

## 15. THECOSOMATA (PTEROPODS) AND THEIR REMAINS IN LATE QUATERNARY DEPOSITS ON THE BOUGAINVILLE GUYOT AND THE CENTRAL NEW HEBRIDES ISLAND ARC<sup>1</sup>

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### ABSTRACT

We undertook a quantitative study of Thecosomata shells (pelagic gastropods) and their remains in Quaternary foraminiferal oozes deposited on the tilted calcareous platform of the Bougainville Guyot (Hole 831A), and in the late Quaternary volcanic siltstones, claystones and sandy interbeds on the upper forearc slope of the central New Hebrides Island Arc (Hole 830A). The distribution of the species is based on the identification of adult shells, juvenile stages, protoconchs, and characteristic shell fragments. By studying thecosomatous shells using a scanning electron microscope (SEM), we were able to specify the fine microstructure of the coiled *Limacina inflata* and compare it with the rod-type crossed-lamellar structure of some other *Limacina* species, as well as with the helical structure of the Cavoliniidae.

### INTRODUCTION

Leg 134 of the Ocean Drilling Program investigated the collision between the d'Entrecasteaux Zone, a topographic high on the India-Australia Plate, and the central New Hebrides Island Arc, a volcanic arc (Fig. 1). The Bougainville Guyot is the easternmost seamount of the South d'Entrecasteaux chain, which impinges upon the New Hebrides Island Arc near the latitude of Espiritu Santo Island (Vanuatu). Thecosomata occur in upper Quaternary sediments, on the Bougainville Guyot, and on the upper forearc slope of the central New Hebrides Island Arc.

Thecosomata are planktonic gastropods with coiled or uncoiled aragonitic shells. The occurrence of their shells distinguishes sediments deposited in open oceans above the aragonite compensation depth (ACD), a depth usually shallower than the foraminiferal lysocline and the calcite compensation depth (CCD) (Berger, 1977, 1978). Furthermore, since particular assemblages of Thecosomata species characterize different water masses in the oceans (Rampal, 1975; Be and Gilmer, 1977; Cifelli and McCloy, 1983), a study of changes in assemblages of species along undisturbed stratigraphical sections may reveal a turnover of the species in pelagic oozes that could indicate paleoclimatic changes useful for more detailed stratigraphic analyses (Chen, 1968; Herman and Rosenberg, 1969; Pastouret, 1970; Herman, 1971; Froget and Pastouret, 1972; Berger, 1977; Almogi-Labin, 1982; Almogi-Labin et al., 1986; Gardulski et al., 1990), and displacement or change in velocity of currents (Chen and Hillman, 1970).

### SAMPLES

Twenty-four upper Quaternary sedimentary samples were selected aboard the ship for Thecosomata study. They came from the following three holes.

Hole 830A is located 30 km south of the southern tip of Espiritu Santo Island, high on the upper forearc slope of the central New

Leg 134	Latitude (south)	Longitude (east)	Depth (mbsf)
Hole 830A	15°57.00'	166°46.79'	1018.4
Hole 831A	16°00.51'	166°40.36'	1077.6
Hole 833A	14°47.77'	167°52.78'	2629.0

Hebrides Island Arc on the northern wall of the 10 km bathymetric Malakula reentrant, an indentation caused by the impact of the Bougainville Guyot (Collot, 1989). Seven 20-cm<sup>3</sup> samples were selected aboard ship from 2.15 to 15.82 meters below seafloor (mbsf), (1H-2, 65–68 cm, to 2H-6, 132–134 cm), all of which are from lithostratigraphic Subunit IA, a fine-grained, nearly structureless, un lithified, volcanic silt with normally graded foraminiferal sandy interbeds occurring below 10 mbsf (Collot, Greene, Stokking, et al., 1992).

Nannofossil zonation established by examination of the samples with a scanning electron microscope (SEM) is shown in Table 1. The lithostratigraphic report (Collot, Greene, Stokking, et al., 1992) indicates that the interval between Sample 830A-2H-3, 110–111 cm and Sample 830A-2H-4, 38–39 cm exhibits oxidation. Because this is also the interval across which the nannofossil *Emiliania huxleyi* first appears in the section, we propose that an unconformity may be present here.

Site 831 is located about 15 km due west of Site 830, in the center of the carbonate-capped platform on the summit of Bougainville Guyot (Fig. 1). The seafloor trace of the subduction zone, as surveyed from the submersible *Nautilé* (SUBPSO cruise, Collot et al., 1989; 1992; Montaggioni et al., 1991), crosses between sites 830 and 831. Seventeen 15 cm<sup>3</sup> samples from 0.81 to 28 mbsf (831A-1H-1, 81–84 cm to 10X-CC, 27–28 cm), were selected on board. Samples from 0 to 16.4 mbsf (831A-1H, 0 cm, to 3H-CC, 6 cm) are from lithostratigraphic Unit I, a foraminiferal ooze with grainstone clasts (Collot, Greene, Stokking, et al., 1992). The contact with lithostratigraphic Unit II is marked by an abrupt faunal transition from pelagic to neritic microfossils. The nannofossil zonation (Table 2) was established with the use of a light-microscope only.

The flow of sandy sediment into the hole degraded the quality of the advanced hydraulic piston core (APC) cores recovered (Collot, Greene, Stokking, et al., 1992). That is particularly true of Core 831A-2H, where 2 m of drilling resulted in 9.64 m recovered.

Site 833 is located approximately 24 km northwest of the northern tip of Maewo Island, on the lower east-central flank of the North Aoba Basin, an intra-arc basin between the Western and Eastern belts of islands in the central New Hebrides Island Arc (Fig. 1). Three 10-cm<sup>3</sup>

<sup>1</sup> Greene, H.G., Collot, J.-Y., Stokking, L.B., et al., 1994. *Proc. ODP, Sci. Results*, 134: College Station, TX (Ocean Drilling Program).

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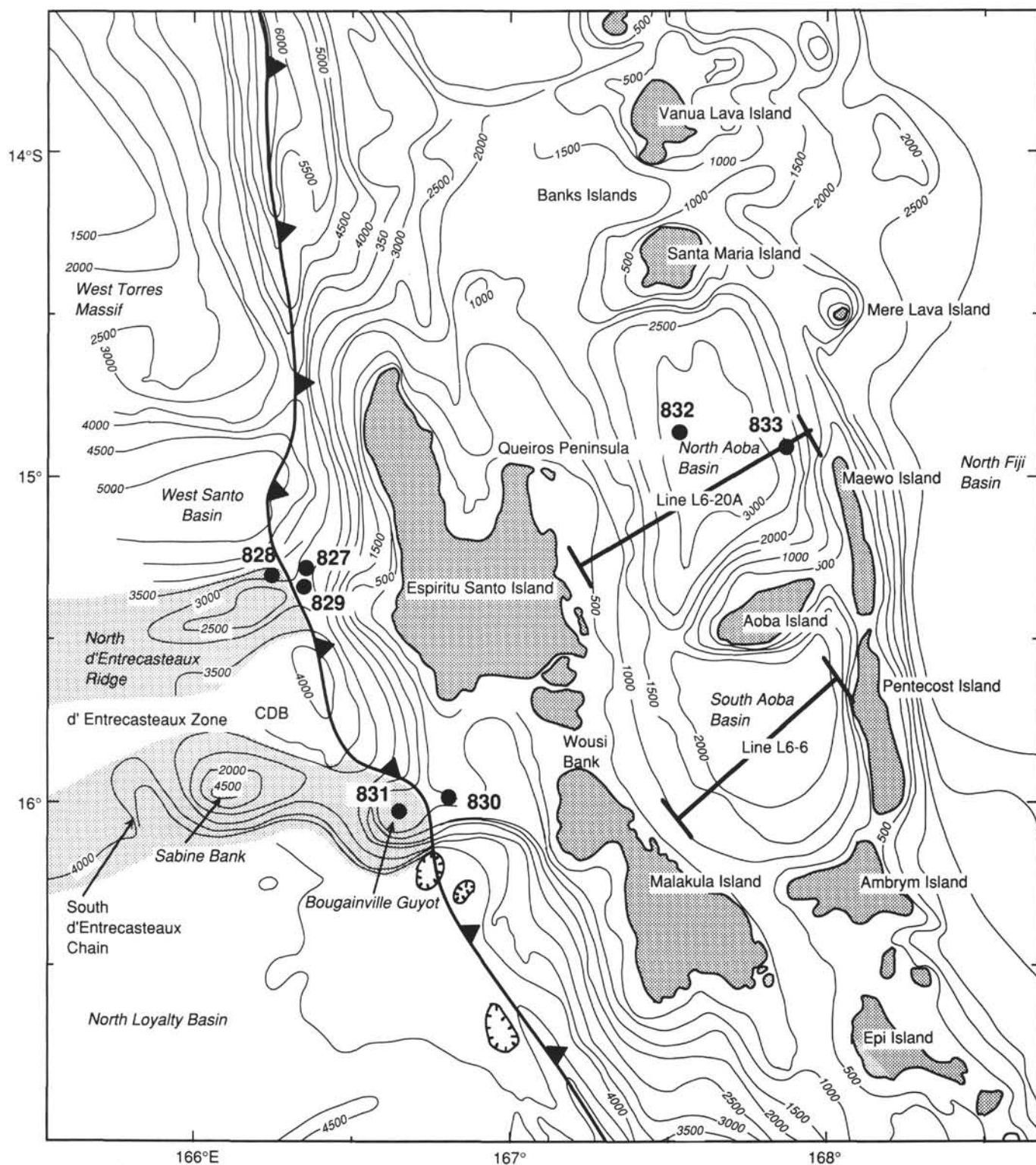


Figure 1. Index map showing Leg 134 drill sites. Bathymetry in meters. Line with teeth indicates plate boundary.

samples from 11.90 to 21.55 mbsf were selected on board ship. All are from lithostratigraphic Subunit IA, clayey to sandy volcanic silt interbedded with numerous volcanic layers (Collot, Greene, Stokking, et al., 1992). On board, the boundary between nannofossil Zones CN15 and CN14 was tentatively located in Core 833A-3H, between 18.9 and 28.5 mbsf.

