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Chapter 9

TAXONOMY, BIOSTRATIGRAPHY, AND PHYLOGENY OF EOCENE *ACARININA*

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ABSTRACT

The taxonomy, phylogeny and biostratigraphic ranges of 28 Eocene species of *Acarinina* are discussed together with detailed synonymies. The early Eocene is characterized by the radiation of two different groups - one characterized by rounded/inflated chambers and the other by anguloconical chambers - which are derived, in turn, from two late Paleocene lineages: the *soldadoensis* lineage (itself derived from *Acarinina mckannai*) and the *esnaensis-wilcoxensis* lineage (itself derived from *Acarinina nitida*). We interpret the genus *Truncorotaloides* as a synonym of *Acarinina. Acarinina* is regarded as paraphyletic, in that it gave rise to *Morozovelloides* Pearson and Berggren n. gen. in the upper part of the lower Eocene (see Pearson and Berggren Chapter 10, this volume).

The following species are recognized in this chapter: *Acarinina africana* (El Naggar), *Acarinina alticonica* Fleisher, *Acarinina angulosa* (Bolli), *Acarinina aspensis* (Colom), *Acarinina boudreauxi* Fleisher, *Acarinina bullbrooki* (Bolli), *Acarinina coalingensis* (Cushman and Hanna), *Acarinina collactea* (Finlay), *Acarinina cuneicamerata* (Blow), *Acarinina echinata* (Bolli), *Acarinina esnaensis* (LeRoy), *Acarinina esnehensis* (Nakkady), *Acarinina interposita* Subbotina, *Acarinina mcgowrani* Wade and Pearson n. sp., *Acarinina medizzai* (Toumarkine and Bolli), *Acarinina pentacamerata* (Subbotina), *Acarinina praetopilensis* (Blow), *Acarinina primitiva* (Finlay), *Acarinina pseudosubsphaerica* Pearson and Berggren n. sp., *Acarinina pseudotopilensis* Subbotina, *Acarinina punctocarinata* Fleisher, *Acarinina quetra* (Bolli), *Acarinina rohri* (Brönnimann and Bermúdez), *Acarinina sibaiyaensis* (El Naggar), *Acarinina soldadoensis* (Brönnimann), *Acarinina subsphaerica* (Subbotina), *Acarinina topilensis* (Cushman), and *Acarinina wilcoxensis* (Cushman and Ponton).

INTRODUCTION

The genus *Acarinina* was named by Subbotina (1953) for planktonic foraminifera that were supposedly intermediate in morphology between *Globigerina* and *Globorotalia* and lacked a keel. It was revised recently by Olsson and others (1999), who discussed the origin of the genus and the taxonomy of the Paleocene species. The high latitude origin and early evolution of *Acarinina* has been studied in detail by Quillévéré and others (2001, 2002). The Eocene species were descended from two late Paleocene stocks, namely *Acarinina soldadoensis* and *A. esnaensis* (which probably evolved from *A. mckannai* and *A. nitida* respectively, in the late Paleocene).

Acarininids were an important, sometimes dominant, component of Eocene assemblages through the early and middle Eocene, particularly in the middle latitudes. Most species seem to have been mixed-layer dwellers with carbon isotopic characteristics suggestive of a photosymbiotic life habit. Unlike the morozovellids, some species were well adapted to cool high-latitude conditions, as well as occurring in the equatorial regions and subtropics. There were three narrow intervals of taxonomic turnover in acarininid evolution: at the Paleocene/Eocene boundary in Zone E1 at the Paleocene-Eocene Thermal Maximum; in lower Eocene Zone E6-7 (P8-9) (the Cenozoic Optimum) and middle Eocene Zone E10. Towards the end of the middle Eocene, they suffered a rapid reduction in diversity, and only the small and relatively inconspicuous species *A. collactea*, *A. echinata* and *A. medizzai* survived into the upper Eocene (Wade, 2004).

The taxonomy of *Acarinina* is complicated by the rather similar, convergent morphology of many of the species, especially those with four chambers in the final whorl. A central feature of the taxonomy presented here is the radiation, in the early Eocene, of two different groups which are derived, in turn, from two late Paleocene groups (see Berggren and Norris, 1997, and Olsson and others, 1999): the *soldadoensis* group (derived from *Acarinina mckannai*) and the *esnaensis-wilcoxensis* group (derived from *Acarinina nitida*). In the early Eocene the *soldadoensis* group (characterized by predominantly inflated/globular chambers) differentiated into several subgroups: 1) the *angulosa-cuneicamerata* group (with angulate and disjunct chambers); 2) the *pentacamerata-aspensis* group (exhibiting a tendency towards an increasing number of chambers in the final whorl, from 4 to 8-10); 3) the *alticonica-pseudosubspherica* group (characterized by a trend towards a higher conical spiral side, reminiscent of the homeomorphic late Paleocene *subsphaerica*); and 4) the stratigraphically restricted (Zone E1) forms *sibaiyaensis* and *africana* which characterize the Paleocene/Eocene boundary warm interval and are interpreted here as having been derived from *esnehensis*. The derivation of a lineage consisting of the diminutive *collactea-medizzai* morphotypes remains enigmatic, but we suggest that the most plausible origin is in high latitude forms related to *Acarinina pentacamerata*.

