Acta Geologica Polonica, Vol. 58 (2008), No. 3, pp. 355-369

Early Pliocene heteropods and pteropods (Mollusca, Gastropoda) from Santa Maria Island (Azores, Portugal): systematics and biostratigraphic implications

ARIE W. JANSSEN[1], ANDREAS KROH[2] & SÉRGIO P. ÁVILA[3]

[1]*Nationaal Natuurhistorisch Museum Naturalis (Palaeontology Department), P.O. Box 9517, 2300 RA Leiden,*
The Netherlands; currently: 12, Triq tal'Hamrija, Xewkija XWK 9033, Gozo, Malta.
E-mail: ariewjanssen@waldonet.net.mt
[2]*Natural History Museum Vienna, Department of Geology & Palaeontology, Burgring 7, 1010 Vienna, Austria.*
E-mail: andreas.kroh@nhm-wien.ac.at
[3]*MPB – Marine Palaeobiogeography Working Group of the University of the Azores, Departamento de Biologia,*
Universidade dos Açores, Rua da Mãe de Deus, Apartado 1422, 9501 - 801 Ponta Delgada, Açores, Portugal;
Centro do IMAR da Universidade dos Açores, 9901-862 Horta, Azores; Portugal.
E-mail: avila@notes.uac.pt

ABSTRACT:

JANSSEN, A.W., KROH, A. & ÁVILA, S.P. 2008. Early Pliocene heteropods and pteropods (Mollusca, Gastropoda) from Santa Maria Island (Azores, Portugal): systematics and biostratigraphic implications. *Acta Geologica Polonica*, **58** (3), 355-369. Warszawa.

A holoplanktonic mollusc assemblage from Neogene sediments of the Azorean island Santa Maria is described and analysed to determine the age of the sediments. Sixteen taxa are documented (three heteropods, thirteen pteropods), fourteen of which are new records for the fossil fauna of Santa Maria Island. The composition of the heteropod and pteropod assemblage indicates a Zanclean age, which contrasts with earlier age assignments to the Early, Middle or Late Miocene based on benthic molluscs, but is in good agreement with more recent data based on foraminiferal and geochemical evidence.

The pteropod *Cavolinia marginata* (BRONN, 1862) is re-described based on abundant topotypic material and a neotype is designated. The species *Cavolinia vendryesiana* (GUPPY, 1873) is considered to be a junior subjective synonym of *C. marginata*. The temporal range of the pteropod *Limacina trochiformis* (D'ORBIGNY, 1836) is extended to the Zanclean.

Key words: Mollusca, Heteropoda, Pteropoda, Pliocene, Biostratigraphy, Azores, Northern Atlantic.

INTRODUCTION (AWJ, AK, SA)

Holoplanktonic gastropods from the Azores (Santa Maria Island, locality Cré) were first described by BRONN (in REISS 1862, pp. 36, 37), who studied collections brought together by Georg HARTUNG (PINTO & BOUHEIRY 2007). BRONN recognised two pteropod species in that material, which he named *Hyalea* (*Diacria*?) *marginata* sp.nov. and *Triptera columnella*. MAYER (1864, pp. 232, 233) included the collections from the Azores described by BRONN in a study of fossils from Madeira and Porto Santo, mentioning the same two species. Almost a hundred years later ZBYSZEWSKI & DA VEIGA FERREIRA (1962) published the next paper on fossils from

Santa Maria, in which they mentioned again the same two pteropod species and introduced a new species, *Cavolinia mariae* Zbyszewski & da Veiga Ferreira, 1962, from a different locality (Ponta do Norte) on the island of Santa Maria. In each of these papers the age of the Santa Maria fossils was considered to be Miocene.

New material collected within the course of the 3rd and 4th workshops "*Palaeontology in the Atlantic Islands*" (June 2006 and June 2007), from the Cré locality, yielding no less than three heteropod and 13 pteropod species, not only enlarged the holoplanktonic mollusc assemblage considerably, but also enabled a more accurate age assignment.

LOCALITY (AK, SA)

Neogene deposits are absent from the young volcanic Azorean Archipelago, Santa Maria, the south-easternmost of the nine islands being an exception to this rule. Composed of subaerial lavas ranging in age from 3.2 to, at least, 8.1 Ma (Abdel-Monem & *al.* 1975; Feraud & *al.* 1980, 1984; Serralheiro & Madeira 1990), Santa Maria is the oldest of the nine islands. It is covered by a thin, discontinuous layer of shallow marine sediments, belonging to the Touril Complex and the Facho-Pico Alto Complex (Serralheiro & *al.* 1987; Serralheiro & Madeira 1990; Serralheiro 2003). Additionally, Pleistocene wave-cut platforms with sands and gravel occur occasionally along the coast (García-Talavera 1990; Callapez & Soares 2000; Ávila & *al.* 2002; Ávila 2005).

The study area lies in north-western Santa Maria, close to the embayment of Baía da Cré (Text-fig. 1). There the sediments of the Touril Complex are exposed in the Lemos river valley, which cuts through the overlying pyroclastics of the basal Facho-Pico Alto Complex (see Serralheiro & *al.* 1987). Most of the area is covered by pastures and shrub, but a series of small outcrops is exposed in road cuttings and disused quarries in the area south and west of the abandoned house "Casa da Cré" (GPS N 37°00'04", W 25° 08'10"). The section studied lies along an old dirt road leading from "Casa da Cré" to an old, overgrown quarry at the bottom of the valley (N 37°00'02", W 25°08'07"), which was used for "limestone" extraction (da Veiga Ferreira 1961). Although there is no continuous outcrop we were able to log most of the sequence with short overlapping sections (Text-fig. 2).

The base of the section is formed by a volcanic conglomerate, belonging to the underlying Anjos Complex. A sequence of strongly bioturbated lithic sandstones overlies the erosive relief on top of the conglomerate. The occurrence of successive erosive hiatuses, pebble seams and shell beds documents reworking and transport, probably related to storms. The section ends with bioclastic, lithic sandstone with rhodoliths, covered by a massive layer of volcanoclastic conglomerate of the Facho-Pico Alto Complex (a more detailed section and its correlation to other outcrops on Santa Maria will be published elsewhere).

The fossils described here were found in a bed of bioturbated, lithic sandstone, approximately 4 metres above the erosive relief at the base of the section. They are ac-

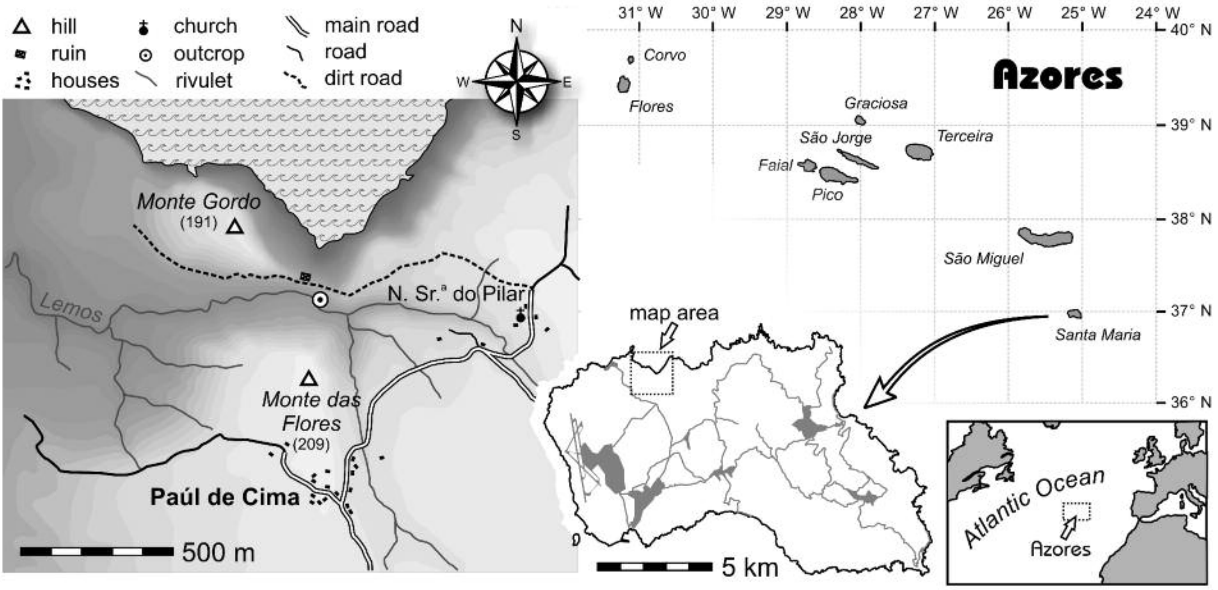


Fig. 1. Location of the outcrop studied. Inset (lower right) shows position of the study area on Santa Maria Island (Azores)

