

Notes on the systematics, morphology and biostratigraphy of fossil holoplanktonic Mollusca, 22¹. Further pelagic gastropods from Viti Levu, Fiji Archipelago

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Two localities in the island of Viti Levu, Fiji Archipelago, yielded together 28 species of Heteropoda (3 species) and Pteropoda (25 species). Two samples from Tabataba, NW Viti Levu, indicate an age of late Miocene to early Pliocene. Two samples from Waila, SE Viti Levu, signify an age of Pliocene (Piacenzian) and closely resemble coeval assemblages described from Pangasinan, Philippines.

Key words: Gastropoda, Pterotracheoidea, Limacinoidea, Cavolinioidea, Clionoidea, late Miocene, Pliocene, biostratigraphy, Fiji archipelago.

INTRODUCTION

In an earlier paper (Janssen, 1999a) some data were given on late Miocene (Tortonian-Messinian) Pteropoda from the Fiji islands, additional to the paper of Ladd (1934). Having seen that publication the junior author made further pteropod and heteropod material available in 1999, collected by

himself during holiday trips in 1995 and 1996, also from Viti Levu, the largest island in the Fiji archipelago. Following an initial evaluation of this material it remained unstudied, however, for a long time. A first inspection acknowledged Andrew's impression that part of the samples was younger than the earlier described material and therefore worth publishing.

After the untimely death of Andrew Grebneff in July 2010 (see the website of the University of Otago, New Zealand (http://www.otago.ac.nz/geology/news/files/andrew_grebneff.html)) it was decided to restart the study of those samples and publish the results with Andrew's name added as a valuable co-author, as he not only collected the specimens but also participated in discussions on their taxonomy and age. Part of the samples was collected in Tabataba, on the property of Mr Parmendra Prasad, who was Andrew's brother-in-law.

General information on the geology of the Fiji archipelago is available on the website of the Fiji Mineral Resources Department of the Ministry of Lands and Mineral Resources (http://www.mrd.gov.fj/gfiji/geology/educate/geo_fiji.html), where also a simplified geological map can be found (<http://www.mrd.gov.fj/gfiji/img/maps/geology/Fijigeo.gif>).

¹ For nr 21 in this series see Basteria 75: 71.

The complicated geological history of the Fiji islands group, situated on the Fiji Plate in between the subduction zones of the Indo-Australian and Pacific plates, and therefore strongly influenced by tectonics and volcanism, is explained in another site of the same institute (<http://www.mrd.gov.fj/gfiji/geology/educate/platect.html>).

In the present paper we analyze the holoplanktonic mollusc species, using these to estimate the age of the source rocks.

MATERIAL AND METHODS

Isolated specimens of hetero- and pteropods were concentrated from fossil samples collected at four localities, two near Tabataba (S of Ba, NE Viti Levu) and two near Waila, NNE of Suva, in the SE of the same island (Fig. 1). From locality Tabataba-1 also a sediment sample was available, yielding some additional specimens. Details of these localities are as follows:

Tabataba-1, NW Viti Levu, Fiji islands; above westward meander of Mavuvu Creek, just east of point 9.05 km due S of east end of Ba river bridge at Ba, map/grid reference 8710 3115, Fiji map M27 (Balevuto). Materials collected ex situ, surfaced by bullock plowing in Parmendra Prasad's peanutfield. Supposed late Miocene/early Pliocene, inferred Ba Volcanic Group. Sediment of tan, tuffaceous silt, breaking into angular fragments. Leg. A. Grebneff (AGF237), 4 January 1996.

Tabataba-2, NW Viti Levu, Fiji islands; 250 m W of Mavuvu Creek, 9 km S of Ba, NW Viti Levu, Fiji; map/grid reference 8705 3100, Fiji map M27 (Balevuto). Small outcrop on Parmendra Prasad's driveway. Supposed late Miocene/early Pliocene, inferred Ba Volcanic Group, probably same level as in locality 1. Sediment of grey, weathering to dull tan coloured, reasonably tough but not hard sediment in 3-15 cm thick beds, decalcified. Leg. A. Grebneff (AGF230A), 4 January 1996.

Waila-1, SE Viti Levu, Fiji islands; sideroad cutting, W of Nausori Bridge, near right bank of Rewa River, N of Suva; probably 500 m north of gridreference 7405 8585, Fiji map O28 (Nausori), edition 1 (1990). Supposed late

Pliocene, Nakasi Beds, N22. Sediment of very soft, almost unconsolidated, massive, darkish-grey silt, weathering to beige, with deepwater appearance (*Argyropeza* present) with micromolluscs in small concentrations. Leg. A. Grebneff (AGF225), 16 January 1995.

Waila-2, SE Viti Levu, Fiji islands; road cut W of Nausori bridge, near right bank of Rewa River, N of Suva; probably 250 m north of gridreference 7405 8585, Fiji map O28 (Nausori), edition 1 (1990). Supposed late Pliocene, Nakasi Beds, N22. Sediment of very soft, almost unconsolidated, massive, darkish-grey silt, weathering to beige, with deepwater appearance (*Argyropeza* present) with micromolluscs in small concentrations. Leg. A. Grebneff (AGF224), 16 January 1995.

All specimens are housed in the NCB Naturalis collections (Leiden, The Netherlands) (RGM registration numbers).

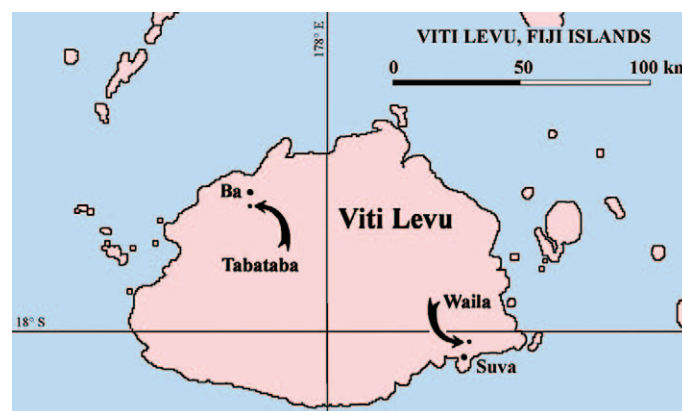


Fig. 1. Outline map of Viti Levu, the largest island of the Fiji Archipelago, with approximate position of the Tabataba and Waila locations.

SYSTEMATIC PALAEOLOGY

Several of the encountered species are merely listed and do not need further discussion, as they are still living and well-known from the literature. On several other species annotations are given concerning morphology or stratigraphic range.

Pterotracheoidea Rafinesque, 1814

Atlantidae Rang, 1829

Atlanta Lesueur, 1817

Type species (by subsequent designation, de Blainville, 1824: 284):

Atlanta peronii Lesueur, 1817 (Recent).

Atlanta plana Richter, 1972 (Fig. 2a, b)

Atlanta plana Richter, 1972: 90, figs 6, 8; Janssen, 2007: 46, pl. 12 figs 4, 5; pl. 13 fig. 1 (with further synonymy); Seapy, 2011: Tree of Life website, 12 figs.

Atlanta sp.; Janssen, 2004: 108, figs 2, 3.