In the late early and particularly the middle Eocene *Acarinina pseudotopilensis,* which is part of the *esnaensis-wilcoxensis* group, spawned a major radiation leading to various forms characterized by anguloconical tests and varying degrees of surface ornamentation (*A. boudreauxi, A. bullbrooki* and *A. punctocarinata*) and development of peripheral pseudocarina owing to partial fusion of peripheral muricae which gave rise to *A. praetopilensis* in the middle Eocene. In the later part of the middle Eocene morphotypes with true (probably) functional supplementary apertures on the spiral side of the test evolved. Such forms, which have commonly been assigned to the genus *Truncorotaloides* (as emended by Blow, 1979), are included here in *Acarinina* and interpreted as having evolved from the *pseudotopilensis* lineage. This group is distinguished by having more slender muricae, more incised chambers and the tendency for a strong coiling bias in either the dextral or sinistral direction. (Up to about Zone E9, populations of the *praetopilensis/mcgowrani* group are generally dextrally coiled whereas forms from Zone E10 and above are dominantly sinistral; Pearson, 1990.)

Despite recent deep sea drilling in the sub-Antarctic, relatively little is known of the high latitude acarininids. In many cases they are similar, but not identical, to the better-known mid-latitude and tropical taxa. In these cases they have been included in synonymy, but we expect that detailed taxonomic study would reveal consistent differences that might allow them to be separated taxonomically. The species level range-chart and phylogeny are presented in Figures 9.1 and 9.2.

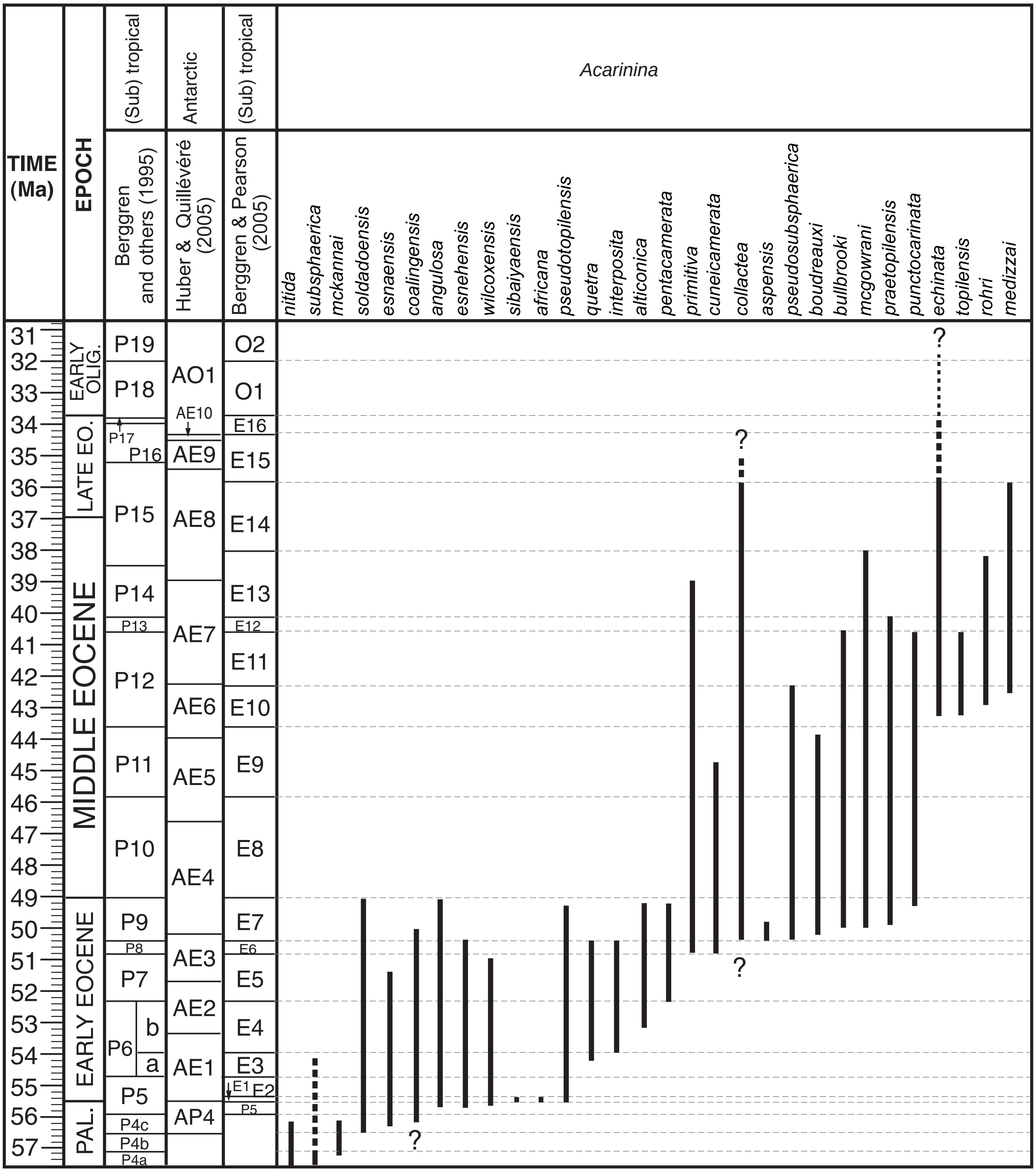

FIGURE 9.1 Stratigraphic ranges of Eocene species of *Acarinina* discussed in this chapter.

