

GLOBOCONELLA PSEUDOSPINOSA, N. SP.: A NEW EARLY PLIOCENE PLANKTONIC FORAMINIFERA FROM THE SOUTHWEST PACIFIC

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ABSTRACT

Studies of topotypes of *Truncorotalia crassaconica* from the East Coast Basin of New Zealand and populations of *Tr. crassaconica* at Ocean Drilling Program Site 1123 and Deep Sea Drilling Project Site 284 in the southwest Pacific revealed two morphospecies. One of these is a late Pliocene species, *Truncorotalia crassaconica* s.s., that has low, slit-like apertures with thin, smooth apertural lips. The other is *Globoconella pseudospinosa* n. sp., an early Pliocene form with arched apertures and pustulose apertural lips. The short stratigraphic ranges of both species are potentially useful as biostratigraphic markers for the subdivision of Plio-Pleistocene stages in New Zealand and the temperate southwest Pacific. Populations of *Gc. pseudospinosa*, with mostly sinistrally coiled specimens, occur throughout the lectostratotype of the New Zealand Opoitian Stage at Mangapoike River in the East Coast Basin and are confined to the early Pliocene (Opoitian) at sites 1123 and 284, between 4.57 and 4.10 Ma. Small populations of *Tr. crassaconica* s.s., with mostly dextrally coiled specimens, occur in the late Pliocene (Waipian Stage) between 3.53 and 2.98 Ma. Sporadic occurrences of relatively rare, mostly sinistrally coiled specimens of *Tr. aff. crassaconica* occur earlier at sites 1123 and 284 in the late Miocene to Pliocene between ca. 5.5 and 3.53 Ma. These specimens are distinguished in having open umbilici and almost straight umbilical sutures, similar to the late Miocene specimens of *Truncorotalia crassaformis*.

INTRODUCTION

The genus *Truncorotalia* Cushman & Bermúdez, 1949 includes species that are important for biostratigraphic subdivision of the Plio-Pleistocene in the southwest Pacific (Hornibrook, 1981, 1982; Kennett & Srinivasan, 1983; Hornibrook et al., 1989; Scott et al., 1990; Cooper, 2004). Truncorotalids are commonly distinguished from other globorotalid genera on the basis of their pustulose (pseudospinose) surface ultrastructure and low slit-like apertures, but the range of species architecture extends to ventroconical, biconvex, and sometimes compressed shells that are keeled or unkeeled and have umbilici that are wide and open, or narrow and almost closed (Kennett & Srinivasan, 1983; Cifelli & Scott, 1986; Hornibrook et al., 1989; Scott et al., 1990; Crundwell, 2015a, b).

Truncorotalids are common in late Miocene to Recent sediments of the southwest Pacific, but the phylogeny of the plexus is still poorly understood. For example, Kennett & Srinivasan (1983) suggested that *Truncorotalia tosaensis*

(Takayanagi & Saito) and *Tr. truncatulinoides* (d'Orbigny) are components of a lineage that originated from *Tr. crassaformis* (Galloway & Wissler). Cifelli & Scott (1986) proposed a more complex phylogeny, with *Tr. crassaformis* giving rise separately to *Tr. crassaconica* (Hornibrook), *Tr. crassula* (Cushman & Stewart), and the *Tr. truncatulinoides* lineage. Scott et al. (1990) include *Tr. crassaconica* (Hornibrook) and *Tr. crassacarina* (Scott, Bishop & Burt) as components of a lineage within the truncorotalid plexus. Scott et al. (2015) also questioned the long-standing taxonomic use of *Tr. crassaformis*, and suggested the name may not be appropriate for unkeeled early Pliocene phenotypes. Such uncertainty adversely affects the biostratigraphic utility of truncorotalid species, especially in the early Pliocene records which contain a paucity of planktonic foraminiferal events suitable for biostratigraphic subdivision of local stages (Hornibrook, 1981).

The aim of this paper is to provide a better understanding of the taxonomy and phylogeny of Pliocene globorotalid foraminifera and to improve the accuracy of biostratigraphic investigations in the southwest Pacific by examining morphological variation in populations of *Tr. crassaconica* originally described by Hornibrook (1981).

MATERIAL AND METHODS

This paper examined early Pliocene to early Pleistocene planktonic foraminiferal faunas from Ocean Drilling Program (ODP) Site 1123 on the Chatham Rise in the southwest Pacific, and Deep Sea Drilling Project (DSDP) Site 284 on the Challenger Plateau in the Tasman Sea (Fig. 1). Records of *Truncorotalia crassaconica* from the East Coast Basin, near Wairoa, New Zealand (Fig. 1), including the type sample from Tahaenui (record number X19/f9493 in the New Zealand Fossil Record File), nearby sample X19/f11, and additional samples from the lectostratotype for the New Zealand early Pliocene Opoitian Stage at Mangapoike River were also used to resolve species concepts and constrain local stage correlations. Scanning electron microscope images were used to elucidate morphological variation within populations associated with the *Tr. crassaconica* plexus (Appendix 1, Pls. 1–14).

The faunal material from ODP Site 1123 used in this study originates from earlier work by George Scott (GNS Science) to calibrate planktonic foraminiferal events for the New Zealand Geological Timescale (Cooper, 2004), and the biostratigraphic data for this site is based on Crundwell (2015a). The faunal material and biostratigraphic data from DSDP Site 284 are sourced from studies by Hornibrook (1982) and Crundwell (2015b), and the faunal material from Mangapoike River is from a biostratigraphic study by McInnes (1964).

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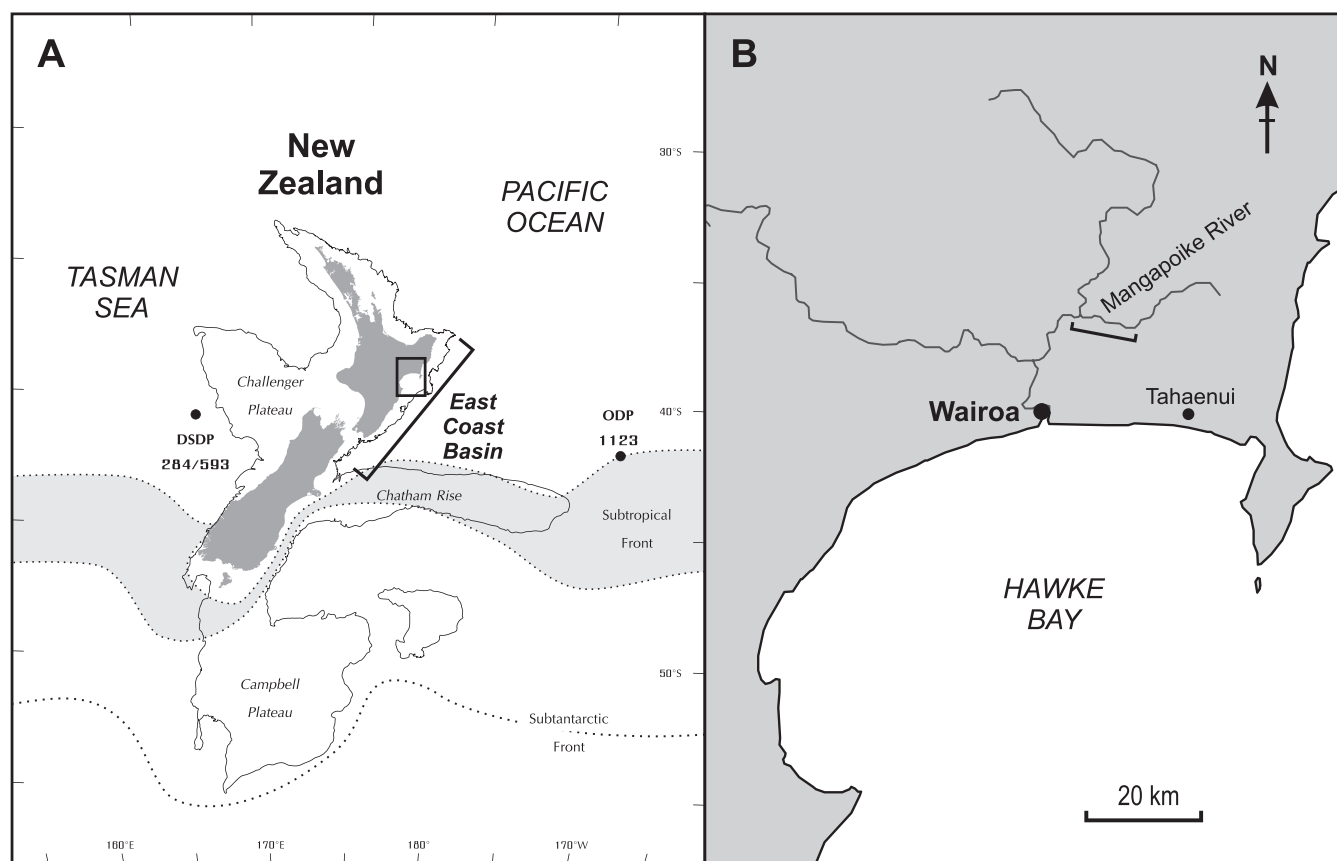


FIGURE 1. Locality map: **A** New Zealand region of the southwest Pacific Ocean and Tasman Sea, showing submarine plateau and rises, oceanic fronts, DSDP (Deep Sea Drilling Project) Site 284 and Site 593, and ODP (Ocean Drilling Program) Site 1123; **B** Enlargement of map A insert, showing geographic localities, sections, and sample sites discussed in this paper.