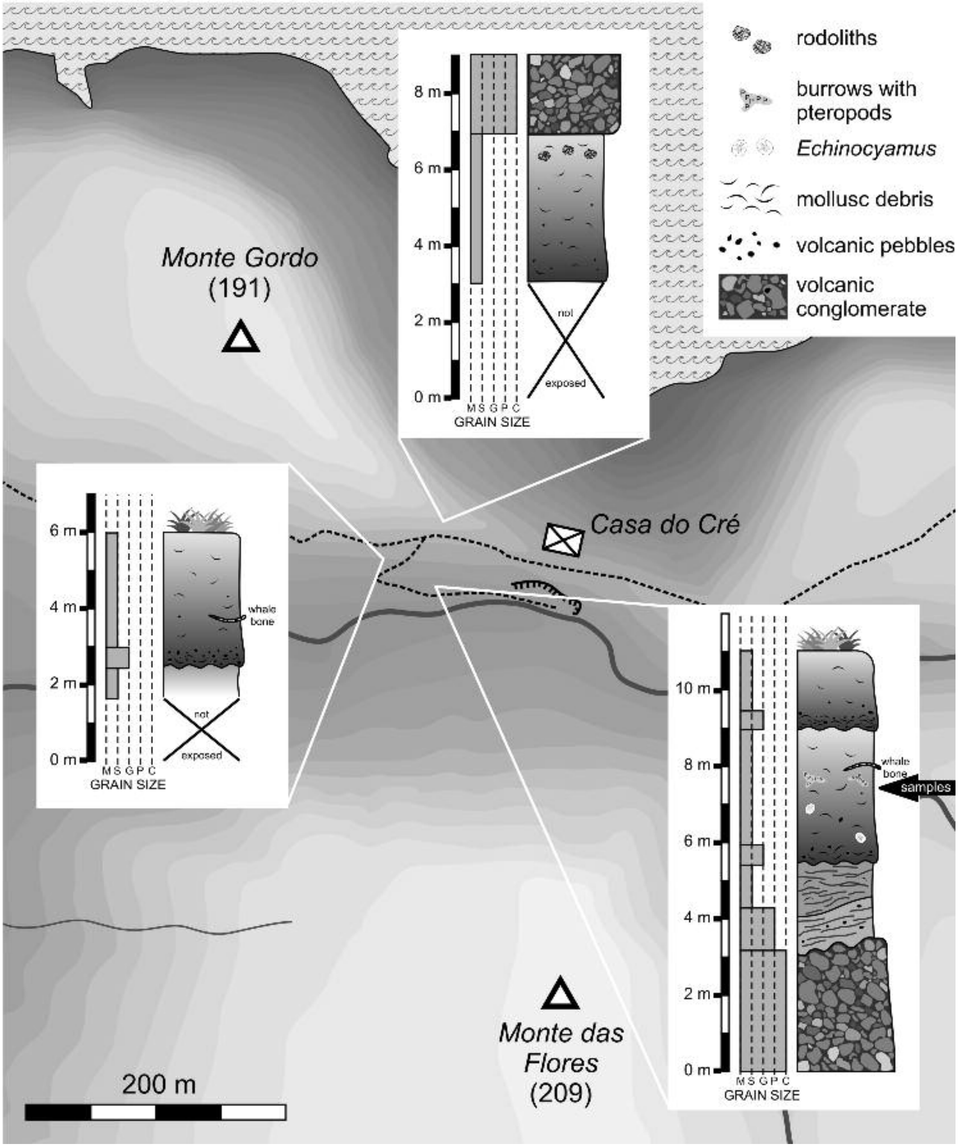


Fig. 2. Sketch of the outcrop situation and general section of the sedimentary strata exposed at Cré, Santa Maria. A black arrow marks the bed with holoplanktonic mollusc assemblage

cumulated in large *Thalassinoides* burrows, locally forming extremely dense aggregations (Text-fig. 3). Outside the burrows, pteropods are present too, but less commonly. They are preserved as internal moulds, composed of calcite fibres or matrix, as well as rare external moulds. The reason for this extreme accumulation of pteropods in burrows is unclear. Other outcrops studied during the fieldwork yielded no heteropod/pteropod remains, but probably represent even shallower, more proximal environments. Remains of other pelagic animals, like whales (ESTEVENS & ÁVILA 2007) and sharks, are also more frequent at Cré.

Based on the detailed description of REISS (1862, pp. 12-13), it is clear that the locality "Bocca do cré" that yielded the two pteropod species described by BRONN (in REISS 1862, pp. 36-37) is identical with the section studied here. For more information on the historical outcrops on Santa Maria Island and the confusion of the area studied here with a region along the southern coast in the Malbusca Area see MADEIRA & *al*. (2007).

MATERIAL AND METHODS (AK, AWJ)

To study the holoplanktonic mollusc assemblage, individual pteropod specimens were collected in the field,

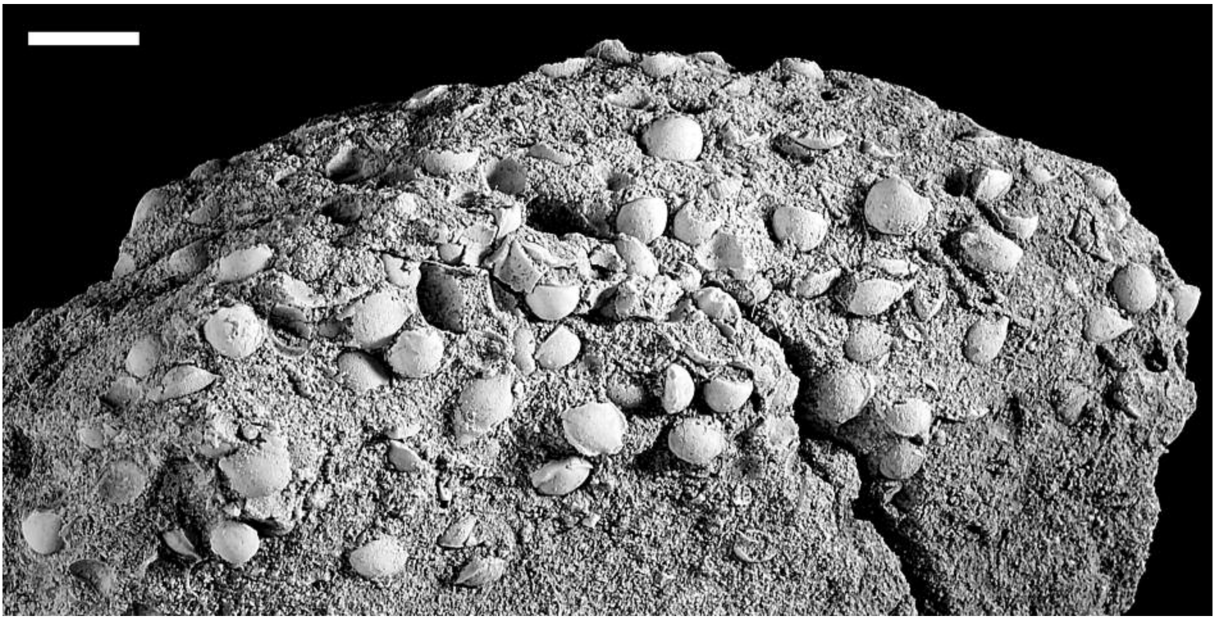


Fig. 3. Mass accumulation of *Cavolinia marginata* (Bronn, 1862) in a crustacean burrow from the Lower Pliocene of Cré, Santa Maria (DBUA-F431-1). Scale bar equals 10 mm

as well as from bulk rock samples containing fossil pteropod accumulations. The bulk samples were carefully disaggregated mechanically. The sediment containing the holoplanktonic molluscs is poorly cemented, rich in lithic fragments and bioclasts. Aragonitic shells are preserved as moulds and casts only, their original shell having been largely removed during diagenesis.

Samples collected in 2006 are indicated 2006/1-7, those collected in 2007 are labelled CC07/1A-1E. The material studied is deposited in the collections of the Departamento de Biologia, Universidade dos Açores, Portugal (DBUA-F, registration numbers DBUA-F379, DBUA-F431) and the Palaeontology Department, Nationaal Natuurhistorisch Museum *Naturalis*, Leiden, The Netherlands (RGM, registration numbers RGM 541 558 – 541 605).

SYSTEMATIC PART (AWJ)

Most of the species encountered are well-known and do not need extensive synonymies or description. The first valid description is given, supplemented by a selection of some modern papers in which the species is described and illustrated.

Superfamily Pterotracheoidea Rafinesque, 1814
Family Atlantidae Rang, 1829
Genus *Atlanta* Lesueur, 1817

TYPE SPECIES: *Atlanta peroni* Lesueur, 1817 (Recent).

Atlanta sp.
(Pl. 1, Fig. 1)

MATERIAL EXAMINED: One specimen in sample CC07/1B (DBUA-F431-2), 2 in sample CC07/1D (DBUA-F431-44) and five in CC07/1E (RGM 541 580 to 541 583), all poorly preserved.

DISCUSSION: The largest available specimen (diameter c. 5 mm; sample CC07/1E) is split into an apical and an umbilical half, preserved on two small slabs of matrix. An artificial cast of the apical part reveals most characters. The number of whorls is 4½, the initial whorls together form a low cone, the 4th whorl widens rapidly and at the same time a relatively wide keel inserts between the whorls, continuing on the body whorl to a short distance behind the apertural margin. These characters compare well with those of the Recent species *Atlanta peroni* Lesueur, 1817, as illustrated e.g. by Seapy (1990, fig. 4) and reported from the recent malacofauna of the Azores (Dautzenberg 1889). Nothing is known, however, about a possible ornament of the protoconch and, furthermore, the separation of the whorls seems to be wider in the fossil specimens and to start earlier.

Genus *Oxygyrus* Benson, 1835

TYPE SPECIES: *Oxygyrus keraudreni* (Lesueur, 1817) (Recent).

Oxygyrus keraudreni (Lesueur, 1817)

1817. Atlante de Keraudren, *A. Keraudreni*; Lesueur, p. 391.
1967. *Oxygyrus keraudreni* (Lesueur); van der Spoel, p. 137, figs 133, 224 (with extensive synonymy).
1998. *Oxygyrus keraudreni* (Lesueur, 1817); Janssen, p. 98, pl. 1, fig. 3a-b.
2007b. *Oxygyrus keraudreni* (Lesueur, 1817); Janssen, p. 51, pl. 1, figs 2, 3; pl. 16, figs 2-4 (with further synonymy).

MATERIAL EXAMINED: Two juvenile specimens were found in sample CC07/1E (RGM 541 584).

DISCUSSION: This species is easily recognisable by its completely involute shell. The two specimens are very small (< 1 mm), poorly preserved and not worth illustrating. *Oxygyrus keraudreni* is known from the Zanclean onwards.

Family Carinariidae Blainville, 1818
Genus *incertae sedis*

Carinariidae sp.
(Pl. 1, Fig. 2)

MATERIAL EXAMINED: A single juvenile specimen (protoconch) from sample CC07/1E (RGM 541 585).

DISCUSSION: The specimen is easily recognisable as belonging to the Carinariidae by the fact that the greatest width of the shell lies above the horizontal midline. As the specimen is preserved as an internal calcitic mould its ornament has disappeared. It could belong either to the genus *Carinaria* or to *Pterosoma*. *Carinaria mediterranea* de Blainville, 1825 (= *C. lamarcki* Péron & Lesueur, 1810) was reported from the Recent fauna of the Azores (Segers 2002).