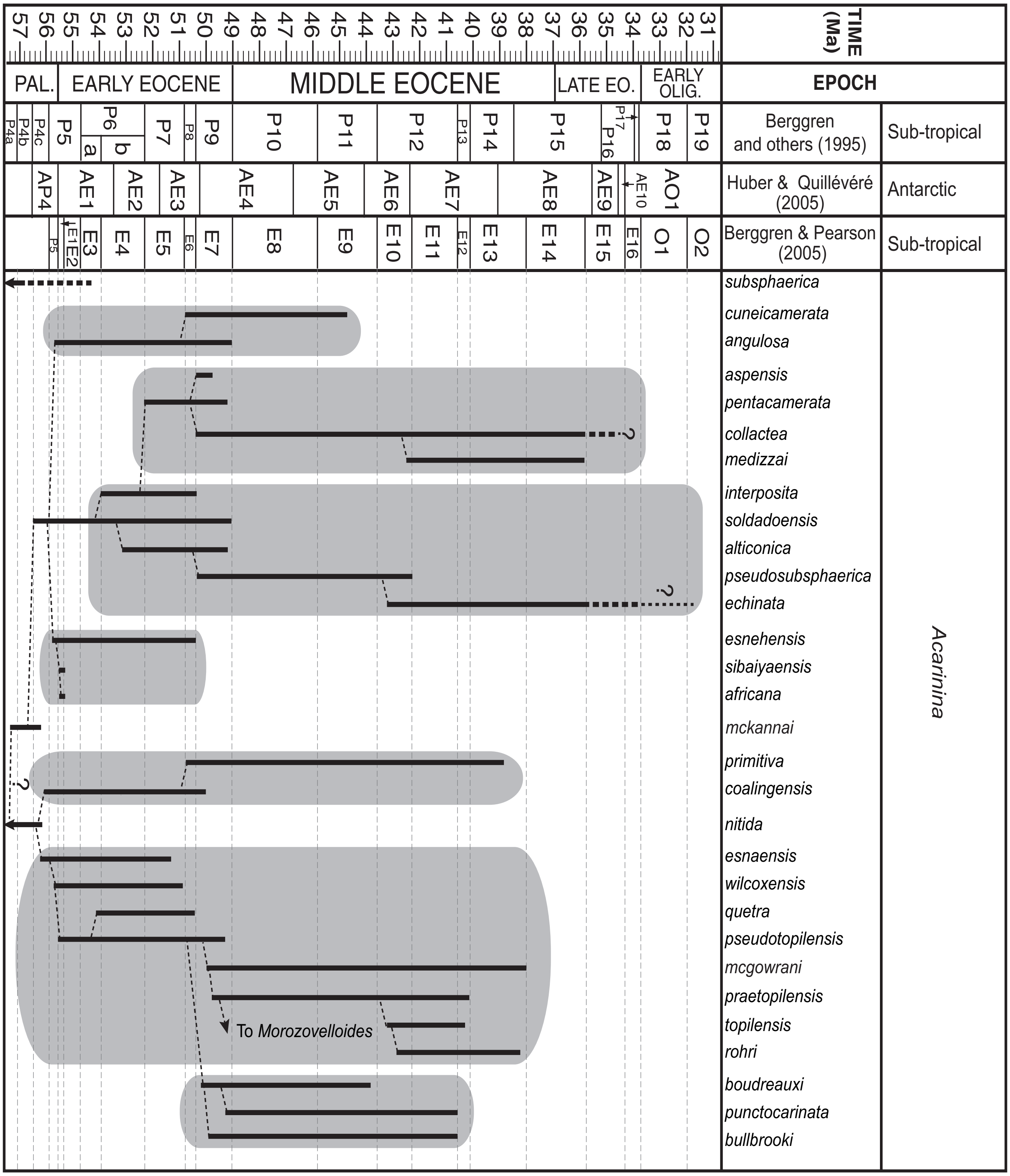

FIGURE 9.2 Inferred phylogenetic relationships of Eocene species of *Acarinina* discussed in this chapter.

SYSTEMATIC TAXONOMY

Order FORAMINIFERIDA Eichwald, 1830
Superfamily GLOBIGERINACEAE Carpenter, Parker and Jones, 1862
Family TRUNCOROTALOIDIDAE Loeblich and Tappan, 1961

DISCUSSION.— See Olsson and others (1999, p. 45).

Genus *Acarinina* Subbotina, 1953

Truncorotaloides Brönnimann and Bermúdez, 1953.
Pseudogloboquadrina Jenkins, 1965b:1122.
Muricoglobigerina Blow, 1979:1118.

TYPE SPECIES.— *Acarinina acarinata* Subbotina, 1953 (=junior subjective synonym of *Globigerina nitida* Martin, 1943; see Olsson and others, 1999).

DISCUSSION.— See Olsson and others (1999 p. 46) for general comments. A particular issue of discussion within the Working Group has been the status of the genus *Truncorotaloides*. Blow (1979, p. 1033-1034) gave a comprehensive overview of the morpho- and phylogenetic trends which he viewed as definitive in delineating the genus *Truncorotaloides* and its differentiation from *Acarinina.* Primary among these was the development of "raised, imperforate (in the sense that normal mural-pores are absent), non-muricate narrow areas of test material usually around the distal (outer) margins of the sutural margins adjacent to the supplementary apertures". These true supplementary apertures were considered functional in life for the extrusion of protoplasm in much the same manner as among the species of modern *Globigerinoides*. The dorsal/spiral apertures seen on *Acarinina* were considered as secondary openings (lacking raised imperforate rims) formed by late stage calcification over previously calcified strongly muricate edges leaving apparent "gaps" in the chamber junctions. Other important aspects of the *Truncorotaloides* stage of evolution included: lateral angulation of the chambers; in advanced (end) members strongly disjunct chambers that bear circumcameral muricocarinae.

