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First Fossil Record of the Pteropod *Limacina* from the Pacific Coast of North America

Richard L. Squires,[1] James L. Goedert,[2] and Steven R. Benham[3]

[1]*Department of Geological Sciences, California State University, Northridge, California 91330-8266*
[2]*15207 84th Ave. Ct. NW. Gig Harbor, Washington 98329-8765, and Section of Vertebrate Paleontology, Natural History Museum of Los Angeles County*
[3]*Department of Geosciences, Pacific Lutheran University, Tacoma, Washington 98447*

Abstract.—Pteropods from upper Eocene to lower Miocene deep-marine rocks in western Washington represent the first fossil record of genus *Limacina* from the Pacific coast of North America and the northernmost fossil occurrence in North America for this genus. Two species were found. Both occur in concretions in siltstone, and one was also found in limestone formed by chemosynthetic processes. Both species closely resemble other late Eocene to early Miocene *Limacina* spp. from Europe, Australia, and New Zealand, but poor preservation of the Washington specimens prevents their identification to the species level.

Pteropods are a group of rather poorly known free-swimming, holoplanktonic gastropods. Generally, they are found only in very restricted numbers. Their shells are thin, very fragile (Janssen 1990a), and consist of aragonite, which is easily subject to dissolution (Hodgkinson et al. 1992; Janssen 1991). Limacinids are euthecosomatous pteropods with a small (1–5 mm in height), sinistrally (left-handed) coiled shell.

Living species of *Limacina* are found in all the world's oceans (Tesch 1946, 1948; McGowan 1968; Bé and Gilmer 1977). Most of these species have a free-swimming veliger stage that hatches from a free-floating egg mass, although some species have developed brood protection through the early or entire larval stage (Bandel et al. 1984). The planktonic mode of life of pteropods can allow for wide geographic distribution, and there are indications that fossil species can be used successfully for long-distance correlations (Janssen 1990a).

The oldest known pteropods are Paleocene in age, but only two species are known. One is *Limacina mercinensis* (Watelet and Lefèvre 1885), and its earliest occurrence is latest Paleocene (Janssen and King 1988; Janssen 1991). It has been reported from Paleocene rocks of Alabama (Tracey et al. 1993), England, and Denmark (Janssen and King 1988). The other species is *Limacina advenulata* (Darragh 1997), from Victoria, Australia. Whether this species is of early or late Paleocene age has not been determined.

Other fossil species of *Limacina* have been reported from Eocene rocks of the southeastern United States (see Hodgkinson et al. 1992 for a modern summary), England and France (Curry 1965, 1981), the Ukraine (Korobkov 1966; Bielokrys 1997), and New Zealand (Maxwell 1992); Eocene/Oligocene rocks of Mississippi (MacNeil and Dockery 1984; Dockery and Zumwalt 1986), Germany (Koenen

1892), and Australia (Janssen 1989a); Oligocene rocks of Denmark (Janssen 1990b); Oligocene/Miocene rocks of the North Sea (Janssen 1989b) and Australia (Janssen 1989a); Miocene of Poland (Janssen and Zorn 1993), other areas in Europe (see Janssen 1984 for a modern summary), Mexico, and the Dominican Republic (Collins 1934); Pliocene rocks of Japan (Ujihara 1996); and Jamaica (Janssen 1998).

The fossil record indicates that *Limacina* was confined to warm waters and had widespread geographic dispersal during the Eocene and early to middle Miocene. The dispersal of this genus to present-day, worldwide distribution (tropical to arctic and antarctic waters) took place relatively recently, probably during the Pleistocene and possibly during the Pliocene. Several modern species of *Limacina* are cosmopolitan (Bernasconi and Robba 1982).