TAXONOMY AND BIOSTRATIGRAPHY

Species identifications and biostratigraphic events cited in this paper are based on Hornibrook (1981, 1982), Hornibrook et al. (1989), Scott et al. (1990), and Crundwell (2015a, b). A taxonomic list of all species mentioned in this paper is provided in Appendix 2. Samples from deep sea sites are referred to using conventional Integrated Ocean Discovery Programme (IODP) nomenclature (Hole-Core-Section, depth in cm), and stratigraphic heights are cited as meters below seafloor (mbsf). The following abbreviations are used for bioevents: HO (highest occurrence) and LO (lowest occurrence). The ranges of globorotalid species used for the correlation of New Zealand Plio-Pleistocene stages, and coiling history of selected truncorotalid species are shown in Figure 2. More detailed species-distribution data from ODP Hole 1123B and DSDP Site 284, including qualitative abundance data and counts of sinistrally- and dextrally-coiled specimens, used to identify changes in coiling, can be found in Crundwell (2015a, b).

All biostratigraphic events are identified in terms of the sample in which they are found and are calibrated against a new magnetostratigraphic age model based on inclination data from Hole 1123B, the age/depth tie points for which are given in Appendix 3. Calibrated events are listed in Appendix 4.

TERMINOLOGY

The use of the descriptive term “pseudospinose surface ultrastructure” in this paper, following Hottinger & Scheuring (1997) and Schiebel & Hemleben (2017), refers to pustulose wall surfaces that are composed of pseudospines (small, pointed, conical protuberances that are generally higher than they are wide). Pseudospines and pseudospinose wall surfaces are often well developed in the genera *Truncorotalia* and *Globoconella* Bandy, 1975 and are best observed in crust-free specimens near the aperture and on the leading sections of chamber walls (Fig. 3).

For consistency, specimens are described and illustrated in standard orientations: spiral, axial, and umbilical. A guide to the nomenclature used to describe globorotalids is shown in Figure 4.

CRASSACONICA PLEXUS

ORIGINAL SPECIES CONCEPT

Hornibrook (1981) introduced the species *Truncorotalia crassaconica* for specimens in Pliocene (Opoitian and Waipipian) populations of *Tr. crassaformis* in New Zealand. This species was described based upon sharply angled ventroconical shells with prominent peak-like terminal apices,

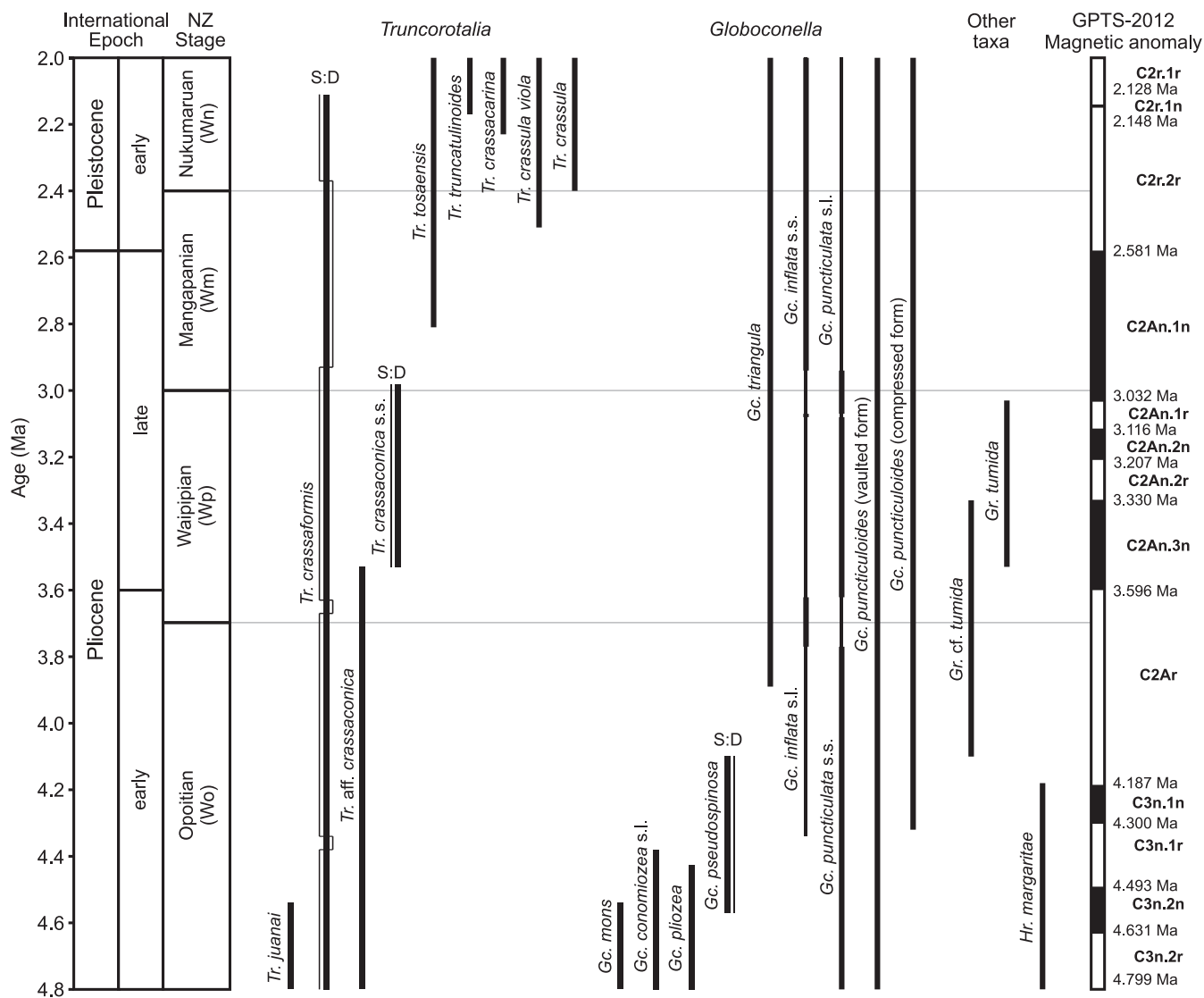


FIGURE 2. Calibrated ranges of globorotalid species used for the correlation of New Zealand Plio-Pleistocene stages and coiling history of selected species; based on magnetostratigraphically-constrained distribution data from ODP Hole 1123B (Crundwell, 2015a). Coiling abbreviations: Sinistral (S), Dextral (D). Taxonomic abbreviations: *Truncorotalia* (Tr.); *Globoconella* (Gc.); *Globoconella* (Gr.); *Hirsutella* (Hr.). New Zealand Plio-Pleistocene stages (Raine et al., 2015) and Geomagnetic Polarity Time Scale (GPTS-2012; Gradstein et al., 2012).

peripheries with thin keels (thickened pustulose rims), and low slit-like apertures. These diagnostic features are evident in specimens from the late Pliocene (Waipipian) type collection X19/f9493 from Tahaenui, East Coast Basin, New Zealand (Hornibrook, 1981, fig. 5g–i) and in topotypes illustrated in Figure 5. The original description of *Tr. crassaconica* did not discuss intraspecific variation, but a typical population was noted in sample X19/f9750 (formerly sample N106/f750) from the Mangapoike River section, near the base of the lectostratotype for the Opoitian Stage. Specimens of *Tr. crassaconica* were also recorded from the lectostratotype, throughout the Opoiti Formation, and in late Pliocene (Waipipian) mudstone overlying the Whakapunake Limestone. Good examples were also noted in mudstone overlying the Whakapunake Limestone, near Nuhaka, and at DSDP Site 284, in cores 10R–12R. The predominance of sinistrally coiled populations of *Tr. crassaconica* at Site 284

and dextrally coiled populations in the East Coast Basin was later commented on by Hornibrook (1982), but no explanation was offered for the differences in coiling.