Blow (1979, p. 1034) recognized three lineages in which these morphogenetic trends were said to have been iteratively produced:

1) *Truncorotaloides quetra* (evolved from *Acarinina pseudotopilensis*) in his Zone P7 (=Zone E4 of this work);
2) *Truncorotaloides rohri* s.l (supposedly evolved from *Acarinina bullbrooki* via the *Acarinina pseudodubia-piparoensis* group in Zone E10/11);
3) *Truncorotaloides topilensis* (evolved from *Acarinina praetopilensis* in uppermost Zone E7).

While we agree with Blow (1979) on the potential significance of supplementary apertures as adaptive features, and agree that in principle they might be used to delimit genera (as in Neogene *Globigerinoides*) we cannot sustain his generic concept of *Truncorotaloides* because it is demonstrably polyphyletic on Blow's original terms and also according to the modified phylogeny presented here. To recognize *rohri* in a monospecific *Truncorotaloides* would also compel us to name a new genus for *quetra*, which seems unnecessary. Similarly, Blow (1979) included various globular forms in his genus *Muricoglobigerina* that are not closely related according to our researches; hence his concept of that genus is not workable either.

With regard to the validity of the Family Truncorotaloididae Loeblich and Tappan, 1961, the International Code of Zoological Nomenclature, Chapter 8, Article 39 states that the family name is invalid only in cases of homonymy or if the type species is found to be invalid. In this case Article 40 applies: "When the name of a type genus of a nominal family-group taxon is considered to be a junior synonym of the name of another nominal genus, the family-group name is not to be replaced on that account alone". The description of the family remains that of the Truncorotaloididae.

Acarinina africana (El Naggar, 1966)

Plate 9.1, Figures 1-16

Globorotalia africana El Naggar, 1966:193-194, pl. 23: figs. 4a-c [*G. aequa* / *G. esnaensis* Subzone, *G. velascoensis* Zone, Gebel Owaina, Egypt].
Morozovella africana (El Naggar).—Kelly and others, 1998:158-159, fig. 5D [upper Zone P5, from within carbon isotope excursion of late Paleocene Thermal Maximum, ODP Hole 865C, Allison Guyot, central equatorial Pacific Ocean].
Not *Globorotalia* (*Morozovella*) *africana* El Naggar.—Blow, 1979:983, pl. 104: figs. 7-10.
Not *Acarinina* aff. *africana* (El Naggar).—Pardo and others, 1999:44, pl. 2: figs. 13-14.

DESCRIPTION.

Type of wall: Muricate, normal perforate, nonspinose.

Test morphology: Peripheral outline oval, elongate, strongly lobulate; weakly planoconvex to biconvex; test axially compressed; peripheral margin acutely pinched, occasionally with weak muricate keel; chambers triangular on both umbilical and spiral sides; low trochospiral; approximately 10-12 chambers arranged in approximately 3 whorls; chambers vary ontogenetically, with early chambers globular to subconical and later chambers more lenticular, strongly compressed; moderate rate of chamber expansion; sutures gently curved, radial, slightly raised to depressed; primary aperture a low umbilical-extraumbilical arch extending to peripheral margin, sometimes with faint lip; typically 4-6 chambers in final whorl; umbilicus narrow.

Size: Diminutive, typically <0.20 mm; holotype dimensions: maximum diameter: 0.30 mm; minimum diameter: 0.20 mm; thickness: 0.14 mm (last chamber) (El Naggar, 1966, p. 194).

DISTINGUISHING FEATURES.— *Acarinina africana* is distinguished from *A. sibaiyaensis* by its axially-compressed test, strongly lobulate peripheral margin, and manner in which its chambers change ontogenetically from globular to more lenticular shapes.

DISCUSSION.— *Acarinina africana* is a very distinctive and short-lived taxon that is characteristic of the Paleocene-Eocene Thermal Maximum (PETM) event (Kelly and others, 1998).

PHYLOGENETIC RELATIONSHIPS.— This species is closely related to *A. sibaiyaensis* and was probably derived from *A. esnehensis* via *A. sibaiyaensis* during the period of intense environmental stress associated with the PETM event.

STRATIGRAPHIC RANGE.— Restricted to Zone E1, most commonly found within carbon isotope excursion interval of the PETM, although rare specimens (?reworked) have been observed at stratigraphically higher horizons (Kelly and others, 1998).

GEOGRAPHIC DISTRIBUTION.— Ranges from tropical to temperate regions; central equatorial Pacific (ODP Site 865), New Jersey Coastal Plain (Bass River), Tethyan deposits of northern Africa (Egypt) and probable occurrences in Spain (Alamedilla).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (P. 45593) deposited at The Natural History Museum, London; Hypotype (USNM 494823) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina alticonica Fleisher, 1974

PLATE 9.2, FIGURES 1-8
(Pl. 9.2, Figs. 1-3: reillustration of holotype of *Acarinina mattseensis alticonica* Fleisher)
(Pl. 9.2, Figs. 4-8: reillustration of holotype and paratypes of *Globorotalia* (*Acarinina*) *appressocamerata* Blow)

Globigerina collactea (Finlay).—Bolli, 1957a:72, pl. 15: figs. 21-23 [*G. rex* Zone, Guayaguayare well 159, Trinidad].—Bolli, 1957b:162, pl. 35: fig. 18a, b [*G. palmerae* Zone, Navet Fm., Trinidad]. [Not Finlay, 1939.]

Acarinina mattseensis alticonica Fleisher, 1974: pl. 2: figs. 1-5 [lower Eocene Zone P8, DSDP Site 229, Arabian Sea].

Globorotalia (*Acarinina*) *appressocamerata* Blow, 1979:907-908, pl. 144: figs. 2, 4-9 (7=holotype) [Zone P8b, DSDP Hole 20C, South Atlantic Ocean].