## METHODS

Samples of about 10 to 20 cm<sup>3</sup> each were dried at 60°C for about 6 hr and then weighed before being washed through a battery of sieves with mesh sizes of 500, 150, 125, and 63 mm, respectively. Each size fraction was again dried and then weighed. The results are illustrated

Table 1. Nannofossil zonation of samples from Hole 830A.

Core, section, interval (cm)	Depth (mbsf)	Nannofossil event	Nannofossil zone	Age (Ma)
134-830A-2H-3, 110-111	11.10	<i>E. huxleyi</i> (common)	CN15	0.46
2H-4, 38-39	11.88	<i>E. huxleyi</i> (absent)	Unconformity? CN14b	
2H-6, 30-31	14.80	<i>P. lacunosa</i> (absent)	CN14b	
2H-6, 110-111	15.60	<i>P. lacunosa</i> (common)	CN14a	

Note: *E.* = *Emiliania*, *P.* = *Pseudoemiliania*.

in Figures 2A, 3A, and 4A. Note that the sample intervals are too large to give a real representation of the evolution of grain size along the cores.

Using a JSM 840A SEM specimens coated with evaporated gold-palladium were examined to determine their state of preservation. To precisely define the microstructure of the shell walls we compared sections obtained using needles to more precisely oriented sections of shells embedded in araldite, then etched them for 1 or 2 s in "RBO" (Dupeage Kinetic Laboratory Illinois) at 12.5% (Pls. 2-6).

Quantitative analysis of the Thecosomata was performed on every sample with a fraction larger than 500  $\mu\text{m}$ . Counts are summarized for Hole 830A in Table 3 and for Hole 831A in Table 4.

Some uncoiled Thecosomata are fragile. They are not always preserved as a whole shell. Therefore, we identified fragments of broken shells to note the occurrence of the species in the sediments. In Table 5, and illustrated in Plate 1, we regroup the characteristic features of the telocochs, protoconchs, or posterior spines of the principal species collected in the western Pacific. Morphological terms are illustrated by Be and Gilmer (1977); microstructural terms are defined and illustrated by Carter et al. (1991).

## RESULTS AND DISCUSSION

Quaternary samples from Holes 830A and 831A contain Thecosomata; however, no Thecosomata remains have been found in the sandy fraction (larger than 63  $\mu\text{m}$  in grain size) of the samples selected on board at Hole 833A.

The number of Thecosomata larger than 500  $\mu\text{m}$  is strongly variable from sample to sample. Quantities ranged from less than 50 to nearly 20,000 individuals per 100 g of original sediment.

At Site 830, in nannofossil Zones CN15 and CN14b (less than 0.46 Ma) the number of Thecosomata correlates crudely with the weight of the sandy fraction, except in Sample 830A-2H-1, 103-107 cm (8.02 mbsf), where volcanic material increases drastically (Figs. 2A, B). At that level, the scarcity of Thecosomata may reflect dilution by volcanoclastic sediment. At 15.82 mbsf the lack of Thecosomata in a sample placed in nannofossil Zone CN14a could be the result of transport with displacement of sandy particles, since silt and clay comprise more than 85% in weight of that sediment.

The downhole contamination of Core 831A-2H observed on board prevents proper correlation of the sample in Hole 831A (Fig. 3). In Core 831A-3H, however, the same crude correlation between the sandy fraction and the number of Thecosomata as found at Site 830 reappears (Fig. 4). It is clear that Thecosomata shells play an important role in the volume of the sandy fraction of the sediments in Hole 831A.

Eighteen species of Thecosomata have been identified in the studied samples. Their distribution is summarized for Hole 830A in Table 3 and for Hole 831A in Table 4. These species are comparable to those identified by Be and Gilmer (1977) with the three exceptions of *Cuvierina columnella*, *Cavolinia uncinata*, and *Creseis virgula* (Table 6). In nannofossil Zone CN15 and in a Zone CN14b horizon,

Table 2. Nannofossil zonation of samples from Hole 831A.

Core, section, interval (cm)	Depth (mbsf)	Nannofossil event	Nannofossil zone
134-831A-1H-3, 116-117	4.16	<i>E. huxleyi</i> (sparse) preservation declines	CN15
2H-2, 29-30	"Soupy"	SEM analysis was required for positive identification of <i>E. huxleyi</i>	CN15
3H-7, 39-40	15.80	Too few nannofossils	

in Hole 830A *Styliola subula* is the dominant species, comprising more than 75% of the Thecosomata. Very rare *Limacina inflata* appear in scattered horizons and are in agreement with the distribution of living forms (Table 6). *Styliola subula* is always present in Hole 831A, but its percentage varies from 5% to 88%. *Limacina inflata* is usually the preponderant species, comprising 42%-85% of the Thecosomata present in poorly preserved nannofossil assemblages identified as Zone CN15 (Table 2). In Samples 831A-3H-5, 75-80 cm, and 3H-2, 75-80 cm, however, *Styliola subula* is dominant with 88% and 54% of the Thecosomata, respectively.

The state of shell preservation varies. Coiled forms, such as *Limacina* species, are usually well-preserved, but ornamentation is missing from the very rare *Peraclis*. Uncoiled forms, such as *Diacria* and *Cavolinia*, are often open, with dorsal and ventral parts of the shell separated. *Clio*, *Styliola* and *Creseis* are always subtransversally broken, and *Hyalocylis* is strongly fragmented. Various protoconchs isolated by breakage occur. Many protoconchs and fragments are specifically identifiable. Plates 1A, 1B, and Table 5 show useful indices for identifying shells or fragments of shells.

Shell damage may result from compaction, transport, biodegradation, or dissolution. However, Berger and Piper (1972) argue that for calcitic foraminiferal tests "it could be difficult to differentiate between dissolution and transport since sediments containing only heavy resistant shells may result from dissolution of less resistant tests or from bottom currents winnowing out the lighter shells." We used the SEM to distinguish between mechanically damaged, biodegraded, and partly dissolved shells. Borings are rare and small. No strong dissolution indices occur, and we can easily observe the characteristic microstructures of the fragmented walls.

Preservation of shell microstructures provides an excellent opportunity to study thecosomatous fragments using the SEM. Previous microstructural descriptions differ on certain points. For a detailed ultrastructural study using the SEM, Be et al. (1972) selected *Cuvierina columnella* (Rang) because "of its relatively uncomplicated shape, resembling a cylindrical bottle and because its structure—prismatic and helical—is characteristic of that of other pteropod species: *Limacina inflata*, *L. bulimoides*, *Euclio pyramidata*, *Creseis virgula*, *Styliola subula*, *Hyalocylis striata*, *Diacria trispinosa*, and *Cavolinia longirostris*." In an addendum to their study on *Cuvierina columnella* they suspected "*Limacina bulimoides* to have crossed-lamellar, not helical structure." Rampal (1972, 1973, 1974, 1975, 1977) distinguishes the prismatic and/or crossed-lamellar shell structure of the Limaciniidae (Pl. 2) from the prismatic and spiral structure of the Cavoliniidae. Following Rampal (1973, 1975), the differences in micro-architectural structures of the shell are critical to phylogeny. The uncoiling of coiling forms induces the inner helical microstructure. Richter (1976) recognized the helical structure of *Limacina inflata* and Cavoliniidae. Be and Gilmer (1977) pointed out that "the shells of the Limaciniidae (coiled forms) and Cavoliniidae (uncoiled forms) are constructed of aragonite, but their microstructures are strikingly different. The Limaciniidae, with the possible exception of *Limacina inflata*, possess a crossed-lamellar shell microstructure. In contrast, the Cavoliniidae have a helical microstructure that is unlike that of any other molluscan group." Poulicek et al. (1991) also re-examined