Scott et al. (1990) subsequently undertook a major review of New Zealand globorotalid foraminifera; he described dextrally coiled specimens of *Tr. crassaconica* from the late Pliocene (Waipipian) type sample as having subangular, strongly ventroconical shells with subquadrate spiral outlines; chambers with radially compressed, wedge-like spiral outlines; well-defined apertural faces; and low slit-like apertures. The early Pliocene (Opoitian) population from Site 284, that Hornibrook (1982) considered to be typical of *Tr. crassaconica*, was also noted to differ from the late Pliocene (Waipipian) type sample. For example, the curvature at the junction of leading and central sections of the outer margins of chambers was described as being less abrupt and the margin almost symmetrical; the apertural

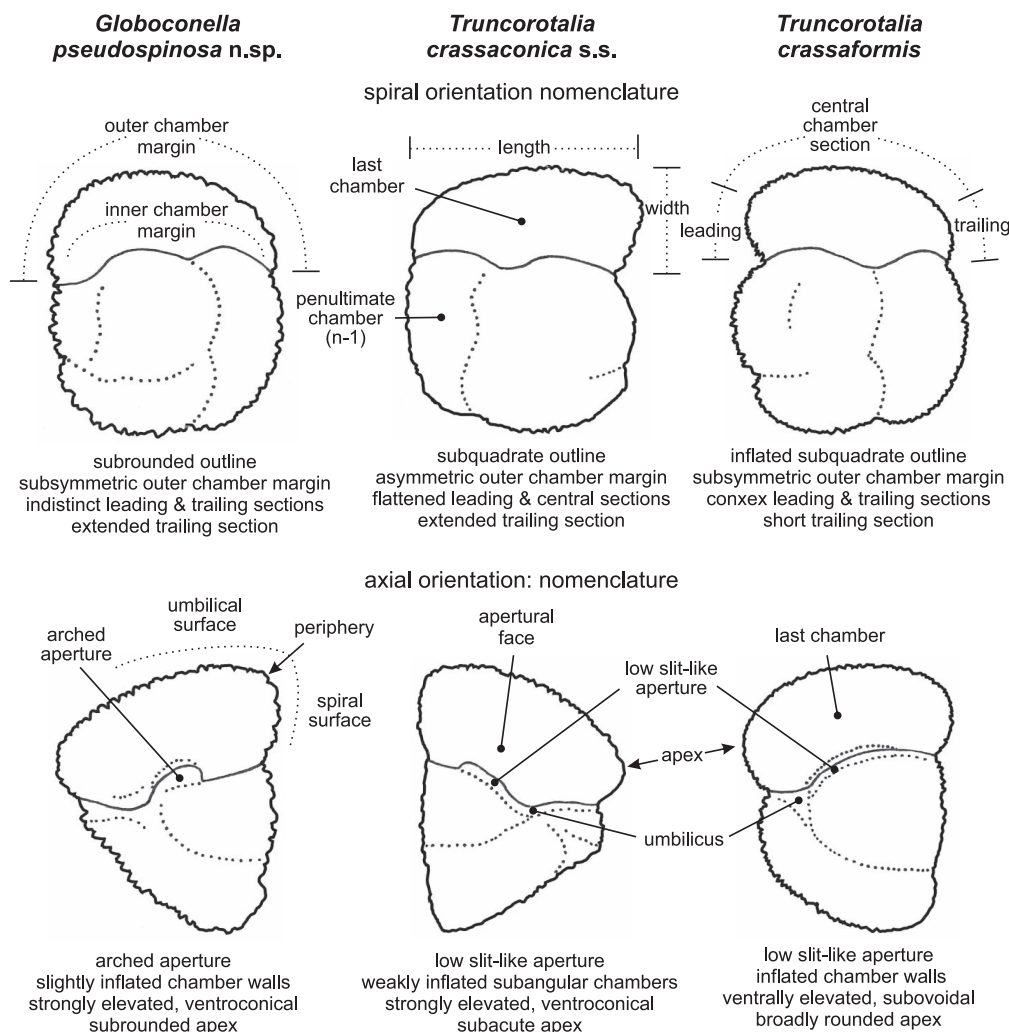


FIGURE 3. Guide to nomenclature used to describe globorotalid species (after Scott et al., 1990).

face to be more-weakly demarcated because of the weakened angularity of the spiral margin; and the apertures significantly wider and often arched (Scott et al., 1990, fig. 70d–i). They also commented that the population was comprised almost entirely of sinistrally coiled specimens. At the time, these differences were attributed to intraspecific morphological variation in *Tr. crassaconica*.

EARLY PLIOCENE POPULATIONS OF *TRUNCOROTALIA CRASSACONICA*

Early Pliocene populations of *Tr. crassaconica* with features like those described by Scott et al. (1990) are common in the Opoitian of DSDP Hole 284 between 111.40 mbsf and 85.30 mbsf (Crundwell, 2015b) and ODP Hole 1123B between 152.90 mbsf and 136.49 mbsf (Crundwell, 2015a). These populations are readily distinguished from topotypes of *Tr. crassaconica* s.s. on the basis that they have less cone-like ventroconical shells with slightly inflated chamber walls; weakly lobate subquadrate spiral outlines; more symmetric outer chamber margins with convex leading, central, and trailing chamber sections; less clearly demarcated

apertural faces; prominent apical terminations that curve towards the penultimate chamber; and higher arched apertures with pustulose apertural lips. Most (>95%) of the specimens in these populations are sinistrally coiled.

Similar populations occur throughout the lectostratotype of the New Zealand early Pliocene Opoitian Stage at Mangapoike River in the East Coast Basin, between samples X19/f9749 and X19/f9773, and are absent in the same section in underlying beds of the Mapiri Formation and overlying mudstone beds above the Whakapuna Limestone.

LATE PLIOCENE POPULATIONS OF *TRUNCOROTALIA CRASSACONICA*

Smaller late Pliocene populations with topotype-like specimens of *Tr. crassaconica* occur in the Waipian of DSDP Hole 284A between 72.90 mbsf and 69.10 mbsf (Crundwell, 2015b) and ODP Hole 1123B between 119.15 mbsf and 98.00 mbsf (Crundwell, 2015a). These populations are distinguished from the early Pliocene populations in having more angular ventroconical shells with prominent cone-like apical terminations; subquadrate spiral outlines with a