Globorotalia (*Acarinina*) cf. *appressocamerata* Blow, 1979:907-908, pl. 144: figs. 1, 3 [Zone P8b, DSDP Hole 20C, South Atlantic Ocean].

Acarinina appressocamerata Blow.—Lu and Keller, 1995: pl. 3: figs. 9, 10 [Zone P7, DSDP Site 577, Shatsky Rise, north-west Pacific Ocean].

DESCRIPTION.

Type of wall: Densely muricate, particularly around umbilicus.

Test morphology: Medium to high trochospiral, biconvex to subspherical, weakly lobulate test; circular outline, rounded periphery in edge view; in umbilical view equatorial profile slightly lobate, 5 moderately inflated, embracing, appressed, angulate chambers in last whorl, gradually increasing in size, tightly coiled around relatively narrow, deep umbilicus which is bordered by circumumbilical coalescence of prominent muricae; intercameral sutures radial, weakly incised; aperture a low arched, umbilical-extraumbilical slit bordered by distinct lip; on spiral side 11-12 chambers, tangentially longer than radially broad, coiled in $2^1/_2$ whorls; intercameral sutures weakly curved and incised; chambers rounded in edge view.

Size: Maximum diameter of holotype of *A. alticonica:* 0.31 mm; axial elevation: 0.30 mm (Fleisher, 1974, p. 1013); Maximum diameter of holotype of *A. appressocamerata*: 0.37 mm (Blow, 1979, p. 907)

DISTINGUISHING FEATURES.— This form is distinguished by its strongly muricate test with a high trochospire and closely appressed, angular chambers. It is distinguished from *A. subsphaerica* and *A. pseudosubsphaerica* n. sp. by having more compressed, angular chambers and a less high-spired test.

DISCUSSION.— This is a distinct early Eocene acarininid with superficial resemblance to the (predominantly) Paleocene morphotype *Acarinina subsphaerica* (Shutskaya). Blow (1979, p. 907) drew attention to these similarities in describing his new species *Acarinina appressocamerata* but observed that *appressocamerata* differed from *subsphaerica* in having more angulate chambers on the umbilical side and a more sharply delimited, more open, quadrate-shaped umbilicus (compared to the more rounded chambers and more restricted umbilicus in *subsphaerica*). Blow (1979, p. 908) also observed the lack of stratigraphic overlap between these two forms. *Acarinina subsphaerica* is abundant in Zone P4, and its last common occurrence in tropical sites has been used to subdivide Zone P4 (Berggren and others, 1995), although it may range higher in higher latitudes (Olsson and others, 1999, Berggren and others, 2000). Our detailed studies in Egypt have shown *A. alticonica* to appear in mid-Zone E4, a little lower than recorded by Blow (1979, p. 908). It forms a distinct component of early Eocene faunas (together with *A. interposita*, *A. pentacamerata*, *A. soldadoensis*, *Morozovella formosa*, *M. lensiformis*, *M. subbotinae*, among others).

Fleisher's (1974) species *Acarinina mattseensis alticonica*, which he described as having a restricted range in Zone P8 (=E6) in the Arabian Sea, appears to be a prior synonym exhibiting the same morphologic characters recorded by Blow (1979) in describing *appressocamerata*. While Fleisher drew attention to superficial resemblance of his taxon with *Subbotina senni*, he firmly rejected any affinity between the two forms.

PHYLOGENETIC RELATIONSHIPS.— Probably descended from *A. soldadoensis* and ancestral to *A. pseudosubsphaerica* n. sp.

STRATIGRAPHIC DISTRIBUTION.— Zone E4-E7.

GEOGRAPHIC DISTRIBUTION.— Caribbean, South Atlantic, Tethys (Egypt).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (USNM 211525) deposited in the Smithsonian Museum of Natural History, Washington, D.C.

***Acarinina angulosa* (Bolli, 1957a)**

Plate 9.3, Figures 11-16
(Pl. 9.3, Figs. 13-15: new SEMs of holotype of *Globigerina soldadoensis angulosa* Bolli)

Globigerina soldadoensis angulosa Bolli, 1957a:71, pl. 16: figs. 4-6 [lower Eocene *Globorotalia formosa formosa* Zone, Lizard Springs area, Trinidad].—Bolli, 1957b:162, pl. 35: figs. 8a-c [lower Eocene *Globorotalia palmerae* Zone, Navet Fm., Trinidad].

Acarinina soldadoensis angulosa (Bolli).— Hillebrandt, 1965:345, pl. 5: fig. 11 [Zone P9, Agost, Alicante Province, Spain].—Fleisher, 1974:1014, pl. 4: fig. 1 [lower Eocene Zone P9, DSDP Site 220, Arabian Sea].

?*Turborotalia* (*Acarinina*) *soldadoensis angulosa* (Bolli).— Samuel and others, 1972:190, pl. 68, figs. 1a-c [lower Eocene *Globorotalia subbotinae* Zone, Hradisko, Middele Váh Valley, West Carpathian].

Muricoglobigerina soldadoensis angulosa (Bolli).—Blow, 1979:1122, pl. 109: fig. 9, pl. 131: figs. 4-5 [lower Eocene Zone P6 of Blow, 1979), DSDP Hole 47.2, Shatsky Rise, north-west Pacific Ocean]—?Belford, 1984:30, pl. 22: figs. 9-12 [lower Eocene Zones P8-9, Papua New Guinea].

DESCRIPTION.

Type of wall: Muricate, normal perforate, nonspinose.