Material examined. – Tabataba 1, RGM 776 656/9, RGM 776 710/1 (Fig. 2).

Discussion. – In the Recent fauna this species is distributed in the Pacific Ocean where it reaches a diameter of c. 4 mm, but the largest Fiji specimen in the present material is barely 2.2 mm. Important characteristics are the presence of two spirals on the second and third protoconch whorls and a rapid widening of the fourth. The Fiji specimens all agree with these data and do not seem to include other species. The species is known as a Pliocene (Piacenzian) fossil from the Philippines (Janssen, 2007) and from SE Spain (Janssen, 2004, as *Atlanta* sp.), the latter being the sole record from the Atlantic realm to date.

Representatives of *Atlanta* are known from the late Oligocene onwards, but are usually unidentifiable to species as the essential characteristics are hardly ever preserved.

Protatlanta Tesch, 1908

Type species (by monotypy): *Atlanta lamanoni* Souleyet, 1852, non Eschscholtz, 1825 = *A. souleyeti* Smith, 1888 (Recent).

Protatlanta rotundata (Gabb, 1873) (Fig. 3a-d)

non *Atlanta rotundata* [sic] d'Orb.; Reuss, 1867: 146 [= *lapsus calami* for '*Allanta*' *rotunda* d'Orbigny, 1834 = *Limacina helicina* (Phipps, 1774) forma *rangii* (d'Orbigny, 1834)].

Atlanta rotundata Gabb, 1873: 201; Pilsbry, 1922: 314, fig. 15; Janssen, 1999b: 12, pl. 2 figs 3-4; 1999c: 115, fig. 1a-c; 2004: 107, pl. 2 fig. 2a-b; 2007: 53, pl. 1 fig. 1; pl. 17 figs 1-3; Janssen, in press: pl. 21 figs 8-10;

?2010: Janssen & Little, 2010: 1114, pl. 5 figs 2, 3.

Atlanta (Atlantidea) lissa Woodring, 1928: 134, pl. 2 figs 26-27.

Protatlanta sp.; D'Alessandro et al., 1979: 78, pl. 15 fig. 4.

Protatlanta kakegawaensis Shibata, 1984: 75, pl. 23 figs 1-3; Shibata & Ujihara, 2008: 3, figs 3/3-4.

Protatlanta lissa (Woodring, 1928); Janssen, 1998: 98, pl. 1 figs 4-5.

Material examined. – Tabataba 1, RGM 776 657/1 (Fig. 3a-d); Tabataba-2, RGM 776 706/1 ? (Fig. 4).

Description. – The single recognizable specimen was embedded in indurated matrix, and could only be isolated with great difficulty. In doing so the specimen broke into three pieces: the protoconch, and the body whorl in two fragments. In a way this was favorable, as now the protoconch (Fig. 3c, d) could be drawn separately, before restoration of the specimen (Fig. 3a, b). The larval shell consists of almost 4½ whorls, together forming a very low cone. The nucleus has a diameter of c. 0.08 mm and is wider than the two subsequent whorls, when seen in apical view. The isolated protoconch is c. 1½ times wider than high, its ultimate whorl is large and has c. 10 very thin, threadlike spirals, regularly distributed over the whorl height. The base is narrowly umbilicate. The adult shell (although considerable pieces of the shell wall are missing) is c. 2.6 times wider than high, with in front of the protoconch just the body whorl. This last whorl widens much more rapidly than the protoconch whorls, near the aperture its width is c. 5.5 times wider than the penultimate whorl.

The growth lines describe a wide forward curvature, both on the apical and the umbilical sides of the shell, on the periphery they are strongly curved backwards, forming a distinct peripheral belt. Some rather vague undulations develop on the apical side of the body whorl and a vague spiral striation is visible in the subsutural half.

The protoconch is not visible in apertural view. During restoration of the specimen it was difficult to decide whether or not the protoconch originally had an oblique position with respect to the body whorl.

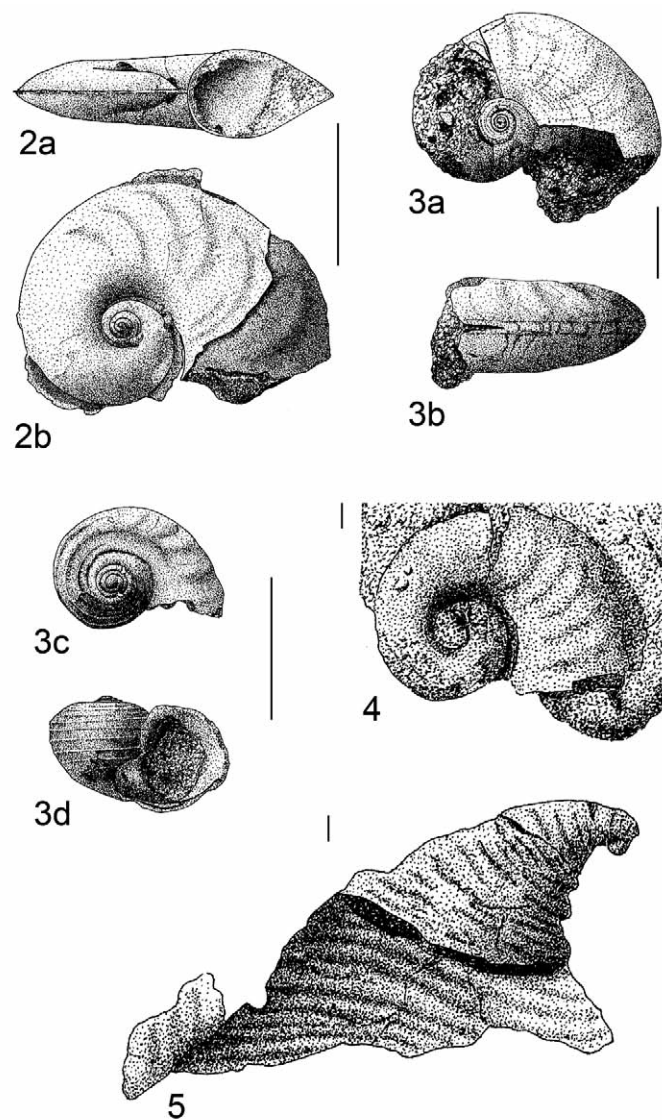
A second, considerably larger specimen (RGM 776 706; W = 10.7 mm; Fig. 4) is poorly preserved as an internal mould lacking the earlier whorls. It cannot be excluded that

it belongs to another *Protatlanta* species. Two further species in this genus are described in Janssen (in press), from the Miocene of the Maltese archipelago, resembling *P. rotundata* closely in the adult stage, but differing in shape and ornamentation of the embryonic whorls.

Discussion. – Comparing the more complete specimen with the material, including the holotype, of *P. rotundata*, from the Dominican Republic (Janssen, 1999b: 12) demonstrates some small differences. The adult shell of typical *P. rotundata* is slightly higher, its protoconch has an oblique position (but this may have been the case in the present specimen as well), the spiral lines on the protoconch show a zig-zag shape, not clearly observed in the Fiji specimen, there are no undulations on the body-whorl, and finally the shell shows spiral microornament covering both the apical and the umbilical side of the body-whorl. These differences are here considered to be due to intraspecific variability.