There are few reports of Tertiary pteropods from the Pacific coast of North America (Collins 1934). The only detailed account is by Squires (1989), who reported three species in two genera, *Praehyalocylis* and *Clio,* from upper Eocene to middle Miocene rocks in Oregon and Washington. Specimens representing a third genus, *Limacina,* are the subject of the present investigation. They are of latest Eocene to early Miocene in age and represent the first known fossil record of genus *Limacina* from the Pacific coast of North America and the northernmost fossil occurrence in North America for this genus. Today, there are five species of *Limacina* found in the northeastern Pacific Ocean, and their geographic distributions are given by McGowan (1968). Only one of these species, *Limacina helicina* (Phipps), is found primarily north of Point Conception, California. The other species are found in southern California and/or Baja California, Mexico.

The pteropod specimens described here, as well as the associated fauna, are reposited in the Natural History Museum of Los Angeles County, Invertebrate Paleontology Section (abbreviated LACMIP).

Systematic Paleontology

Class Gastropoda Cuvier, 1797

Order Thecosomata Blainville, 1824

Suborder Euthecosomata Meisenheimer, 1905

Family Limacinidae Gray, 1847 [=Spiratellidae Dall, 1921]

Genus *Limacina* Bosc, 1817

Type species.—*Clio helicina* Phipps, 1774, by monotypy; Recent, polar seas, North Atlantic, and Pacific coast of North America.

Remarks.—There has been considerable inconsistency and confusion in the literature regarding the proper generic name to use for this group of pteropods. As reported by Janssen (1989a) and Janssen and Zorn (1993), biologists usually use the name *Limacina,* but paleontologists commonly use the name *Spiratella* Blainville 1817. Both genera were named in the same month (December) of 1817, and both have the same type species. Curry (1981) reported that the name *Spiratella* was registered in the archives of the "Bibliothèque Nationale de Paris" before the name *Limacina* was registered, and some workers (e.g., Curry 1981; Maxwell 1992) have argued that the name *Spiratella* should be used in preference to the name *Limacina.* There has not been uniform acceptance of this informal conclusion (e.g., Janssen 1989a; Ujihara 1996), and it is apparent that an application to the International Commission on Zoological Nomenclature (abbreviated

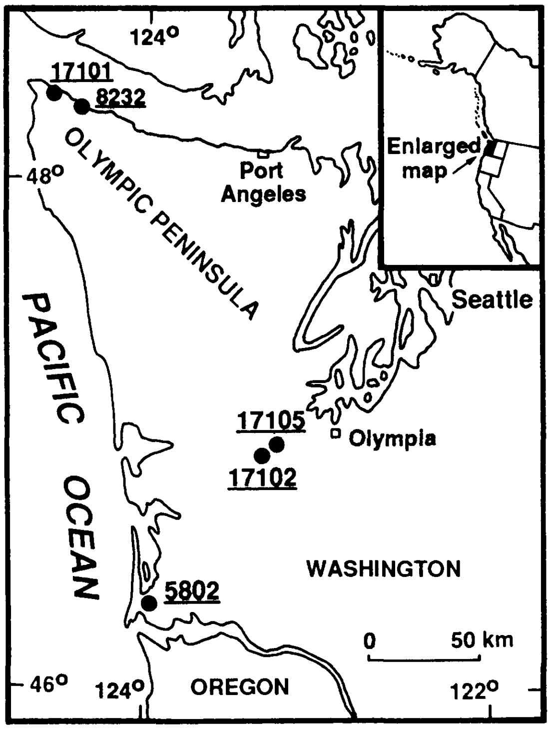


Fig. 1. Index map to LACMIP localities where fossil *Limacina* spp. have been found in Washington.

ICZN) is necessary for a formal decision of name priority. To date, no application has been made, but one will be made in the near future by A. W. Janssen (pers. comm.). Pending the ICZN decision, we have subjectively decided, like Bé and Gilmer (1977) and Janssen (1989a), to use the name *Limacina* because it is more frequently used than *Spiratella.* In addition, usage of the name *Limacina* will help bring the work of paleontologists and biologists in line.

Adding to the confusion around the synonymous taxa *Limacina* and *Spiratella,* in older papers (e.g., Kittl 1886) the name *Spirialis* Eydoux and Souleyet 1840 has been used (at least, in part) for this same group of pteropods. For a full synonymy of genus *Limacina,* see Spoel (1967:36).

