



Research paper

Clinal variation in aperture shape in Southwest Pacific *Globorotalia partimlabiata* and its ancestor about the time of the Middle Miocene Climatic Transition

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ABSTRACT

To clarify the taxonomy and biostratigraphy of Southwest Pacific populations currently identified as *Fohsella peripheroronda* a morphometric study is reported on the shape of its aperture in collections from DSDP Sites 588A and 593, and from the stratotype of the New Zealand Lillburnian Stage. This material is compared with *Globorotalia partimlabiata* from Serravallian strata in Sicily. Shape analyses use 50 equally-spaced coordinates along the margin of the apertural re-entrant of the last-preserved chamber. Data are aligned by the Procrustes algorithm and projected onto principal component axes. Canonical discriminant analysis of these scores shows that convexity of the margin increases clinally. The cline is interpreted as primary evidence for a previously unrecognized lineage for which a provisional taxonomy is advanced. *Globorotalia partimlabiata*, which has individuals with strongly convex margins, represents the climax of the cline. The highest occurrence of its ancestor, recognized here informally as *Globorotalia cf. peripheroronda*, is determined by the highest sample whose mean shape does not differ significantly from its earliest representative at Site 593. There and at Site 588A that datum is close to, or within, Miocene isotope event Mi-3b. The architectural history of the lineage differs from the tropical fohsellids and its relation to them is unresolved.

1. Introduction

Since Jenkins (1960) identified *Globorotalia barisanensis* from his *Globigerinoides glomerosa curva* Zone in a southeastern Australian section it has been reported in the Southwest Pacific as *Globorotalia peripheroronda* (e.g., Hoskins, 1984; Hornibrook et al., 1989) and latterly as *Fohsella peripheroronda* (e.g., Scott et al., 1990; Cooper, 2004). However, its history is quite different from the tropical record of *Fohsella peripheroronda*. Axial compression of the shell did not occur; indeed in some Southwest Pacific populations identified as *Fohsella peripheroronda* this profile is further inflated. But the outstanding feature of late populations is the presence of specimens in which the aperture is high and strongly convex as in *Globorotalia partimlabiata*, described by Ruggieri and Sprovieri (1970) from the Mediterranean Serravallian Stage. These distinctive morphotypes are present about the time of the Middle Miocene Climate Transition (MMCT). They are not found in the tropical *Fohsella* populations. Their identity in Southwest Pacific populations has been variously interpreted which has affected their use in biostratigraphy (Fig. 1).

A first step towards resolving the confused taxonomy and biostratigraphy of Southwest Pacific populations currently referred to

Fohsella peripheroronda is to map their aperture shape through sections in several regional water masses and relate it to the oxygen isotope record. These data facilitate the detection of population mixtures, trends, and climate influences. Procrustes analysis shows that a cline in Southwest Pacific populations developed about the time of the MMCT which led to aperture shapes comparable with those in a near-topotypic sample of *Globorotalia partimlabiata*. These results indicate that Southwest Pacific populations have been misidentified as *Fohsella peripheroronda* although they have some homologous characters. Based on the morphometric data a provisional taxonomy is introduced which recognizes early populations as *Globorotalia cf. peripheroronda* and descendant populations as *Globorotalia partimlabiata*. Their transition marks a useful biostratigraphic event in the vicinity of event Mi-3b.

2. Material and methods

DSDP Site 593 (Kennett et al., 1986) on Challenger Plateau (Fig. 2) at a Middle Miocene paleolatitude of 44°S (Flower and Kennett, 1994) is an oceanic locus with cool subtropical Miocene planktonic foraminiferal assemblages comparable with those from New Zealand. Six populations were sampled between cores 42-3-90–41-4-138 mbsf. The

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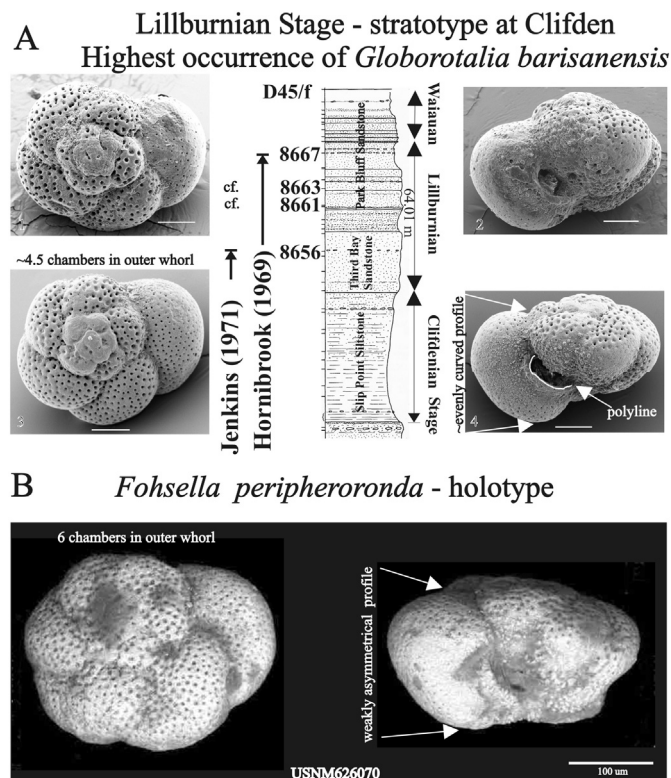


Fig. 1. A. Highest occurrence of *Globorotalia barisanensis* in the Lillburnian stratotype recorded by Hornibrook (1969) and Jenkins (1971). Hornibrook (1969), followed by later authors, included specimens in which the margin of the aperture is strongly convex. B. Holotype of *Globorotalia peripheroronda* Blow and Banner. The images are mirrored to facilitate comparisons with specimens in A. A #4 shows the position of the polyline around the apertural re-entrant used as a measure of aperture shape.