Test morphology: Low trochospiral test with lobulate peripheral outline; about 10-12 chambers in 2 $^1/_2$ whorls; $4^1/_2$-5 subangular chambers in last whorl gradually increasing in size, separated by straight, radial and depressed sutures; spiral side flat to slightly convex, sutures curved/oblique; umbilicus moderately wide, open, deep; aperture a low interiomarginal-umbilical arch extending nearly to the periphery; axial / edge view subangular.

Size: Maximum diameter of holotype 0.40 mm, thickness 0.28 mm.

DISTINGUISHING FEATURES.—The diagnostic features of *Acarinina angulosa* are the strongly angular disposition of the chambers of the last whorl and the strongly lobulate peripheral outline.

DISCUSSION.—This distinctive taxon is a common component of lower Eocene (sub)tropical assemblages where it is associated with other acarininids (*soldadoensis, interposita, pentacamerata, pseudotopilensis*) and morozovellids (*subbotinae, formosa, gracilis, aragonensis*). In the course of our studies in Egypt we have found that this taxon has its FAD just below the base of the CIE / PETM interval, i.e., within the uppermost part of Zone P5 (as redefined in Berggren and Pearson, 2005).

PHYLOGENETIC RELATIONSHIPS.— This species evolved from *Acarinina soldadoensis* in uppermost Zone P5 and probably gave rise to *A. cuneicamerata.*

STRATIGRAPHIC RANGE.— Zone P5 (uppermost part) to Zone E7. Note that the Paleocene part of the range was not recorded by Olsson and others (1999).

GEOGRAPHIC DISTRIBUTION.— Ranges from tropical to temperate regions; Arabian Sea, north Pacific Ocean (DSDP Site 47), New Jersey Coastal Plain (Bass River), Tethyan deposits of northern Africa (Egypt) and occurrences in Spain (Alicante Province) and New Guinea.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (USNM P5037) deposited in the Smithsonian Museum of Natural History, Washington, D. C.

Acarinina aspensis (Colom, 1954)

PLATE 9.4, FIGURES 1-16
(Pl. 9.4, Fig. 1: reillustration of lectotype of *Globigerina aspensis* Colom)

Globigerina aspensis Colom, 1954:151, pl. 3: figs. 1-35 (flattened forms); pl. 4: figs. 1-31 (trochoid forms) (No holotype designated; lectotype, pl. 3: fig. 16 selected by Blow, 1979:908) [Upper Ypresian - Lower Lutetian, Aspe, Alicante, Spain.].— Bermúdez, 1961:1157-1158, pl. 1: fig. 2a-c [Lower Eocene, Universidad Fm., Havana Province, Cuba].

Globorotalia aspensis (Colom).—Bolli, 1957b:167-168, pl. 37: figs. 18a-c [Lower Eocene *Globorotalia palmerae* Zone, Navet Fm., Trinidad].

Acarinina aspensis (Colom).—Hillebrandt, 1965:340, pl. 5: figs. 8, 12, 13 [Lower Eocene *G. palmerae* Zone, Alicante, Spain].—Lu and Keller, 1995, pl. 3: figs. 16-18 [lower Eocene, DSDP Site 577, Shatsky Rise, northwest Pacific Ocean].— Poag and Commeau, 1995: pl. 2: figs. 28-29 [lower Eocene, Hammond Core, Maryland].

Turborotalia (*?Acarinina*) *aspensis* (Colom).—Samuel and Salaj, 1968:162, pl: 18, fig. 4 [Eocene, Carpathian Mountains, Slovakia].

Globorotalia (*Acarinina*) *aspensis* (Colom).—Blow, 1979:908-911, pl. 148: figs. 7-9; pl. 153: figs. 5-6; pl. 157: figs. 1-6; pl. 165: figs. 5-6; pl. 203: fig. 6 [Zones P9-P10, Kane 9-C piston core, Endeavour seamount, North Atlantic Ocean].

Acarinina pentacamerata Subbotina *acceleratoria* Khalilov, 1956:253, pl. 5: figs. 7a-c [lower Eocene, north-eastern Azerbaidjan].

Globigerina colomi Bermúdez, 1961:1167, pl. 2: fig 6a-c [lower Eocene, Universidad Fm., Cuba].

Plate 9.1 *Acarinina africana* (El Naggar, 1966)

1-11, 13-16, Zone E1, Bass River Borehole, New Jersey, ODP 174AX: 1150.0-1171.5 feet; **12**, Zone P5, equatorial Pacific Ocean, ODP 199/1220A/20X, CC. Scale bar: **1-16** = 100 µm.

