perhaps the largest specimen of the speeies collected. The largest specimen noted by Hickman (1969:31) measured 26 mm in length. *Yoldia reagani* Dall (1922:306) was considered a synonym of *Portlandia chehalisensis* (Hickman, 1969:30).

Living eastern Pacific species of *Portlandia* occur no farther south than latitude 54°N and are found at depths of 10 to 2560 m and temperatures from −2° to +6°C (Bernard, 1983:13).

Solemyidae

Acharax dalli (Clark)

Figures 108–111, 114

Solemya dalli Clark, 1925:73, pl. 9, fig. 3.

Acharax dalli is represented by six specimens, all but one double-valved. Fingerlike projections of the periostracum are partially preserved on some specimens (Fig. 108). *Acharax ventricosa* (Conrad, 1849:723, pl. 17, figs. 7, 8), a species found in the Astoria Formation in Oregon and Washington, is higher in proportion to length than *A. dalli.*

The eastern Pacific Holocene species *Acharax johnsoni* (Dall, 1891) lives at a depth between 800 and 3000 m at temperatures of 1° to 9°C (Bernard, 1983:9). Vokes (1955:536–537) said that living species of *Acharax* are found at depths of 5 to 3180 m and that the controlling factor in their distribution may be water temperature.

Limopsidae

Limopsis nitens (Conrad)

Figures 112, 113, 115, 116

Pectunculus nitens Conrad, 1849:726, pl. 18, figs. 9a–b.

Limopsis nitens occurs as numerous single valves (Figs. 112, 113) and occasional paired valves (Figs. 115, 116). Radial lines of sculptural punctures are preserved on some specimens.

The lithology of the concretions from Knappton and the clustering together of many specimens is similar to the concretion presumably from the Astoria Formation, at Astoria, Oregon, that contains the lectotype of *L. nitens* (Moore, 1963:61–62, pl. 15, figs. 2, 5). Weaver (1942:76) suggested that the lectotype was collected at Knappton, rather than at Astoria, because he had found nodules containing large numbers of *L. nitens* at Knappton and had not found any specimens at Astoria. Howe (1922:70) did not find any specimens of *L. nitens* at Astoria and I found none in the Astoria Formation farther south (Moore, 1963:62). The rock eontaining the lectotype of *L. nitens* may have come from Knappton, or the upper part of the Lincoln Creek Formation may have been exposed on the Columbia River terrace at Astoria when Dana made his collection in 1841, yet no other mollusks typical of the Lincoln Creek Formation were collected by him.

Most species of *Limopsis* live in deep water (Keen, 1971:54); *Limopsis diegensis* Dall has been collected at depths of 120 to 1500 m and at temperatures between 3° and 27°C (Bernard, 1983:17). The fact that *Limopsis nitens* most commonly occurs in clumps suggests that the species was gregarious.

Mytilidae

***Modiolus addicotti* n. sp.**

Figures 117, 125

Modiolus n. sp.? aff. *M. restorationensis* Van Winkle. Addicott, 1976c:28, pl. 5, fig. 5.

Modiolus addicotti is a rather small *Modiolus* with weakly inflated valves, a markedly thin shell, and a convex dorsal margin. The posterior end is only moderately enlarged, and slightly longer near the ventral margin. The anterior end is small and evenly curved. The umbones are close to the anterior margin. Patches of preserved shell are light brown and iridescent with mostly evenly spaced growth lines but with a few bunched together forming low ridges.

HOLOTYPE. LACMIP 6672, length 47 mm, height 25 mm.

TYPE LOCALITY. LAM 5842.

Modiolus addicotti differs from *Modiolus restorationensis* Van Winkle (1918:82, pl. 4, fig. 5) in having a convex dorsal margin and a narrower posterior end.

Modiolus lives intertidally to 360 m in the eastern Pacific, but most species are found at depths no greater than 50 m (Bernard, 1983:19).

OCCURRENCE ELSEWHERE. Lowermost part of the Clallam Formation, northwestern Washington.

This species is named in honor of Warren O. Addicott.

Limidae

Acesta (*Acesta*) *twinensis* (Durham)

Figures 119, 123, 124

Lima twinensis Durham, 1944:139, pl. 13, fig. 11.

Acesta (*Acesta*) *twinensis* is represented by one incomplete double-valved specimen and four incomplete single valves all of which are preserved intact with their original inflation. The anterior ears are small and well defined by a deep concave groove along the anterior margin (Fig. 124). The anterior margin is straight, not concave, and joins the ventral margin without an abrupt break in alignment. The posterior ears are large and indistinctly delineated (Figs. 119, 124). The shells are large (maximum estimated height 140 mm), thin, and smooth in the center but with rounded ribs of varying widths at the shell margins (Fig. 124). The shells are inflated, and the largest specimen suggests a thickness of 25 mm (one valve). Portions of the brown translucent outer shell layer are preserved on most specimens, but this shell layer tends to stay attached to the enclosing rock when the specimens are broken away.

Acesta twinensis is distinguished by its sharply truncated anterior margin, which differentiates it from *Acesta robertsae* (Durham, 1944), an early Oligocene species that has a more rounded anterior margin.

Acesta (*Acesta*) *oregonensis* Clark (1925:84, pl. 14, figs. 3, 4), a species from the upper Eocene and lower Oligocene Keasey Formation, Oregon, has an arcuate anterior margin.

Acesta twinensis ranges from the Matlockian through the Juanian Molluscan Stages. Living species of *Acesta* (*Acesta*) are found in the eastern Pacific at depths between 600 and 2200 m and at temperatures of 1° to 8°C (Bernard, 1983:22). One species has been collected in the western Pacific near Japan at a depth of 185 m.

OCCURRENCE ELSEWHERE. Blakeley Formation, Washington.

***Acesta* (*Plicacesta*) *wilsoni* n. sp.**

Figures 118, 132, 134

Acesta (*Plicacesta*) *wilsoni* is of moderate size and subovate in outline, with a thicker shell than *Acesta* (*Acesta*) and radial ribs of varying widths and spacing that are rounded and most prominent on the middle portion of the shell but that persist to the shell margins. Beaks small; anterior auricle presumed small and delineated; posterior auricle large and not delin-

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Figures 96–117. *Megasurcula*? sp. cf. *wynoocheensis* (Weaver), *Turricula*? n. sp.?, *Microglyphus*? n. sp.?, *Aforia wardi* (Tegland), *Acila* (*Acila*) *gettysburgensis* (Reagan), *Portlandia* (*Portlandia*) *chehalisensis* (Arnold), *Acharax dalli* (Clark), *Limopsis nitens* (Conrad), and *Modiolus addicotti* n. sp.