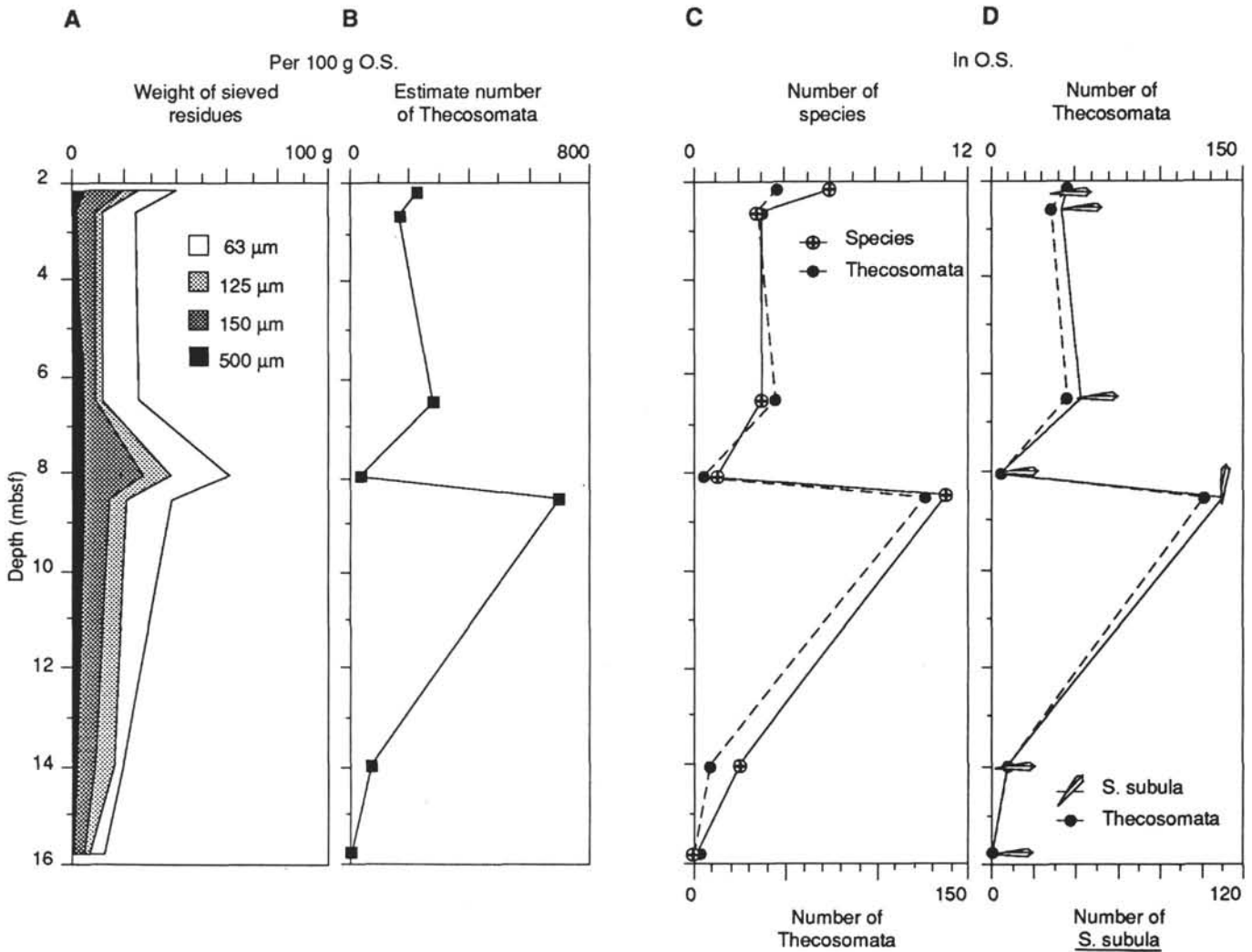


Figure 2. The distribution of Thecosomata and their species in Hole 830A core samples. **A.** Variation in the weight of residues per 100 g original sample (OS) from every sieve, using 63, 125, 150, and 500 µm mesh-size sieves. **B.** Estimate of the number of Thecosomata larger than 500 µm per 100 g original samples. **C.** Comparison of the number of Thecosomata and the number of species found in the original sample. **D.** Comparison of the number of *Styliola subula* and the number of Thecosomata in original samples.

*Limacina inflata* and concluded that "under a thin granular layer there are two poorly individualized layers of somewhat disorganized crossed acicular-fabric." We note that they studied "pieces of shell cut from the last whorl some distance away from the aperture." That could explain why they do not describe the helical structure we found in previous coiling turns of the shell (Pls. 3, 4), which compares well with the helical structure of Cavoliniidae (Pls. 5, 6). If we compare the coiling mode of the species (Pl. 4, Figs. 8–11) we see that the tightly coiled, high-spined *Limacina bulimoides* has a more closely crossed-lamellar shell than the others. Adult *L. inflata* is flat with the apex invisible in profile view. It has fewer coils and a spire that grows faster than in other *Limacina*. Perhaps the tendency to become uncoiled could be hypothesized.

The microstructure of a thecosomatous shell varies according to the area observed. That is clearly demonstrated for *Cuvierina columella* by Be et al. (1972). In Plates 3 and 4 we show *Limacina inflata* with the prismatic layer close to the aperture and the helical layer (one turn) formed away from the aperture. Another prismatic layer different from that of the aperture—the prisms are shorter—occurs below the helical layer in the inner part of cross sections. Crossed-acicular structure (sensu Carter) seems to occur close to the aperture (Pl. 3,

Fig. 1). Poulicek et al. (1991) stated "apart from *Limacina inflata*, the shells of *Creseis acicula*, *Hyalocyclus striata*, *Euclio pyramidata*, *Diacria trispinosa* and *Cavolinia longirostris* are built, following the same scheme: under a thin granular layer, there is a crossed-acicular layer progressively becoming helicoidal close to the inner side of the shell." The Cavoliniidae we illustrate are all of the helical type, but we distinguished species with one helical turn (Pl. 5) from species with multi-helical turns (Pl. 6).

## SUMMARY

From the quantitative study of thecosomatous shells in late Quaternary sediments of Holes 830A and 831A, Zones CN15–CN14b, we note some changes in thecosomatous distribution. *Styliola subula* is always present and usually abundant, but *Limacina inflata* declines from 0.46 Ma until the Holocene.

The fragmentation of many shells provided an opportunity to determine how to identify species from protoconchs, juvenile stages, or shell fragments only. The type of shell fragmentation is characteristic of the species. Fragmentation more often seems to be mechanically induced rather than the result of differential dissolution or



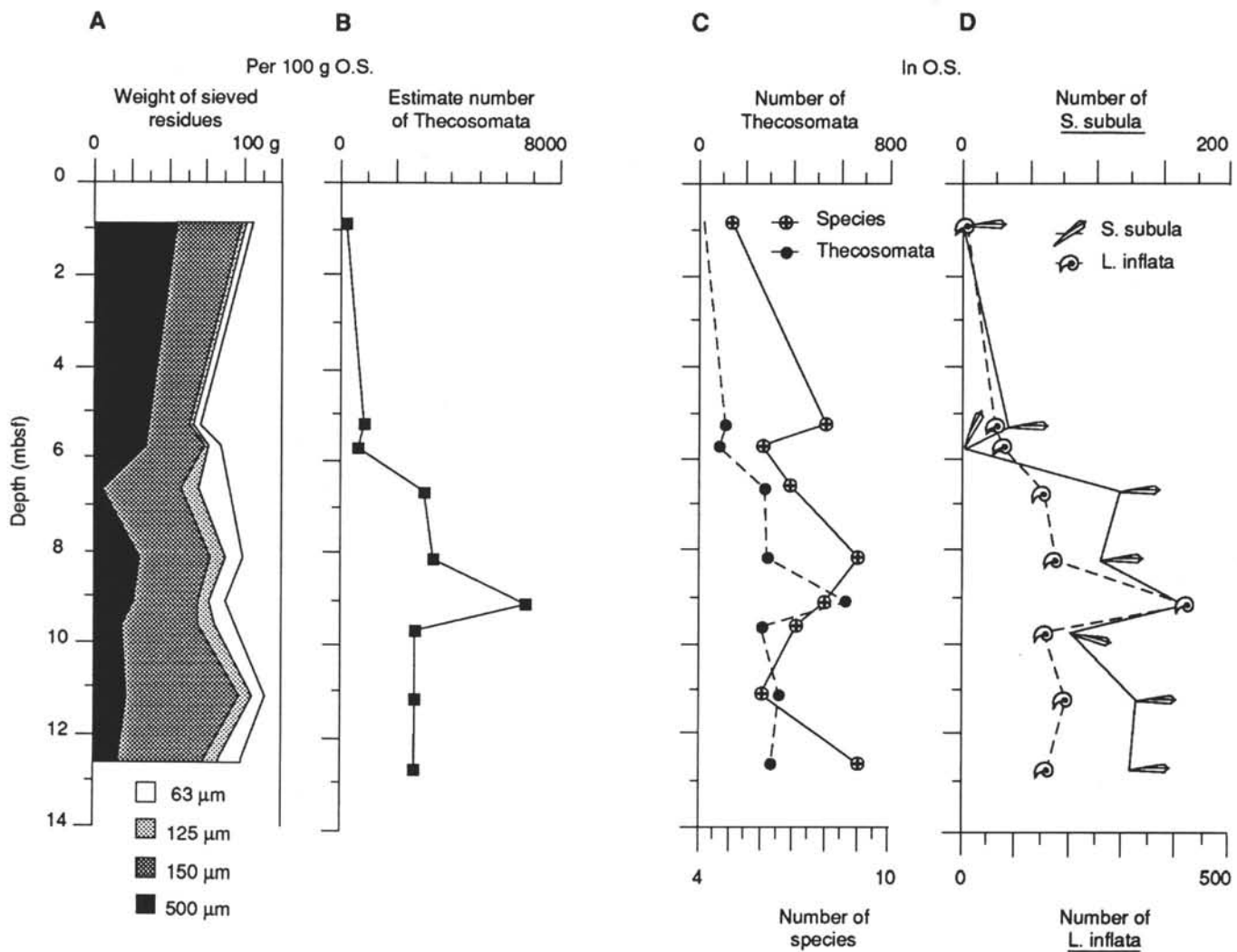


Figure 3. The distribution of Thecosomata and their species in samples from Cores 831A-1H and -2H. **A.** Variation in the weight of residues per 100 g original sample (OS) from every sieve, using 63, 125, 150, and 500 µm mesh-size sieves. **B.** Estimate of the number of Thecosomata per 100 g of original samples. **C.** Comparison of the number of Thecosomata and the number of species found in original samples. **D.** Comparison of the frequency of *Limacina inflata* and *Styliola subula* in original samples. In Table 4 we noted the "soupy" nature of some samples from Core 831A-2H. Two meters of drilling resulted in 9.64 m recovered core. Thus, to plot Thecosomata frequency vs. sand size fraction from samples of Core 831A-2H, we use the apparent "soupy depths" to properly place the samples in the expanded core.

biodegradation. The state of preservation of the microstructure of shell walls was studied using the SEM. Thecosomata show ontogenic changes in shell structure. The microstructure of the coiled *Limacina inflata* compares well with the helical structure of uncoiled Cavoliniidae, in opposition to the rod-type crossed lamellar structure observed in other coiled *Limacina*, *L. bulimoides*, *L. lesueuri*, and *L. trochiformis*. This particular structure of *Limacina inflata* could be an index of its key location on the phyletic tree of uncoiled Thecosomata, like *Creseis*, *Hyalocyclus striata*, and *Styliola subula*.