Superfamily Limacinoidea Gray, 1847
Family Limacinidae Gray, 1847
Genus *Heliconoides* d'Orbigny, 1836

TYPE SPECIES: *Heliconoides inflata* (d'Orbigny, 1836) (Recent).

Heliconoides inflata (d'Orbigny, 1836)
(Pl. 1, Fig. 3a-d)

1836. *Atlanta inflata*, d'Orb.; d'Orbigny, p. 174, pl. 12, figs 16-19.
1967. *Oxygyrus keraudreni* (Lesueur); van der Spoel, p. 50, figs 17, 18 (with extensive synonymy).
2004. *Heliconoides inflata* (d'Orbigny, 1836) type A; Janssen, p. 110, pl. 1, figs 1-3.
2007b. *Oxygyrus keraudreni* (Lesueur, 1817); Janssen, p. 60, pl. 2, figs 1-3; pl. 21, figs. 1-3 (with further synonymy).

MATERIAL EXAMINED: Thirteen specimens were found in the samples collected in 2006 (DBUA-F379-1, 379-13), almost a hundred were present in the 2007 samples (DBUA-F431-3 to 431-6, 431-8, 431-45; RGM 541 563, 541 586, 541 587).

DISCUSSION: All specimens are preserved as internal moulds, filled either with matrix or calcite crystals. Many specimens among the 2007 samples clearly show the presence of a subperipheral belt all over the body whorl, as is typical of *Heliconoides inflata* type A, described by Janssen (2004). A falciform thickening, typical of type B specimens, could not be seen in any of the shells available. *H. inflata* is known from the early Miocene onwards, occurring abundantly in the living fauna of tropical and subtropical water masses, also reported from the D. João de Castro seamount (Azores), today (Ávila & *al*. 2004).

Genus *Limacina* Bosc, 1817

TYPE SPECIES: *Limacina helicina* (Phipps, 1774) (Recent).

Limacina cf. *bulimoides* (d'Orbigny, 1836)
(Pl. 1, Fig. 4)

MATERIAL EXAMINED: A single internal calcitic mould was found in sample CC07-1B (RGM 541 562).

DISCUSSION: The present specimen co-occurs with *Heliconoides inflata*. It is a bit less slender than Recent specimens of *L. bulimoides* examined and the tangents of the spira are more convex. Compared to *Limacina trochiformis* from the same location (see below), however, the shell is distinctly more slender and its whorls are less convex. In the absence of further material, the identification has to remain uncertain. *Limacina bulimoides* is reported from the Recent fauna of the Azores (Segers 2002).

Limacina trochiformis (d'Orbigny, 1836)
(Pl. 1, Fig. 5)

1836. *Atlanta* (*Heliconoides*) *trochiformis*, D'ORB.; D'ORBIGNY, p. 177, pl. 12, figs 29-31.
1977. *Limacina trochiformis* (D'ORBIGNY, 1836); BÉ & GILMER, p. 745, fig. 15, pl. 3, fig. 2a-d.
2007a. *Limacina trochiformis* (D'ORBIGNY, 1836); JANSSEN, p. 152, pl. 15, figs 6-9; pl. 16, figs 1, 2.

MATERIAL EXAMINED: Four doubtful specimens in the 2006 material (one in sample 1 and three in sample 7 – DBUA-F379-2, 379-20); three specimens in sample CC07-1D (DBUA-F431-46) and 42 in sample CC07-1E (RGM 541 589, 541 590).

DISCUSSION: All specimens are preserved as internal moulds, agreeing fairly well with Recent specimens examined. *L. trochiformis* has not yet been reported from deposits older than Quaternary.

Genus *incertae sedis*

Limacinidae sp.
(Pl. 1, Fig. 6)

MATERIAL EXAMINED: Three immature specimens from sample CC07-1E (RGM 541 588, 541 591).

DISCUSSION: The depressed conical shape of the shells is reminiscent of the Quaternary to Recent species *Limacina lesueuri* (D'ORBIGNY, 1836), occurring worldwide in tropical and subtropical waters, but the preservation as internal calcitic moulds prevents observation of the presence or absence of spiral ornament on the base of the shell. A very similar shell form is seen in juvenile specimens of *Heliconoides sondaari* JANSSEN, 2007b (p. 61, pl. 1, fig. 7; pl. 21, figs 4-7; pl. 22, fig. 1), described from the Pliocene (Piacenzian) of the Philippines. *L. lesueuri* to date is exclusively known from much younger deposits but, on the other hand, the juvenile specimens from the present locality cannot be related with any degree of certainty to the Philippine species, which shows a reinforced apertural margin when full grown. However, in view of the Early Pliocene age of the present specimens, it seems more likely that they belong to *H. sondaari*.

Also similar are four juvenile/defective specimens recorded by JANSSEN (1998, p. 99, pl. 1, fig. 11), as *Limacina* sp. 1, from the Piacenzian Bowden Beds in Jamaica.

Superfamily Cavolinioidea GRAY, 1850
Family Creseidae CURRY, 1982
Genus *Bowdenatheca* COLLINS, 1934

TYPE SPECIES: *Bowdenatheca jamaicensis* COLLINS, 1934 (Pliocene).

Bowdenatheca jamaicensis COLLINS, 1934
(Pl. 1, Figs 7a-c, 8a-d)

1934. *Bowdenatheca jamaicensis* n. sp.; COLLINS, p. 221, pl. 13, figs 13-15.
1959. *Bowdenatheca jamaicensis* R.L. COLLINS; ZILCH, p. 51. fig. 171.
1982. *Bowdenatheca jamaicensis* COLLINS; LOZOUET & MAESTRATI, p. 184.
1982. *Bowdenatheca jamaicensis* COLLINS; BERNASCONI & ROBBA, p. 218.
1983. *Bowdenatheca jamaicensis* COLLINS; SHIBATA, p. 80.
1995. Creseinae sp. ? nov.; JANSSEN, p. 30, pl. 2, fig. 3a-d.
1996? *Bowdenatheca* ? sp.; UJIHARA, p. 781, fig. 5/43-49.
1997. *Bowdenatheca jamaicensis* COLLINS; ZORN, p. 35, pl. 4, figs 1-4.
1998. *Bowdenatheca jamaicensis* COLLINS; JANSSEN, p. 100, pl. 1, figs 14-15.

MATERIAL EXAMINED: A total of 45 more or less fragmentary specimens was found in samples CC07/1B to 1E (DBUA-F431-11, DBUA-F431-47, RGM 541 564, RGM 541 592, RGM 541 593).

DISCUSSION: Originally described from the Piacenzian of Jamaica, this species was later also recorded from the Mediterranean Messinian and Zanclean. Furthermore, an unpublished occurrence is documented in the RGM collections from Tortonian, or possibly Messinian, marls at Pallagorio (Calabria, southern Italy; leg./don. T.J. Bor). The Azores specimens connect the Mediterranean occurrences nicely with the Caribbean ones.

Bowdenatheca sp., recorded by SHIBATA (1980, p. 64) from the Yatsuo Formation (Miocene) of Japan, was later described as *Vaginella katoi* SHIBATA (1983, p. 79), a species that from the presence of lateral grooves (especially in its apical part) belongs in the genus *Edithinella*.

Bowdenatheca ? sp., as described by UJIHARA (1996) from the Japanese Miyazaki Group, Kawabaru Member (Pliocene, Zanclean, zones N18-20) probably belongs to the present species.

Genus *Styliola* GRAY, 1850

TYPE SPECIES: *Styliola subula* (QUOY & GAIMARD, 1827) (Recent).

Styliola subula (Quoy & Gaimard, 1827)
(Pl. 1, Figs 9a-b, 10)

1827. *Cleodora subula*; Quoy & Gaimard, p. 233, pl. 8D, figs 1-3.
1990a. *Styliola subula* (Quoy & Gaimard, 1827); Janssen, p. 32, pl. 5, figs 13-19; pl. 6, figs 1-9 (with extensive synonymy).
1999. *Styliola subula* (Quoy & Gaimard, 1827); Janssen, p. 18, pl. 3, figs 7-9 (with neotype designation).

MATERIAL EXAMINED: Sample 2006/1 yielded two fragments (DBUA-F379-3), from samples 2007/1B-1E approximately 45 mainly fragmentary specimens were isolated (DBUA-F431-16, 431-48, 431-49; RGM 541 565, 541 566, 541 594 to 541 596).

DISCUSSION: This well-known species appears to be quite common in the Santa Maria deposit. Isolated specimens in the form of internal moulds are easily recognisable by the presence of an oblique dorsal furrow in the shell. Specimens in matrix may be more difficult to identify when the sulcus is hidden in the sediment (Pl. 1, Fig. 9a). *Bowdenatheca* specimens in particular may look quite similar, but these have a somewhat flattened shell. *Styliola subula* is now known to occur during the Late Oligocene to Recent interval, also occurring in the Azores today (Segers 2002).

Family Cuvierinidae van der Spoel, 1967
Genus *Cuvierina* Boas, 1886
Subgenus *Urceolarica* Janssen, 2006
(= *Urceolaria* Janssen, 2005 *non* Lamarck, 1801)

TYPE SPECIES: *Cuvierina* (*Urceolarica*) *urceolaris* (Mörch, 1850) (Recent).

Cuvierina (*Urceolarica*) *intermedia* (Bellardi, 1873)
(Pl. 1, Fig. 11a-c)

1862. *Triptera columnella*; Bronn, *in* Reiss, p. 37, pl. 1, fig. 15 (non *columnella* Rang).
1873. *Cuvieria intermedia* Bell.; Bellardi, p. 36, pl. 3, fig. 20.
1995. *Cuvierina intermedia* (Bellardi, 1873); Janssen, p. 39, pl. 3, figs 5-6 (with further synonymy and lectotype designation).

MATERIAL EXAMINED: Six specimens in samples CC07/1B-1E (DBUA-F431-17, 431-50, 431-51; RGM 541 567, 541 597).

DISCUSSION: The newly collected specimens make it clear that the *Cuvierina* specimens described from Santa Maria in the older literature do not belong to *C. columnella* (Rang, 1827). In spite of the impossibility of observing the presence or absence of surface micro-ornament, *C. intermedia* can easily be recognised by the slightly convex shape of the shell. This species is known from the Tortonian-Piacenzian time interval.