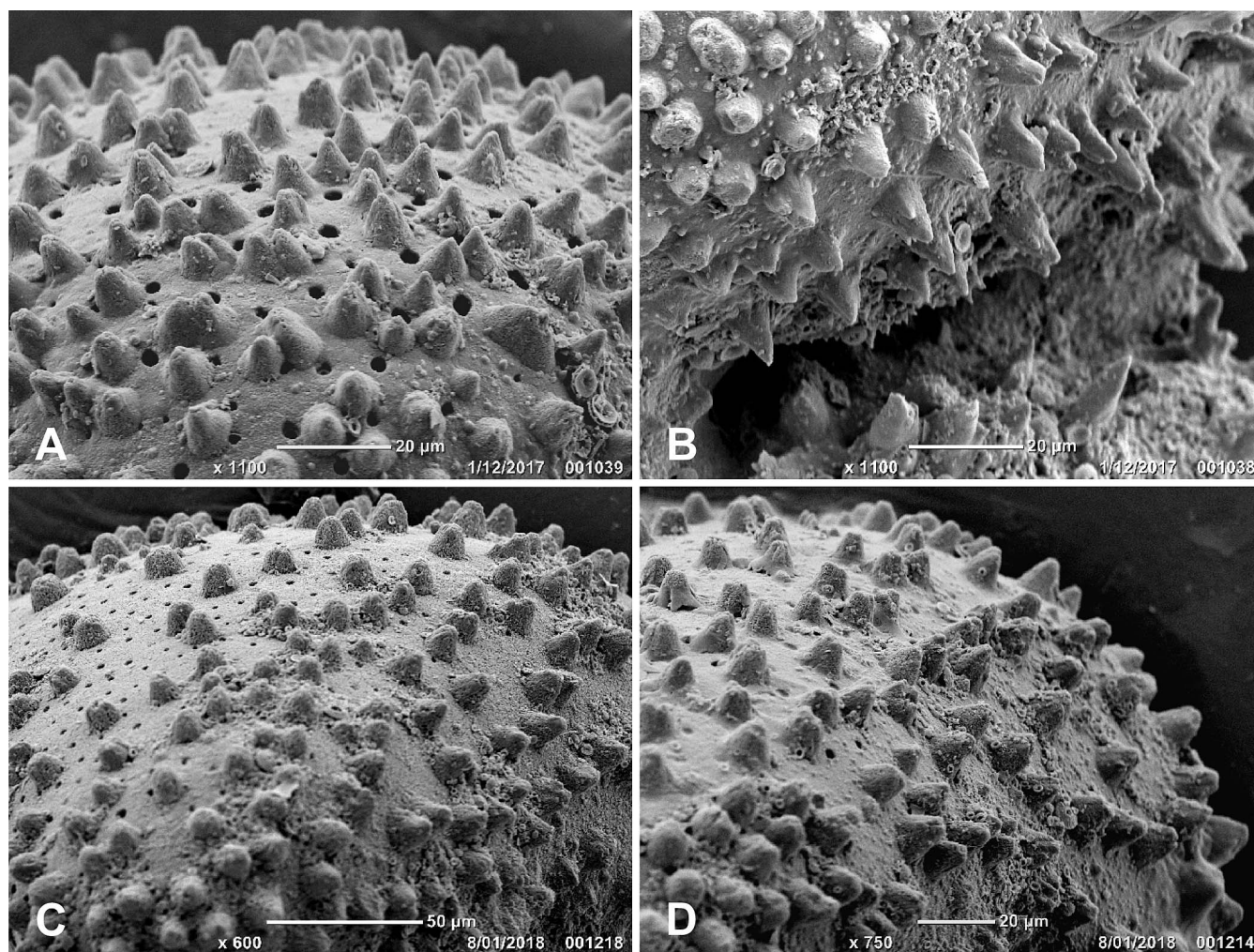


FIGURE 4. Pustulose (pseudospinose) surface ultrastructure. **A–B** Outer umbilical wall surface of last-formed chamber and apertural region in a crust-free specimen of *Truncorotalia crassaformis*, DSDP Site 284-12R-6, 20 cm (112.20 mbsf); **C–D** Outer umbilical wall surfaces of last-formed chambers in specimens of *Globoconella pseudospinosa* n. sp., DSDP Site 284-11R-1, 35 cm (94.35 mbsf).

wide-angled, shallow re-entrant above the aperture; asymmetric outer-chamber margins with subradial, almost straight, leading sections and tapered weakly convex central and trailing sections; thickened pustulose rims around the outer margins of spiral-side chamber walls; tight and almost closed umbilici; sinuous umbilical sutures; clearly demarcated, almost flat apertural faces; and low slit-like apertures with thin smooth apertural lips. Most specimens in these populations (>95%) are dextrally coiled.

Rare topotype-like specimens of *Tr. crassaconica* occur in the Mangapoike River section in Waipipian mudstone beds above the Whakapunake Limestone and are absent in underlying beds of the Opoitian lectostratotype.

SPECIMENS OF *TRUNCOROTALIA* AFF. *CRASSACONICA*

Sporadic occurrences of relatively rare, mostly sinistrally coiled specimens of *Tr.* aff. *crassaconica* are present in the Pliocene strata (Opoitian and early Waipipian) at Sites 1123 and 284 (Crundwell, 2015a, b). They have also been noted in

the late Miocene and early Pliocene at Site 593 (Crundwell, 2004). These specimens resemble *Tr. crassaconica* s.s. in having angular ventroconical shells with highly elevated umbilical surfaces, subquadrate spiral outlines, thickened pustulose rims around the outer margins of spiral-side chamber walls, low slit-like apertures with thin smooth apertural lips, and pseudospinose surface ultrastructures (e.g., compare Fig. 6A with Figs. 6B–C), but differ in having open umbilici and almost straight umbilical sutures, like late Miocene specimens of *Tr. crassaformis* (compare Fig. 6A with Fig. 6D). Until more is known about the geographic distribution of these specimens and how they relate to *Tr. crassaconica* s.s. and *Tr. crassaformis*, I recommend that they be described in open nomenclature.

TAXONOMIC STATUS OF THE NEW SPECIES

The early Pliocene species, *Globoconella pseudospinosa* n. sp., is readily distinguished from species of *Truncorotalia* on the basis of apertural shape (Fig. 7) and the surface