Figure 96. *Megasurcula*? sp. cf. *wynoocheensis* (Weaver). Rear view, ×1.5; height 32 mm, width 20 mm. USGS Loc. 7891, USNM 363990.

Figure 97. *Turricula*? n. sp.? Showing spiral sculpture, ×2.0; height 15 mm, width 10 mm. LACMIP 6657.

Figure 98. *Microglyphus*? n. sp.? Showing outline and spiral sculpture, ×5.0; height 2.7 mm, width 2.4 mm. LACMIP 6658.

Figure 99. *Aforia wardi* (Tegland). Showing pagodaform outline, ×1.5; height 28 mm, width 14 mm. LACMIP 6659.

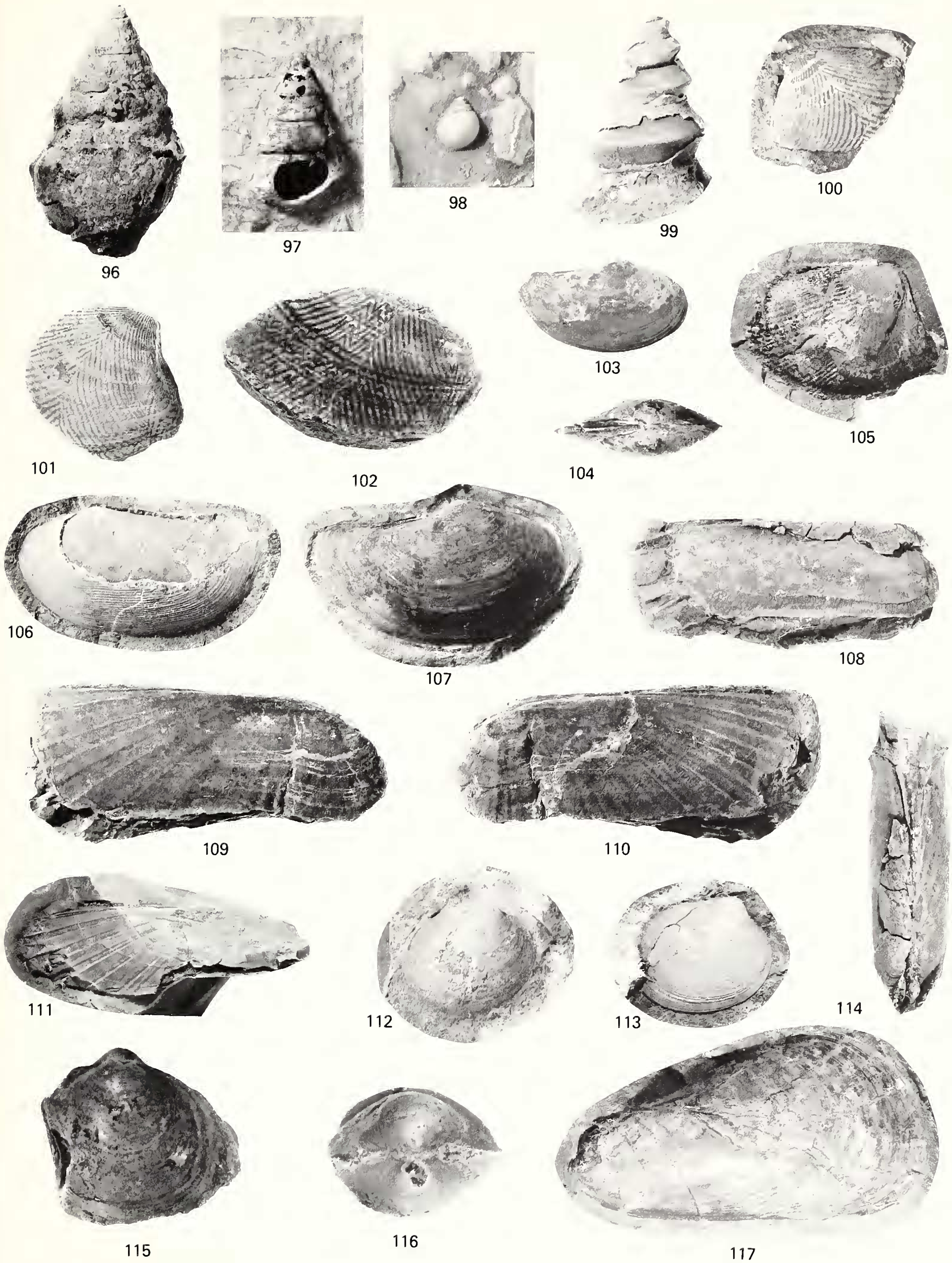
Figures 100–102, 105. *Acila* (*Acila*) *gettysburgensis* (Reagan). **100.** Showing primary bifurcation, ×2; length 13 mm, height 11 mm. LACMIP 6660. **101.** Showing sulcus ×1.5; height 17 mm. LACMIP 6661. **102.** Showing secondary bifurcation, ×2. LACMIP 6662. **105.** Showing outline and bifurcation, ×1.5; length 25 mm, height 20 mm. LACMIP 6663.

Figures 103, 104, 106, 107. *Portlandia* (*Portlandia*) *chehalisensis* (Arnold). **103, 104.** Double-valved specimen showing sculpture and lunule, ×1.5; length 21 mm, height 12 mm, width 8 mm (both valves). LACMIP 6664. **106.** Showing *Saccella*-like sculpture, ×2; length 22 mm, height 13 mm. LACMIP 6665. **107.** Showing outline and sculpture, ×1.5; length 32 mm, height 18 mm. LACMIP 6666.

Figures 108–111, 114. *Acharax dalli* (Clark). **108, 114.** Showing extensions of fingerlike periostracum and dorsal side; length 28 mm, height 24 mm, width 16 mm (both valves). LACMIP 6667. **109, 110.** Showing sculpture of double-valved specimen, ×1.5; length 45 mm, height 20 mm, width 11 mm (both valves). LACMIP 6668. **111.** Showing sculpture ×1.5; length 35 mm, height 13 mm. LACMIP 6669.

Figures 112, 113, 115, 116. *Limopsis nitens* (Conrad). **112.** Showing outline, ×3; 10 mm long, 7 mm high. LACMIP 6670. **113.** Showing radial punctae, ×3; length 9 mm, height 7 mm. LACMIP 6671. **115, 116.** Double-valved specimen showing thickness of valves, ×5; length 8 mm, height 6 mm, width 5 mm (both valves). USGS Loc. 7891, USNM 363991.