The Japanese Plio-Pleistocene *Protatlanta kakegawaensis* Shibata, 1984, resembles the Fiji shell in being flatter, but its spiral striation is even stronger than in Dominican *P. rotundata*, which might be a further indication of a relatively wide range of variability.

Apart from the present Fiji occurrence *Protatlanta rotundata* is now recorded from the Langhian and Serravallian of the Maltese archipelago (Janssen, in press), from the Tortonian of Sicily (Janssen, 1999b), from the late Miocene of the Dominican Republic (Gabb, 1873; Janssen, 1999b), from the Pliocene (Piacenzian) of Bowden, Jamaica (Janssen, 1998), Spain (Janssen, 2004) and the Philippines (Janssen, 2007), and from the Plio/Pleistocene of Japan (Shibata, 1984; Shibata & Ujihara, 2008; as *P. kakegawaensis*). From the Miocene (Langhian) of Cyprus Janssen & Little (2010) mentioned a number of specimens as *P. rotundata*, which, however, are too poorly preserved (not showing their initial whorls) to be certain of their identification.



Figs 2-5. Fossil Heteropoda from Viti Levu, Fiji. 2, *Atlanta plana* Richter, 1972, Tabataba-1, RGM 776 656, a: apertural, b: apical views. 3, *Protatlanta rotundata* (Gabb, 1873), Tabataba-1, RGM 776 657, a-b: adult specimen, a: apical, b: lateral views, c-d: protoconch, c: apical, d: apertural views. 4, *Protatlanta rotundata* ? (Gabb, 1873), Tabataba-2, RGM 776 706, apical view. 5, *Carinaria lamarckii* de Blainville, 1817, Tabataba-2, RGM 776 682, umbilical view. Bar 1 mm.

Carinariidae de Blainville, 1818

Carinaria Lamarck, 1801

Type species (by monotypy): *Carinaria vitrea* (Gmelin, 1791) = *C. cristata* (Linné, 1767) (Recent).

Carinaria lamarckii de Blainville, 1817 (Fig. 5)

Carinaire Lamarck Péron & Lesueur, 1810: 69, pl. 2 fig. 15.

La Carinaire de Lamarck, *C. Lamarckii* [sic] Péron et Lesueur; de Blainville, 1817: 107.

Carinaria lamarcki Péron & Lesueur, 1810 – van der Spoel, 1976: 152, fig. 152a, 152c-h (non fig. 152b-c = *Heliconoides inflata*?) (with extensive synonymy of Recent occurrences); Zorn, 1997: 34, pl. 3 figs 2, 3; Seapy, 2011: Tree of Life website, 9 figs; Janssen, 2012, p. 22., fig. 35A-G.

Material examined. – Tabataba-1, RGM 776 682/1 (Fig. 5).

Discussion. – Although very poorly preserved as an external mould in hard matrix with the internal mould partly present, the specimen can be easily recognized as belonging to this species by the long diameter of its aperture which is larger than the shell height. *Carinaria lamarckii* has been reported from the Messinian of Crete (Zorn, 1997) and from younger deposits, and still forms part of the living fauna.

Limacinoidea Gray, 1847

Limacinidae Gray, 1847

Heliconoides d'Orbigny, 1834

Type species (by subsequent designation, Adams & Adams, 1858): *Heliconoides inflata* (d'Orbigny, 1834) (Recent).

Heliconoides inflata (d'Orbigny, 1834)

Atlanta inflata d'Orbigny, 1834: pl. 12 figs 16-19.

Limacina (*Thilea*) *inflata* (Orbigny, 1836) – van der Spoel, 1967: 50, figs 17, 18 (with extensive synonymy).

Heliconoides inflata (d'Orbigny) form B – Janssen, 2004: 110, pl. 1 figs 4-6.

Material examined. – Tabataba 1, RGM 776 659/many; Waila-1, RGM

776 697/12; Waila-2, RGM 776 683/8.

Notes – As far as can be decided by their state of preservation, all specimens belong to the form B (see Janssen, 2004), characterized by the presence of a falciform reinforcement in the proximal half of the body whorl from which a thickened subperipheral belt on the inner shell wall projects forward. As the extremely thin shell wall above and below the belt is virtually always broken it appears as a rostrum on the apertural margin.

Limacina Bosc, 1817

Type species (by monotypy): 'le Clío hélicine' = *Limacina helicina* (Phipps, 1774) (Recent).

Limacina bulimoides (d'Orbigny, 1834)

Material examined. – Tabataba 1, RGM 776 658/6; Waila-1, RGM 776 698/2; Waila-2, RGM 776 684/3.

Limacina lesueurii (d'Orbigny, 1834)

Material examined. – Waila-1, RGM 776 699/1; Waila-2, RGM 776 685/1.

Striolimacina Janssen, 1999

Type species (by monotypy): *Limacina imitans* (Gabb, 1873) (Miocene).

Striolimacina andaensis Janssen, 2007 (Fig. 6)

Striolimacina andaensis Janssen, 2007: 63, pl. 2, figs 4, 5; pl. 22 figs 4, 5

Material examined. – Waila-1, RGM 776 700/1 (Fig. 6).

Note. – The single available specimen is a juvenile shell (H = 0.52 mm, W = 0.88 mm, H/W-ratio = 1.69), but easily recognized as a *Striolimacina* species by the characteristic backward diverging microornament preserved on the second half of the body whorl, only visible at a magnification of 50 x. The specimen differs from the Philippine type series of this species by a somewhat lower shell shape and a more rounded transition from the lower apertural margin into the columella. Previously, this species was exclusively known from the Piacenzian of the Philippines.

Creseidae Rampal, 1973

Bowdenatheca Collins, 1934

Type species (by monotypy): *Bowdenatheca jamaicensis* Collins, 1934 (Pliocene).

Bowdenatheca jamaicensis Collins, 1934 (Fig. 7a, b)

Bowdenatheca jamaicensis Collins, 1934: 221, pl. 13 figs 13-15; Zorn, 1997:

35, pl. 4 figs 1-4; Janssen, 1998: 100, pl. 1 figs 14a-c, 15a-c.

Creseinae sp. ? nov. – Janssen, 1995: 30, pl. 2 fig. 3a-d.

Bowdenatheca ? sp. – Ujihara, 1996: 780, fig. 5/43-49.

Material examined. – Tabataba 1, RGM 776 660/7, RGM 776 711/1 (Fig. 7).

Discussion. – In spite of their poor preservation, these specimens could be recognized as belonging to this (Tortonian?)-Messinian-Piacenzian species, originally described from Jamaica, but in the meantime also known from the Mediterranean and Japan. The illustrated specimen is an internal mould with remnants of the actual shell, slightly compressed dorso-ventrally.

Creseis Rang, 1828

Type species (subsequent designation by van der Spoel, 1967: 57):

Cleodora (*Creseis*) *virgula* Rang, 1828 (Recent).

Creseis chierchiai (Boas, 1886) forma *constricta*

Chen & Bé, 1964

Material examined. – Tabataba 1, RGM 776 662/2, 3 protoconchs.

Creseis clava (Rang, 1828)

Material examined. – Tabataba 1, RGM 776 661/3 fragments; Waila-2, RGM 776 686/1.