Family Cliidae Jeffreys, 1869
Genus *Clio* Linné, 1967

TYPE SPECIES: *Clio* (*Clio*) *pyramidata* Linné, 1767 (Recent).

Subgenus *Balantium* Bellardi, 1873

TYPE SPECIES: *Clio* (*Balantium*) *recurva* (Children, 1823) (Recent).

Clio (*Balantium*) sp. nov.
(Pl. 1, Figs 12, 13a-b)

MATERIAL EXAMINED: One external mould from sample CC07/1B (DBUA-F431-12) and two fragmentary internal moulds from sample CC07/1C (RGM 541 568), all poorly preserved.

DESCRIPTION: The shell is triangular in shape with slightly flexuous sidelines in its near-apical part (Pl. 1, Fig. 12). Initially its apical angle is approximately 30°, increasing to c. 60° towards the aperture. The dorsal side is convex and bears comparatively coarse transverse ribs, strongly curved adaperturally and separated by somewhat wider interspaces. These ribs do not reach the sides of the shell. The ventral side is flat and has a single flattened central radial rib, occupying one third of the shell's width. The lateral carinae are squareish in transverse section. Apical shell part with protoconch and aperture are not preserved.

DISCUSSION: In spite of the poor state of the three available specimens, the characteristic features of this species are clear. Its dorsal side at first glance resembles the Miocene *Clio* (*Balantium*) *pedemontana* (Mayer, 1867), but that species has a narrower apical angle and both the dorsal and the ventral side have a similar ornament of curved transverse ribs. Also in that species the transverse ornament is less coarse, and the sides are not flexuous. The ventral side (Pl. 1, Fig. 13b), with a single wide longitudinal rib agrees with most other *Clio* (*Balantium*) species, but the dorsal side in all such species has additional radial ornament (only lacking in *C. pedemontana*). This leads to the conclusion that the present three specimens represent a species unknown to science. I refrain, however, from introducing a new taxon, because of the poor state of the specimens.

Subgenus *Bellardiclio* JANSSEN, 2004

TYPE SPECIES: *Clio* (*Bellardiclio*) *cuspidata* (BOSC, 1802) (Recent).

Clio (*Bellardiclio*) *braidensis* (BELLARDI, 1873)
(Pl. 1, Fig. 14a-c)

1873. *Balantium (Flabellulum) braidense* BELL.; BELLARDI, p. 32, pl. 3, fig. 12.
1878. *Balantium braidense* BELLARDI; TIBERI, p. 73.
1880. *Balantium braidense* BELLARDI; TIBERI, p. 34.
1897. *Clio braidense* BELLARDI sp.; AUDENINO, p. 103.
1898. *Balantium braidense* BELLARDI; BORTOLOTTI, p. 56.
1904. *Balantium (Flabellulum) braidense* BELL.; SACCO, p. 14, 15.
1905. *Cleodora pyramidata* var. *Braidense*, BELLARDI sp.; BELLINI, p. 36, fig. 27.
1958. *Euclio* cf. *braidense* (BELLARDI); ERÜNAL-ERENTÖZ, p. 129, 202, pl. 21, figs 6-10.
1977. *Clio braidensis* (BELLARDI, 1873); ROBBA, p. 594, pl. 19, fig. 6; pl. 20, figs 2-3.
1982. *Clio braidensis* (BELLARDI, 1873); BERNASCONI & ROBBA, p. 217.
1983. *Balantium braidense* BELLARDI; FERRERO MORTARA & *al.*, p. 28, pl. 1, fig. 2.
1990b. *Clio braidensis* (BELLARDI, 1873); JANSSEN, p. 88.
1995. *Clio braidensis* (BELLARDI, 1873); JANSSEN, p. 62, pl. 5, figs 3-5.

MATERIAL EXAMINED: One fragment in sample CC07-1C (RGM 541 569), one specimen (internal and external mould) in sample CC07-1E (RGM 541 598).

DISCUSSION: This easily recognisable species, characterised by its curved transverse riblets on both sides of the shell and three central radial ribs on the dorsal side is only known with certainty from Mediterranean Zanclean sediments. Doubtful specimens were recorded from the Jamaican Bowden Beds (Piacenzian) by JANSSEN (1998, p. 101), which differ considerably in their reduced ornamentation.

Subgenus *Clio s. str.*

Clio (*Clio*) *pyramidata* LINNÉ, 1767

For extensive synonymy see JANSSEN (1995, p. 83; 2007b, p. 81).

MATERIAL EXAMINED: Sample CC07-1B (two specimens – DBUA-F431-13, DBUA-F431-18), CC07-1C (four specimens – RGM 541 570), CC07-1D (three specimens – DBUA-F431-52), CC07-1E (eight specimens – RGM 541 599). All specimens are no more than fragments and poorly preserved.

DISCUSSION: The state of preservation of the available specimens makes it impossible to decide whether or not they belong to the forma *lanceolata* (LESUEUR, 1813), which is at least probable, as it is the only form known from Neogene (from Serravallian onwards) deposits. Typical *C. pyramidata* is exclusively known from Holocene and Recent deposits. The specimens are too poorly preserved to illustrate. This species is also reported from the Recent malacofauna of the Azores (SEGERS 2002).

Family Cavoliniidae GRAY, 1850
Genus *Cavolinia* ABILDGAARD, 1791
(emend. PHILIPPI, 1853)

TYPE SPECIES: *Cavolinia tridentata* (NIEBUHR, 1775) (Recent).

Cavolinia grandis (BELLARDI, 1873)
(Pl. 1, Fig, 15)

1992. *Cavolinia tridentata* (NIEBUHR, 1775 ex FORSKAL m.s.); CAVALLO & REPETTO, p. 170, fig. 495 [non NIEBUHR].
1995. *Cavolinia grandis* (BELLARDI, 1873); JANSSEN, p. 97, pl. 8, fig. 8 [see for description and earlier synonymy].
1996. *Cavolinia rattonei* SIMONELLI, 1896; UJIHARA, p. 783, figs 7.10-7.14.
1999. *Cavolinia* cf. *tridentata* (NIEBUHR, 1775); JANSSEN, p. 25, pl. 5, fig. 1 [*non* NIEBUHR].
2000. *Cavolinia grandis* (BELLARDI, 1873); JANSSEN, p. 45, figs 10-11.

MATERIAL EXAMINED: Four specimens are available in the 2006 material [one in sample 1 (RGM 541 558) and three in sample 6 (DBUA-F379-14)]. In 2007 *c.* six specimens were collected, *c.* five in sample CC07-1B (DBUA-F431-19, 431-21, 431-22, 431-24, 431-25) and two in sample CC07-1C (RGM 541 571). Most specimens are either fragments or severely damaged.

DISCUSSION: An internal mould of the dorsal side from sample 2006/1 (Pl. 1, Fig. 15) clearly demonstrates the most typical character of this species, *viz*. the oblique transverse folds on the dorsal part of the shell. In other specimens, this feature is not developed and it is invisible in the fragmentary specimens, which therefore resemble the species *Cavolinia tridentata*. However, in that species the lateral ribs on the dorsal side are doubled (JANSSEN 2004, pl. 4, fig, 2a), which is not the case in the present specimens. Furthermore, in *C. grandis* the transverse ornament is sometimes present only on parts of the dorsal part of the shell. Therefore all specimens are identified as *C. grandis*. An internal mould of the ventral side does not show any feature enabling a distinction between *C. tridentata* and *C. grandis*, but the co-occurrence of these species is taken as an indication of conspecificity.

Cavolinia marginata (BRONN, 1862)
(Pl. 1, Figs 16a-c, 17a-b; Text-figs 3, 4, 5D)

1862. *Hyalea* (*Diacria* ?) *marginata* n. sp.; BRONN, *in* REISS, p. 36, fig. 15a-c.
1864. *Hyala marginata* BRONN; MAYER, p. 232, pl. 4, fig. 36a-c.
1873. *Hyalaea* (*Diacria*) *vendryesiana* n. sp.; GUPPY, p. 74, pl. 2, fig. 2b [non fig. 2a = *Diacria digitata*].
1943. *Cavolina limatula* spec. nov.; BEETS, p. 305, pl. 29, figs 117-119.
1962. *Hyala (Diacria) marginata* BRONN; ZBYSZEWSKI & DA VEIGA FERREIRA, p. 284.
1996. *Cavolinia vendryesiana hyugaensis* new subspecies; UJIHARA, p. 785, figs 7.18-7.30.
2004. *Cavolinia vendryesiana* (GUPPY, 1873) f. *pliomediterranea* f. nov.; JANSSEN, p. 118, pl. 4, fig. 4a-c [further synonymy herein].

DESCRIPTION: All specimens are preserved as internal or (rarely) external moulds, with parts of the apical and apertural shell parts missing. The shell is moderately large (height c. 8 mm, width c. 5 mm), with a convex ventral and a flatter dorsal part of the shell. The apical spine is distinctly curved dorsally (Pl. 1, Fig. 18 right), not shed in adult specimens (but usually broken). The ventral part of the shell is especially convex in its apertural half and has a recurved apertural margin. The dorsal part of the shell is higher and has a distinct marginal rim, in front of which an apertural lip is developed (Pl. 1, Fig. 18 left).

MATERIAL EXAMINED: This species occurs abundantly in all available samples. Hundreds of specimens were counted (DBUA-F379-4, 379-9 to 379-12, 379-15, 379-16, 379-19, 431-1, 431-9, 431-14, 431-26 to 431-28, 431-53 to 431-55; RGM 541 559 to 541 561, 541 572 to 541 577, 541 600 to 541 602, 605).