Figure 117. *Modiolus addicotti* n. sp. Holotype LACMIP 6672. Showing outline of valve; length 47 mm, height 25 mm.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eated. No concentric sculpture is preserved. The holotype (incomplete) is 60 mm high and 50 mm wide and the thickness of one valve is 13 mm (Figs. 118, 132). The paratype (incomplete) is 63 mm high and 40 mm wide and the thickness of one valve is 11 mm (Fig. 134).

HOLOTYPE. LACMIP 6673, length 51 mm, height 61 mm, width 10 mm (one valve); paratype LAM 6686, length 41 mm, height 61 mm.

TYPE LOCALITY. LAM 5842.

Acesta wilsoni is smaller than *Acesta* (*Plicacesta*) *oakvillensis* (Clark, 1925:84, pl. 15, figs. 1, 3) and has fewer ribs and a more rounded anterior margin. A topotype specimen, earlier illustrated by Weaver (1942, pl. 21, fig. 1), is figured for comparison (Fig. 126). *Acesta* cf. *A. oakvillensis* Clark of Addicott (1976b, figs. 6a, c) has narrower ribs that are more widely and evenly spaced than on *A. wilsoni* and may be a new species.

Acesta wilsoni and *A. oakvillensis* are the only Tertiary species of *Plicacesta* known in North America. *Acesta* n. sp. of Addicott (1976b, figs. 6x, z, ab) may also be a *Plicacesta.*

The Holocene species *Acesta* (*Plicacesta*) *sphoni* (Hertlein, 1963) was collected at latitude 33°N at a depth between 455 and 550 m and a temperature between 4° and 9°C. *Acesta* (*Plicacesta*) *smithi* (Sowerby) occurs off Honshu, Japan, at depths between 90 and 185 m (Kira, 1962:145).

This species is named in honor of Edward C. Wilson.

Ostreidae

Crassostrea? sp.

Figure 127

Crassostrea? sp. is represented by a single double-valved specimen preserved in a concretion and broken upon removal from the matrix. Indigenous Holocene species of *Crassostrea* live intertidally to a depth of 7 m in the eastern Pacific (Bernard, 1983:23).

Lucinidae

Lucinoma hannibali (Clark)

Figures 120–122

Phacoides (*Lucinoma*) *hannibali* Clark, 1925:89, pl. 22, figs. 2, 4.

Lucinoma hannibali is represented by six double-valved specimens (Figs. 120–122) from the upper part of the Lincoln Creek Formation, one with the shell replaced by barite. The specimens range in height from 27 mm to 52 mm. *Lucinoma acutilineata* (Conrad, 1849:725, pl. 18, figs. 2, 2a, 2b) has a shorter more concave dorsal margin than *L. hannibali.* Variation has been noted (Moore, 1963:70) in the spacing of concentric lamellae within single lots of the Holocene species *Lucinoma annulata* (Reeve, 1850) and by Addicott (1976c: 30) in the Oligocene to Miocene species *L. acutilineata,* yet specimens of *L. hannibali* from the upper part of the Lincoln Creek Formation have concentric lamellae rather consistently less densely spaced (Figs. 120–122) than the lamellae on *L. acutilineata* from the lower part of the Astoria Formation. *Lucinoma acutilineata* has been found in the Eugene Formation (upper Eocene to middle Oligocene) in Oregon (Hickman, 1969:38, 42) and in the lower and middle Miocene Astoria Formation (Moore, 1963:70–71, pl. 15, figs. 7–10, 12) in Oregon and Washington. If *L. hannibali* and *L. acutilineata* are distinct species, and I believe that they are, *L. acutilineata* may have preferred somewhat shallower water (50 m or less) than *L. hannibali,* and the two species coexisted at different depths. *Lucinoma annulata* lives today from latitude 33° to 47°N at depths of 25 to 750 m and *L. aequizonata* (Stearns, 1891) lives from latitude 34° to 37°N at depths of 400 to 650 m (Bernard, 1983:29). *Lucinoma hannibali* has a wider escutcheon and less concave dorsal margin than *L. columbiana* (Clark and Arnold, 1923:144–145, pl. 25, figs. 2a–b) from the Sooke Formation, Vancouver Island, and the Blakeley Formation of Weaver (1912). *Lucinoma hannibali* ranges from the Matlockian through the Juanian Molluscan Stages.

Thyasiridae

Thyasira (*Conchocele*) *disjuncta* (Gabb)

Figures 136, 138, 142

Conchocele disjuncta Gabb, 1866:28; 1869:99, pl. 7, figs. 48a–b.

Thyasira (*Conchocele*) *disjuncta* is larger, more quadrate, and has a more truncated anterior end than *Thyasira bisecta* (Conrad, 1849:724, pl. 17, figs. 10, 10a) from the Astoria Formation in Oregon (Moore, 1963:72, pl. 23, figs. 8, 14, 15). *Thyasira disjuncta* occurs in the Clallam Formation (Addicott, 1976c:30, pl. 6, fig. 7) and is living today (Bernard, 1983:29). The presence of two internal casts (Figs. 136, 138) and one specimen with the outer shell preserved (Fig. 142)

Figures 118–125. *Acesta* (*Plicacesta*) *wilsoni* n. sp., *Acesta* (*Acesta*) *twinensis* (Durham), *Lucinoma hannibali* (Clark), and *Modiolus addicotti* n. sp.

Figure 118. *Acesta* (*Plicacesta*) *wilsoni* n. sp. showing outline and radial ribs, ×1.5; length 51 mm, height 61 mm, width 10 mm (one valve). Holotype LACMP 6673.

Figures 119, 123, 124. *Acesta* (*Acesta*) *twinensis* (Durham). **119, 123.** Showing posterior ears. **119.** Length 74 mm, height 93 mm, width 22 mm (one valve). LACMP 6675. **123.** Length 92 mm, height 75 mm. LACMP 6674. **124.** Showing anterior ear and axial ribs, ×1.5; length 60 mm, height 70 mm. LACMP 6676.

Figures 120–122. *Lucinoma hannibali* (Clark). **120.** Showing profile of lunule; length 29 mm, height 27 mm, width 11 mm (both valves). LACMP 6677. **121.** Showing sulcus; length 39 mm, height 34 mm, width 16 mm (both valves). LACMP 6678. **122.** Showing concentric sculpture; length 40 mm, height 37 mm, width 27 mm (both valves). LACMP 6679.