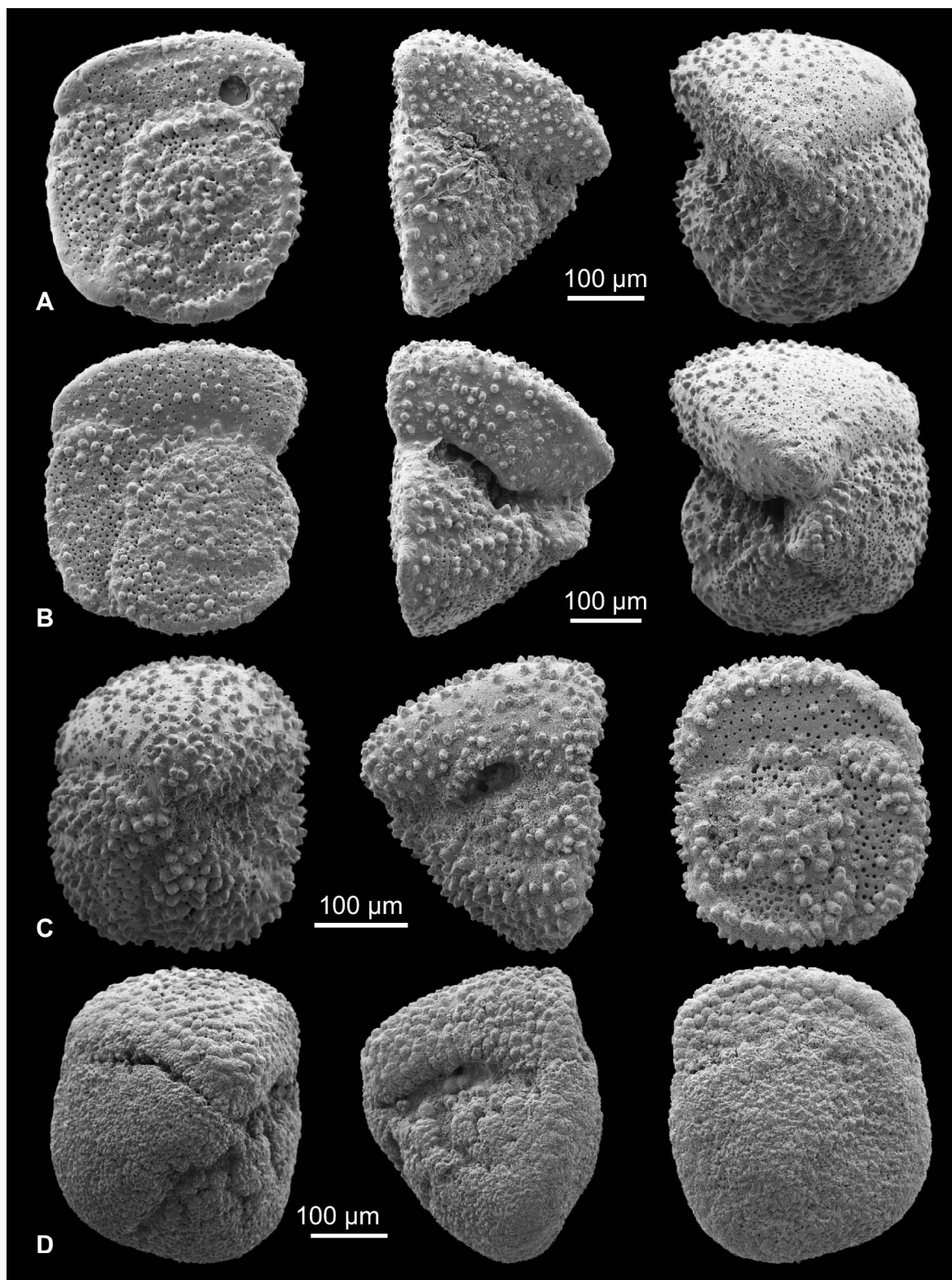


FIGURE 5. Scanning electron micrographs of *Truncorotalia crassaconica* s.s. and *Globoconella pseudospinosa*. **A** (FP5554), **B** (FP5555) Crust-free, dextrally coiled topotypes of *Truncorotalia crassaconica* s.s. with angular, strongly ventroconical shells, prominent cone-like apical terminations, and pseudospinose surface ultrastructures with denser pseudospines near the aperture and leading chamber sections; sample X19/f9493, Tahaenui near Wairoa, East Coast Basin, New Zealand (additional topotypes and specimens of *Tr. crassaconica* s.s. from nearby sample locality X19/f11 are figured in Appendix 1; Pls. 11, 12). **C**, **D** Type specimens of *Globoconella pseudospinosa*, with moderately dense, unevenly distributed pseudospines on shell wall surfaces and arched apertures with a pustulose apertural lip, DSDP Site 284-10R-6, 140 cm (93.40 mbsf). **A** Crust-free holotype, TF1677 (1), with a thickened pustulose rim around the outer margins of spiral-side chamber walls, maximum diameter 320 µm; **B** paratype TF1677 (10), maximum diameter 400 µm (additional paratypes are figured in Appendix 1; Pls. 5, 6).

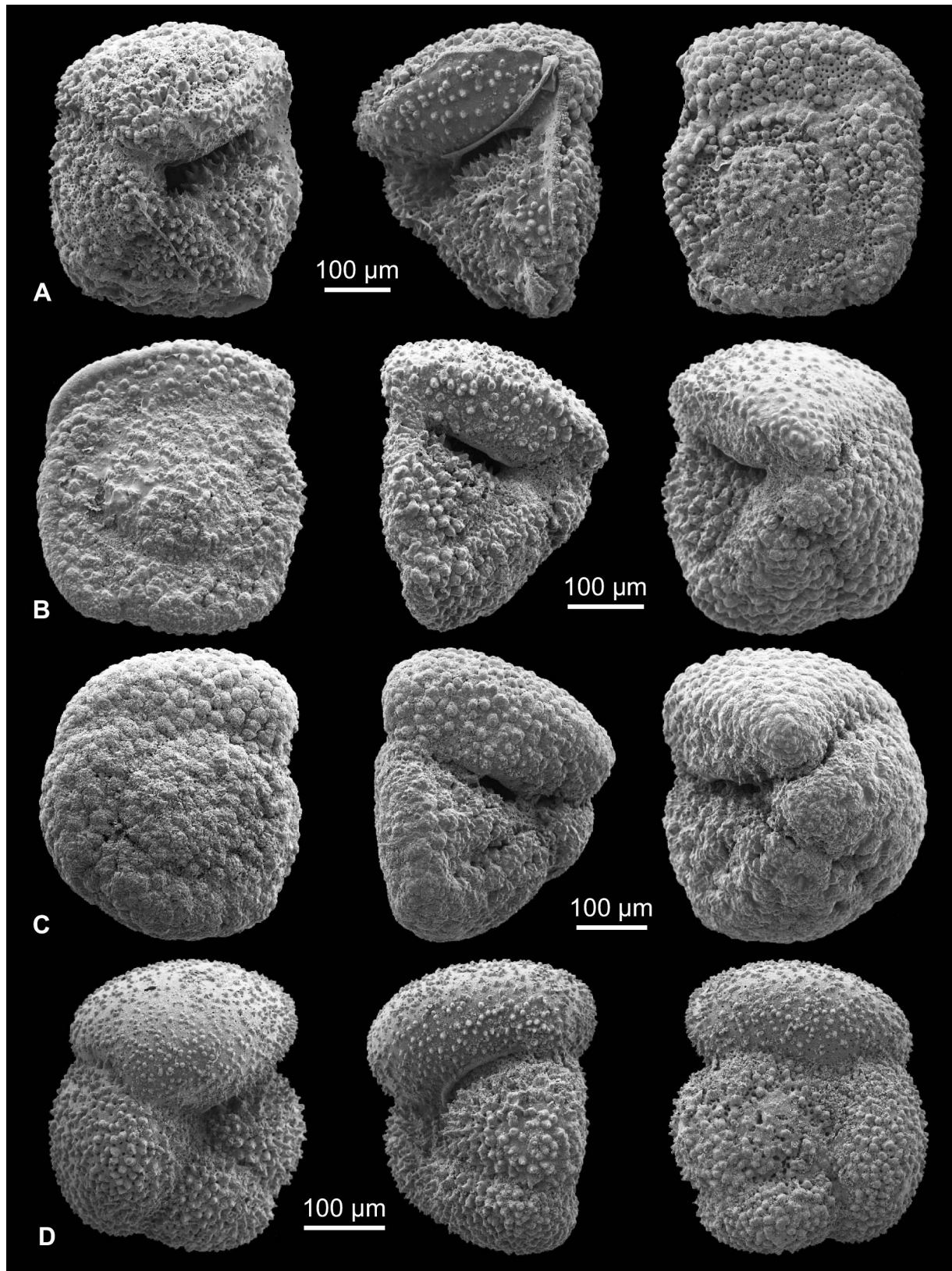


FIGURE 6. Truncorotalids with dense pseudospines on shell wall surfaces and low slit-like apertures with thin smooth apertural lips: **A** Moderately encrusted specimen of *Truncorotalia* aff. *crassaconica*, FP5567, ODP1123B-15H-7, 5–10 cm (136.01 mbsf); **B**, **C** specimens of *Truncorotalia crassaconica* s.s., FP5581 and FP5582, 1123B-13H-5, 90–94 cm (114.80 mbsf); **D** unkeeled, crust-free specimen of *Truncorotalia crassaformis*, FP5568, DSDP284-12R-1, 20 cm (103.90 mbsf).