NEOTYPE DESIGNATION: MAYER (1864, p. 183), in revising the fossil collection from the Azores earlier studied by BRONN (in REISS 1862), referred to collections received on loan from the 'Heidelberger geologische Sammlungen', which material indeed included the two pteropod species, '*Triptera columnella*' and '*Hyalea marginata'*, already referred to by BRONN. Unfortunately, to date these samples, including syntypes of *Hyalea marginata*, cannot be traced in the BRONN collection, housed in the Geologisch-Paläontologisches Institut, Heidelberg University (Germany) (Mrs Dr Johanna KONTNY, in litt., 2006). Following suggestions, the responsible curators of the Palaeontology Department of the Natural History Museum, London (UK), both the malacological and palaeontological departments of the Muséum nationale d'Histoire naturelle, (Paris, France), and the Musée Océanographique de Monaco (Monaco), were also consulted. In none of these collections are syntypes available. Moreover, the specimens apparently did not remain in the MAYER collection, which for a long time was housed in the Eidgenössisch Technische Hochschule in Zürich, but nowadays is kept in the Naturhistorisches Museum, Basel (Switzerland). ZORN (1995) studied the pteropods in the MAYER collection, but did not refer to any specimen from the Azores. Likewise, a recently published historical account of George HARTUNG's travels (PINTO & BOUHEIRY 2007) provided no further clues to the whereabouts of the original specimens.

In view of the confusion with *C. vendryesiana* (see Discussion) it seems necessary to designate a neotype here for *H. marginata*, for which one of the presently available specimens from the type locality (Pl. 1, Fig. 16a-c; RGM 541 561) is chosen.

DISCUSSION: With the new Santa Maria material at hand it was quite a surprise to find out that *Cavolinia marginata* must be considered an earlier synonym of *C. vendryesiana*, which was introduced for a form from the Pliocene (Piacenzian) Bowden Beds of Jamaica. *C. marginata* had so far only been recorded under that name from Santa Maria, Azores, and the original illustrations are quite poor. That, and the lack of topotypical specimens, explains why the identity of these two taxa was never noted. The numerous specimens available now indicate beyond doubt that the Azores *Cavolinia* belongs to the same species as the Jamaican *C. vendryesiana*, which taxon therefore becomes a junior subjective synonym of *C. marginata*.

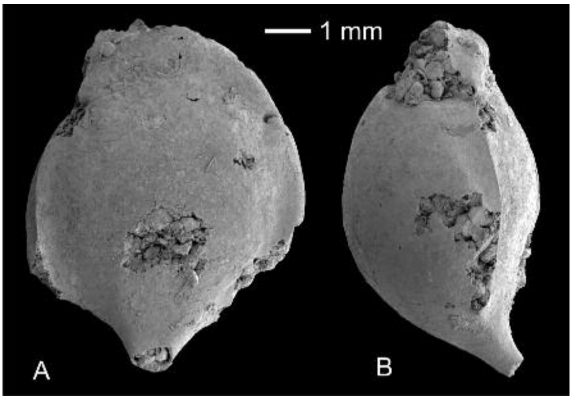


Fig. 4. SEM images of an internal mould of *Cavolinia marginata* (BRONN, 1862) from the Lower Pliocene of Cré, Santa Maria (RGM 541 559)

The main features of *C. marginata* (Text-fig. 4; Pl. 1, Figs 16-18) agree with those of typical *C. vendryesiana*. Both, to some extent, resemble the Recent *C. inflexa* (LESUEUR, 1813), but differ in the presence of an obvious reinforcement rim along the anterior margin of the dorsal part of the shell, which is absent in *C. inflexa*. In the latter species radial folds, reaching the apertural margin, are present on the dorsal side, which do not occur in the other two taxa, or are only very vaguely indicated in some specimens of *C. vendryesiana*.

Compared, however, to topotypical material of *C. vendryesiana* from Bowden, Jamaica, there are also differences between the two fossil forms, which are here interpreted as infrasubspecific. Specimens from the Azores reach a larger size and are more convex, especially the ventral part of the shell. In the Jamaican form, the greatest width of the shell is situated at the lateral spines, but lies above these spines in the Azores specimens. It might be that these differences (apart from size) are influenced by preservation: the Bowden specimens are in shell preservation; those from the Azores are internal moulds with parts of the lateral and apical spines and apertural lip missing in almost all specimens.

Furthermore, these differences may have an ecological and/or evolutionary cause: the Bowden Beds were deposited in a more or less restricted basin (Caribbean

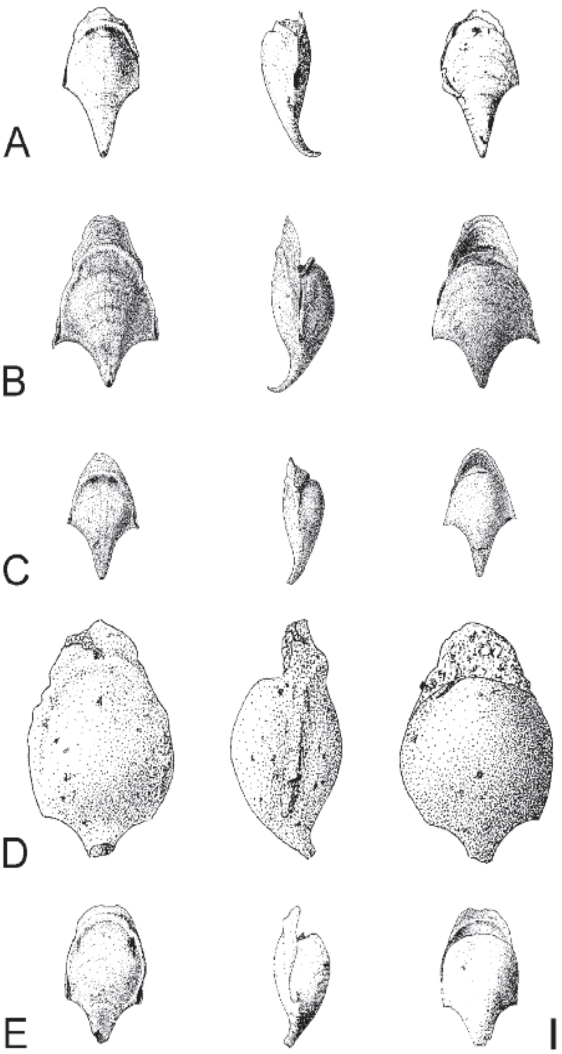


Fig. 5. Formae of *Cavolinia marginata* (BRONN, 1862). A – forma *vendryesiana* (GUPPY, 1873), Piacenzian, Bowden, Jamaica; B – forma *pliomediterranea* JANSSEN, 2004, Piacenzian, Spain; C – forma *hyugaensis* UJIHARA, 1996, Piacenzian, Philippines; D – forma *marginata* (BRONN, 1862), Zanclean, Santa Maria, Azores; E – forma *limatula* (BEETS, 1943), Tortonian/Messinian, Sulawesi, Indonesia. Left – dorsal views, middle – lateral views, right – ventral views. Bar length equals 1 mm for all figures

Name	Age	Known distribution	Fig.
C. marginata f. *vendryesiana*	Piacenzian	Jamaica (Bowden)	5A
C. marginata f. *pliomediterranea*	Piacenzian	Spain (Estepona)	5B
C. marginata f. *hyugaensis*	Zanclean/Piacenzian	Japan, Philippines	5C
C. marginata s. str.	Zanclean	Azores (Sta Maria)	5D
C. marginata f. *limatula*	Tortonian/Messinian	Indonesia (Sulawesi)	5E

Table 1. Age and distribution of *Cavolinia marginata* formae

Sea), whereas the Santa Maria beds are fully open-oceanic. The Bowden material is younger, Piacenzian in age, the Santa Maria specimens are Zanclean (see below).

The various morphs described for *C. vendryesiana* now have to be considered formae of *C. marginata* (see Table 1). See also the discussion of *C. vendryesiana* formae in JANSSEN (2004, p. 118). Drawings of the five formae now recognised are presented in Text-fig. 5.

NOTE: The name "*Hyalea marginata* D'ORB." (in DESHAYES 1849) predates *H. marginata* BRONN, 1862, but is here considered to be a *lapsus calami* for *H. limbata* D'ORBIGNY, 1836 and hence not available. The Latin words *marginata* and *limbata* have the same meaning "with a border" (= "bordé" in French). DESHAYES erroneously used the name *H. marginata* in the explanation of pl. 17 fig. 4 ("Hyale bordée"), as is clear from the plate itself, where the name "*Hyalœa limbata* D'ORB." is printed for fig. 4. A name *H. marginata* had never been introduced by D'ORBIGNY. Therefore *H. marginata* DESHAYES (1849, explanation of pl. 17, fig. 4) is here corrected to *H. limbata*.

Genus *Diacria* GRAY, 1847

TYPE SPECIES: *Diacria trispinosa* (BLAINVILLE, 1821) (Recent).

Diacria trispinosa (BLAINVILLE, 1821)
(Pl. 1, Fig. 19)

1821. *Hyalœa trispinosa*, LESUEUR; BLAINVILLE, p. 82.
2004. *Diacria trispinosa* (BLAINVILLE, 1821); JANSSEN, p. 120, pl. 3, figs 5, 6.

MATERIAL EXAMINED: Five damaged specimens and six fragments in samples CC07/1C-1E (DBUA-F431-56, 431-57; RGM 541 578, 541 579, 541 603, 541 604)

DISCUSSION: All specimens are fragmentary and poorly preserved. *Diacria trispinosa* is known to occur from the Tortonian onwards, and is still present in the living fauna, occurring also in the Azores (ÁVILA & AZEVEDO 1997). For a discussion of the various taxa separated from this taxon in recent years, see JANSSEN (2004).

BIOSTRATIGRAPHY (AWJ, AK)

The age of the Santa Maria deposits has been a matter of debate for a long time. Initially they were correlated with the Swiss "Helvetien" (BRONN in HARTUNG 1860; REISS 1862; MAYER 1864; COTTER 1892), which (in the type area) corresponds to the Early Burdigalian nowadays (HARZHAUSER & *al.* 2003, p. 325). Later workers assumed a younger, Middle to early Late Miocene age (DA VEIGA FERREIRA 1952, 1955; ZBYSZEWSKY & DA VEIGA FERREIRA 1962: "vindobonienne"), based on benthic molluscs. COLOM (in KREJCI-GRAF & *al.* 1958), however, proposed a Late Miocene to Pliocene age based on foraminiferal evidence from the south coast of Santa Maria. The same is true for K-Ar dates of the volcanics below and above, as well as within the Touril Complex (ABDEL-MONEM & *al.* 1975; FERAUD & *al.* 1980, 1984; but see SERRALHEIRO & MADEIRA 1990 for discussion). Recent data obtained from Strontium stable isotope analysis (KIRBY & *al.* 2007) yielded compatible age estimates for the "Pedra-que-Pica" sections on the south-eastern coast of the island.