#### ACKNOWLEDGMENTS

We are indebted to the Ocean Drilling Program and the U.S. National Science Foundation for providing samples. We thank those who sampled for us on board ship. The authors greatly acknowledge J.-Y. Collot, H. G. Greene, M. Poulíček, and S. van der Spoel for their constructive criticism. L. Dearmont greatly improved the original manuscript. We also wish to thank M. Lécorché for help, particularly

with the computer graphics, and J.-J. Cornée and J.-P. Saint Martin for interesting discussions. The Institut National des Sciences de l'Univers (INSU) provided G. Glaçon with funds to attend the Scientific Meeting in Villefranche-sur-Mer. Unité de Recherches Associées 1208 (URA) helped in printing the draft of this manuscript.

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Date of initial receipt: 9 April 1992

Date of acceptance: 18 December 1992

Ms 134SR-014

**Table 3. Number of identified Thecosomata in sieved residues larger than 500  $\mu\text{m}$  in grain size from Hole 830A samples.**

Section 134-830A- Sample interval (cm)	1H-2 65–68	1H-2 111–114	1H-5 49–52	2H-1 103–107	2H-2 2–6	2H-52 95–97	H-6 132–134
Depth (mbsf)	2.15	2.61	6.49	8.03	8.52	13.95	15.82
Graphic lithology	T5	T5	T5	T5	T5	T8	T8
Drilling disturbance	Slight	Slight	Slight	Slight	Slight	Slight	Slight
Nannofossil zonation			CN15			CN14b	CN14a
Weight of original sample (g)	20.18	21.60	16.39	15.19	18.16	13.25	17.95
<i>Cavolinia inflexa</i>	2				3		Barren
<i>Cavolinia tridentata</i>					2		"
<i>Clio convexa</i>					1		"
<i>Clio pyramidata</i>					1	1	"
<i>Creseis acicula</i>	2	1			2		"
<i>Diacria quadridentata</i>	3				2		"
<i>Diacria trispinosa</i>	1	2	2		1		"
<i>Hyalocyllis striata</i>			1		1		"
<i>Limacina inflata</i>	2				2		"
<i>Styliola subula</i>	36	33	42	5	110	8	"
<i>Peraclis</i> sp. (ornament. lost)					1		"

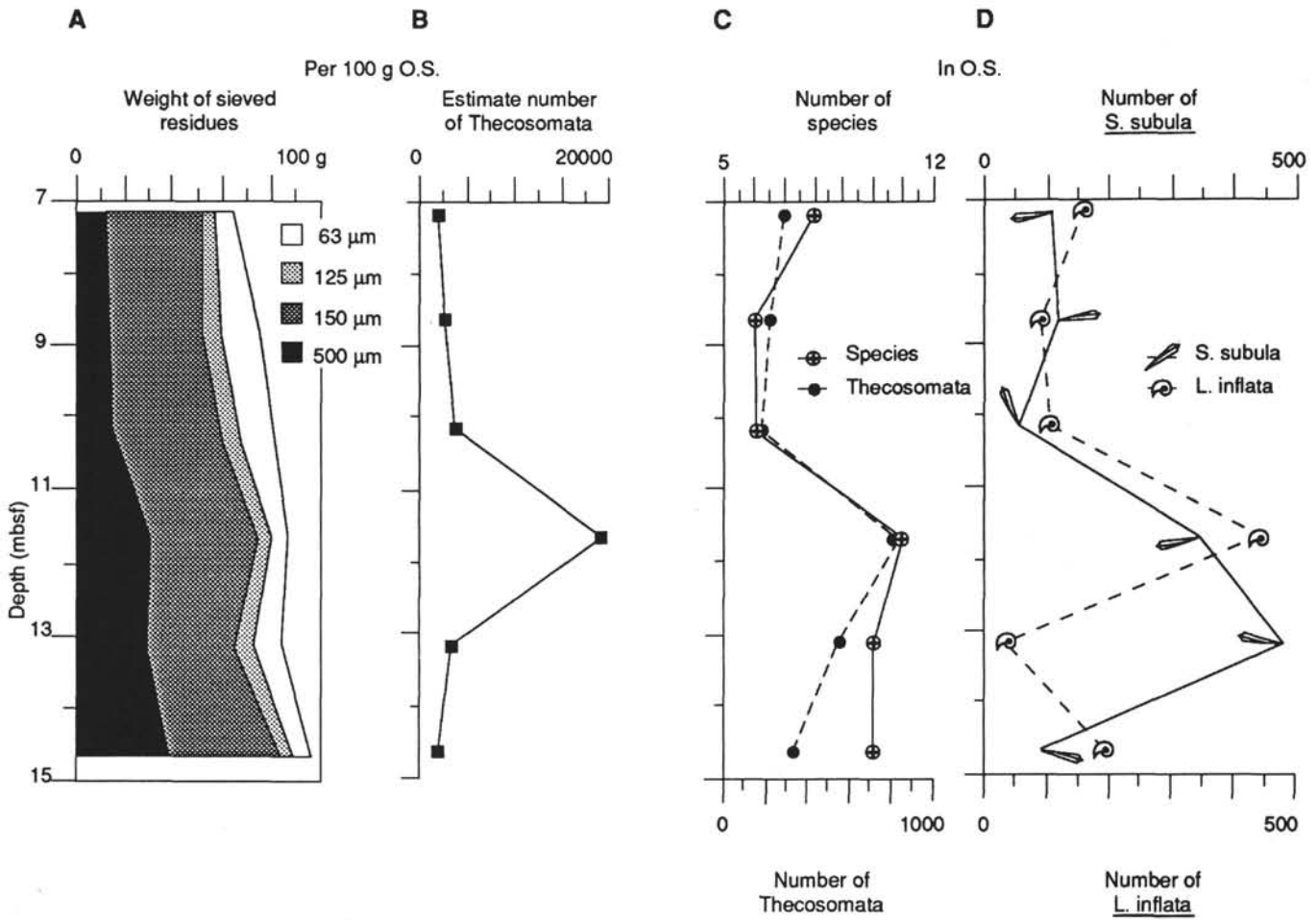


Figure 4. The distribution of Thecosomata and their species in samples from Cores 831A-3H to -10X. **A.** Variation in the weight of residues per 100 g original sample (OS), using 63, 125, 150, and 500 µm mesh-size sieves. **B.** Estimate of the number of Thecosomata per 100 g of original samples. **C.** Comparison of the number of Thecosomata and the number of species found in original samples. **D.** Comparison of the frequency of *Limacina inflata* and *Styliola subula* in original samples.

Table 4. Numbers of identified Thecosomata in sieved residues larger than 500 µm in grain size of every sample from Hole 831A.

Section 134-831A-	1H-1	2H-1	2H-1	2H-2	2H-3	2H-4	2H-5	2H-5	2H-6	3H-1	3H-2	3H-3	3H-4	3H-5	3H-6	8X-CC	10X-CC
Sample interval (cm)	81-84	87-89	134-136	73-77	73-77	18-22	73-77	73-77	73-77	75-80	75-80	75-80	75-80	75-80	75-80	14-16	27-28
Depth (mbsf)	0.81	5.27	5.74	6.63	8.13	9.08	9.63	11.13	12.63	7.15	8.65	10.15	11.65	13.15	14.65	48.5	58.27
Graphic lithology	SR2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	CB2	N3	N4
Drilling disturbance	Mod.	High	High	Soupy	Soupy	Soupy	High	Soupy	Mod.	Slight	Soupy	Slight	Slight	Slight	Slight	High	Mod
Nannofossil zonation								CN15								Barren	Barren
Weight of original sample (g)	14.52	13.65	13.71	9.21	8.71	9.15	9.63	12.46	11.41	14.51	8.36	4.76	4.29	16.85	17.93	42.39	18.44
<i>Cavolinia gibbosa</i>										1			1			Barren	Barren
<i>Cavolinia globulosa</i>															1	"	"
<i>Cavolinia inflexa</i>	2				1	7	3	3	5	6	3		6	4	1	"	"
<i>Cavolinia longirostris</i>									1							"	"
<i>Clio convexa</i>		2	1											1		"	"
<i>Clio cuspidata</i>									1							"	"
<i>Clio pyramidata</i>		1				6	3	1	1		?		3	1		"	"
<i>Creseis acicula</i>	1			2	2	4							5			"	"
<i>Diacria quadridentata</i>		5		1	1	4	3	2	1	3	4		5	3	3	"	"
<i>Diacria trispinosa</i>			1	1	1								1	1	1	"	"
<i>Hyalocylis striata</i>					1					1			1	1		"	"
<i>Limacina bulimoides</i>		3	4	6	8	9			6	6			4	13	4	14	"
<i>Limacina inflata</i>	13	64	75	152	173	417	154	197	161	158	91	106	442	35	192	"	"
<i>Limacina lesueurii</i>	2	3	4	2	1	10	8	9	5	6	3	6	10	11	15	"	"
<i>Limacina trochiformis</i>		2											3	2	5	"	"
<i>Styliola subula</i>	2	35	4	117	103	167	82	130	126	108	117	55	344	479	93	"	"