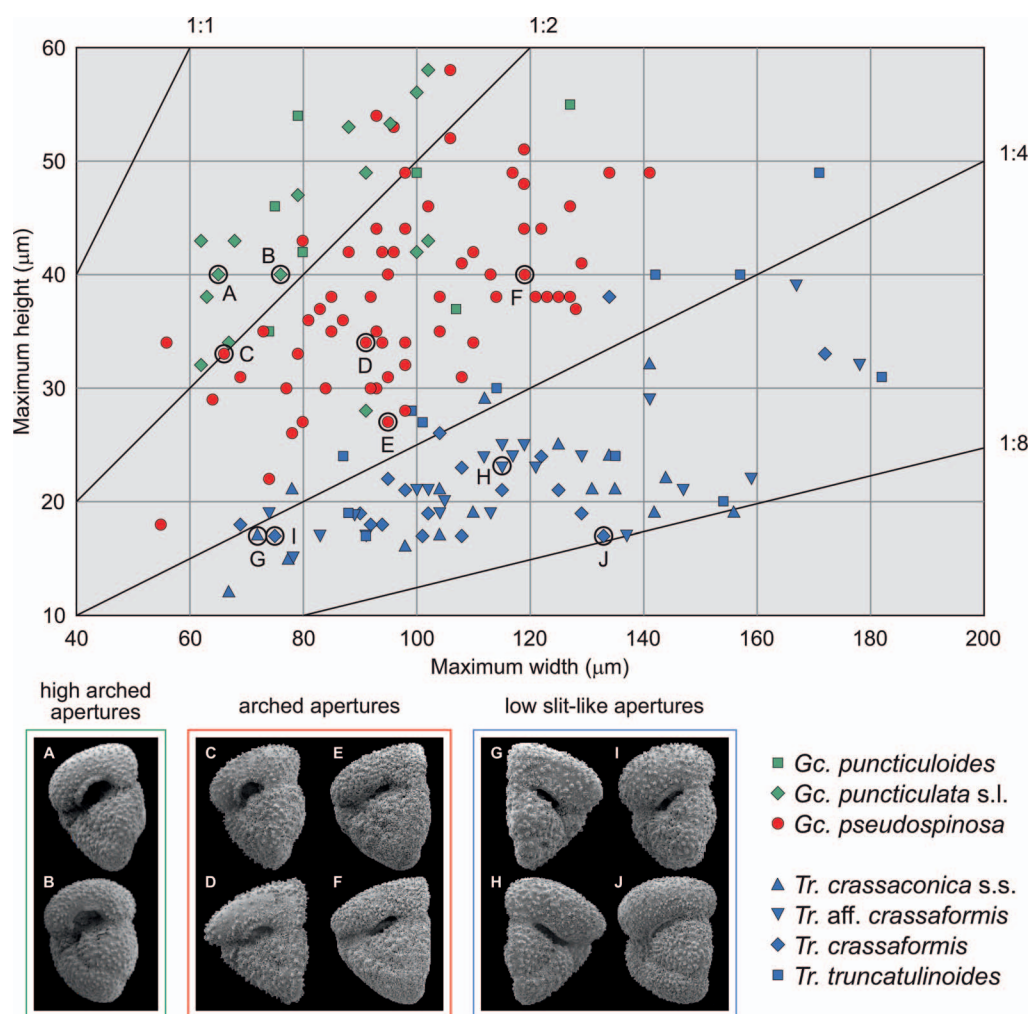


FIGURE 7. Plot of aperture shapes (maximum height vs. maximum width) for Pliocene truncorotalid and globoconellid species (figured in Appendix 1; Pls. 1–14). Figured specimens (A–J) marked in plot with black open circles.

morphology of apertural lips (Fig. 8). For example, *Gc. pseudospinosa* has high-arched apertures bordered by pustulose apertural lips, while *Tr. crassaconica* s.s. and other species of *Truncorotalia* have low elongate apertures with thin, smooth apertural lips at the base of apertural faces (Figs. 7, 8). In terms of original taxonomic descriptions, the former apertural characteristics are typical of the genus *Globoconella* (Bandy, 1975) and the latter are diagnostic of the genus *Truncorotalia* (Cushman & Bermúdez, 1949). Consequently, the new species is assigned to the genus *Globoconella* and named *Gc. pseudospinosa* in recognition of the pseudospinose surface ultrastructure.

SYSTEMATIC TAXONOMY

Order ROTALIIDA Delage & Hérouard, 1896
 Suborder GLOBIGERININA Delage & Hérouard, 1896
 Superfamily GLOBOROTALIOIDEA Delage & Hérouard, 1896
 Family GLOBOROTALIIDAE Cushman, 1927

Genus *Globoconella* Bandy, 1975; subgenus of *Globorotalia* Cushman, 1927

Type species: *Globorotalia conomiozea* Kennett, 1966

Globoconella pseudospinosa n. sp.

Fig. 5C–D, Fig. 9, and Appendix 1, Pl. 1–10

Globorotalia crassaconica Hornibrook, 1982, p. 91, fig. 5a–c.
Globorotalia crassaconica Scott et al., 1990, p. 105–108, fig. 70d–i.

Description. Low trochospiral, compactly coiled shell; four chambers in the outer whorl, increasing rapidly in elevation; spiral side relatively flat to slightly convex, umbilical side highly vaulted. Shell walls finely perforate. Surface ultrastructure pseudospinose; pseudospines are generally denser and higher near the aperture and on the leading sections of chamber walls; in encrusted specimens, the pseudospines become wider and more mound-like with the addition of secondary calcite, and they are generally covered on earlier formed chambers.

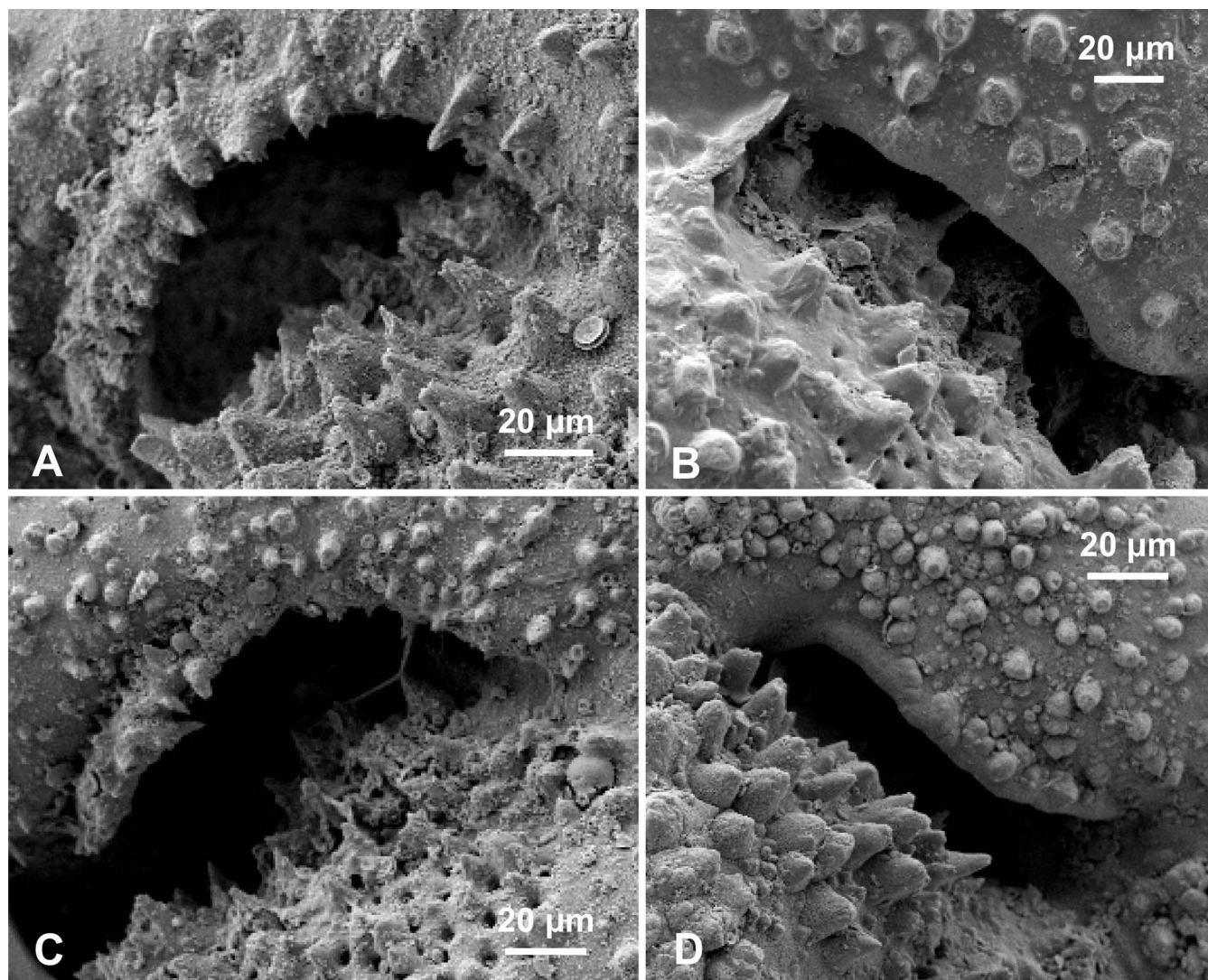


FIGURE 8. Detail of conservative apertural features in the clades *Globoconella* and *Truncorotalia*. **A** *Globoconella pseudospinosa* [284-11R-5, 20 cm (100.20 mbsf)]; **C** *Globoconella conomiozea* [284-16R-2, 20 cm (143.43 mbsf)] with arched apertures bordered by pustulose apertural lips; and **B** *Truncorotalia crassaconica* s.s. [topotype, X19/f9493 Tahaenui] and **D** *Truncorotalia truncatulinoides* [284-1R-3, 20 cm (3.20 mbsf)] with elongate slit-like apertures and thin, smooth apertural lips at the base of the apertural face.

Spiral orientation: equatorial outline subquadrate, slightly lobate, bordered by a thickened pustulose rim; outer chamber margins radially compressed, asymmetric, with subradial convex leading sections, and slightly convex central and trailing sections; radial sutures limbate, linear initially and tightly curved near periphery.

Axial orientation: shell outline strongly ventroconical, with a prominent acutely rounded apical termination; periphery acutely rounded; apertural face weakly demarcated; aperture interiomarginal, umbilical-extraumbilical, a moderate to high arch with a pustulose apertural lip.