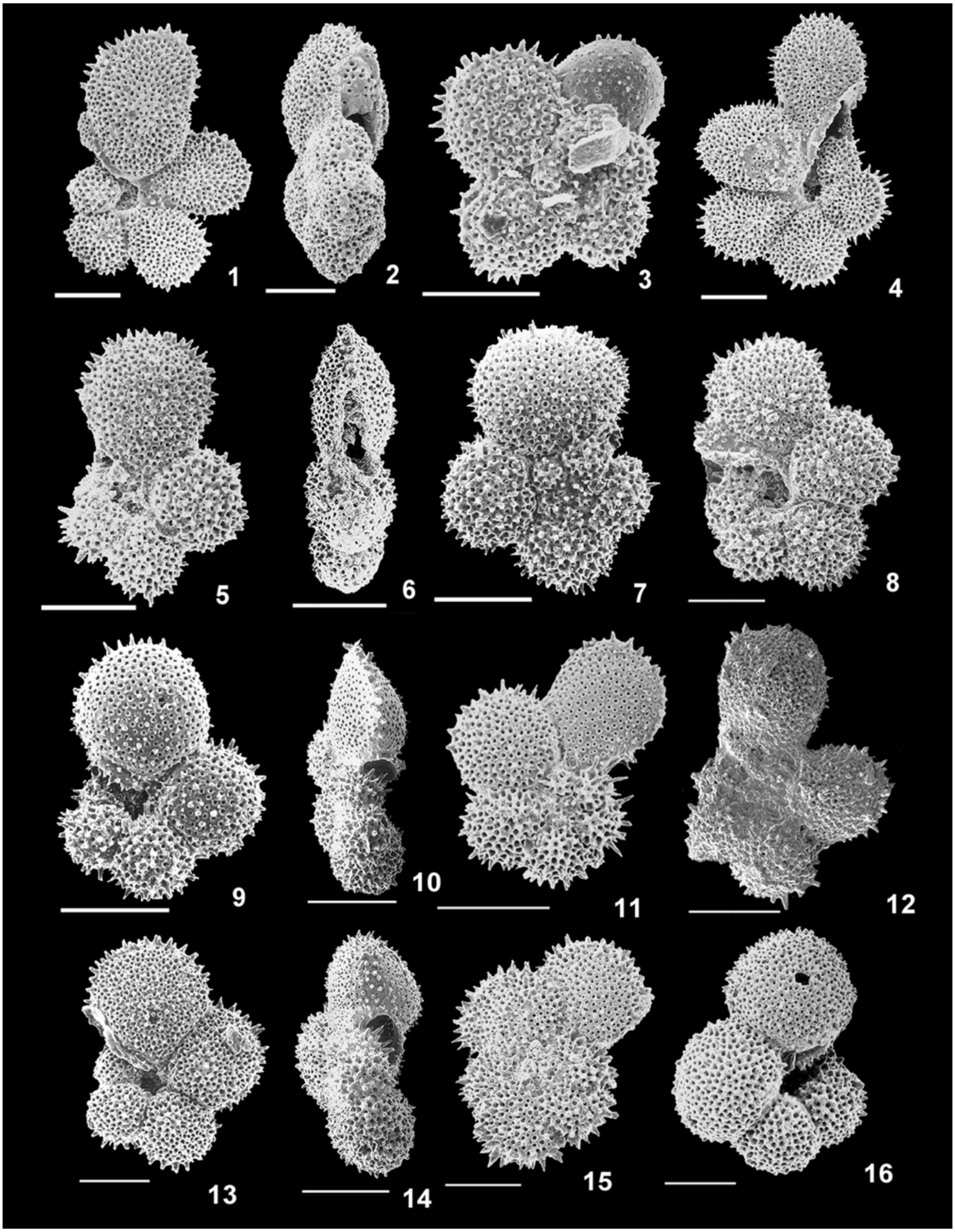

Plate 9.1 *Acarinina africana* (El Naggar, 1966)

DESCRIPTION.

Type of wall: Normal perforate, non-spinose with coarse muricae.

Test morphology: Low trochospiral, variable number of subglobular chambers (ranging from 6-8, rarely to 10) in last whorl; intercameral sutures radial, moderately depressed between weakly embracing chambers; umbilicus deep, wide as a result of relatively lax/evolute coiling, no circum-umbilical concentration of muricae; 2-2 1/2 whorls on spiral side; intercameral sutures weakly recurved between early chambers, straight, radial between later chambers; rounded periphery in edge view with no evidence of circum-peripheral concentration of muricae; aperture interiomarginal, umbilical-extraumbilical, extending to peripheral margin in last chamber.

Size: Dimensions of holotype unknown; this is, however, a relatively large form that can exceed 0.5 mm in maximum diameter.

DISTINGUISHING FEATURES.— This taxon is distinguished by its large and widely open umbilicus and high but variable number (6-8; rarely to 10) of chambers in the last whorl.

DISCUSSION.— In comparison to *Acarinina pentacamerata, A. aspensis* is characterized by an increase in the number of chambers in the final whorl, a more evolute spire and concomitant increase in the width of the umbilicus. This form was originally described from the lower Eocene of Spain, at which time a large number of specimens were illustrated but no holotype designated. Blow (1979, p. 909) designated the specimen illustrated by Colom (1954, pl. 3: fig. 16, reillustrated on Pl. 9.4, Fig. 1) as a lectotype, perpetuating the taxonomic concept of this form established by Bolli (1957a, p. 167-168, pl. 37, figs. 18a-c).

PHYLOGENETIC RELATIONSHIPS.— Bolli (1957b, p. 167) suggested derivation of *aspensis* from *angulosa*. Berggren (1964) and Blow (1979) suggested instead that it evolved from *pentacamerata*, a view which we uphold here.

STRATIGRAPHIC RANGE.— Confirmed occurrences only in the lower part of Zone E7. Our studies suggest that *aspensis* may prove to be a very useful biostratigraphic marker. Some previous authors, since Bolli (1957b, p. 167) have probably confused *aspensis* with *cuneicamerata* and hence suggested a much longer stratigraphic range, into the middle Eocene (see also Berggren 1977, p. 259 and Blow, 1979, p. 911).

GEOGRAPHIC DISTRIBUTION.— Widespread in (sub)tropical regions of the world; not reliably reported (to our knowledge) from austral or boreal regions.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Lectotype (Blow, 1979, p. 909) reported to be in the personal collection of G. Colom.

Acarinina boudreauxi Fleisher, 1974

Plate 9.5, Figures 9-16
(Pl. 9.5, Figs. 9-11: new SEMs of holotype of *Acarinina boudreauxi* Fleisher)

Acarinina boudreauxi Fleisher, 1974:1112, pl. 1: figs. 2-5 [lower middle Eocene Zone P11, DSDP Site 219, Arabian Sea].