Figure 125. *Modiolus addicotti* n. sp. Holotype LACMP 6672. Tipped to show configuration of double-valved specimen, ×1.5; length 47 mm, height 25 mm. Same specimen shown in Figure 117.


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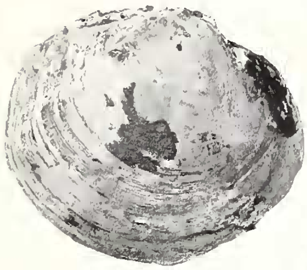
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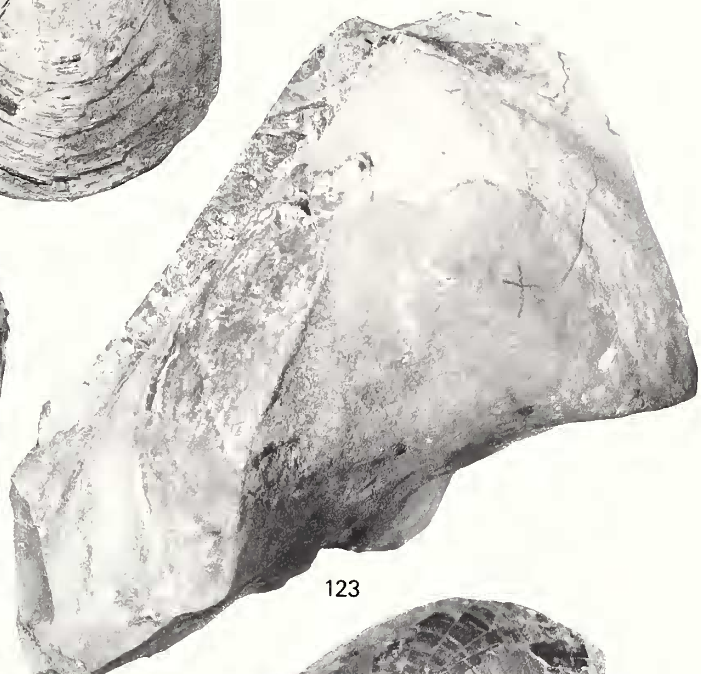
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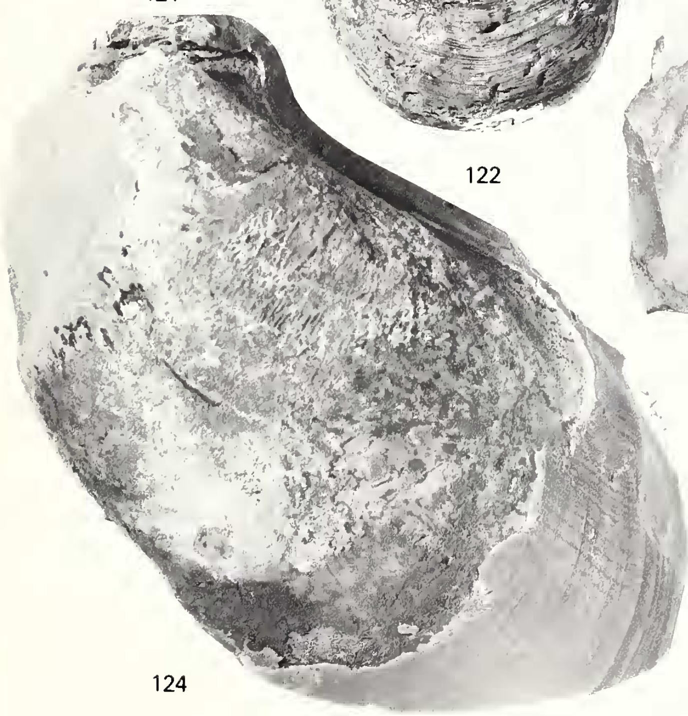
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in the upper part of the Lincoln Creek Formation extends the range of the species downward into the upper part of the Juanian Molluscan Stage. *Thyasira disjuncta* lives today from latitude 48° to 54°N at depths of 100 to 750 m and at temperatures between 0° and 7°C. *Thyasira bisecta* lives from latitude 43° to 57°N at depths between 50 and 300 m and temperatures between −1° and +11°C (Bernard, 1983:29). The occurrence of *T. disjuncta* in the Lincoln Creek Formation and of *T. bisecta* in the Astoria Formation is related to depth of water; the Astoria Formation represents a shallower-water facies than the Lincoln Creek Formation.

Cardiidae

Nemocardium? sp. cf. *N. lorenzanum* (Arnold)

Figure 130

Nemocardium? sp. cf. *N. lorenzanum* (Arnold, 1908:366, pl. 33, fig. 6) is represented by two poorly preserved single valves; one is illustrated (Fig. 130).

Tellinidae

Macoma sp. cf. *M. twinensis* Clark

Figure 128

Macoma sp. cf. *M. twinensis* Clark is represented by a single valve that does not have the hinge exposed (Fig. 128). In size, outline, and position of umbo, the specimen resembles *M. twinensis* Clark (1925:96, pl. 12, fig. 7), which ranges from late Oligocene to early Miocene.

Periplomatidae

Cochlodesma bainbridgensis Clark

Figures 139, 141

Cochlodesma bainbridgensis Clark, 1925:86, pl. 13, figs. 3, 4.

Cochlodesma bainbridgensis Clark has a thin, internally nacreous, fragile shell, that is sculptured with concentric undulations (Figs. 139, 141). Five specimens and one possible juvenile (Fig. 131) were collected from the upper part of the Lincoln Creek Formation. As noted by Moore (1976:53, pl. 16, figs. 4, 6–11), the variation in outline is great and not useful in the discrimination of fossil species. Holocene species of the closely related genus *Periploma* live intertidally to a depth of 380 m (Bernard, 1983:64).

Teredinidae

Figures 172, 177, 179

Teredinid burrows are preserved in wood and the tubes are filled with quartz (Fig. 172) or with sediment (Figs. 177, 179). No pallets are preserved, enabling generic differentiation, but

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Figures 126-134. *Acesta* (*Plicacesta*) *oakvillensis* (Clark), *Crassostrea*? sp., *Macoma* sp. cf. *M. twinensis* Clark, *Flabellum* sp., *Nemocardium*? sp. cf. *N. lorenzanum* (Arnold), *Cochlodesma*? sp., *Lima* (*Plicacesta*) *wilsoni* n. sp., and *Aturia angustata* (Conrad).