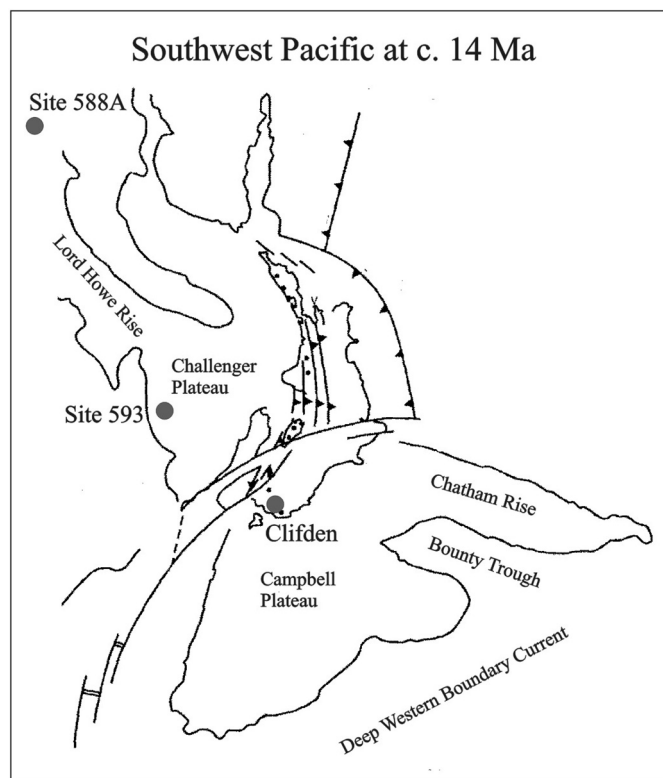


Fig. 2. Paleogeographic map of Southwest Pacific at 14 Ma adapted from King (2000) and Field et al. (2002). Location of sites sampled in this study.

lowest sample is closely above the appearance of *Globorotalia peripheroronda* (core 42-4-6-8 mbsf) in Jenkins and Srinivasan (1986).

DSDP Site 588A (Kennett et al., 1986) on Lord Howe Rise at a paleolatitude of 30°S is valuable, because cores 9-1-81 - 7-3-3 mbsf (4 samples), span a highly resolved benthic foraminiferal $\delta^{18}\text{O}$ record over the MMCT.

Three samples from the Nga Pari Formation at Clifden (Hornibrook, 1969) allow the morphologies in the oceanic collections to be linked to those in the shelfal setting of the Lillburnian stratotype (Fig. 2) which lay near the southern limit of Miocene subtropical water.

In the Mediterranean province *Globorotalia partimlabiata* appeared as a migrant (Chamley et al., 1986) at 12.77 Ma (Hilgen et al., 2009). It has individuals whose aperture compares closely with some in South-west Pacific populations. For comparison, specimens were examined from a residue of sample #12 (hereafter RS12) in Ruggieri and Sprovieri (1970, Fig. 2). They described the species from this section through the San Cipirello Marls, western Sicily.

The primary aperture is identified as the re-entrant on the axial face of a chamber, near the umbilicus, which opens between its junction with the preceding chamber and its junction with a chamber in the preceding whorl. Conventionally, gross dimensions have been used to estimate its shape (e.g., Scott, 1972; Spezzaferri et al., 2015). Here, it is recorded from SEM imagery as a polyline (Fig. 1 #4) of 50 equally-spaced coordinates around the margin of the re-entrant of the last-preserved chamber using tpsdig2 (<http://life.bio.sunysb.edu/morph/soft-dataacq.html>). Dextrally-coiled shells were mirrored to sinistral. These data are more informative about shape variation than are gross dimensions. Although ‘aperture’ is used in the following text, note that the data are specific to the polyline around its margin.

The Procrustes algorithm (procGPA <http://cran.r-project.org/web/packages/shapes>) is used to align specimens on the centroids of the polylines after removing the effects of size and position. Adams et al. (2004) and Mitteroecker and Gunz (2009) introduce the geometric morphometric approach to the analysis of biological structures. Analyses of the aligned data are based on their projection from the curved shape space onto the euclidean coordinates of principal component axes. Tests of the null hypothesis for differences in mean shape use the F-ratio (Goodall, 1991) with bootstrap resampling.

3. Results

3.1. Within-sample variation

Of interest is the distribution of within-sample scores in principal component space: evidence of bimodality might indicate population partitioning or replacement. This is not apparent in the PC1 scores (51–72% variation) for Site 588A (Fig. 3A) where the highest collection (273.6 mbsf) is similarly approximated by the normal distribution as the lowest. Data from Site 593 and from the Lillburnian stratotype are comparably distributed. Although constrained by small sample sizes, the data suggest that the collections come from unitary shape populations.

The pattern of shape variation within samples is distinctive. This is demonstrated with samples from Site 588A. Models of shape (Fig. 3B) at ± 3 standard deviations ($\pm 3\sigma$) from the mean show that innovation primarily occurs towards one extremity of the distribution, hereafter called the convex tail. It is easily recognized, visually. At the opposite extremity (linear tail) there is very minor evolution in form and outliers persist in which much of the apertural trace is very weakly convex.

3.2. Stratigraphic pattern

In this application of canonical discriminant analysis a linear model regresses discriminant scores derived from PC1-PC8 on the stratigraphic order of samples in each section (the predictor variable). There is substantial overlap in scores (Fig. 4) but median (50th percentile)

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