Traditionally, *Limacina* is the only genus recognized within this family. Attempts to split the genus into three subgenera have not received wide acceptance because the boundaries between the subgenera are unclear (Bielokrys 1997) and the fossil forms were not fully treated (Janssen 1989a).

Limacina is characterized by a sinistrally coiled shell (anatomically dextral) that can be conispiral (the term "trochoid" is used by some authors) or more flattened and involute. Characters such as relative whorl height, aperture outline or aperture elongation, and development of the umbilicus are quite variable and can coincide in different species (Bielokrys 1997). In order to differentiate species, it is critical to have the entire adult teleoconch preserved.

Limacina sp. 1
Figures 2–5

Description.—Shell very small (height 0.7 to 0.83 mm), smooth, sinistral, with up to five whorls, rather quickly increasing in diameter; shell is 1.7 times wider than high. Apical side of the body whorl flat, with the spire barely protruding. Protoconch smooth. Aperture oval, slightly opisthocline, periphery seemingly evenly rounded; outer lip broken but apparently with a slight flare. Umbilicus about 20 percent of shell diameter. Large specimens with faint axial and spiral threads on body whorl.

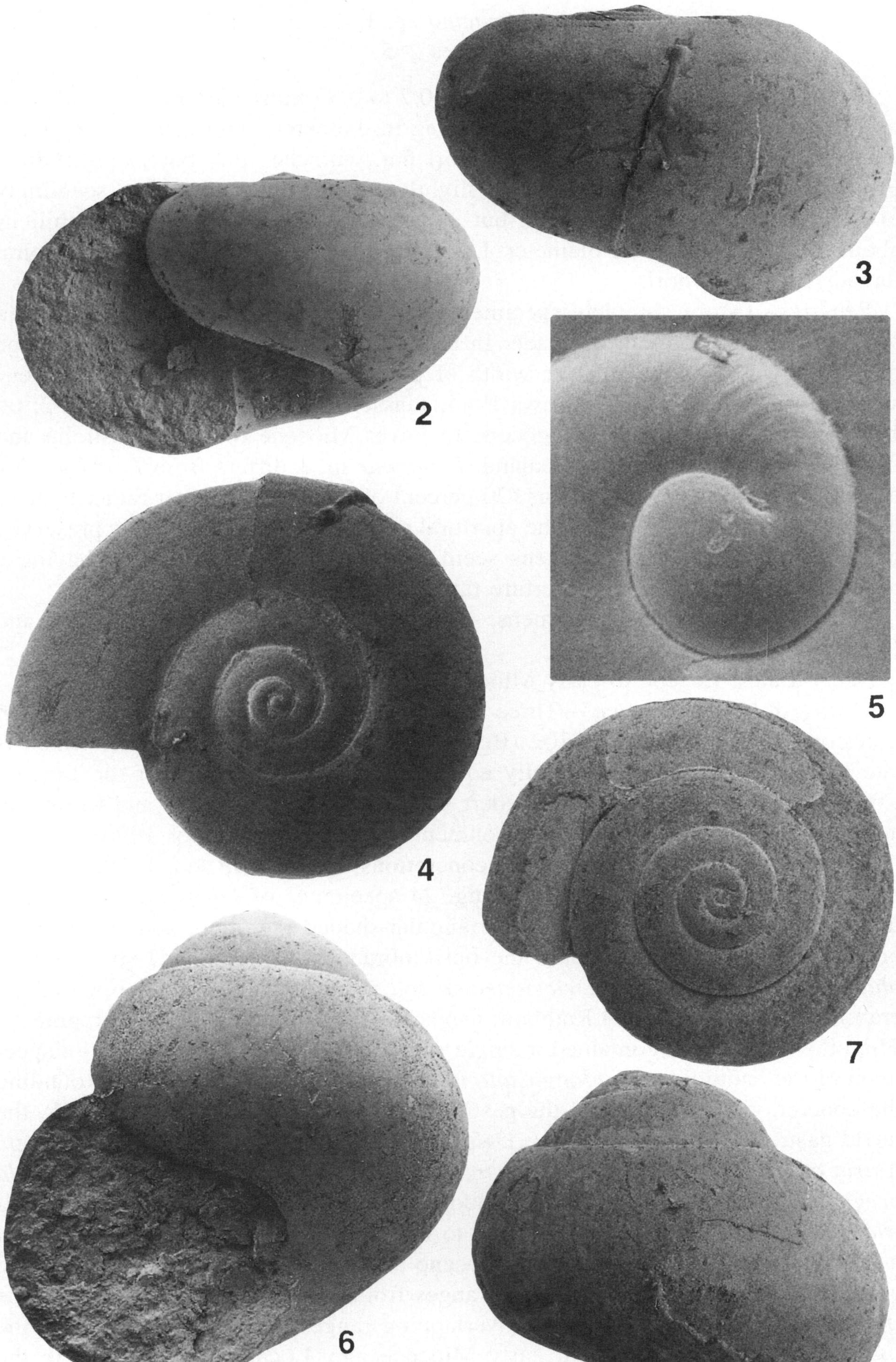
Remarks.—More complete specimens of *Limacina* sp. 1 are needed before a species identification can be made. In terms of the nearly flattened spire, shape of the body whorl, and relative width of the umbilicus, *Limacina* sp. 1 is very similar to *Limacina atypica* (Laws 1944; Janssen 1989a:7–8, pl. 1, figs. 1–2; pl. 10, figs. 1–3) from ?upper Oligocene to lower Miocene rocks in Australia and from Miocene rocks in New Zealand. *Limacina* sp. 1 differs from *L. atypica* by having a slightly wider umbilicus (20 percent of the shell diameter rather than 15 percent). In addition, although the apertural periphery is not completely preserved on *Limacina* sp. 1, the specimens seem to differ from *L. atypica* by having a rounded anterior part of the aperture rather than a projected anterior part.