Umbilical orientation: sutures on umbilical side depressed, subradial and sinuous; umbilicus tight and closed; apical termination curves towards the penultimate chamber.

Dimensions. Holotype, maximum spiral diameter: 320 µm, ventral elevation: 265 µm (Fig. 5C).

Types. GNS Science Register No. TF1677: Holotype TF1677 (1) and 11 paratypes TF1677 (2–12). Topotypes

will also be deposited with the British Museum of Natural History in London, and the Smithsonian Institution Museum of Natural History in Washington, D.C., USA.

Type sample and level. DSDP Site 284-10R-6, 140 cm (93.40 mbsf), early Pliocene (NZ Opoitian Stage), immediately above the top of the lowest interval of dextrally coiled *Truncorotalia crassaformis*.

Variation. Early populations generally have weaker ventroconical shells with more inflated chambers and less asymmetric outer chamber sections (Appendix 1; Pls. 1–4). Specimens with more symmetric, convex outer chamber sections and very weakly developed pustulose rims around the outer margins of spiral-side chamber walls are also present in early populations (e.g., Fig. 6A–B).

Populations from later in the Opoitian typically have stronger ventroconical shells, less inflated chambers with flatter central chamber sections, thicker pustulose rims around the outer margins of spiral-side chamber walls, and

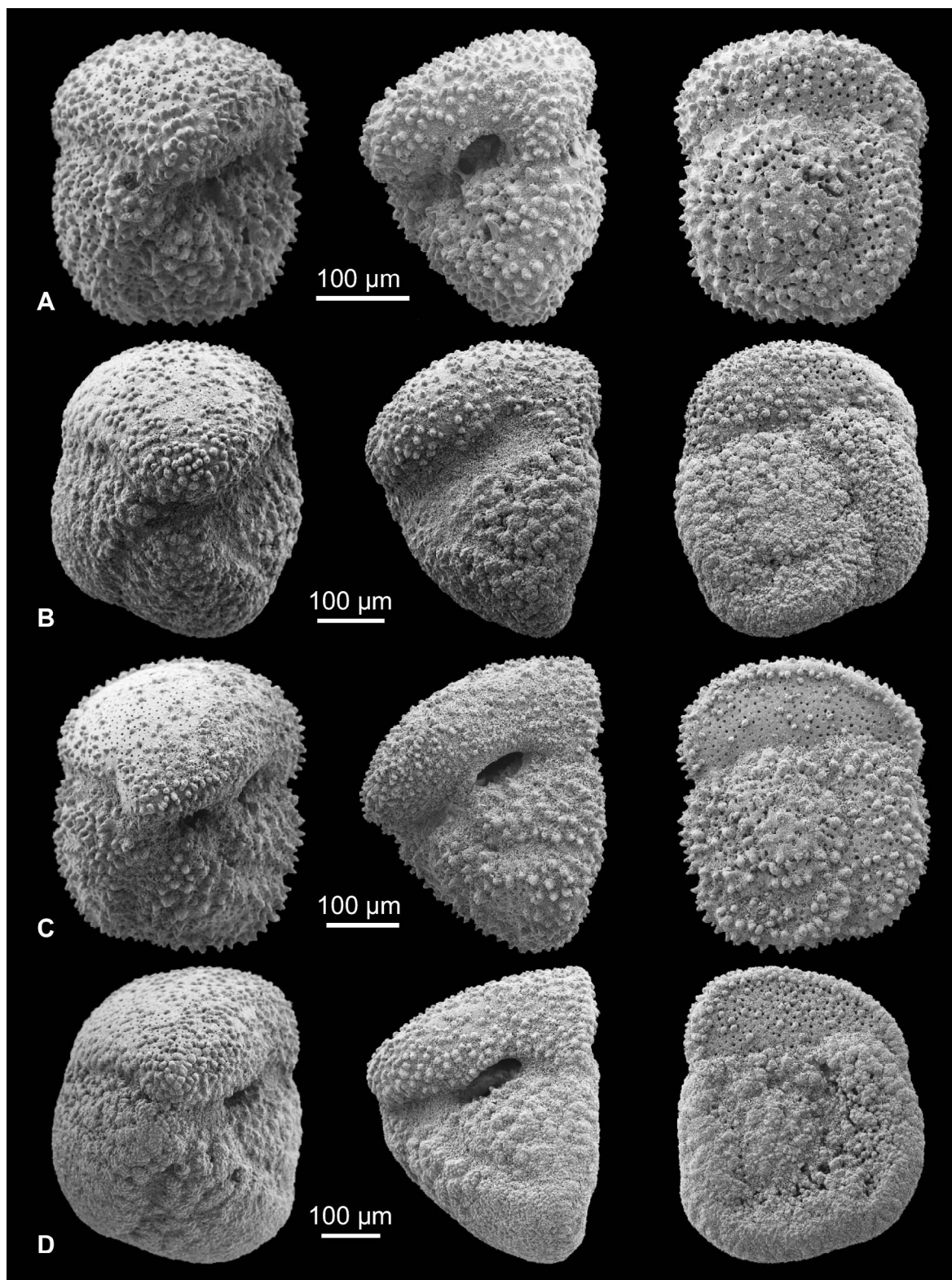


FIGURE 9. *Globoconella pseudospinosa* specimens: **A, B** Early phenotypes with moderately inflated chambers, DSDP 284-12R-4, 20 cm (108.40 mbsf). **A** Crust-free specimen FP5501, with weakly asymmetric spiral-side chamber outlines; short, tapered trailing chamber sections; acutely rounded periphery with a non-perforate pustulose rim around the outer margins of spiral-side chamber walls; and dense, evenly dispersed pseudospines on chamber wall surfaces. **B** Encrusted specimen FP5511, with strongly asymmetric spiral-side chamber outlines and a thickened pustulose rim around the outer margins of spiral-side chamber walls. **C, D** Late phenotypes with less inflated chambers; strongly ventroconical shells; low arched apertures with pustulose apertural lips; thickened pustulose rims around the outer margins of spiral chamber walls; and asymmetric chamber outlines on the spiral side with narrow, tapered trailing sections; DSDP 284-10R-3, 100 cm (88.50 mbsf), ~4.2 Ma. **A** Crust-free specimen FP5525; **B** Encrusted specimen FP5534.

slightly lower arched apertures (Fig. 6C, D and Appendix 1, Pls. 5–10). Specimens with low arched apertures are relatively rare, even in the most advanced populations, and generally only occur in variants where the leading section of the outer chamber margin of the final chamber is raised above earlier chambers.

Encrusted specimens exhibit similar features, but the surface ultrastructure is usually modified by a layer of secondary calcite that covers pores in the wall and the pseudospinose surface ultrastructure (e.g., Fig. 5D). There is also a tendency for the shells of encrusted specimens to have lower arched apertures and more inflated ventroconical outlines.

Discrimination. *Globoconella pseudospinosa* is distinguished from *Tr. crassaconica* s.s. on the basis of having less cone-like ventroconical shells with slightly inflated chamber walls; weakly lobate subquadrate spiral outlines; more symmetric outer chamber margins with convex leading, central, and trailing chamber sections; less clearly demarcated apertural faces; apical terminations that curve towards the penultimate chamber; and more highly arched apertures with a pustulose apertural lip. The arched apertures and pustulose apertural lips also distinguish *Gc. pseudospinosa* from other truncorotalids, while the thickened pustulose rim around the outer margins of spiral-side chamber walls distinguish *Gc. pseudospinosa* from other globoconellids.

Relationships. The presence of specimens in early populations of *Gc. pseudospinosa* with dense, evenly dispersed pseudospinose surface ultrastructures and very weakly developed pustulose rims around the outer margins of spiral-side chamber walls (e.g., Fig. 6A) suggests *Gc. pseudospinosa* is likely to have evolved from an unkeeled globoconellid ancestor like *Gc. puncticulata* (e.g., Scott et al., 1990, fig. 42), rather than a keeled globoconellid ancestor like *Gc. conomiozea* or *Gc. mons* (e.g., Scott et al., 1990, fig. 30).