Figure 126. *Acesta* (*Plicacesta*) *oakvillensis* (Clark). Showing closely spaced axial ribs; length 79 mm, height 95 mm. UC Loc. A368, lower part of the Lincoln Creek Formation, Grays Harbor County, Washington. UCMP 32405.

Figure 127. *Crassostrea*? sp. Showing configuration; length 70 mm, height 102 mm. LACMP 6680.

Figure 128. *Macoma* sp. cf. *M. twinensis* Clark. Showing outline and concentric lines, ×1.5; length 15 mm, height 10 mm. LACMP 6681.

Figure 129. *Flabellum* sp. ×1.5; height 22 mm. LACMP 6682.

Figure 130. *Nemocardium*? sp. cf. *N. lorenzanum* (Arnold). Showing configuration and radial ribs, ×1.5; height 20 mm. LACMP 6683.

Figure 131. *Cochlodesma*? sp. Showing outline, ×2; length 11 mm, height 8 mm. LACMP 6684.

Figures 132, 134. *Lima* (*Plicacesta*) *wilsoni* n. sp. **132.** Showing outline and radial ribs, ×1.5; length 51 mm, height 61 mm, width 10 mm (one valve). Holotype LACMP 6673. **134.** Showing radial ribs ×1.5; length 41 mm, height 61 mm. Paratype LACMP 6686.

Figure 133. *Aturia angustata* (Conrad). Immature specimen, ×1.5; height 24 mm. LACMP 6687.

Figures 135-145. *Aturia angustata* (Conrad), *Thyasira* (*Conchochele*) *disjuncta* (Gabb), and *Cochlodesma bainbridgensis* Clark.

Figures 135, 137, 140, 143-145. *Aturia angustata* (Conrad). **135.** Showing outer shell and growth lines, ×0.7; height 150 mm. LACMP 6688. **137.** Cross section showing funnel-shaped septal structures; height 29 mm. LACMP 6689. **140.** Cross section showing septal structures; height 37 mm. LACMP 6690. **143.** Apertural view of broken specimen showing siphuncular orifices; height 90 mm. LACMP 6691. **144.** Cross section showing septal structures; height 60 mm. LAM Loc. 5843, LACMP 6692. **145.** Side view showing sutures; height 65 mm, width 27 mm (maximum diameter). Same specimen shown in Figure 150. LACMP 6693.

Figures 136, 138, 142. *Thyasira* (*Conchochele*) *disjuncta* (Gabb). **136.** Showing sulcus and configuration; length 70 mm, height 67 mm. LACMP 6694. **138.** Showing sulcus and configuration; length 52 mm, height 43 mm. LACMP 6695. **142.** Showing outer shell and concentric lines, ×1.5; length 37 mm, height 32 mm. LACMP 6696.

Figures 139, 141. *Cochlodesma bainbridgensis* Clark. **139.** Showing concentric undulations, ×1.5; length 34 mm, height 27 mm. LACMP 6697. **141.** Showing outline, ×1.5; length 30 mm, height 25 mm. LACMP 6698.

Figures 146-154. *Aturia angustata* (Conrad) and a crab claw.

Figures 146, 147, 149, 150, 152-154. *Aturia angustata* (Conrad). **146.** Thin section showing radiating calcite within phragmocone chamber in crossed-polarized light, ×70. LACMP 6699. **147.** Showing suture, ×0.8; height 95 mm. LAM Loc. 5287, LACMP 6700. **149.** Showing silicified siphuncular neck and orifice; height 43 mm. LACMP 6701. **150.** Showing sutures; height 65 mm, width 27 mm (maximum diameter). Same specimen shown in Figure 145. LACMP 6693. **152.** Broken specimen showing siphuncular orifice and neck; height 114 mm. LACMP 6702. **153.** Cross section showing funnel-shaped siphuncular necks, ×2.0; length 45 mm. LACMP 6703. **154.** Broken specimen showing siphuncular orifice; height 75 mm. LACMP 6704.

Figures 148, 151. Crab claw; length 40 mm. LACMP 6705.

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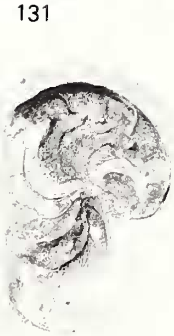

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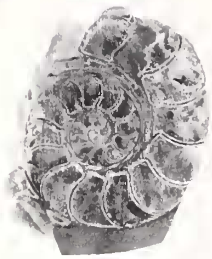

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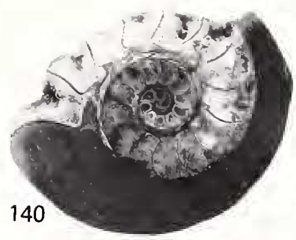

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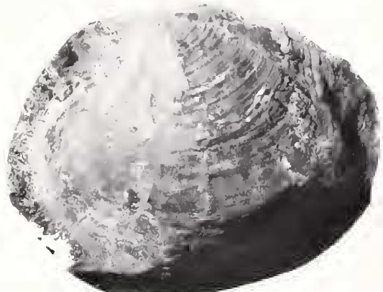

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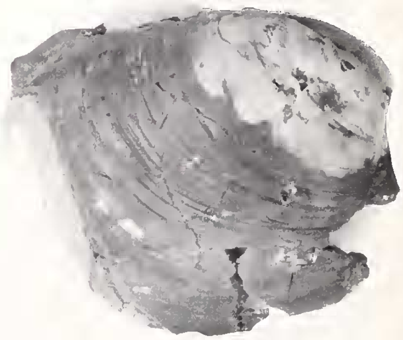

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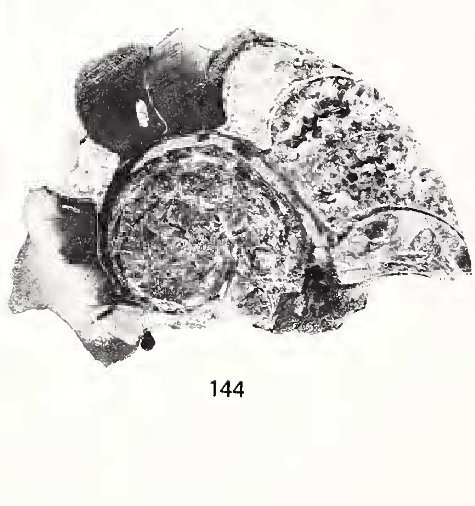