Material.—Thirty-five specimens, including hypotypes LACMIP 12722 and 12723.

Age.—Latest Eocene to early Miocene.

Stratigraphic occurrence.—Three specimens of *Limacina* sp. 1 were found in limestone at LACMIP loc. 5802 (Bear River deposit). The limestone, which is late Eocene in age and temporally equivalent to the lower part of the Lincoln Creek Formation (Squires and Goedert 1991), is rich in mollusks and formed in a deep-marine chemosynthetic environment (Goedert and Squires 1990).

Limacina sp. 1 was found in two concretions at LACMIP loc. 17102. One of the concretions contained the following: 24 specimens of *Limacina* sp. 1, a few internal molds of an unidentifiable triangular-shaped pteropod, some specimens of minute gastropods (including the opisthobranchs *Tornatellaea*? sp. and *Scaphander*? sp.), the bivalve *Delectopecten* sp., minute bivalves, a cheliped of the crab *Portunites triangulum* Rathbun, fish scales, and carbonized-wood fragments. The other concretion contained a single specimen of *Limacina* sp. 1 and a specimen of the nautiloid *Aturia angustata* (Conrad). In the gray siltstone surrounding the concretions, specimens of the gastropod *Turritella oregonensis* (Conrad), the turrid gastropod *Spirotropsis*? sp., *Delectopecten* sp., the bivalve *Cyclocardia* sp., *Aturia angustata,* and *Portunites triangulum* were moderately common. *Turritella oregonensis* ranges from early to middle Miocene (Addicott 1976). *Portunites triangulum* ranges from latest Eocene to latest Oligocene or early Miocene, but it is most common in rocks of late Eocene to early Oligocene age (R. Berglund person. commun.). *Aturia angustata* ranges from latest Eocene to early Miocene (Armentrout 1973). Based on the overlapping ranges of these three species, the rocks at locality 17102 are of early Miocene age. Locality 17102 plots in the Lincoln Creek Formation on the geologic map of Pease and Hoover (1957). This formation ranges in age from late Eocene to early Miocene (Moore 1984), and the rocks at locality 17102 are assignable to the upper part of the formation.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The association at locality 17102 of pteropods, other small gastropods, small bivalves (including the "mud pecten" *Delectopecten*), crab remains, fish scales, and carbonized wood is very similar to other pteropod-bearing bathyal (greater than 200 m depth) assemblages found elsewhere in Tertiary formations of Washington and Oregon. These other bathyal assemblages commonly are a mixture of faunal remains derived from pelagic communities (pteropods, fish scales) and from nearby nonmarine communities (wood) (Squires 1989). The nautiloid at locality 17102 is a pelagic component, and the *Turritella* specimens probably represent a shallow-marine component that underwent post-mortem transport by turbidity currents.