Hyalocyclus Fol, 1875

Type species (by original designation): '*Hyalocyclus striata* = *Cleodora striata* (Rang)' (Recent).

Hyalocyclus striata (Rang, 1828) ?

Material examined. – Waila-1, RGM 776 701/1 juvenile; Waila-2, RGM 776 687/4.

Discussion. – The few Waila specimens agree completely with the Recent *Hyalocyclus striata*, but it cannot be excluded that they are juvenile or damaged specimens of *H. marginata* Janssen, 2007, a species hitherto only known from the Piacenzian of Pangasinan, Philippines, only differing from *H. striata* by the possession of a reinforced apertural margin, not present or preserved in the Fiji specimens. As several further species from Waila point to a correlation with the Pangasinan fauna, the possibility should be kept in mind, but can only be demonstrated by more completely preserved material.

Styliola subula (Quoy & Gaimard, 1827)

Material examined. – Tabataba 1, RGM 776 663/54; Waila-1, RGM 776 702/7; Waila-2, RGM 776 688/many (> 150).

Cuvierinidae Gray, 1847

Cuvierina Boas, 1886

Cuvierina s.str.

Type species) (by monotypy): *Cuvierina columnella* (Rang, 1827) (Recent) (redefined by neotype designation, Janssen, 2005: 45, fig. 10a-c).

Cuvierina (*Cuvierina*) spec. (Fig. 9a-c)

Material examined. – Tabataba 1, RGM 776.664/3, 15 fragments, RGM 776 712/1 (Fig. 9).

Discussion. – Small (H = 6.75 mm, H/W-ratio = 4.44; Fig. 9), slender, cylindrical cuvierinid with a not inflated shell, without radial microornament, aperture reniform in adapical view.

The Fiji specimens differ from two equally slender species, namely *Cuvierina jagti* Janssen, 1995 (H/W-ratio ~ 5.0), known from the Miocene (Tortonian) of northern Italy and Sicily, and *C. ludbrookii* (Caprotti, 1962) (H/W-ratio ~ 4.44), occurring in Pliocene (Piacenzian) deposits of northern Italy and Spain. Both species have a more triangular aperture, and in *C. jagti* a radial microornament is present. The Fiji specimens are far more slender than the Pliocene (Zan-clear-Piacenzian) *C. astesana* Rang, (1829) (H/W-ratio ~ 3.75).

None of the species referred to is known to date from the Pacific realm, but equally slender specimens were described and illustrated by Ujihara (1996: 778, figs 5.1-5.15) as *Cuvierina* cf. *C. tubulata* Collins, 1934, from the Miyazaki Group, Japan. The latter taxon, however, is considered a synonym of *C. astesana* (Rang, 1829) (see Janssen, 2006: 87). The Japanese specimens are insufficiently well preserved to ascertain presence or absence of microornament (A. Ujihara, pers. comm.). As they originate from Pliocene deposits (referred by Ujihara [1996] to planktonic foraminifera zone interval N18-20, but later by Torii & Oda (2001) recognized as the lower part of zone N 21 = Piacenzian; A. Ujihara, pers. comm.) it is more likely that they represent *C. ludbrookii*. The identity of the Fiji specimens remains enigmatic; they might represent an undescribed species.

Urceolarica Janssen, 2006

Type species (by original diagnosis): *Cuvieria urceolaris* Mörch, 1850 (Recent).

Cuvierina (*Urceolarica*) *intermedia* (Bellardi, 1873)

(Fig. 8a-c)

Cuvieria intermedia Bellardi, 1873: 36, pl. 3 fig. 20.

Cuvierina intermedia (Bellardi, 1873); Janssen, 1995: 39, pl. 3 figs 5, 6 (with lectotype designation); Janssen, 2005: fig. 36; non Ujihara, 1996: 777, figs 5.16-5.28 [= *Cuvierina inflata* (Bellardi, 1873)].

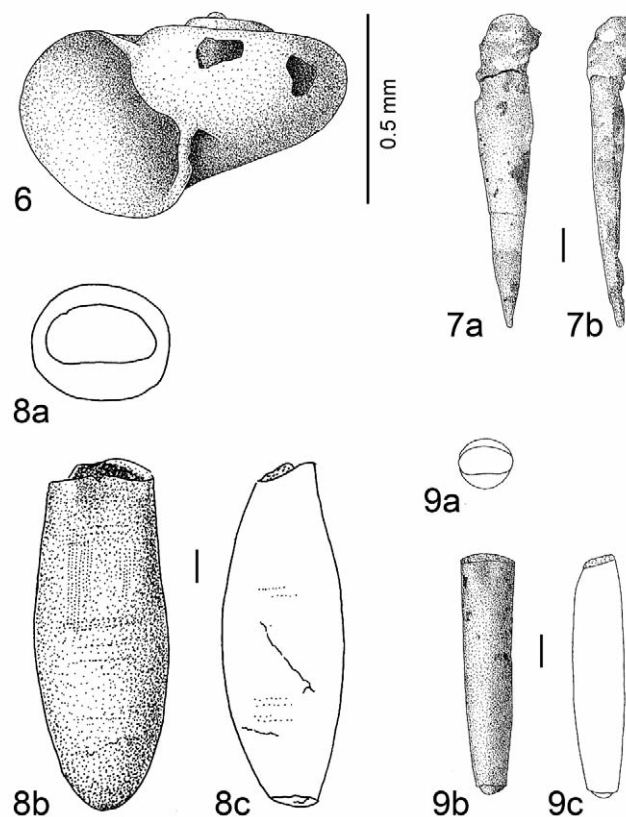
Cuvierina (*Urceolarica*) *intermedia* (Bellardi, 1873); Janssen et al., 2008: 361, pl. 1 fig. 11; Janssen, in press: pl. 6 fig. 3.

Material examined. – Tabataba 1, RGM 776 665/8, RGM 776 713/1 (Fig. 8).

Discussion. – The species *Cuvierina urceolaris* (Mörch, 1850), *C. inflata* (Bellardi, 1873) and *C. intermedia* are characterized by a variably inflated shell shape and sometimes it is rather difficult to assign certain specimens to one of these taxa. In *C. urceolaris* and *C. inflata*, however, the inflation is stronger and the lateral outlines of the shell below the inflation are straight or slightly concave, in that way accentuating the position of the point of strongest inflation. In *C. intermedia* the inflation is not so strong and very gradual. Especially in the lower half of the shell the lateral outlines are never concave (see illustrations of type specimens in Janssen, 1995, pl. 3).

Well-preserved specimens of all three species possess radial microornament.

Specimens from the Miyazaki Group (Pliocene) of Japan, illustrated by Ujihara (1996, figs 5.16-28, as *C. intermedia*) have the lateral outlines of the lower shell part distinctly concave and therefore agree better with *C. inflata* or *urceolaris*. The Fiji specimens, by their more gradually convex sidelines belong to *C. intermedia*. That species is known from the Serravallian to the Zanclean.