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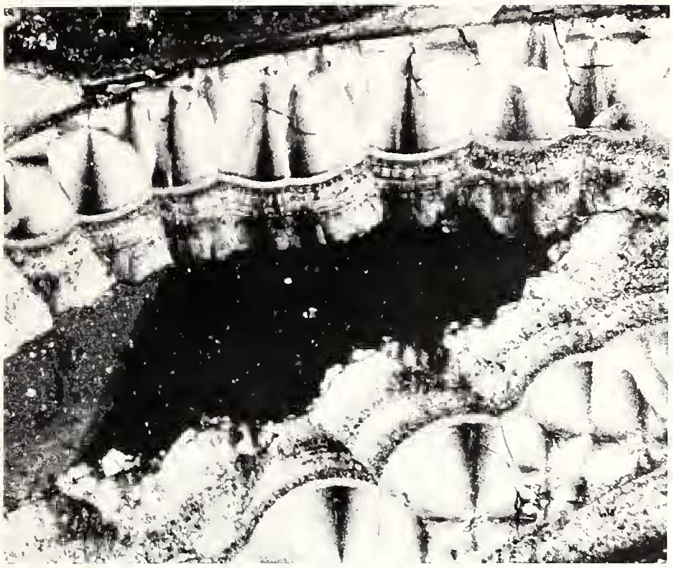

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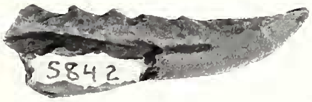

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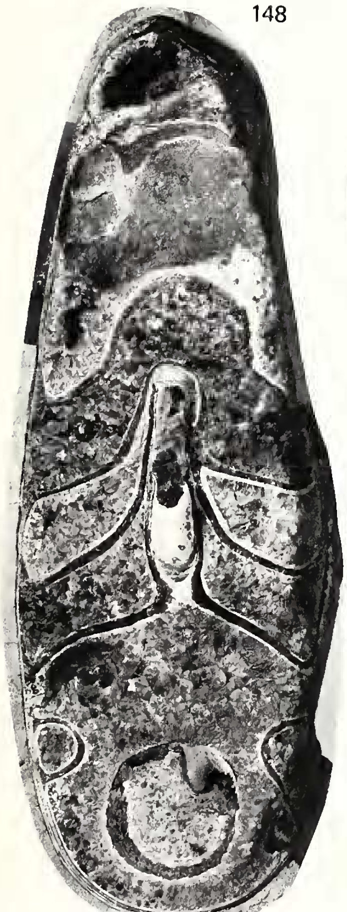

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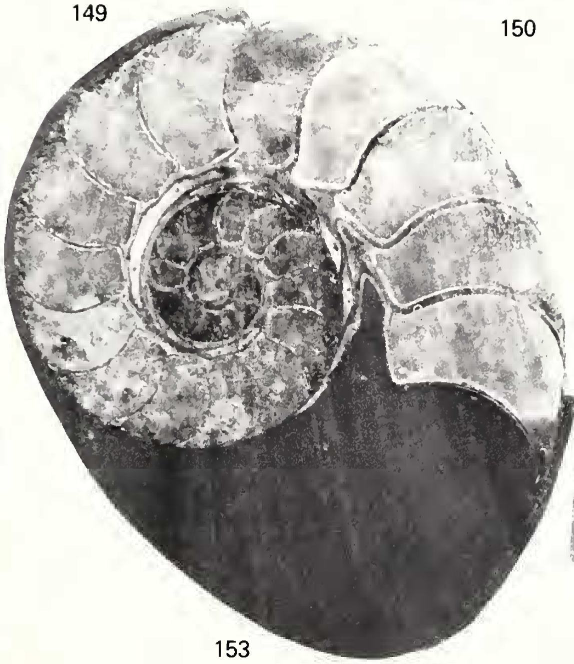

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on the basis of the size and configuration of the burrows, two different genera may be present.

SCAPHOPOD

Dentaliidae

Dentalium (*Fissidentalium*?) sp. cf. *D. porterensis* (Weaver)

Dentalium (*Fissidentalium*?) sp. cf. *D. porterensis* (Weaver, 1912:79, pl. 13, fig. 113) is circular in cross section, slightly tapered, and has perhaps 32 (16 exposed on one half) fine radial riblets crossed by strong concentric threads that produce a basket-weave sculpture. The preservation does not permit comparison with other ribbed Tertiary dentaliids.

CEPHALOPODS

Aturidae

Aturia angustata (Conrad)

Figures 133, 135, 137, 140, 143–145, 146, 147, 149, 150, 152–154, 155–159

Nautilus angustatus Conrad, 1848:728, pl. 20, figs. 5, 6.

Aturia angustata has been described in detail by Schenck (1931:457–462) and Miller (1947:85–88), and the type specimen figured and discussed by Moore (1963:85–86, pl. 31, figs. 1, 5).

A total of 180 specimens of *A. angustata* is in the Knappton collections, making this cephalopod by far the most abundant mollusk collected. Taking into account a possible bias in favor of collecting *Aturia*, this is still a large number. Kummel (1956:330–331) called attention to the rarity of post-Triassic nautiloids saying that no large collection representing a population had ever been assembled from a single horizon and locality. Stenzel (*in* Ladd, 1957:893) noted that there are in excess of 1000 mollusks representing other classes for every nautiloid shell and that the proportion may actually surpass 10,000 to 1.

The shell of the preserved portion of the living chamber is commonly slightly broken but more frequently is intact. The outer shell layer is dark brown and the entire shell or venter is thin, thinner than that of the living *Nautilus*. Faint, closely spaced growth lines can be seen on some specimens (Fig. 135). The lateral lobes are tongue-shaped and ascending on young specimens (Figs. 133, 145, 150), but not on more mature specimens (Fig. 147).

The specimens are believed to range in size from 30 to 180 mm in greatest diameter. The smallest specimens (25 mm) are not complete and so were probably 5 to 10 mm larger, and the largest specimen measures 170 mm but is incomplete and has an estimated size of 180 mm. The largest number of specimens sufficiently complete to make size measurement meaningful (22%) are 90 mm in greatest diameter. Presumably, this means that many of the specimens had not reached maturity before death. About 24% of the specimens are 100 to 180 mm in maximum diameter and are assumed to have been mature. The specimens are not crushed, and none shows any indication that it imploded as a result of having been transported to great depths.