The holoplanktonic mollusc assemblage described above gives new, independent age estimates for the marine sediments of the Touril Complex. Though some of the species found are very long ranging, such as *Heliconoides inflata* (Early Miocene–Recent) and *Styliola subula* (Late Oligocene–Recent), many holoplanktonic molluscs are excellent index fossils, having wide spatial, but limited temporal distributions.

Oxygyrus keraudreni is recorded from the Zanclean onwards, still occurring in the living fauna. *Bowdenatheca jamaicensis* was recorded from the Messinian to the Piacenzian. *Cuvierina intermedia* ranges from the Tortonian to the Piacenzian. *Clio braidensis* and *Cavolinia grandis* are restricted to the Early Pliocene (Zanclean). *C. grandis* is the forerunner species of the Piacenzian to Recent species *C. tridentata* (NIEBUHR, 1775). *Clio pyramidata* and *Diacria trispinosa* appear during the Middle/Late Miocene and still occur in the present-day fauna. *Cavolinia marginata*, including the various formae (Text-fig. 5) as mentioned above, is known to occur from the Late Miocene (Tortonian/Messinian) to Middle Pliocene (Piacenzian). The present record extends the range of the pteropod *Limacina trochiformis*, which was only known from Quaternary deposits before.

The assemblage of heteropods and pteropods encountered at Cré therefore convincingly supports an age assignment of Early Pliocene (Zanclean), based on the occurrence of *Clio braidensis* and *Cavolinia grandis*, and the overlapping ranges of several other species. This age assignment is thus in good agreement with the micropalaeontological and geochemical data discussed above (Text-fig. 6).

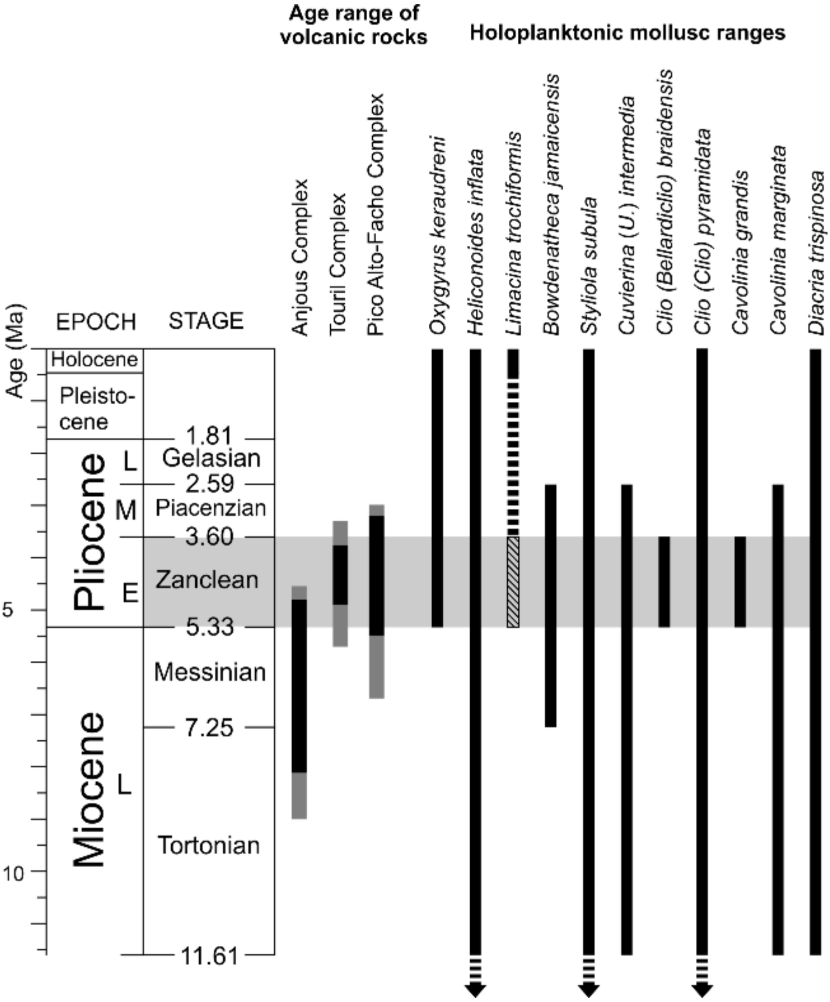


Fig. 6. Temporal ranges of the holoplanktonic mollusc assemblage of Cré, Santa Maria and K-Ar age ranges of the volcanic rocks below, within and above the sediments of the Touril complex (K-Ar age data from ABDEL-MONEM & *al*. 1975; FERAUD & *al*. 1980, 1984; SERRALHEIRO & MADEIRA 1990). Solid black bars – temporal range of the mollusc species and age dates respectively; hatched bar – range extension for *L. trochiformis*; dark grey – statistical error of age dates; light grey – inferred age of the Cré assemblage

Acknowledgements

S.P. ÁVILA was supported by grant SFRH/BPD/22913/2005 (FCT – Fundação para a Ciência e Tecnologia) of the Portuguese government. We would like to thank the organization of the "III Workshop Palaeontology in Atlantic Islands" (15 -25 June 2006), and of the "IV Workshop Palaeontology in Atlantic Islands" (17-25 June 2007), and all the students that helped in the collecting during this period, as well as Direcção Regional da Ciência e Tecnologia (Açores), Direcção Regional do Ambiente (Açores), Direcção Regional da Juventude (Açores) and Câmara Municipal de Vila do Porto, for financial support.

Field work was carried out by the Marine Palaeo-Biogeography Working Group of the Universidade dos Açores. We gratefully acknowledge the assistance of Dr. Mário CACHÃO and Dr. Marques DA SILVA (both Universidade de Lisboa), Dr. Michael X. KIRBY (Florida Museum of Natural History), Dr. Sergio RAFFI (Universidade de Bologna), Patrícia MADEIRA, André MONTEIRO, Ana Cristina REBELO, and Cidalina GOMES (all Universidade dos Açores), and Pedro MONTEIRO (Correio dos Açores).

For information on collections in their care we want to thank Mrs Dr. Michèle BRUNI, Service des Collections, Musée océanographique de Monaco (Monaco), Mrs Dr. Johanna KONTNY, Geologisch-Paläontologisches Institut, Heidelberg University, Heidelberg (Germany), Dr. Pierre LOZOUET, Laboratoire de Biologie des Invertébrés et de Malacologie, Muséum national d'Histoire naturelle, Paris (France). Dr. Jean-Michel PACAUD, Collection d'Invertébrés fossiles, typothèque, Muséum national d'Histoire naturelle, Paris (France) and Dr. John TODD, The Natural History Museum, London (UK).

We gratefully acknowledge the critical reviews of Professor Atsushi Ujihara (Department of Geology, College of General Education, Nagoya University, Nagoya, Japan) and an anonymous reviewer.

REFERENCES

Abdel-Monem, A.A., Fernandez, L.A. & Boone, G.M. 1975. K/Ar ages from the eastern Azores group (Santa Maria, São Miguel and the Formigas Islands). *Lithos*, **4**, 247-254.

Audenino, L. 1897. Pteropodi miocenici del Monte dei Cappucini in Torino. *Bullettino della Società Malacologica Italiana*, **20**, 97-114.

Ávila, S.P. 2005. Processos e Padrões de Dispersão e Colonização nos Rissoidae (Mollusca: Gastropoda) dos Açores, x+329 pp. PhD Thesis, Universidade dos Açores, Ponta Delgada.

Ávila, S.P., Amen, R., Azevedo, J.M.N., Cachão, M. & García-Talavera, F. 2002. Checklist of the Pleistocene marine molluscs of Praínha and Lagoínhas (Santa Maria Island, Azores). *Açoreana*, **9** (4), 343-370.

Ávila, S.P. & Azevedo, J.M.N. 1997. Shallow-water molluscs from the Formigas islets, Azores, collected during the "Santa Maria e Formigas 1990" scientific expedition. *Açoreana*, **8** (3), 323-330.

Ávila, S.P., Cardigos, F. & Santos, R.S. 2004. D. João de Castro bank, a shallow-water hydrothermal-vent in the Azores: checklist of the marine mollusks. *Arquipélago*, *Life and Marine Sciences*, **21A**, 75-80.

Bé, A.W.H. & Gilmer, R.W. 1977. A zoogeographic and taxonomic review of euthecosomatous Pteropoda. *In*: A.T.S. Ramsay (*Ed.*), Oceanic micropaleontology, 1, pp. 733-807. *Academic Press*; London.

Beets, C. 1943. Beiträge zur Kenntnis der angeblich oberoligocänen Mollusken-Fauna der Insel Buton, Niederländisch-Ostindien. *Leidse Geologische Mededelingen*, **13**, 256-328.

Bellardi, L. 1873. I molluschi dei terreni terziari del Piemonte e della Liguria, 1. Cephalopoda, Pteropoda, Heteropoda, Gastropoda (Muricidae et Tritonidae). *Memorie delle Reale Accademia delle Scienze di Torino (2)*, **27**, 1-264.

Bellini, R. 1905. Le varie facies del Miocene medio nelle colline di Torino. *Bolletino della Società Geologica Italiana*, **24** (2), 607-652.

Bernasconi, M.P., & Robba, E. 1982. The thecosomatous pteropods, a contribution towards the Cenozoic Tethyan paleobiogeography. *Bollettino della Società Paleontologico Italiana*, **21** (2-3), 211-222.

Blainville, [H.M.D.] de 1821. Hyale, Hyaloea (Malacoz.). *Dictionnaire des Sciences naturelles*, **22**, 65-83.

Bortolotti, E. 1898. Contribuzione alla conoscenza dei fossili del Miocene medio nel Bolognese. *Rivista Italiana di Paleontologia*, **4**, 55-61.