Figs 6-9. Fossil Pteropoda from Viti Levu, Fiji. 6, *Striolimacina andaensis* Janssen, 2007, Waiala-1, RGM 776 700, apertural view. 7, *Bowdenatheca jamaicensis* Collins, 1934, Tabataba-1, RGM 776 711; a: frontal, b: lateral view. 8, *Cuvierina* (*Urceolarica*) *intermedia* (Bellardi, 1873), Tabataba-1, RGM 776 713, a: apertural, b: ventral, c: left lateral views. 9, *Cuvierina* (*Cuvierina*) sp., Tabataba-1, RGM 776 712, a: apertural, b: ventral, c: left lateral views. Bar 0.5 mm for Fig. 6, 1 mm other figs.

Clio Linné, 1767

Clio s.str.

Type species (by subsequent designation, Gray, 1847: 203): *Clio pyramidata* Linné, 1767 (Recent).

Clio (Clio) convexa convexa Boas, 1886

Cleodora pyramidata (L.) var. *convexa* Boas, 1886: 73, 203, pl. 6 fig. 97a-d.

Clio pyramidata convexa (Boas); ? Tesch, 1913: 37, fig. 33.

Clio teschi McGowan, 1960: 101, fig. 35 (*nomen nudum*).

Clio pyramidata Linnaeus forma *convexa* (Boas) – van der Spoel, 1967: 70, figs 55, 59; 1973: 17, figs 1-8 (with lectotype designation); Richter, 1979: 16, pl. 2 fig. 15a-c.

Clio pyramidata forma *convexa* Boas; van der Spoel, 1976: 190, fig. 33a, b.

Clio convexa (Boas, 1886); Bé & Gilmer, 1977: 773, pl. 7, figs 20a-e; Al-mogi-Labin, 1982: 58, pl. 2, fig. 7.

Clio pyramidata (Linné) forma *lanceolata* (Lesueur) – Janssen, 1999b: pl. 3 figs 14a-d, 18a-c (partim, non *pyramidata* Linné, nec *lanceolata* Lesueur; non figs 13, 15, 16 = *C. pyramidata* f. *lanceolata*).

Clio sp. Janssen, 1999b: 22, pl. 3 fig. 18a-c.

Clio convexa convexa (Boas); Rampal, 2002: 237, figs 15D, 16F-L; Janssen, 2007: 79, pl. 3 fig. 13; pl. 4 figs 1, 3; pl. 24 figs 6, 7.

Material examined. – Tabataba-1, RGM 776 666/14, 7 protoconchs, RGM 776 667/13 protoconchs; Waila-1, RGM 776 703/1 juvenile; Waila-2, RGM 776 689/9, 3 fragments.

Discussion. – The specimens are too small or too strongly damaged to obtain a fair impression of their side view outline, but none of the shells demonstrates the ‘hump-backed’ shape described for *Clio convexa cyphosa* Rampal, 2002, therefore they are included here in the typical subspecies. For a discussion see Janssen (2007: 80). So far this species is not known to occur older than Zanclean. The present distribution of this species is restricted to the Indo-Pacific basin, Red Sea included. The only observations from the Atlantic realm are a few specimens from the Pliocene of the Dominican Republic, misidentified by Janssen (1999b).

Clio (Clio) pyramidata Linné, 1767,

f. *lanceolata* (Lesueur, 1813)

Material examined. – Tabataba-1, RGM 776 668/6, RGM 776 669/c. 100; Waila-1, RGM 776 704/2 juveniles; Waila-2, RGM 776 690/28 juveniles, some fragments.

Cavoliniidae Gray, 1850

Cavolinia Abildgaard, 1791, emend. Philippi, 1853

Type species (by monotypy): *Cavolinia natans* Abildgaard, 1791 = *C. tridentata* (Forskål, in Niebuhr, 1775) (Recent).

Cavolinia bituminata (Beets, 1953) (Fig. 10a, b)

Cavolinia bituminata Beets, 1953: 251, pl. 1 figs 5-7; Skwarko & Sufiati, 1994: y3; Janssen, 1999a: 180, pl. 1, fig. 2a-c.

Material examined. – Tabataba-1, RGM 776 673/1 (Fig. 10); Tabataba-2, RGM 776 707/1.

Discussion. – This species so far was exclusively known by its holotype from the late Miocene asphaltic deposits of Waisiu (= Wasioe, in Dutch), Buton (Indonesia). The two specimens in the present Fiji material agree with the type but differ somewhat in size (holotype H = 3.3 mm, RGM 776 673 H = 3.44+ mm, RGM 776 707 H = 4.23 mm). Such differences in size are not unusual for *Cavolinia* species.

Cavolinia marginata (Bronn, 1862),

f. *hyugaensis* Ujihara, 1996 (Fig. 11)

Cavolinia vendryesiana hyugaensis Ujihara, 1996: 785, figs 7.18-7.30.

Cavolinia marginata (Bronn, 1862) forma *hyugaensis* Ujihara, 1996; Janssen et al., 2008: 364, fig. 5C.

Material examined. – Tabataba-2, RGM 776 708/1 (Fig. 11).

Discussion. – Various forms of *Cavolinia marginata* are known from late Miocene and Pliocene assemblages. The f. *hyugaensis* is characterized by the possession of two weak depressions below the rim around the apertural side of the dorsal shell part. In the late Miocene f. *limatula* Beets, 1943, and three further Pliocene forms these depressions are not developed.

Cavolinia mexicana (Collins, 1934) (Fig. 11a, b)

Cavolinia mexicana Collins, 1934: 182, pl. 7 figs 12-15.

Cavolinia globulosa Rang – Ladd, 1934: 235, pl. 42 figs 2,3 (non Rang).

Cavolinia (Gamopleura) cranioides Beets, 1943: 306.

Cavolinia (Gamopleura) cranioides [sic] – Beets, 1943: pl. 29 figs 120-123.

Cavolinia globulosa cranioides Beets, 1950: 336.

Cavolinia globulosa (Gray, 1850) – Shibata, Ishigaki & Ujihara, 1986: 50, pl. 8 fig. 9 (non Gray).

Cavolinia mexicana (Collins, 1934) - Ujihara, Shibata & Saito, 1990: 321, pl. 2 figs 11-12; Ujihara, 1996: 783, figs 7.1-7.9; Janssen, 1999a: 181, 187, pl. 1 figs 3a-c, 4a-c; pl. 11 fig. 9a-c; 1999b: 24, pl. 4 figs 5-7.

Material examined. – Tabataba-1, RGM 776 670/1 (Fig. 11), RGM 776 671/14.

Discussion. – *Cavolinia mexicana* is known from late Miocene (Tortonian-Messinian) localities in the Dominican Republic and Indonesia, and from early Pliocene rocks in Mexico and Japan. The specimen illustrated herein (Fig. 11) is one of the very few specimens retaining the complete larval shell (thanks to a bit of matrix filling up the space) that is so strongly curved that the apex almost touches the base of the dorsal shell part.

Cavolinia shibatai Janssen, 2007 (Fig. 13)

Cavolinia longirostris longirostris (Lesueur); Shibata, 1979: 119, pl. 19 figs 25-28 (non Lesueur).

Cavolinia longirostris forma *longirostris* (Blainville); Shibata, 1984: 86, pl. 25 figs 5, 6 (non de Blainville).