The suture is simple with a broad flattened ventral saddle, a narrow pointed lateral lobe on the umbilical slope and dorsal area, and a broad saddle on the dorsal area divided by a deep, narrow lobe (Figs. 145, 147, 150). The siphuncle is moderate in size, subdorsal and marginal in position (Figs. 137, 140, 143, 144, 149, 152, 154, 155, 157), and located near the apex in the adapical flexure of the septa. The siphuncular tube consists of a series of cone-in-cone necks, or long funnel-shaped connecting rings (Fig. 157) without the long gaps between the necks that are present in *Nautilus*.

The phragmocone chambers may be filled with sediment (Fig. 154) but are more commonly partially filled with calcite or completely filled with calcite, barite, quartz, or combinations of these minerals (Fig. 153). A phragmocone chamber of one specimen is filled with glauconite. Some of the specimens have empty phragmocone chambers except for a calcite buttress, and these chambers may be followed or preceded by sediment-filled chambers, indicating that the sediment did not enter through the siphuncular tube but entered through a puncture in the shell. The body chamber, of course, is always filled with sediment.

Most of the shells of *Aturia angustata* are preserved in concretions as almost complete specimens, but some are fragments that may have weathered out of concretions or not have been so preserved. The specimens that show a sequence of mineralization, which is currently being studied in detail, begin with a buttressing of the shell walls with as many as nine layers of radial calcite (Fig. 146), followed by the dissolution of the aragonitic shell, and then the filling of the shell cavities and the remaining chamber voids with calcite, barite, and/or quartz in that sequence.

Sepiidae?

A trace fossil that may represent the cuttlebone of a sepiid is illustrated (Fig. 178).

FOSSILS OTHER THAN MOLLUSKS

SPONGES

Two sponges have been described by J.K. Rigby and D.E. Jenkins (1983) from the upper part of the Lincoln Creek Formation: *Aphrocallistes polytretos* (Fig. 180) and *Eurete*

Figures 155–159. *Aturia angustata* (Conrad). **155.** Broken specimen showing siphuncular orifices, ×3; height 80 mm. LACMP 6706. **156.** Showing phragmocone chambers filled with wood fragments and sediment. LACMP 6707. **157.** Silicified specimen etched in dilute hydrochloric acid to show cone-in-cone, funnel-shaped septal necks, ×1.5; 47 mm greatest diameter. LACMP 6708. **158.** Fecal pellets probably formed by a marine worm in phragmocone chamber, ×3. LACMP 6709. **159.** Fecal pellets in phragmocone chamber, ×5. LACMP 6710.


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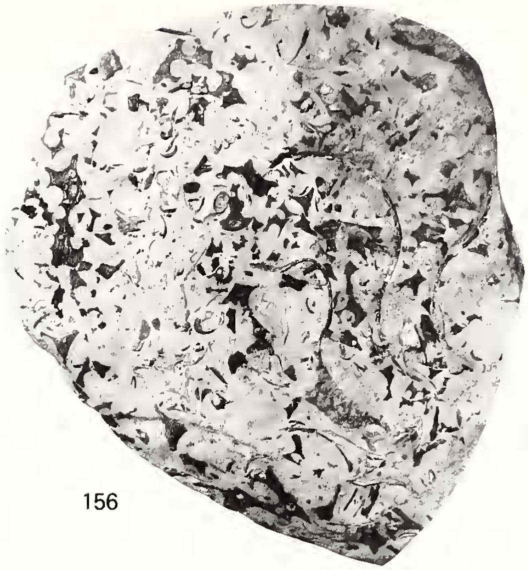
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goederti. In addition, hexactinellid root tuffs were identified that may represent a third sponge. Although the sponges are most common stratigraphically just below the major mollusk locality, they also occur within it. *Aphrocallistes* lives at depths of 100 to 1700 m (Schulze, 1887) and *Eurete* between 220 and 715 m, with the majority of species living at depths between 300 and 360 m (Rigby and Jenkins, 1983).

CORALS

Dendrophyllia hannibali Nomland (1916:67, pl. 6, figs. 1–3) was found in one concretion that also contains abundant fish debris and a small patch of the siliceous sponge, *Eurete goederti* Rigby and Jenkins (1983). The specimens are poorly exposed and recrystallized (Fig. 175), but some show septa (Fig. 176).

Dendrophyllia hannibali was described by Nomland (1916:67) as colonial, branching, and forming several vertical series that unite when coming in contact. It has deep nearly round calices with about 42 to 48 septa. The maximum number of preserved septa counted on the specimens described by Nomland is about 20, but recrystallization is believed to have destroyed many of the septa.

Dendrophyllia is a scleractinian, ahermatypic (nonreef-building; capable of living in cold deep water) coral. According to Wells (1956:F362, F435), "the greatest development of ahermatypic corals occurs near and down the edges of continental slopes and the equivalent bathymetric zone around oceanic islands in depths from 175 to about 800 m . . . in temperatures of 4° to 21°C." *Dendrophyllia* is cosmopolitan in its modern distribution and is known from the Eocene through the Holocene at depths ranging from 0 to 1370 m.

Flabellum sp. (Fig. 129) has also been collected.

BRACHIOPOD

Laqueus? sp. cf. *L. vancouverensis* Davidson is poorly preserved and only three (or possibly four) specimens have been collected. The outer shell is smooth (Figs. 166, 168, 169), or may possibly on some specimens be finely ribbed (Fig. 167), and the inner fibrous layer is punctate. The specimens resemble *L. vancouverensis* (Davidson, 1887:113, pl. 18, figs. 10–13b) more than any other described species. Gradational variation in sculpture between subspecies of the terebratellids (Hertlein and Grant, 1944:132) seems to be sufficient to perhaps allow for both smooth-shelled and finely ribbed forms in one species.

ECHINOIDS

Most of the echinoids (Figs. 160–162, 164, 170) are tests of a spatangoid (heart urchin) that was probably buried in living position since so many of its spines are attached (Porter M. Kier, written commun., 1980). The species probably lived in a burrow at a depth of one to several centimeters within the sediment. All the tests are broken, perhaps by the weight of the overburden as the attached spines suggest the specimens were not transported. The echinoids have not been found in the center of spherical concretions typical of the rest of the fauna.

A single specimen thought to be a madreporite, a sievelike structure that provides access to the water-vascular system (Fig. 163), was also collected.

LOCALITIES

NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY

5787. From landslide block in upper part of the Lincoln Creek Formation between Knappton and Grays Point, NW ¼ sec. 9, T. 9 N., R. 9 W., Knappton 7½-minute quadrangle (1973 edition), on the Columbia River, Washington. (General locality that includes 5842, 5843, 5844, and 5852.)