Callapez, P. & Soares, A.F. 2000. Late Quaternary marine mollusks from Santa Maria (Azores); paleoecologic and paleobiogeographic considerations. *Ciências da Terra (UNL)*, **14**, 313-322.

Cavallo, O. & Repetto, G. 1992. Conchilie fossili del Roero. Atlante iconografico. *Associazione naturalistica Piemontese, Memorie*, **2**, 1-251.

Collins, R.L. 1934. A monograph of the American Tertiary pteropod mollusks. *Johns Hopkins University Studies in Geology*, **11**, 137-234.

Cotter, J.C.B. 1892. Notícia de alguns fósseis terciários da ilha de Santa Maria no Archipélago dos Açores. *Comuniações da Comissão de Trabalhos Geológicos de Portugal*, **2**, 255-287.

Dautzenberg, P. 1889. Contribution à la faune malacologique des Iles Açores. Résultats des dragages effectués par le yacht l'*Hirondelle* pendant sa campagne scientifique de 1887. Révision des mollusques marins des Açores. *Résultats des Campagnes Scientifiques du Prince de Monaco*, **1**, 112 pp.

Deshayes, G.P. 1849. Les mollusques. *In*: G. Cuvier. Le règne animal distribué d'après son organisation, pour servir de base à l'histoire naturelle des animaux, et d'introduction à l'anatomie comparée. [Third] édition accompagnée de planches gravées, représentant les types de tous les genres, les caractères distinctifs des divers groupes et les modifications de structure sur lesquelles repose cette classification par une réunion de disciples de Cuvier, MM. Audouin, Blanchard, Deshayes, Alcide d'Orbigny, Doyère, Dugès, Duvernoy, Laurillard, Milne Edwards, Roulin et Valenciennes, pp. 1-266. *Fortin, Masson & Cie*; Paris.

Erünal-Erentöz, L. 1958. Mollusques du Néogène des bassins de Karaman, Adana et Hatay (Turquie). *Publications de l'Institut d'Études et Recherches Minières de Turquie (C)*, **4**, 232 pp.

Estevens, M. & Ávila, S.P. 2007. Fossil whales from the Azores. *In*: S.P. Ávila & A.M. de Frias Martin (*Eds*), Proceedings of the 1st "Atlantic Islands Neogene" International Congress, Ponta Delgada, 12-14 June 2006. *Açoreana, Suplemento,* **5**, 140-161.

Feraud, G., Kaneoka, J. & Allègre, C.J. 1980. K/Ar ages and stress patterns in the Azores, geodynamic implications. *Earth and planetary science letters*, **142**, 275-286.

Feraud, G., Schmincke, H.U., Lietz, J., Gostaud, J., Pritchard, G. & Bleil, U. 1984. New K-Ar ages, chemical analysis and magnetic data of rocks from the islands of Santa Maria (Azores), Porto Santo and Madeira (Madeira archipelago) and Gran Canaria (Canary islands). *Arquipélago, Séries Ciências da Naturezza*, **5**, 213-240.

Ferrero Mortara, E., Montefameglio, L., Pavia, G. & Tampieri, R. (1981)1983. Cataloghi VI. Catalogo dei tipi e degli esemplari figurati della collezione Bellardi e Sacco, 1.

Museo regionale di Scienze Naturali; Torino, pp. 1-327.

García-Talavera, F. 1990. Fauna tropical en el Neotirreniense de Santa Maria (I. Azores). *Lavori S.I.M.*, **23**, 439-443.

Guppy, R.J.L. 1873. On some new Tertiary fossils from Jamaica. *Proceedings of the Scientific Association of Trinidad*, **2**(2/10), 72-88.

Hartung, G. 1860. Die Azoren in ihrer äusseren Erscheinung und nach ihrer geognostischen Natur, pp. viii+350. *Wilhelm Engelmann*; Leipzig.

Harzhauser, M., Mandic, O. & Zuschin, M. 2003. Changes in Paratethyan marine molluscs at the Early/Middle Miocene transition: diversity, palaeogeography and palaeoclimate. *Acta Geologica Polonica*, **53** (4), 323-339.

Janssen, A.W. 1990a. Pteropoda (Gastropoda, Euthecosomata) from the Australian Cainozoic. *Scripta Geologica*, **91** (1989), 1-76.

— 1990b. Pteropod species (Mollusca, Gastropoda, Euthecosomata) from the Late Oligocene of Mogenstrup, Jylland, Denmark. *Contributions to Tertiary and Quaternary Geology*, **27** (2-3), 83-91.

— 1995. Systematic revision of holoplanktonic Mollusca in the collections of the 'Dipartimento di Scienze della Terra' at Torino, Italy. *Museo regionale di Scienze naturali, Torino, Monografie*, **17**, 1-233.

— 1998. Holoplanktonic Mollusca (Gastropoda, Heteropoda and Thecosomata) from the Pliocene Bowden Beds, Jamaica. *Contributions to Tertiary and Quaternary Geology*, **35**, 95-111.

— 1999. Neogene paleontology in the northern Dominican Republic, 20. Holoplanktonic molluscs (Gastropoda, Heteropoda and Thecosomata). *Bulletins of American Paleontology*, **358**, 1-40.

— 2000. Notes on the systematics, morphology and biostratigraphy of fossil holoplanktonic Mollusca, 8, *Cavolinia grandis* (Bellardi, 1873) from the Early Pliocene of New Zealand, a further example of long-distance correlation by means of pteropods. *Basteria*, **64**, 45-47.

— 2004. Holoplanktonic molluscan assemblages (Gastropoda, Heteropoda, Thecosomata) from the Pliocene of Estepona, Spain, Málaga. *Palaeontos*, **5**, 103-131.

— 2007a. Holoplanktonic Mollusca (Gastropoda) from the Gulf of Aqaba, Red Sea and Gulf of Aden (Late Holocene-Recent). *The Veliger*, **49** (3), 140-195.

— 2007b. Holoplanktonic Mollusca (Gastropoda, Pterotracheoidea, Janthinoidea, Thecosomata and Gymnosomata) from the Pliocene of Pangasinan (Luzon, Philippines). *Scripta Geologica*, **135**, 29-177.

Kirby, M.X., Jones, D.S. & Ávila, S.P. 2007. Neogene shallow-marine palaeoenvironments and preliminary Strontium isotope chronostratigraphy of Santa Maria Island, Azores. *In*: S.P. Ávila & A.M. de Frias Martin (*Eds*), Proceedings of the 1st "Atlantic Islands Neogene" International Congress, Ponta Delgada, 12-14 June 2006. Açoreana, Suplemento, **5**, 112-125.

Krejci-Graf, K., Frechen, J., Wetzel, W. & Colom, G. 1958. Gesteine und Fossilien von den Azoren. *Senckenbergiana lethaea*, **39** (5-6), 303-351.

Lesueur, [J.A.] 1813. Mémoire sur quelques espèces d'animaux mollusques et radiaires recueillis dans la Méditerranée, près de Nice. *Nouveau Bulletin des Sciences, par la Société Philomatique*, **3** (69), 281-285.

Lozouet, P. & Maestrati, P. 1982. Nouvelles espèces de mollusques de l'Oligocène (Stampien) pour les bassins de Paris et d'Aquitaine. *Archiv für Molluskenkunde*, **112** (1-6), 165-189.

Madeira, P., Kroh, A., Frias Martins, A.M. de & Ávila, S.P. 2007. The marine fossils from Santa Maria Island (Azores, Portugal): a historical overview. *In*: S.P. Ávila & A.M. de Frias Martin (*Eds*), Proceedings of the 1st "Atlantic Islands Neogene" International Congress, Ponta Delgada, 12-14 June 2006. Açoreana, Suplemento, **5**, 59-73.

Mayer, K. 1864. Systematisches Verzeichniss der fossilen Reste von Madeira, Porto Santo und Santa Maria nebst Beschreibung der neuen Arten. *In*: G. Hartung, Geologische Beschreibung der Inseln Madeira und Porto Santo, pp. 183-298. *W. Engelmann*; Leipzig.

Orbigny, A. d'. 1836-1846. Voyage dans l'Amérique méridionale (le Brésil, la république orientale de l'Uruguay, la république Argentine, la Patagonie, la république du Chili, la république de Bolivia, la république du Pérou), exécuté pendant les années 1826, 1827, 1828, 1829, 1830, 1831, 1832 et 1833, 5(3). Mollusques, pp. 49-184 (1836); Atlas 20 pls (1846). *Bertrand*; Paris.

Pinto, M.S. & Bouheiry, A. 2007. The German geologist Georg Hartung (1821-1891) and the geology of the Azores and Madeira islands. *In*: P.N. Wyse Jackson (*Ed.*), Four Centuries of Geological Travel: The Search for Knowledge on Foot, Bicycle, Sledge and Camel. *Geological Society Special Publication*, **287**, 209-238.

Quoy, [J.R.C.], & Gaimard, [J.P.], 1827. Observations zoologiques faites à bord de l'Astrolabe, en Mai 1826, dans le détroit de Gibraltar (suite et fin). Description des genres biphore, carinaire, hyale, flèche, cléodore, anatife et briarée. *Annales des Sciences Naturelles*, **10**, 225-239.

Reiss, W. 1862. Mittheilungen über die tertiären Schichten von Santa Maria, der südlichsten der Azoren, und ihre organische Einschlüsse. Nebst Beschreibung dieser letzten und Abbildung der neuen Arten. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde*, **1862**, 1-48.

Robba, E. 1977. Pteropodi serravalliani della Langhe (Piemonte). *Rivista Italiana di Paleontologia*, **83** (3), 575-640.

Sacco, F. 1904. I molluschi dei terreni terziarii del Piemonte e della Liguria, 30. Aggiunte e correzzione. Considerazioni generali. Indice generale del'opera, pp. 1-203, i-xxxvi. *Clausen*; Torino.

SEAPY, R.R. 1990. The pelagic family Atlantidae (Gastropoda, Heteropoda) from Hawaiian waters, a faunistic survey. *Malacologia*, **32** (1), 107-130.

SEGERS, W. 2002. On some shallow-water marine molluscs of the Azores. *Gloria Maris*, **41** (4-5), 84-104.