**Table 5. Special specific characteristics of teloconchs, protoconchs, or posterior spines of the principal species collected in the western Pacific.**

Species	Teloconch	Protoconch or posterior spines
	<b>Conical shell</b>	<b>Protoconch</b>
	<i>Round transversal section</i>	
<i>Creseis acicula</i>	Longitudinal sides almost parallel maximum diameter about 1mm	Longitudinal sides parallel 2 rings
<i>Creseis conica</i>	Longitudinal sides weakly divergent maximum diameter about 2mm	Longitudinal sides weakly divergent weak or absent constriction
<i>Creseis virgula</i>	Longitudinal sides strongly divergent maximum diameter about 2-2.5mm	Longitudinal sides strongly divergent strong constriction
<i>Creseis chierchiaie</i>	Longitudinal sides weakly divergent sometimes transverse ripples maximum diameter about 0.5mm	Longitudinal sides weakly divergent strong constriction
<i>Styliola subula</i>	Longitudinal groove running obliquely on almost all the dorsal length maximum diameter about 1.5mm	short and sharp
	<i>Oval transversal section</i>	
<i>Hyalocyclus striata</i>	Strong transverse ripples, truncate shell maximum diameter about 1mm	Decaying; very rare
	<b>Subcylindrical shell</b>	
	<i>Oval transversal section</i>	
<i>Cuvierina columnella</i>	Aperture lemniscate-shaped, truncate shell maximum diameter about 2mm	Decaying; very rare
	<b>Subpyramidal shell</b>	
	(Lateral spines, wide open aperture)	
	<i>Lenticular transversal section</i>	
<i>Clio polita</i>	Almost smooth very flat shell	Spherical
	<i>Triangular section</i>	
<i>Clio pyramidata</i>	Lateral spines, angular in cross section 3 dorsal longitudinal ridges	Oval
<i>Clio convexa</i>	Lateral spines flat in cross section 1 dorsal longitudinal ridge	Blunt equilateral triangular
<i>Clio cuspidata</i>	Long lateral and dorsal spines deep and large transversal ripples	Spherical with an apical spine
	<b>Swollen Shell</b>	
	(Lateral spines, restricted aperture)	
	<i>Lenticular transversal section</i>	
	Thick dorsal lip with strips	
<i>Diacria trispinosa</i>	Dorso-ventrally flattened	Spherical; juvenile shell with flat sides/persistent
<i>Diacria quadridentata</i>	Swollen	Oval elongated juvenile shell with flat sides decaying
	Thin dorsal lip	
		<b>Posterior spine</b>
<i>Cavolinia inflexa</i>	Dorso-ventrally flattened right dorsal lip	Weakly dorsally curved
<i>Cavolinia gibbosa</i>	Swollen, ventral side sharply angular protruding	Curved except the extremity
<i>Cavolinia tridentata</i>	Thick brown shell, high dorsal transverse ribs	Straight
<i>Cavolinia uncinata</i>	Brown shell, obvious dorsal ribs	Strongly curved dorsally
<i>Cavolinia globulosa</i>	Swollen, almost spherical	Strongly curved dorsally
<i>Cavolinia longirostris</i>	Dorsal apertural lip like a beak, channel- shaped flattened lateral spines	Truncated

Note: For the genus *Creseis* we follow the terminology of Rampal (1985).



**Table 6. Expected Thecosomata assemblage in the studied area.**

Common species		Present species	
<i>Cavolinia gibbosa</i>	cw	<i>Cavolinia globulosa</i>	t
<i>Cavolinia inflexa</i>	cw	<i>Cavolinia longirostris</i>	ww
<i>Cavolinia tridentata</i>	ww	<i>Cavolinia uncinata</i>	t
<i>Clio cuspidata</i>	ww	<i>Clio convexa</i>	t
<i>Diacria quadridentata</i>	ww	<i>Clio pyramidata</i>	cw
<i>Diacria trispinosa</i>	ww	<i>Creseis acicula</i>	ww
<i>Limacina lesueurii</i>	cw	<i>Creseis virgula</i>	ww
<i>Styliola subula</i>	cw	<i>Cuvierina columnella</i>	ww
		<i>Hyalocylis striata</i>	t
		<i>Limacina bulimoides</i>	cw
		<i>Limacina inflata</i>	ww
		<i>Limacina trochiformis</i>	t

Note: Based on the "crude semiquantitative maps intended as a general synthesis of the zoogeographic patterns of euthecosomatous pteropods" by Bé and Gilmer (1977). For every species the distribution is indicated by the following abbreviations after Bé and Gilmer: ww = warm water cosmopolitan province, cw = subtropical central water masses, and t = tropical province.

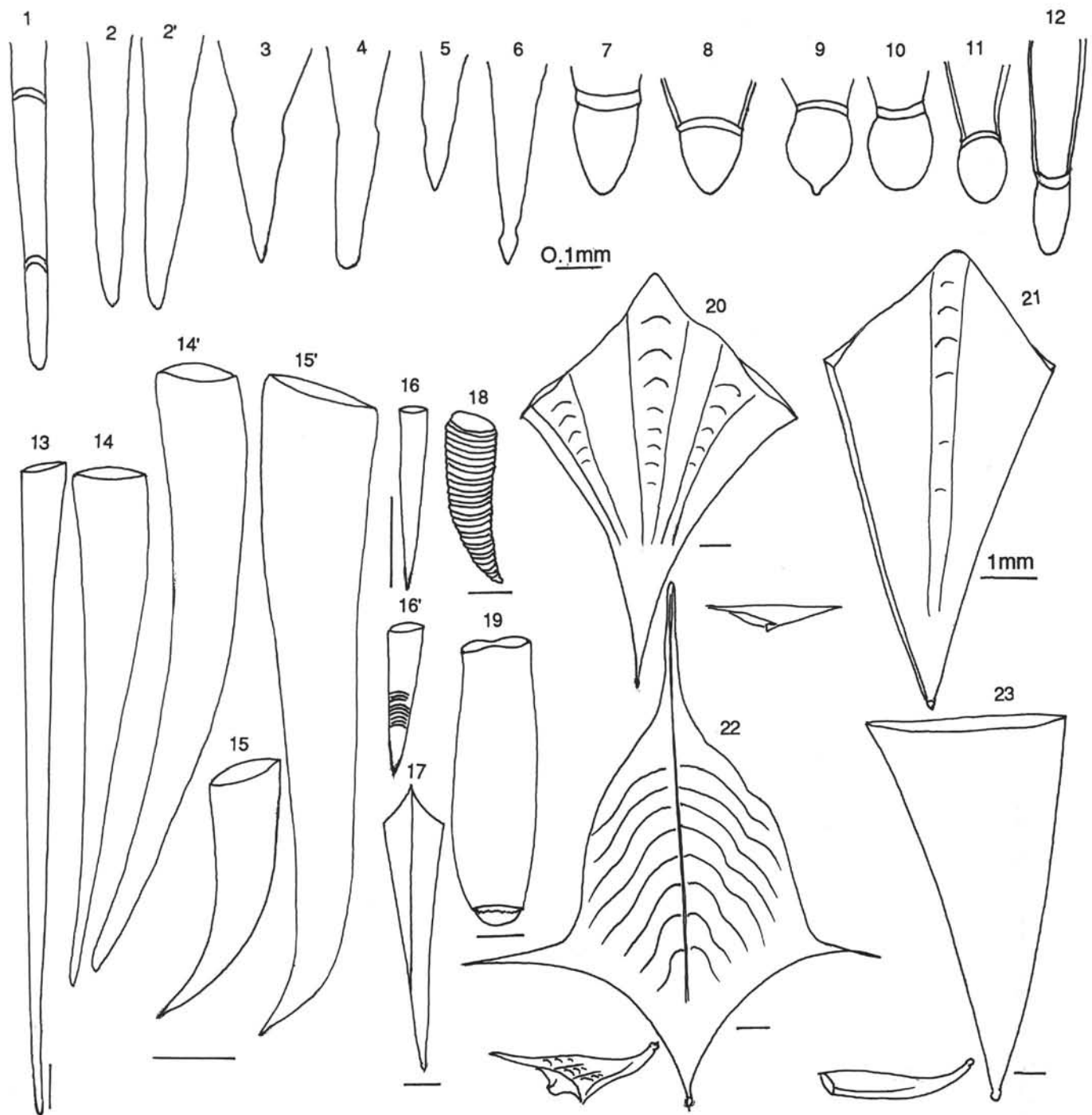


Plate 1A. Uncoiled thecosomatous protoconchs and teloconchs from the western Pacific. 1–12. Protoconchs (scale bar 0.1 mm for Figs. 1–4; 0.2 mm for Figs. 5–12), (1) *Creseis acicula*, (2, 2') *Creseis conica*, (3) *Creseis virgula*, (4) *Creseis chierchiae*, (5) *Styliola subula*, (6) *Cuvierina columnella*, protoconch and juvenile shell, (7) *Clio pyramidata*, (8) *Clio convexa*, (9) *Clio cuspidata*, (10) *Clio polita*, (11) *Diacria trispinosa*, (12) *Diacria quadridentata*, protoconch and juvenile shell. 13–23. Teloconchs (scale bar 1 mm), (13) *Creseis acicula*, (14, 14') *Creseis conica*, (15, 15') *Creseis virgula*, (16, 16') *Creseis chierchiae*, (17) *Styliola subula*, (18) *Hyalocylis striata*, (19) *Cuvierina columnella*, (20) *Clio pyramidata*, (21) *Clio convexa*, (22) *Clio cuspidata*, (23) *Clio polita*.