Five specimens of *Limacina* sp. 1 were found in a concretion in the Lincoln Creek Formation at LACMIP locality 17105, which is stratigraphically and paleoenvironmentally equal to locality 17102. Also in the concretion were some specimens of the scaphopod *Fustiaria*? sp., a few unidentified turrids, *Delectopecten* sp., and a crab fragment.

A single specimen of *Limacina* sp. 1 was found in a concretion at LACMIP locality 8232, and the concretion also contained a specimen of the scaphopod *Dentalium* sp., minute bivalves, and wood fragments. This locality is in the lower Oligocene undifferentiated part of the Makah Formation, and this part of the formation, like the rest of the Makah Formation, was deposited in a predominantly lower to middle bathyal environment (Snavely et al. 1980).

A single specimen of *Limacina* sp. 1 was found in deep-marine rocks in the lower Oligocene Jansen Creek Member of the Makah Formation at LACMIP loc. 17101, in association with *Limacina* sp. 2.

Limacina sp. 2
Figures 6–8

Description.—Shell minute (up to 5 mm in height), conispiral (naticiform), slightly higher than wide, sinistral, 4 to 5 whorls, spire low to moderately low; shell smooth except for regularly spaced sinuous, shallow axial grooves (growth lines?); suture moderately impressed, protoconch smooth. Aperture large, outer lip mostly incomplete, columella missing. Umbilicus area mostly missing, apparently narrow.

Remarks.—More complete specimens of *Limacina* sp. 2 are needed before a species identification can be made. In terms of the relatively low spire, subglobose body whorl, relative height of the aperture versus the height and width of the body whorl, and the apparently very narrow umbilicus, *Limacina* sp. 2 has the most similarity to some specimens of *Limacina pygmaea* (Lamarck 1804:30; Watelet and Lefèvre 1885:101, pl. 5, figs. 3a–c; Curry 1965:362, figs. 18a, 18b, 19;

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Figs. 2–8. SEM micrographs of fossil *Limacina* spp. from Washington; 2–5, *Limacina* sp. 1, LACMIP loc. 17102, lower Miocene part of the Lincoln Creek Formation, Washington; 2–4, hypotype LACMIP 12722, ×50, height 0.83 mm; 2, apertural view; 3, abapertural view; 4, apical view; 5, hypotype LACMIP 12723, ×500, maximum diagonal distance 0.14 mm, apical view showing protoconch; 6–8, *Limacina* sp. 2, LACMIP loc. 17101, lower Oligocene Jansen Creek Member of the Makah Formation, Washington; 6–7, hypotype LACMIP 12724, ×35, height 1.9 mm; 6, apertural view; 7, apical view; 8, hypotype LACMIP 12725, abapertural view, ×34, height 1.6 mm.

Curry 1981:37, pl. 1, figs. 3a, 3b; Hodgkinson et al. 1992:19, pl. 3, figs. 14, 15) from middle Eocene (Lutetian Stage) rocks of Paris Basin, France, England, and Texas. *Limacina pygmaea* has considerable morphologic variation in the relative spire height, from flush to nearly half of the height of the shell. Because of this variation, some authors have recognized subspecies of *L. pygmaea. Limacina pygmaea bernayi* (Laubrière 1881:377, pl. 8, fig. 5; Cossmann and Pissarro 1910–1913:pl. 60, figs. 1–2 of the pteropods) from middle Eocene (Lutetian Stage) rocks of France is one of these subspecies, and it has a relatively low spire and can have axial grooves. In these two features, it is closely similar to the specimens of *Limacina* sp. 2.