SERRALHEIRO, A. 2003. A geologia da Ilha de Santa Maria, Açores. *Açoreana*, **10** (1), 141-192.

SERRALHEIRO, A., ALVES, C.A. DE M., FORJAZ, V.H. & RODRIGUES, B. 1987. *Carta Vulcanológica dos Açores. Ilha de Santa Maria*. 1:15.000. Centro Vulcanologia do I.N.I.C.; Ponta Delgada.

SERRALHEIRO, A. & MADEIRA, J. 1990. Stratigraphy and geochronology of Santa Maria Island (Azores). *In*: Livro de Homenagem a Carlos Romariz, pp. 357-376. Secção de Geologia e Economica Aplicada, Departamento Ciências da Universidade de Lisboa; Lisboa.

SHIBATA, H. 1980. Pteropods from the Early Miocene (Kurami and Saigo Groups) of the Kakegawa District and the Early to Middle Miocene (Yatsuo Formation) of the Yatsuo District, central Japan. *Bulletin of the Mizunami Fossil Museum*, **7**, 59-68. [*In Japanese with English summary*]

— 1983. Miocene pteropods from central Honshu, Japan. *Research Bulletin, College of General Education, Nagoya University (B)*, **27**, 65-86.

SPOEL, S. VAN DER 1967. Euthecosomata, a group with remarkable developmental stages (Gastropoda, Pteropoda), 375 pp. Gorinchem (J. Noorduijn); thesis, University of Amsterdam.

TIBERI, N. 1878. Mollusques marins d'Italie. Céphalopodes, ptéropodes, hétéropodes vivant de la Méditerranée et fossiles du terrain tertiaire d'Italie. *Mémoires de la Société Malacologique de Belgique*, **13**, (2)3, 52-84.

— 1880. Cefalopodi, pteropodi, eteropodi viventi nel Mediterraneo e fossili nel terreno terziario italiano con aggiunte e correzioni. *Bullettino della Società Malacologica Italiana*, **6**, 5-49.

UJIHARA, A. 1996. Pteropods (Mollusca, Gastropoda) from the Pliocene Miyazaki Group, Miyazaki Prefecture, Japan. *Journal of Paleontology*, **70**, 771-788.

VEIGA FERREIRA, O. DA 1952. Os pectinídeos do Miocénico da ilha de Santa Maria (Açores). *Revista da Faculdade de Cięncias de Lisboa, 2a Série, C*, **2**/2, 243-258.

— 1955. A Fauna Miocénica da Ilha de Santa Maria (Açores). *Comunicações dos Serviços Geológicos de Portugal*, **36**, 9-44.

— 1961. Afloramentos de calcário miocénico da Ilha de Santa Maria (Açores). *Comunicações dos Serviços Geológicos de Portugal*, **45**, 493-502.

ZBYSZEWSKI, G., & VEIGA FERREIRA, O. DA 1962. La faune miocène de l'île de Santa Maria (Açores). *Comunicações dos Serviços Geológicos de Portugal*, **46**, 247-292.

ZILCH, A. 1959. Gastropoda, 2. Euthyneura, 1. *In*: W. WENZ (*Ed.*), Handbuch der Paläozoologie, **6**, pp. xii + 200 pp. *Bornträger*; Berlin.

ZORN, I. 1995. Planktonische Gastropoden (Euthocosomata und Heteropoda) in der Sammlung MAYER-EYMAR im Naturhistorischen Museum in Basel. *Eclogae geologicae Helvetiae*, **88** (3), 743-759.

— 1997. Holoplanktonic gastropods from the Early Messinian of the Heraklion Basin (Crete, Greece). *Contributions to Tertiary and Quaternary Geology*, **34** (1-2), 31-45.

Manuscript submitted: 16th October 2007
Revised version accepted: 27th June 2008

PLATE 1

Camera-lucida drawing of heteropods and pteropods from the Early Pliocene of Cré (Santa Maria, Azores)

1 – *Atlanta* sp.; apical view (RGM 541 580).

2 – Carinariidae sp.; ventral view (protoconch; RGM 541 585).

3a-d – *Heliconoides inflata* (D'ORBIGNY, 1836); a – ventral, b – apical, c – dorsal, d – umbilical view (RGM 541 586).

4 – *Limacina* cf. *bulimoides* (D'ORBIGNY, 1836); ventral view (RGM 541 562).

5 – *Limacina trochiformis* (D'ORBIGNY, 1836); ventral view (RGM 541 589).

6 – Limacinidae *incertae sedis*; ventral view (RGM 541 591).

7a-c, 8a-d – *Bowdenatheca jamaicensis* COLLINS, 1934; 7a – apertural, 7b – ventral, 7c – left lateral view; 8a – apertural, 8b – dorsal or ventral, 8c – apical, 8d – lateral view (RGM 541 592).

9a-b, 10 – *Styliola subula* (QUOY & GAIMARD, 1827); 9a – ventral view, 9b – protoconch enlarged; 10 – dorsal view (RGM 541 594).

11a-c – *Cuvierina* (*Urceolarica*) *intermedia* (BELLARDI, 1873); a – apertural, b – ventral, c – left lateral view (RGM 541 597).

12, 13a-b – *Clio* (*Balantium*) sp. nov.; 12 and 13a – dorsal view, 13b – ventral view (RGM 541 568).

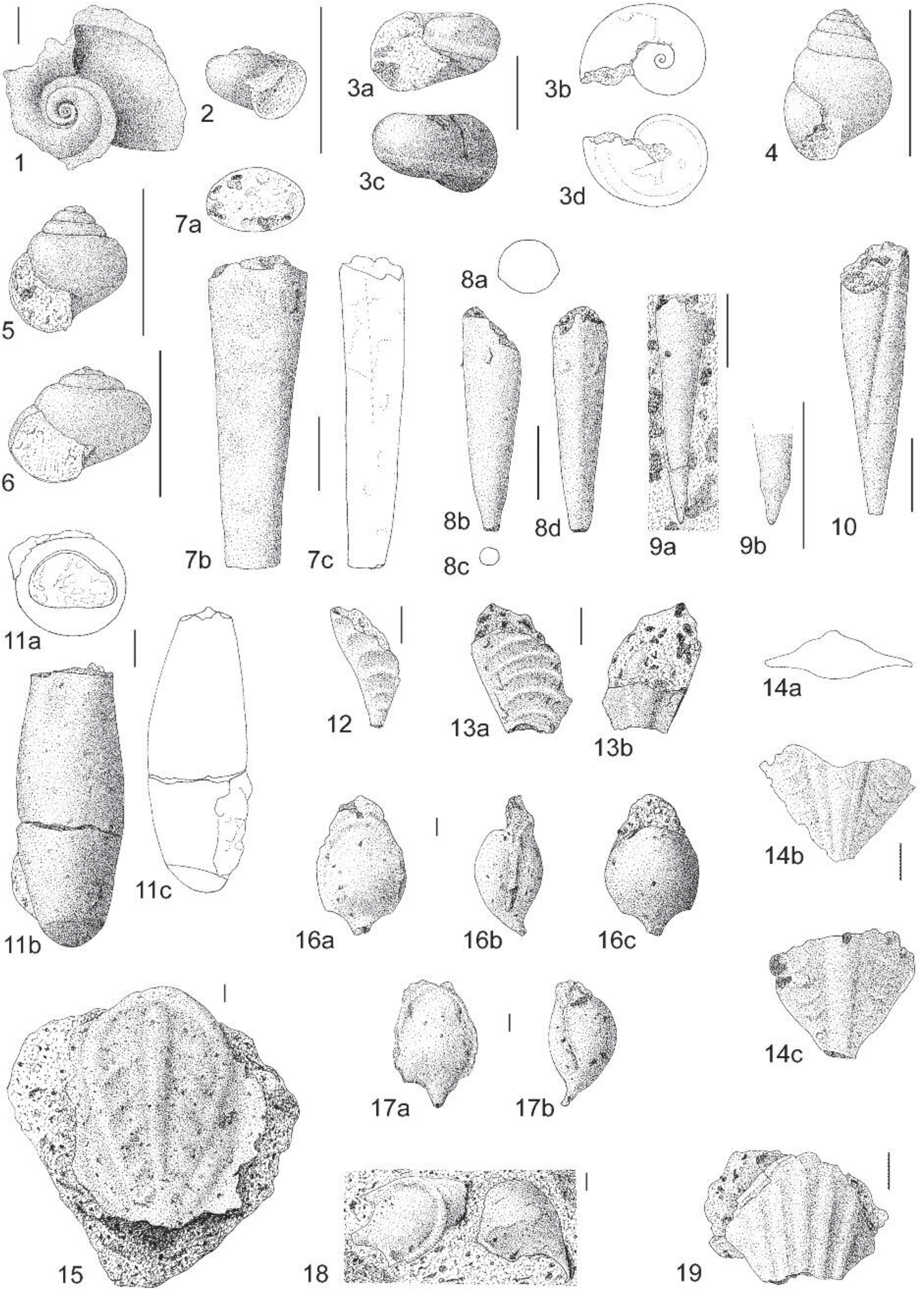
14a-c – *Clio* (*Bellardiclio*) *braidensis* (BELLARDI, 1873); a – apertutral, b – dorsal, c – ventral view (RGM 541 598).

15 – *Cavolinia grandis* (BELLARDI, 1873); dorsal view (RGM 541 558).

16a-c, 17a-b, 18 – *Cavolinia marginata* (BRONN, 1862); 16a – dorsal, 16b – left lateral, 16c – ventral view; 17a – dorsal, 17b – right lateral view, 18 – two specimens, left one in dorsal, right one in ventral view (16 – neotype, RGM 541 561; 17 – RGM 541 560; 18 – RGM 541 575).

19 – *Diacria trispinosa* (BLAINVILLE, 1821); dorsal view (RGM 541 579).

Scale bars equal 1 mm


1
2
3a
3b
3c
3d
4
5
6
7a
7b
7c
8a
8b
8c
8d
9a
9b
10
11a
11b
11c
12
13a
13b
14a
14b
14c
15
16a
16b
16c
17a
17b
18
19