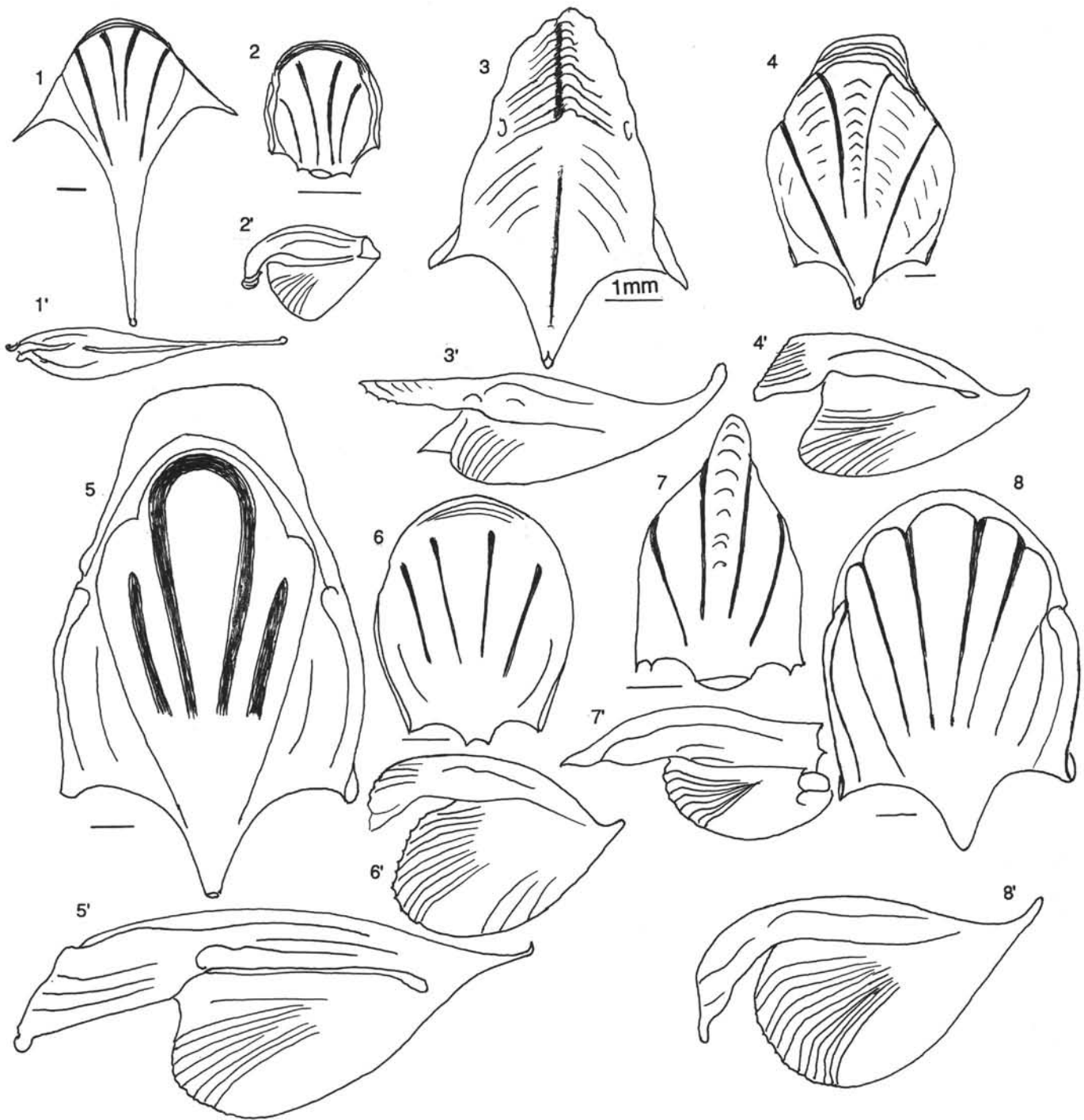


Plate 1B. Uncoiled thecosomatous telocochs from the western Pacific, dorsal and profile views (scale bar 1 mm). 1, 1'. *Diacria trispinosa*. 2, 2'. *Diacria quadridentata*. 3, 3'. *Cavolinia inflexa*. 4, 4'. *Cavolinia gibbosa*. 5, 5'. *Cavolinia tridentata*. 6, 6'. *Cavolinia globulosa*. 7, 7'. *Cavolinia longirostris*. 8, 8'. *Cavolinia uncinata*.

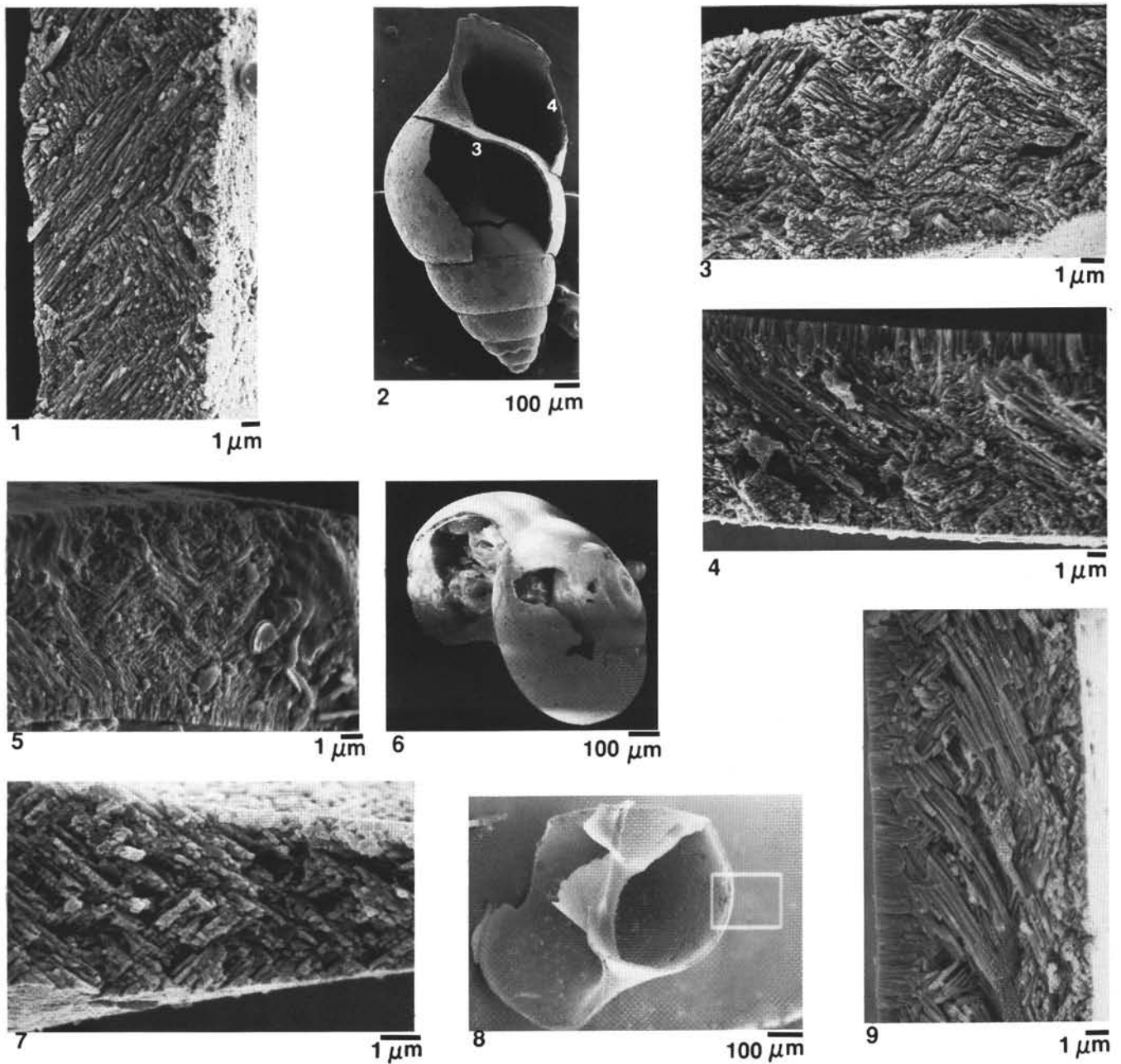


Plate 2. Rod-type crossed lamellar structure. **1–4.** *Limacina bulimoides*, Sample 134-831A-3H-5, 75–80 cm, (1) longitudinal section at the penultimate coil, (3) subtransverse section of the same individual, (4) longitudinal section at the margin of the aperture (note the inner prismatic layer). **5, 6.** *Limacina lesueuri*, Sample 134-831A-3H-4, 75–80 cm, (5) longitudinal section near the aperture (note the inner prismatic layer), (6) profile of the same individual. **7–9.** *Limacina trochiformis*, Sample 134-831A-3-6, 75–80 cm, (7) transverse section, (8) axial section of the same individual, (9) longitudinal section with an inner prismatic layer.