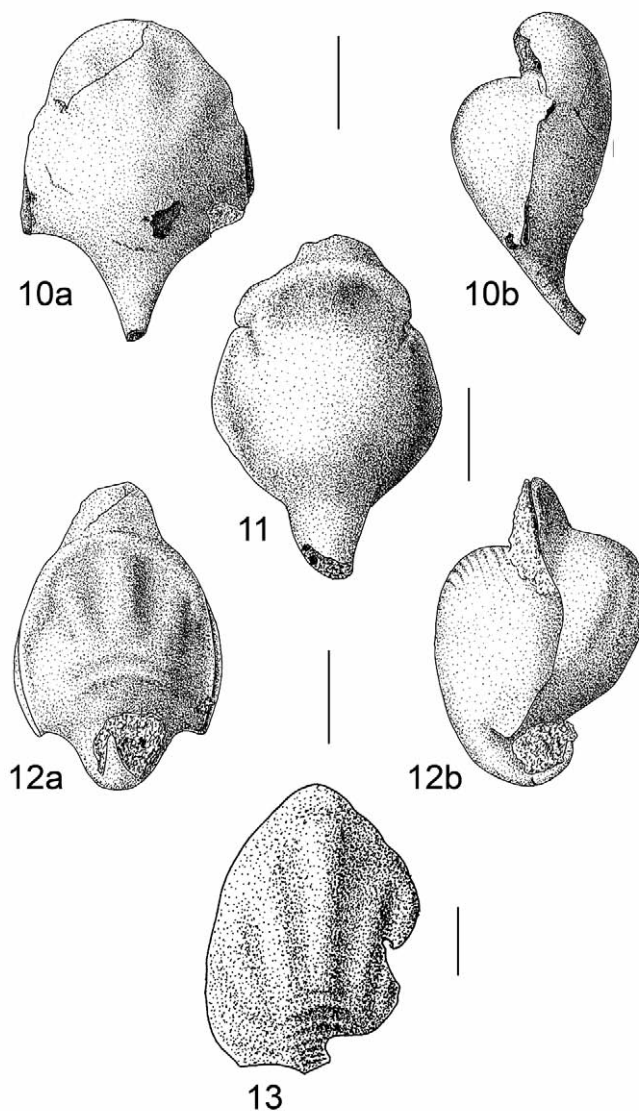
Cavolinia sp. – Ujihara, 1996: 785, fig. 7.15.

Cavolinia shibatai Janssen, 2007: 87, pl. 5 figs 4-6.

Material examined. – Waila-2, RGM 776 695/1, 22 fragments, RGM 776 716/1 fragment (Fig. 13).

Discussion. – Some fragmentary specimens from Waila agree with *Cavolinia shibatai*, introduced from the Pliocene (Piacenzian) of Pangasinan, Philippines (Janssen, 2007). The Japanese specimens referred to are Pliocene (N 19-21, Zanclean-Piacenzian) or early Pleistocene (N 22). Adult shell parts of this species resemble several *Diacavolinia* species closely, but in at least two fragmentary specimens the caudal

spine is partly preserved, indicating that these specimens do not belong to that genus.



Figs 10-13. Fossil *Cavolinia* species from Viti Levu, Fiji. 10, *C. bituminata* (Beets, 1953), Tabataba-1, RGM 776 673, a: dorsal, b: left lateral views. 11, *C. marginata* (Bronn, 1862) f. *hyugaensis* Ujihara, 1996, Tabataba-2, RGM 776 708, dorsal view. 12, *C. mexicana* Collins, 1934, Tabataba-1, RGM 776 670, a: dorsal, b: left lateral views. 13, *C. shibatai* Janssen, 2007, Waila-2, RGM 776 695, fragment, dorsal view. Bar 1 mm.

Cavolinia tridentata (Forskål, 1775)

Material examined. – Waila-2, RGM 776 691/3 fragments.

Cavolinia spec. indet.

Material examined. – RGM 776 672/1, RGM 776 674/10

Diacria J.E. Gray, 1847

Type species (by original designation, J.E. Gray, 1847: 203): *Hyalea trispinosa*.

Diacria mbaensis Ladd, 1934 (Fig. 14a-c)

Diacria mbaensis Ladd, 1934: 234, 237, pl. 42 figs 6,7; Beets, 1950: 336; Skwarko & Sufiati, 1994: y4; Janssen, 1999a: 183, pl. 1 figs 6a-c, 7a, b, 13a, b, 14a, b.

Diacra kipsisiformis Beets, 1943: 304, figs 98-100.

Clio asphaltodes Beets, 1943: 304, figs 101-103; Skwarko & Sufiati, 1994: y4.

Material examined. – Tabataba-1, RGM 776 675/1 (Fig. 14), RGM 776 676/21, RGM 776 677/1 protoconch, RGM 776 681/1 retaining protoconch; Tabataba-2, RGM 776 709/1.

Discussion. – If seen from the dorsal side *Diacria mbaensis* resembles small specimens of the species *D. trispinosa* (de Blainville, 1821) closely. The ventral side, however, differs distinctly by the absence of the two narrow ribs situated next to the central swelling, as a result of which the ventral shell part is regularly vaulted. The species is exclusively known from late Miocene (Tortonian, ?Messinian) age deposits. Intermediate forms between *D. trispinosa* and *D. mbaensis* are not known.

Diacria microstriata Janssen, 2007 (Fig. 15a, b)

Diacria microstriata Janssen, 2007: 97, pl. 8 fig. 1.

Material examined. – Waila-2, RGM 776 693/1 (Fig. 15).

Discussion. – This curious species, until now only known from its type locality in Pangasinan, Philippines, was found in a single, rather damaged specimen, but was nevertheless well identifiable. Pliocene (Piacenzian).

Diacria philippinensis Janssen, 2007 (Fig. 16a-c)

Diacria philippinensis Janssen, 2007: 100, pl. 7 fig. 3; pl. 8 fig. 6; pl. 25 fig. 1.

Material examined. – Waila-1, RGM 776 705/4, 3 fragments; RGM 776 714/1 (Fig. 16); Waila-2, RGM 776 694/2, c. 70 fragments.

Discussion. – Also this species was hitherto only known from the Philippines. Many specimens were found, most of them fragmentary, agreeing completely with the Pangasinan specimens. Pliocene (Piacenzian).

Diacria trispinosa (de Blainville, 1821)

Material examined. – Tabataba-1, RGM 776 678/1, 1 fragment, RGM 776 679/1, 5 fragments.

Diacria trispinosa (de Blainville, 1821),
f. *bisulcata* Gabb, 1873 (Fig. 17a, b)

Diacria bisulcata Gabb, 1873: 200; Guppy, 1882: 175 (reprinted in Harris, 1921: 244); Pilsbry, 1922: 309, text-fig. 4 (3 figs); Collins, 1934: 197, pl. 9 figs 18-20 (copied from Pilsbry, 1922) (non pl. 9 figs 15-17, pl. 10 figs 1-3 (= *D. trispinosa* s. str.); Noda, 1972: 478, pl. 57 fig. 18.

Cavolinia (*Diacria*) *bisulcata* Gabb – Dall, 1893: 430.

Diacria trispinosa forma *trispinosa* (Blainville, 1821); Shibata, 1984: 84, pl. 25 figs 1-3 (non f. *trispinosa*).

Diacria piccola Bleeker & van der Spoel, 1988: 60, figs 2-4.