5802. From a limestone quarry in the siltstones of Cliff Point unit (Wells, 1979) in the bluff on the south side of Bear River, 2.3 km northeast of Goulter Ranch, on the section line between secs. 20 and 21, T. 10 N., R. 10 W., Chinook

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Figures 160–170. Spatangoid echinoids and a brachiopod.

Figures 160–162, 164, 170. Spatangoid echinoids. **160.** Showing test outline and spines, ×6.0; 8 mm greatest diameter of test. LACMP 6491. **161.** Showing ambulacral area and spines, ×3.0. LACMP 6710. **162.** Showing test outline and attached spines, ×3.0; 20 mm greatest diameter of test. LACMP 6492. **164.** Showing broken test with preserved ambulacral areas, ×2.0; 52 mm greatest diameter of test. LACMP 6711. **170.** Showing outline of several tests with associated wood fragments. LACMP 6712.

Figure 163. Madreporite? of spatangoid echinoid, ×12.0; 2.4 mm greatest diameter. LACMP 6713.

Figures 165–169. *Laqueus*? sp. cf. *L. vancouverensis* Davidson. **165.** View of apex, ×1.5. LACMP 6714. **166.** Showing configuration and narrow axial ribs; length 23 mm, width 23 mm. LACMP 6715. **167.** Showing radial ribs, ×1.5; width 23 mm. LACMP 6716. **168.** Showing configuration; height 17 mm. LACMP 6717. **169.** Showing configuration and smooth shell; length 35 mm, width 34 mm. Same specimen shown in Figure 165. LACMP 6714.

Figures 171–180. Teredinid bores, crab claw, *Dendrophyllia hannibali* Nomland, a trace fossil, and *Aphrocallistes polytretos* Rigby and Jenkins.

Figures 171, 172, 177, 179. Teredinid-bored wood. **171.** View of bored wood within *Aturia.* Same specimen shown in Figure 156, ×3.0. LACMP 6707. **177, 179.** Teredinid tubes in wood. LACMP 6716. **177.** Cross-sectional view. **179.** Longitudinal view, ×0.8.

Figures 173, 174. Crab claw showing nodes, ×1.5; length 35 mm. USNM 363992.

Figures 175, 176. *Dendrophyllia hannibali* Nomland. **175.** Showing configuration, ×1.5. LACMP 6719. **176.** Showing septa, ×3.0. LACMP 6720.

Figure 178. Trace fossil, possibly cuttlebone of sepiid, ×1.5; length 45 mm. LACMP 6721.

Figure 180. *Aphrocallistes polytretos* Rigby and Jenkins. Showing irregular branching growth. LACMP 6722.

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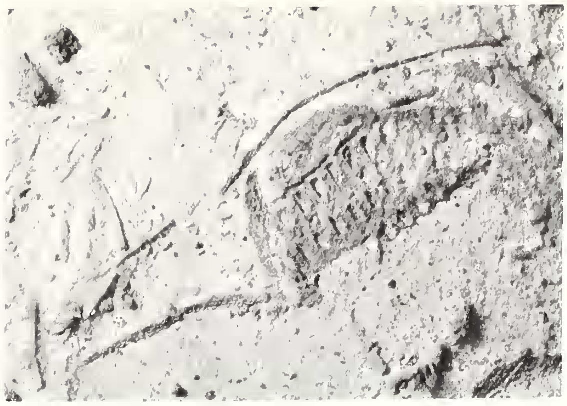

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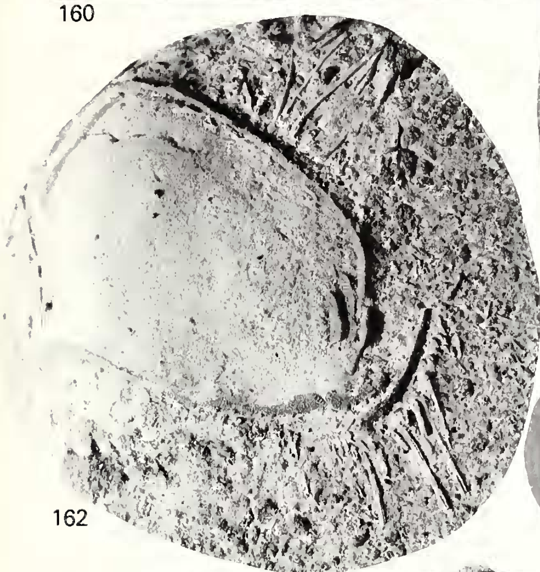

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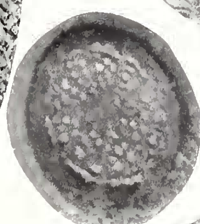

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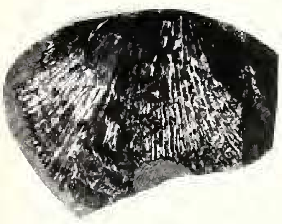

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7½-minute quadrangle, about 15 km northwest of Knappton, Pacific County, Washington.

5842. From landslide block in upper part of the Lincoln Creek Formation between Knappton and Grays Point, in the center of the N ½, N ½ sec. 9, T. 9 N., R. 9 W., Knappton 7½-minute quadrangle, on the Columbia River, Washington.

5843. From landslide block in upper part of the Lincoln Creek Formation between Knappton and Grays Point, 305 m south and 430 m east of NW cor. sec. 9, T. 9 N., R. 9 W., Knappton 7½-minute quadrangle, on the Columbia River, Washington.

5844. From landslide block in upper part of the Lincoln Creek Formation between Knappton and Grays Point, 122 m east and 520 m south of NW cor. sec. 9, T. 9 N., R. 9 W., Knappton 7½-minute quadrangle, on the Columbia River, Washington.

5852. From landslide block in upper part of the Lincoln Creek Formation between Knappton and Grays Point, NE ¼, NW ¼ sec. 9, T. 9 N., R. 9 W., Knappton 7½-minute quadrangle, on the Columbia River, Washington.

5863. From the Astoria Formation between Knappton and Grays Point, SE ¼, NW ¼ sec. 10, T. 9 N., R. 9 W., Knappton 7½-minute quadrangle, on the Columbia River, Washington.

U.S. GEOLOGICAL SURVEY, MENLO PARK, CALIFORNIA

M7891. The same locality as LAM 5842, but collected by E.J. Moore.

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