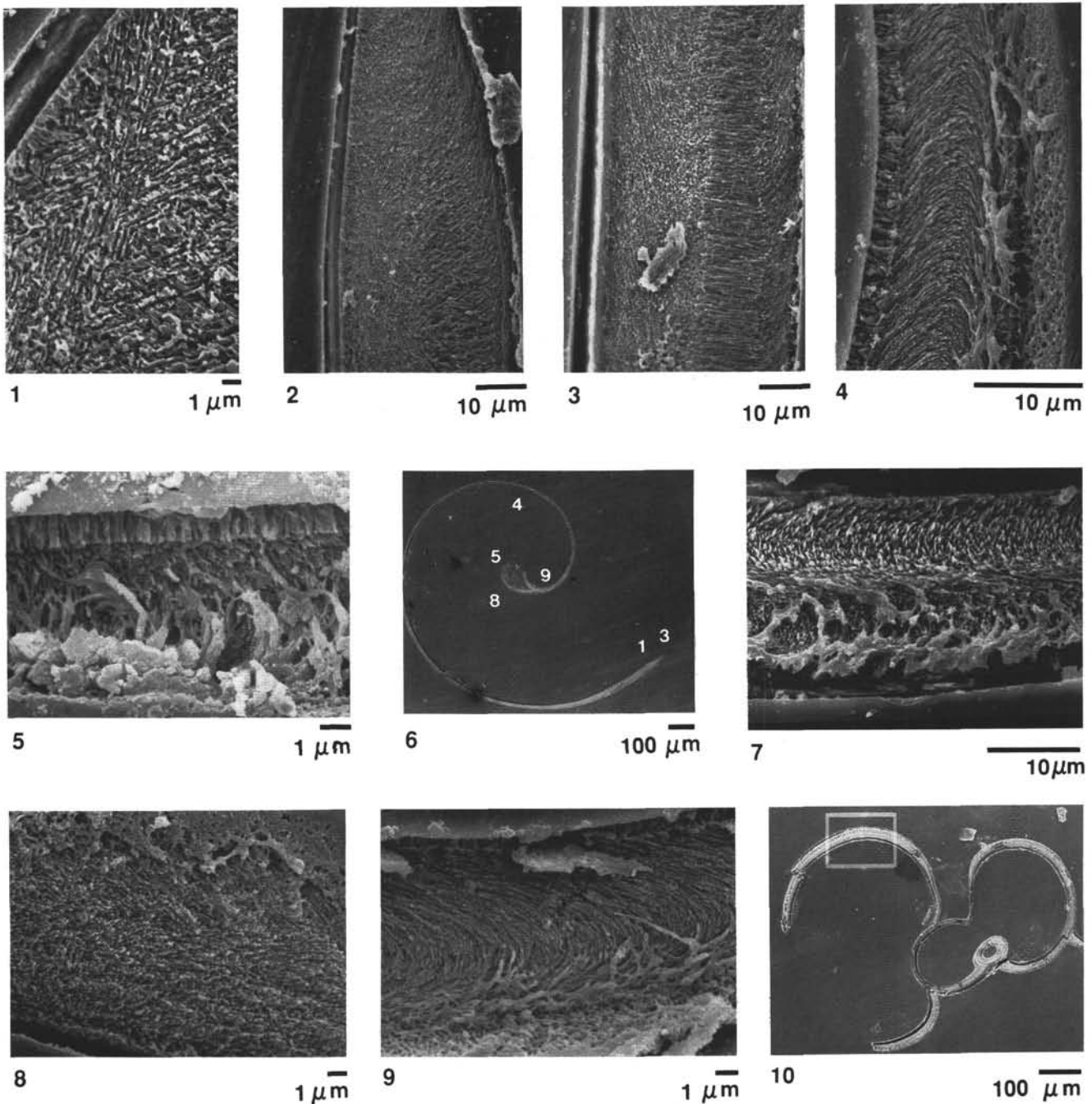


Plate 3. Study of two *Limacina inflata* embedded in araldite. 1-3. Detail of the structures found near the aperture, (1) crossed-acicular, (2) locally crossed-acicular, locally confused, (3) locally prismatic. 4. Helical structure. 5. Inner prismatic layer away from the aperture. 6. Transversal section of the first individual illustrated in detail of Figures 1-5, 8-9. 7. Typical helical structure of specimen, inner wall at the top of the illustration; see also Figure 10. 8, 9. Sections of the apex of the first specimen, see Figure 6 for location, (8) confused structure, (9) typical helical structure. 10. Subaxial section. The rectangle to locate Figure 7.



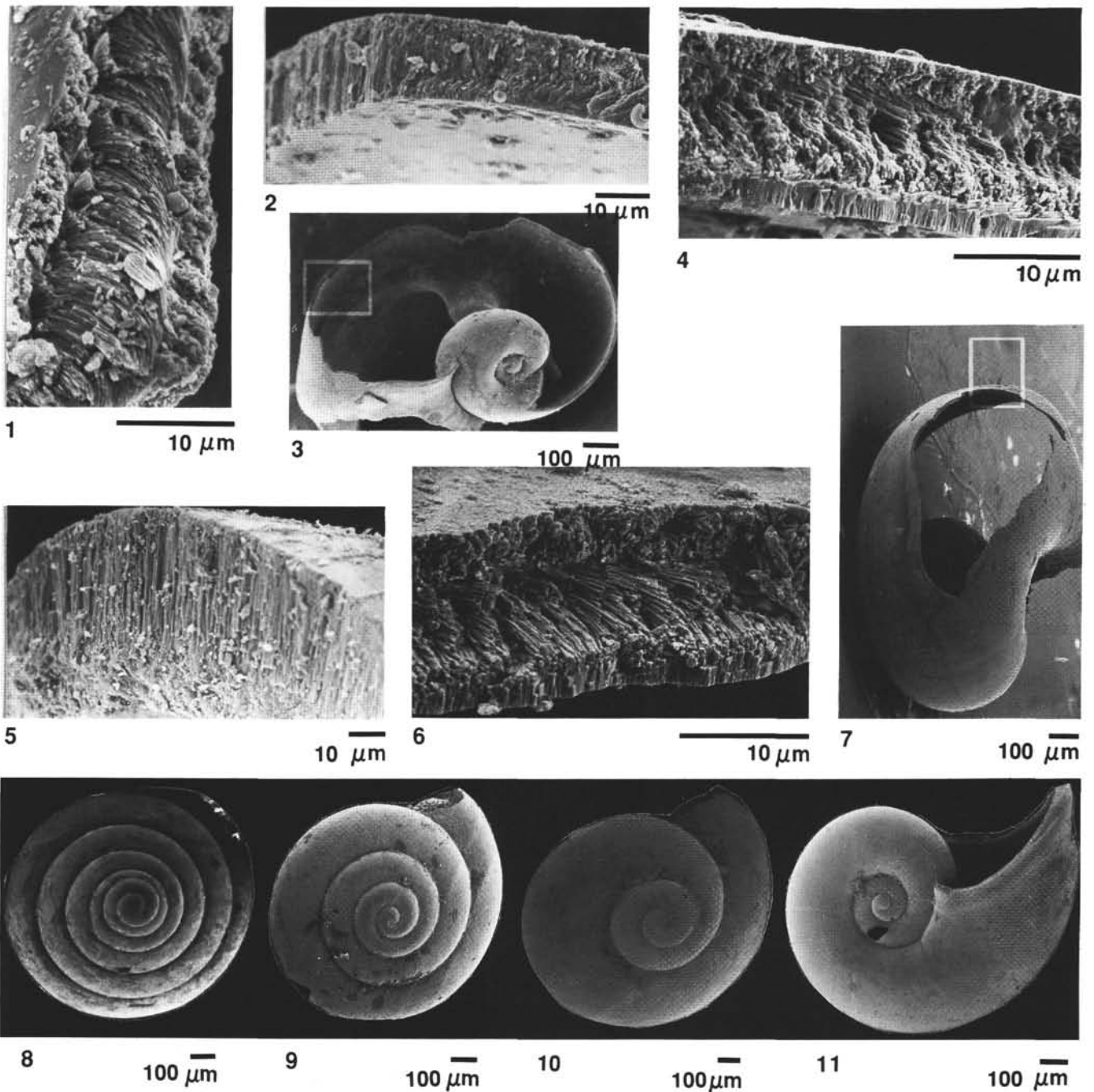


Plate 4. 1–7. Two *Limacina inflata*, Sample 134-831A-3H-4, 75–80 cm, (1, 2) sublongitudinal sections of specimen (3) (2, passage from helical to prismatic structure); (5) prismatic structure in the apertural zone of specimen (3) (note the longitudinal striations); (4, 6) two longitudinal sections showing the helical structure of specimen (7). 8–11. Apical views of the following species of *Limacina*, (8) *L. bulimoides*, (9) *L. lesueuri*, (10) *L. trochiformis*, (11) *L. inflata*.