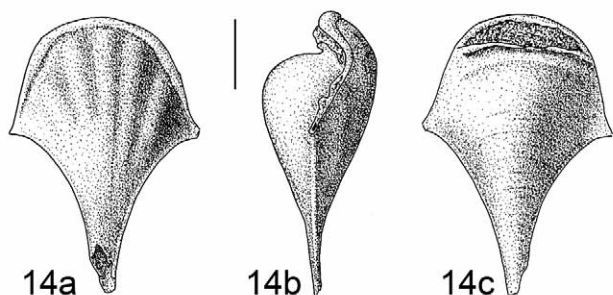
Diacria trispinosa (de Blainville); Janssen, 1995: 107, pl. 9 figs 3, 4 (excl. synonymy).

Diacria trispinosa (de Blainville) forma *bisulcata* Gabb; Janssen, 1998: 104, pl. 2 fig. 14; 1999b: 27, pl. 5 figs 6-8; 2007: 102, pl. 7 fig. 4; pl. 8 fig. 5; pl. 25 figs 2, 3.

Material examined. – Waila-2, RGM 776 692/1 fragment, RGM 776 715/1 (Fig. 17).

Discussion. – Just a single damaged specimen and a dorsal fragment are available, both convincingly demonstrating the typical feature of this form, in which the central three dorsal radial ribs present in the typical form of *Diacria trispinosa* are fused to form a single wide swelling. The forma is known from unspecified late Miocene assemblages in the Dominican Republic and Italy, from the Pliocene of Italy, Jamaica and the Philippines, as well as from unspecified

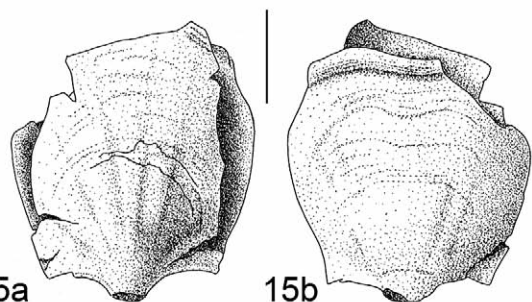
Pliocene/Pleistocene rocks in Japan. The (late Pleistocene-Recent ?) *D. piccola* was described from a bottom sample taken in the Philippines near Mindanao. The almost complete



14a

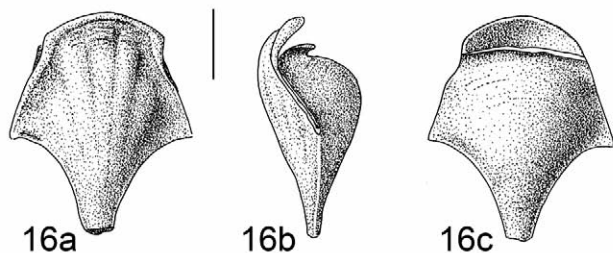
14b

14c



15a

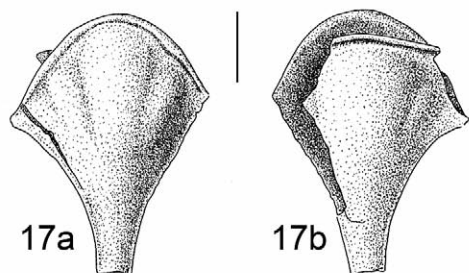
15b



16a

16b

16c



17a

17b

specimen from Fiji (Fig. 17) has a shell height of 3.78 mm and is therefore one of the smallest specimens known. Specimens from Pangasinan, Philippines (Janssen, 2007) range between H = 4.48 and 8.22 mm. The holotype of *D. piccola* reaches only H = 3.32 mm.

In some specimens of *Diacria trispinosa* (e.g. Janssen, 1995: pl. 9 fig. 3) the normally present three radial ribs in the centre of the dorsal shell part fade out with growth, which makes such specimens resemble the f. *bisulcata* closely. As they are apparently transitional forms I consider *D. bisulcata* not an independent species, but just a form of *D. trispinosa*.

Sphaerocinidae Janssen & Maxwell, in Janssen, 1995

Sphaerocina Jung, 1971

Type species (by monotypy): *Limacina formae* Audenino, 1899 (Miocene).

Sphaerocina convolvula Janssen, 2007 (Fig. 18)

Sphaerocina convolvula Janssen, 2007: 104, pl. 8 fig. 8; pl. 25 fig. 7.

Material examined. – Waila-2, RGM 776 716 (Fig. 18)

25

Discussion. – The single available Fiji specimen resembles the holotype of this species closely in shape and size, as well as in the irregular form of the protoconch. The species previously was known exclusively from Pangasinan, Philippines (Pliocene, Piacenzian).

Figs 14-17. Fossil *Diacria* species from Viti Levu, Fiji. 14, *D. mbaensis* Ladd, 1934, Tabataba-1, RGM 776 675, a: dorsal, b: left lateral, c: ventral views. 15, *D. microstriata* Janssen, 2007, Waila-2, RGM 776 693; a: dorsal, b: ventral views. 16, *D. philippinensis* Janssen, 2007, Waila-1, RGM 776 713; a: dorsal, b: right lateral, c: ventral views. 17, *D. trispinosa* (de Blainville, 1821) f. *bisulcata* Gabb, 1873, Waila-2, RGM 776 692, a: dorsal, b: ventral views. Bar 1 mm.

Clionoidea Rafinesque, 1815
Clionidae Rafinesque, 1815

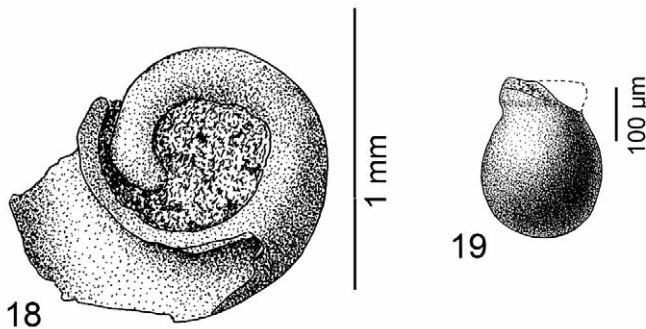
Note: For the use of the expression 'Genus Clionidarum', as a name for a 'collective group', meant in art. 1.2.1, 10.3 and 42.2.1 ICZN (1999), see the extensive discussion in Janssen (in press)

Genus Clionidarum spec. (Fig. 19)

Material examined. – Tabataba-1, RGM 776 680/1 protoconch (Fig. 19).

Description – The single specimen is preserved as an internal mould. Protoconch 1 is almost perfectly spherical in frontal view, but with the dorso-ventral diameter slightly less than shell width. A distinct constriction separates a slightly swollen shell part that is only partly preserved, but has an elliptical shape in apertural view. A protoconch 2 is not clearly developed.

Discussion. – This tiny specimen with a shell height of barely 0.3 mm resembles 'Genus Clionidarum type 2' as described by Janssen (in press, pl. 26 fig. 13), but because of the state of preservation nothing is known of a possible ornament on the youngest shell parts.