Distribution. Specimens of *Gc. pseudospinosa* are common throughout the early Pliocene (Opoitian) sections of ODP Hole 1123B (152.90–136.49 mbsf) and DSDP Site 284 (111.40–85.30 mbsf). The only exception to the persistence of *Gc. pseudospinosa* is a very short interval at Site 284 (101.70–101.00 mbsf), where specimens are absent. In the Mangapoike River section near Wairoa, specimens of *Gc. pseudospinosa* occur throughout the Opoiti Formation, between samples X19/t9749 and X19/t9773. The species has also been identified by the author in other samples from New Zealand, the East Coast Basin, the Wanganui Basin, and petroleum exploration wells in the Taranaki Basin.

Correlation. In the lectostratotype for the New Zealand Opoitian Stage at Mangapoike River near Wairoa, the earliest populations of *Gc. pseudospinosa* occur in sample X19/t7750, 2.4 m above the base of the Opoiti Formation. At Site 1123, the LO of *Gc. pseudospinosa* occurs close to the HOs of *Truncorotalia juanai* and *Globoconella mons* and is correlated with the middle part of Chron C3n.2n (4.57 ± 0.01 Ma); the HO of *Gc. pseudospinosa* occurs just above the LO of angular intergrades of *Tr. aff. crassaconica* and the HO of *Hirsutella margaritae* and is correlated with the lower part of Chron C2Ar (4.10 ± 0.01 Ma).

Etymology. The species name *Gc. pseudospinosa* was chosen to draw attention to the species relatively dense pseudospinose surface ultrastructure, which is denser (per unit

area of test surface) than the pseudospinose surface ultrastructure of keeled late Miocene globoconellids. These features are best observed in crust-free specimens.

Genus *Truncorotalia* Cushman & Bermúdez, 1949,
emended Bermúdez, 1961

Type species: *Rotalia truncatulinoidea* d'Orbigny, 1839,
p. 132

Truncorotalia crassaconica (Hornibrook, 1981) emended
herein
Fig. 5

Globorotalia crassaconica Hornibrook, 1981, p. 271–272,
fig. 5g–i, 9 a–c.

Globorotalia crassaconica Scott et al., 1990, p. 105–108,
fig. 70a–c.

Description. Low trochospiral, compactly coiled shell; four chambers in the outer whorl, increasing rapidly in elevation. Shell walls finely perforate. Surface ultrastructure pseudospinose; pseudospines denser and higher near the aperture and the leading sections of chamber surfaces; with the addition of secondary calcite, the pseudospines become wider and more mound-like before they merge on the surfaces of earlier formed chambers.

Spiral orientation: equatorial outline subquadrate, slightly lobate, with a wide-angled shallow re-entrant above the aperture, periphery bordered by a thickened pustulose rim; chambers strongly asymmetric, wedge-like, with almost straight subradial leading sections, long radially-compressed central sections that taper towards trailing chamber sections, and short convex trailing sections; radial sutures, straight initially and tightly convex near the periphery.

Axial orientation: axial outline angular, strongly ventroconical, with a prominent apical termination; spiral side almost flat, umbilical side highly vaulted, central chambers radially-compressed; apertural face clearly demarcated, almost flat; aperture a low elongate slit, with a thin, smooth apertural lip.

Umbilical orientation: sutures slightly depressed, subradial, slightly sinuous; umbilicus tight and closed.

Variation. Specimens with less elevated umbilical surfaces are also present in some populations.

Discrimination. *Truncorotalia crassaconica* differs from *Tr. aff. crassaconica* by having a tight, closed umbilicus and sinuous umbilical sutures; it is distinguished from other truncorotalids on the basis of having angular, strongly ventroconical shells with prominent cone-like apical terminations and subquadrate equatorial spiral outlines; wedge-like chamber outlines on the spiral side, accentuated by long, almost straight central chamber sections that slope downwards towards trailing chamber sections; and clearly demarcated almost flat apertural faces.

Distribution. Dextrally coiled populations of *Tr. crassaconica* s.s. are present within the early Pliocene (Waipipian) sections of ODP Site 1123, between cores 1123B-14H-2, 25–29 cm (119.15 mbsf) and 1123B-11H-7, 10–15 cm (98.00 mbsf), and DSDP Site 284, between cores 284A-3R-5, 100 cm (72.90 mbsf) and 284A-3R-3, 20 cm (69.10 mbsf). Typical specimens are also noted in Waipipian sediments of the East Coast Basin of New

Zealand, close to the type collection (e.g., sample X19/f11); in the Mangapoike River section above the Whakapuna Limestone (sample X19/f7706); and in the Rangitikei River section of Wanganui Basin, in sample T22/f81, below the base of the proposed standard section and point for the base of the New Zealand Mangapanian Stage (Crundwell & McDonnell, 2014).

Relationships. At Sites 1123 and 284, dextrally coiled populations of *Tr. crassaconica* are preceded by relatively rare specimens of *Tr. aff. crassaconica* that occur sporadically in the late Miocene (Kapitean) to Pliocene (early Waipipian). These earlier specimens are predominantly sinistrally coiled, and they become slightly more common in the late Opoitian to early Waipipian, prior to the appearance of *Tr. crassaconica*. The more angular intergrades, *Tr. aff. crassaconica*, appear in this interval in increased abundance. The taxonomic status of these early morphotypes is uncertain, but they are likely to be geographic outliers of populations that lived outside the temperate southwest Pacific.

Correlation. At ODP Site 1123, the LO of *Tr. crassaconica* s.s. occurs in the late Pliocene (Waipipian) near the LO of *Globorotalia tumida*, and is correlated with the lower part of Chron C2An.3n (3.53 ± 0.01 Ma). The HO of *Tr. crassaconica* s.s. occurs near the base of a late Pliocene (Mangapanian) zone of dextrally coiled *Tr. crassaformis* and is correlated with the lower part of Chron C2An.1n (2.90 ± 0.01 Ma). At Site 284, *Tr. crassaconica* s.s. is confined to a relatively short Waipipian section, below the base of a well-defined Mangapanian zone of dextrally coiled *Tr. crassaformis*. The LO of *Tr. aff. crassaconica* occurs just below the LO of *Tr. crassaformis*, at ca. 5.5 Ma (Crundwell, 2004); rare specimens occur sporadically up to the LO of *Tr. crassaconica* s.s.

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APPENDIX

Appendices 1, 3, and 4 can be found on the Cushman Foundation website in the JFR Article Data Repository (<https://cushmanfoundation.allenpress.com/JournalofForaminiferal-Research/DataRepository>) as item number JFR_DR_20180008.

APPENDIX 1

Supplementary Plates 1–13, planktonic foraminifera related to the *Truncorotalia crassaconica* plexus.

APPENDIX 2

Taxonomic list of foraminiferal species referred to in this study.

Globoconella Bandy, 1975
Globoconella conomiozea (Kennett, 1966)
Globoconella conomiozea (Kennett) subspecies *mons* Hornibrook, 1982
Globoconella inflata (Orbigny, 1839)
Globoconella inflata (Orbigny) subspecies *triangula* Theyer, 1973
Globoconella pliozea (Hornibrook, 1982)
Globoconella puncticulata (Deshayes, 1832)
Globoconella puncticulata (Deshayes) subspecies *puncticuloides* Hornibrook, 1981
Globorotalia Cushman, 1927; emended Blow, 1979

Globorotalia tumida (Brady, 1877)
Hirsutella Bandy, 1973
Hirsutella margaritae (Bolli & Bermúdez, 1965)
Truncorotalia Cushman & Bermúdez, 1949
Truncorotalia crassacarina (Scott, Bishop & Burt, 1990)
Truncorotalia crassaconica (Hornibrook, 1981)
Truncorotalia crassaformis (Galloway & Wissler, 1927)
Truncorotalia crassula (Cushman & Stewart, 1930)
Truncorotalia crassula (Cushman & Stewart) subspecies *viola* Blow, 1969
Truncorotalia juanai Bermúdez & Bolli, 1969
Truncorotalia tosaensis (Takayanagi & Saito, 1962)
Truncorotalia truncatulinoides (d'Orbigny, 1839)

APPENDIX 3

Magnetostratigraphic inclination data from ODP Hole 1123B (Shipboard Scientific Party, 1998) and age/depth tie points for magnetic reversals (chron bases) used for the calibration of Plio-Pleistocene bioevents.

APPENDIX 4

Calibrated Plio-Pleistocene planktonic foraminiferal events from ODP Hole 1123B (Crundwell, 2015a) and New Zealand Stages (Raine et al., 2015).