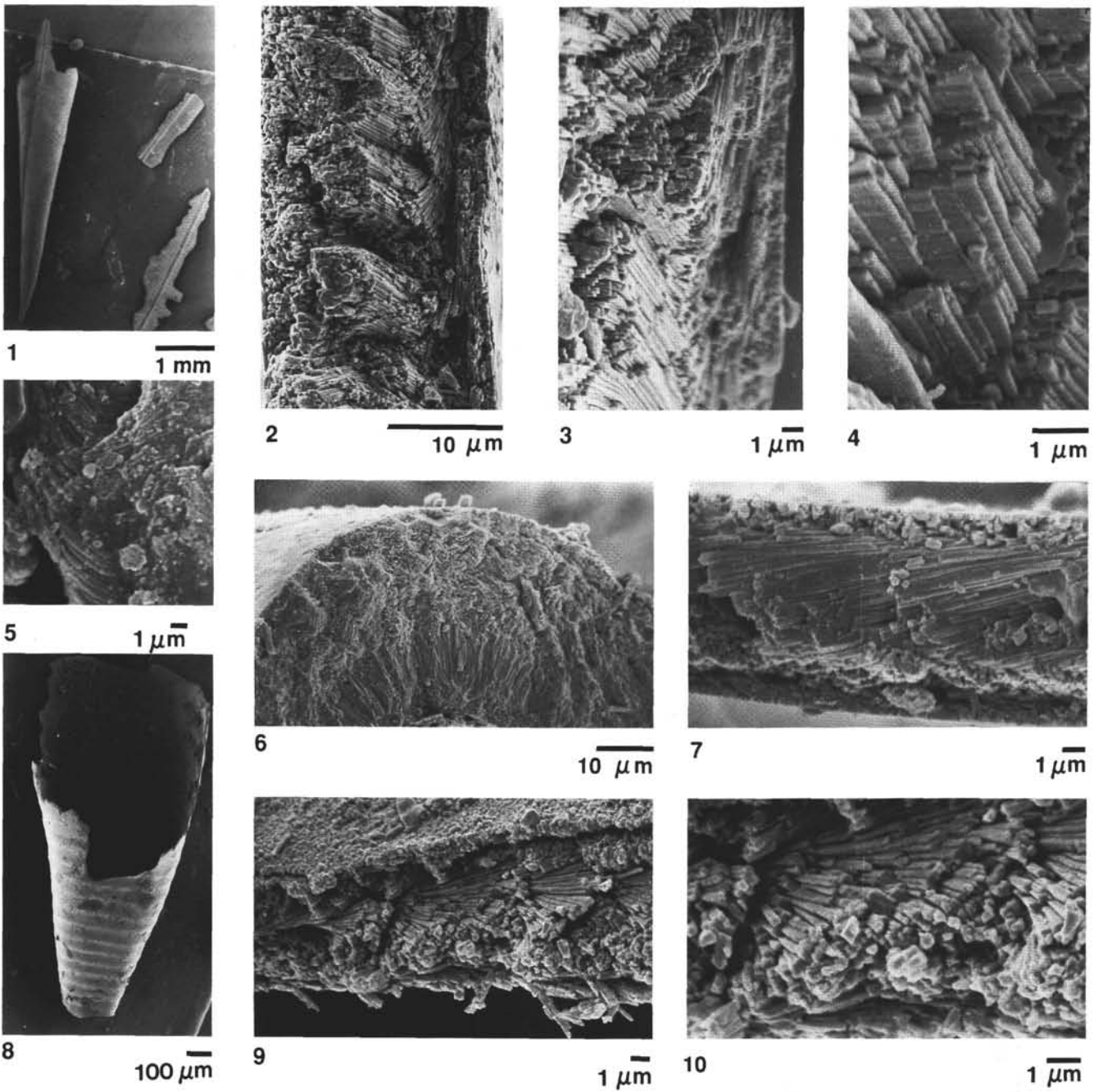


Plate 5. Helical structure of *Styliola subula* and *Hyalocylis striata*, Sample 134-831A-3H-4, 75-80 cm. 1-7. *Styliola subula*, (1, broken individual with two identifiable fragments, longitudinal groove running obliquely, 2-4, longitudinal sections; 5, tangential section; 6, transverse section of the longitudinal groove showing a thick prismatic inner layer; 7, transverse section). 8-10. *Hyalocylis striata* (9, 10, longitudinal sections).

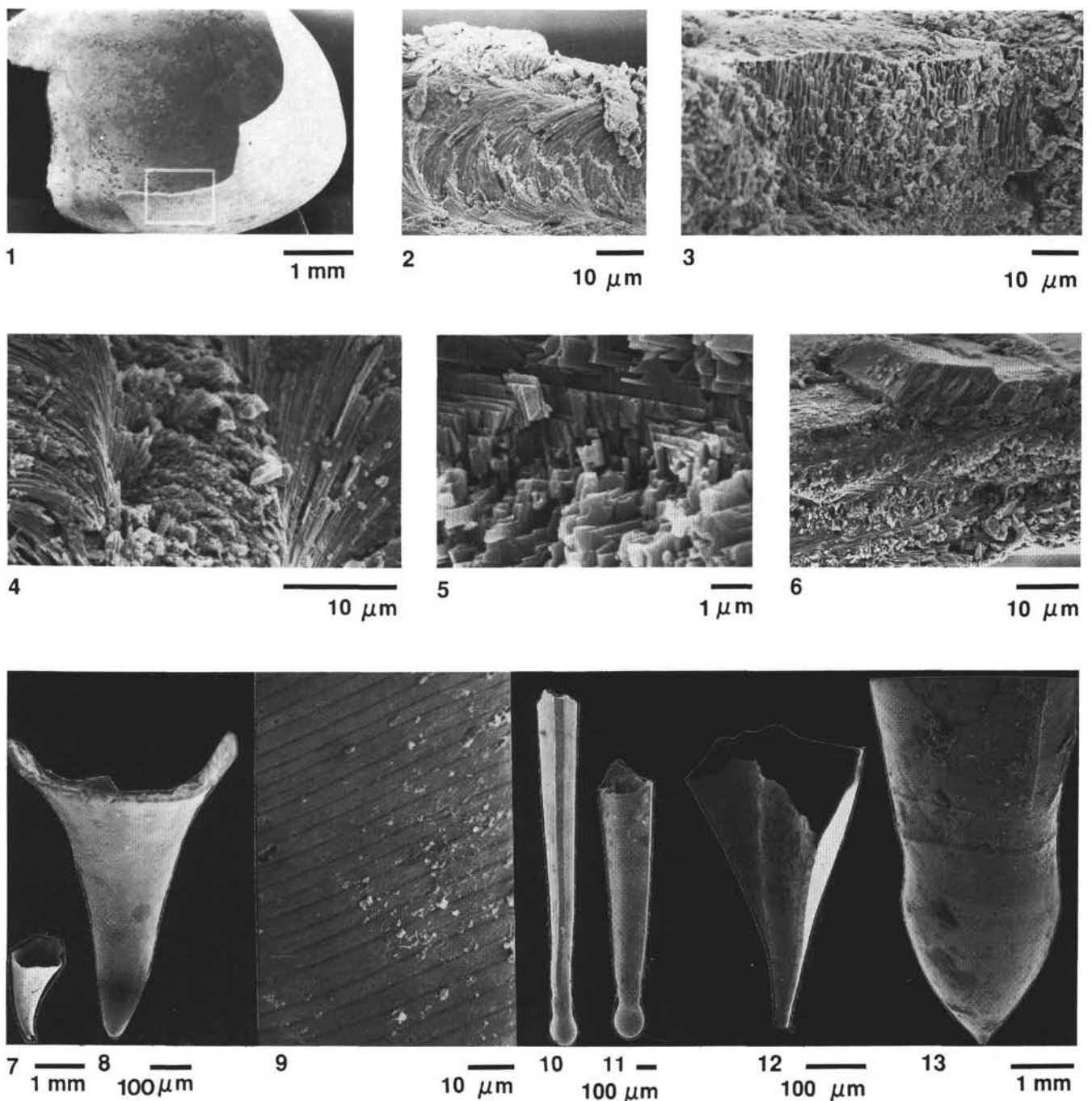


Plate 6. 1–6. Examples of structures of the shells of Cavoliniidae. (1–3) *Cavolinia globulosa*, Sample 134-831A-3H-4, 75–80 cm, (2) longitudinal section of the ventral face, (3) prismatic structure of the dorsal lip, (4) *Cavolinia gibbosa*, Sample 134-831A-3H-4, 75–80 cm, subtransverse section of the posterior spine. (5, 6) *Diacria quadridentata*, Sample 134-831A-2H-4, 18–22 cm, (5) detail of a longitudinal section of the ventral face, (6) longitudinal section of the ventral face crossing transverse ribs. 7–13. Examples of identifiable shell remains and protoconchs, (7–9) two protoconchs of *Cavolinia inflexa* and their superficial ornamentation, Sample 134-831-3H-4, 75–80 cm, (10, 11) *Diacria trispinosa* protoconchs, Sample 134-831A-3H-4, 75–80 cm, (10) profile, (11) ventral face. (12, 13) *Clio convexa*, Sample 134-831A-2H-4, 18–22 cm, (12) damaged specimen, (13) protoconch.