Figs 18-19. Fossil Pteropoda from Viti Levu, Fiji. 18, *Sphaerocina convolvula* Janssen, 2007, Waila-2, RGM 776 696, left lateral view. 19, Genus Clionidarum spec., Tabataba-1, RGM 776 680, frontal view.

Sample	Tabataba		Waila	
	1	2	1	2
Pterotracheoidea				
<i>Atlanta plana</i>	10	-	-	-
<i>Protatlanta rotundata</i>	1	1?	-	-
<i>Carinaria lamarckii</i>	1	-	-	-
Limacinoidea				
<i>Heliconoides inflata</i>	>100	-	12	8
<i>Limacina bulimoides</i>	6	-	2	3
<i>Limacina lesueurii</i>	-	-	1	1
<i>Striolimacina andaensis</i>	-	-	1	-
Cavolinioida				
<i>Bowdenathea jamaicensis</i>	8	-	-	-
<i>Creseis clava ?</i>	3	-	-	1
<i>Creseis chierchiae f. constricta ?</i>	3	-	-	-
<i>Hyalocylis striata ?</i>	-	-	1	4
<i>Styliola subula</i>	54	-	7	>150
<i>Cuvierina (Cuvierina) spec.</i>	18	-	-	-
<i>Cuvierina (Urceolarica) intermedia</i>	9	-	-	-
<i>Clio convexa convexa</i>	21	-	1	9
<i>Clio pyramidata f. lanceolata</i>	~100	-	2	28
<i>Cavolinia bituminata</i>	1	1	-	-
<i>Cavolinia marginata f. hyugaensis</i>	-	1	-	-
<i>Cavolinia mexicana</i>	15	-	-	-
<i>Cavolinia shibatai</i>	-	-	-	20
<i>Cavolinia spec. indet.</i>	11	-	-	3
<i>Diacria mbaensis</i>	24	1	-	-
<i>Diacria microstriata</i>	-	-	-	1
<i>Diacria philippinensis</i>	-	-	7	30
<i>Diacria trispinosa</i>	8	-	-	-
<i>Diacria trispinosa f. bisulcata</i>	-	-	-	2
<i>Sphaerocina convolvula</i>	-	-	-	1
Clionoidea				
Genus Clionidarum spec.	1	-	-	-

Table 1. Distribution of taxa over the sampled localities. As most material is quite fragmentary the minimum number of represented specimens is given.

AGE ASSIGNMENTS

All available material of the four samples is summarized in Table 1.

Samples Tabataba-1 and -2 were collected close to each other and originate from the same stratigraphical unit. The Tabataba-2 material is decalcified and yielded only four species, each of these with just one specimen. Three of the species are also represented in sample Tabataba-1. In Table 2 only the known stratigraphical range of the fifteen identified taxa is given, as unidentified material does not contribute to an estimate of sample age. All taxa are known to occur in the Tortonian to Piacenzian (late Miocene to late Pliocene) interval. Two species, *Cavolinia bituminata* and *Diacria mbaensis*, are only known from the Tortonian-Messinian (late Miocene), but two other species, *Atlanta plana* and

	Burdigalian	Langhian	Serravallian	Tortonian	Messinian	Zanclean	Piacenzian
<i>Atlanta plana</i>	-	-	-	-	-	?	+
<i>Protatlanta rotundata</i>	-	+	+	+	+	+	+
<i>Carinaria lamarckii</i>	-	-	-	-	+	+	+
<i>Heliconoides inflata</i>	+	+	+	+	+	+	+
<i>Limacina bulimoides</i>	+	+	?	+	?	+	+
<i>Creseis clava</i> ?	-	-	-	?	+	+	+
<i>Styliola subula</i>	+	+	+	+	+	+	+
<i>Cuvierina intermedia</i>	-	-	+	+	?	+	-
<i>Clio convexa convexa</i>	-	-	-	-	-	+	+
<i>Clio pyramidata f. lanceolata</i>	-	-	+	+	+	+	+
<i>Cavolinia bituminata</i>	-	-	-	+	?	-	-
<i>Cavolinia marginata f. hyugaensis</i>	-	-	-	?	+	+	+
<i>Cavolinia mexicana</i>	-	-	-	+	+	+	?
<i>Diacria mbaensis</i>	-	-	-	+	?	-	-
<i>Diacria trispinosa</i>	-	-	-	+	+	+	+

Table 2. Known vertical distribution of identified Tabataba species.

Clio convexa convexa, have only been collected previously from Pliocene (Zanclean-Piacenzian) deposits. Unidentified *Atlanta* species, however, are known from much older rocks elsewhere. As a more precise age is impossible to establish on the basis of the represented pelagic molluscs it seems advisable to indicate the age as 'late Miocene, possibly early Pliocene'. The species *Cavolinia mexicana* and *Diacria mbaensis*, among others, were also recorded from another locality in Viti Levu, as published by Ladd (1934; his localities 304 and 306). From that locality, however, also the species *Cavolinia gypсорum* (Bellardi, 1873) was recorded, which is a more secure index fossil for the Tortonian-Messinian interval.

Also the two samples from Wailea originate from the same stratigraphical unit and are here considered together. Fifteen species are represented, 14 of which are identified to

	Burdigalian	Langhian	Serravallian	Tortonian	Messinian	Zanclean	Piacenzian
<i>Heliconoides inflata</i>	+	+	+	+	+	+	+
<i>Limacina bulimoides</i>	+	+	?	+	?	+	+
<i>Limacina lesueurii</i>	-	-	-	-	-	+	+
<i>Bowdenathea jamaicensis</i>	-	-	-	+	+	+	+
<i>Creseis clava</i> ?	-	-	-	?	+	+	+
<i>Styliola subula</i>	+	+	+	+	+	+	+
<i>Cuvierina intermedia</i>	-	-	+	+	?	+	+
<i>Clio convexa convexa</i>	-	-	-	-	-	+	+
<i>Clio pyramidata f. lanceolata</i>	-	-	+	+	+	+	+
<i>Cavolinia shibatai</i>	-	-	-	-	-	-	+
<i>Diacria microstriata</i>	-	-	-	-	-	-	+
<i>Diacria philippinensis</i>	-	-	-	-	-	-	+
<i>Diacria trispinosa f. bisulcata</i>	-	-	-	+	+	+	+
<i>Sphaerocina convolvula</i>	-	-	-	-	-	-	+

Table 3. Known vertical distribution of identified Wailea species.

species. All of them are known to occur during the Piacenzian, whereas only ten are also known from the Zanclean. From the later stages of the Miocene only seven or eight of the *Waila* species have been recorded. The assemblages, in fact, show a remarkable resemblance with the holoplanktonic mollusc fauna described from Pagasinan, Philippines (localities Anda and Tiep, near Bolinao), as described by Janssen (2007) and it must be concluded that their age likewise is Pliocene (Piacenzian). Several of the *Waila* species are exclusively known from these Philippine rocks, that furthermore were correlated with the Japanese Takanabe Member of the Miyazaki Group (SW Japan), planktonic foraminifera zone N 21 (Piacenzian).

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Alan Beu (Paleontology Department, Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand) and A-tsushi Ujihara (Nagoya University, Graduate School of Environmental Studies, Department of Earth and Environmental Sciences, Nagoya, Japan) were kind enough to review the manuscript and improved contents and English language with their much appreciated comments.

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