Limacina sp. 2 also has some close similarity to *Limacina nemoris* (Curry 1965: 362, figs. 16a–b; Curry 1981:37, pl. 1, figs. 5a, b; Hodgkinson et al. 1991:18, pl. 3, figs. 9, 10) from the middle Eocene upper Bracklesham Beds of southern England, the upper Eocene "marnes bleues" of France, the upper Eocene Stone City and Cook Mountain formations of eastern Texas, and the upper Eocene Lisbon Formation of Alabama. *Limacina* sp. 2 does not have the inclined suture that can be present on some specimens of *L. nemoris.*

Material.—Twelve specimens, including hypotypes LACMIP 12724 and 12725.

Age.—Early Oligocene.

Stratigraphic occurrence.—The specimens were found in a concretion at LACMIP locality 17101, and they were in the matrix that surrounded fragments of a small squat crab (*Munida*? sp., R. Berglund pers. comm.). This locality is in the lower Oligocene Jansen Creek Member of the Makah Formation, and this member represents a transported olistostromal rock unit containing mostly shallow-water marine conglomerate and fossiliferous sandstone enclosed in deep-water (1,000 to 2,000 m) marine siltstone and sandstone (Snavely et al. 1980; Squires and Goedert 1994).

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Appendix

Localities

LACMIP 5802. "Bear River deposit". In an abandoned quarry on the south side of Bear River in the SE ¼, SE ¼ of section 20, T. 10 N, R. 10 W, U.S. Geological Survey 15-minute Chinook Quadrangle, 1949 (photorevised 1984), Pacific County, Washington. Strata temporally equivalent to the lower part of the Lincoln Creek Formation. Collectors: J. L. and G. H. Goedert, May 30, 1998.

LACMIP 8232. Float from beach terrace exposures approximately 2000 m northwest of the mouth of the Sekiu River, near center of SW ¼ NW ¼ sec. 5, T. 32 N, R. 13 W, U.S. Geological Survey 7.5-minute Sekiu River Quadrangle, 1984 (provisional edition), south shore of Strait of Juan de Fuca, Clallam County, Washington. Lower Oligocene part of the Makah Formation. Collector: J. L. Goedert, April 30, 1998.

LACMIP 17101. Approximately 320 m northwest of the mouth of Jansen Creek, near center of sec.

26, T. 33 N, R. 14 W, U.S. Geological Survey 7.5-minute Sekiu River Quadrangle, 1984 (provisional edition), south shore of Strait of Juan de Fuca, Clallam County, Washington. Lower Oligocene, Jansen Creek Member of the Makah Formation. Collector: J. L. Goedert, March, 1997.

LACMIP 17102. Siltstone 2 m below a hardground with reworked concretions, on the east side of a logging road, approximately 360 m north and 230 m west of the southwest corner of sec. 31, T. 17 N, R. 6 W, U.S. Geological Survey 7.5-minute South Elma Quadrangle, 1986 (provisional edition, minor revisions 1993), Grays Harbor County, Washington. Lower Miocene part of the Lincoln Creek Formation. Collectors: J. L. Goedert, G. H. Goedert, and E. Z. Nordlander, Spring, 1998.

LACMIP 17105. Concretion 1 m below a 4 cm-thick hardground (with reworked crab fossils) on steep slope on north side of ridge, approximately 720 m east and 480 m north of the southwest corner of sec. 28, T. 17 N, R. 6 W, U.S. Geological Survey 7.5-minute South Elma Quadrangle, 1986 (provisional edition, minor revisions 1993), Grays Harbor County, Washington. Lower Miocene part of the Lincoln Creek Formation. Collectors: J. L. and G. H. Goedert, May 23, 1998.