DESCRIPTION.

Type of wall: Robust, heavily calcified, wall with blocky fused muricae.

Plate 9.2, 1-8, *Acarinina alticonica* Fleisher, 1974; 9-16, *Acarinina pseudosubsphaerica* Pearson and Berggren n. sp.

Acarinina alticonica **1-3** (holotype, USNM 211525), DSDP Site 220/16/2, 68-70 cm, Arabian Sea. **4-8** *Acarinina appressocamerata* (5, holotype, Blow pl. 144, figs. 7, 4, 6-8, paratypes, pl. 144, figs. 1, 2, 5, 8), Zone E6, DSDP Hole 20C/5/4: 77-79 cm, Gulf of Mexico. *Acarinina pseudosubsphaerica* **9-10, 14** (9-10, holotype, USNM 523427; 14, paratype, USNM 523428a), Zone E9, TDP Site 2/9CC; **13** (paratype, USNM 523428b), Zone E8, TDP Site 2/18/1, 20-26 cm; **15** (paratype, USNM 523428c), Zone E8, TDP Site 2/19/1: 10-20 cm, Kilwa, Tanzania; **11**, **16,** Zone E9, ODP Site 549/7/3, 100-103 cm, North Atlantic Ocean; **12**, Zone E9, ODP Site 523/47/1, 118-120 cm, South Atlantic Ocean. Scale bar: **1-16:** = 100 µm.

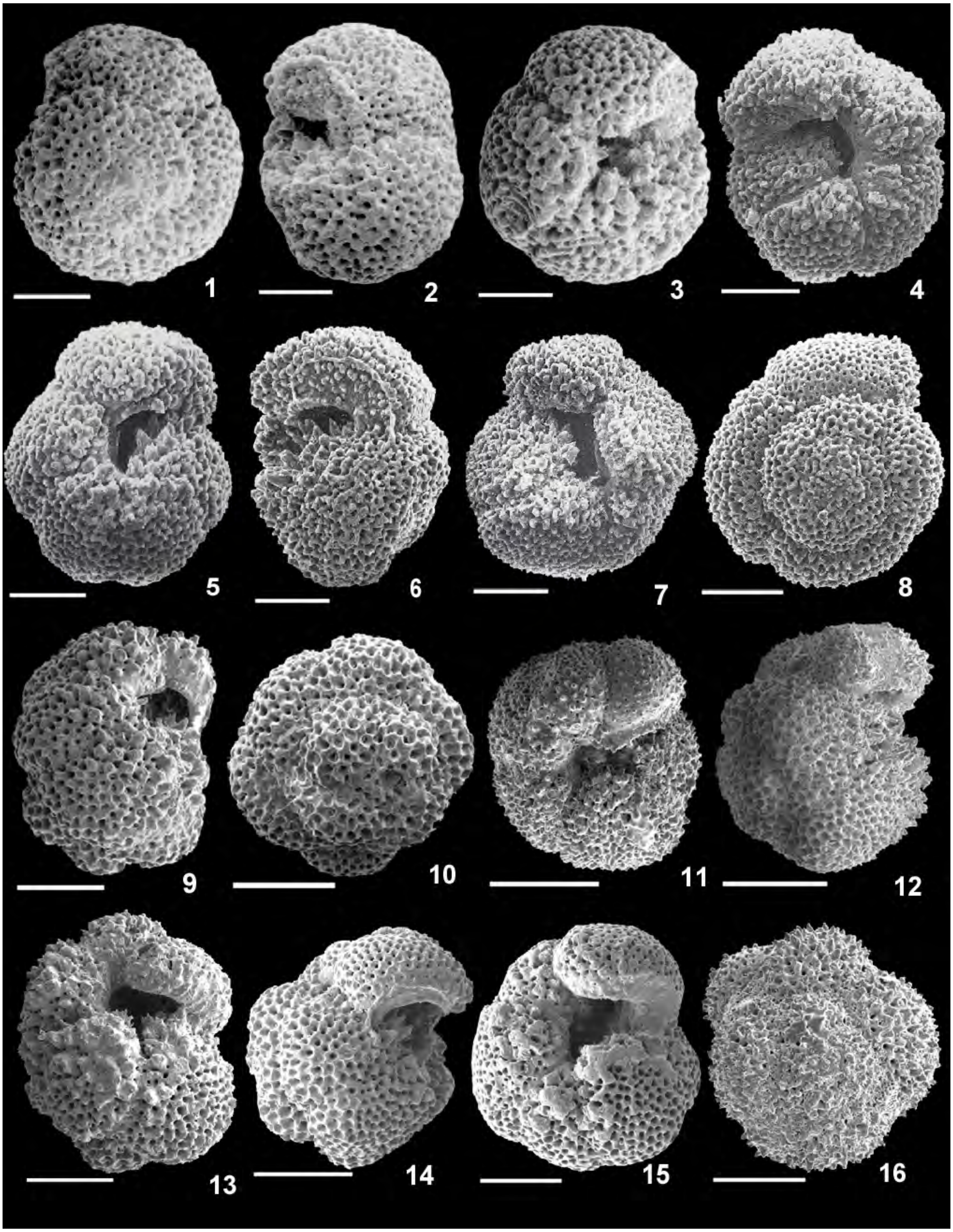

Plate 9.2 *Acarinina alticonica* Fleisher, 1974, *Acarinina pseudosubsphaerica* Pearson and Berggren n. sp.

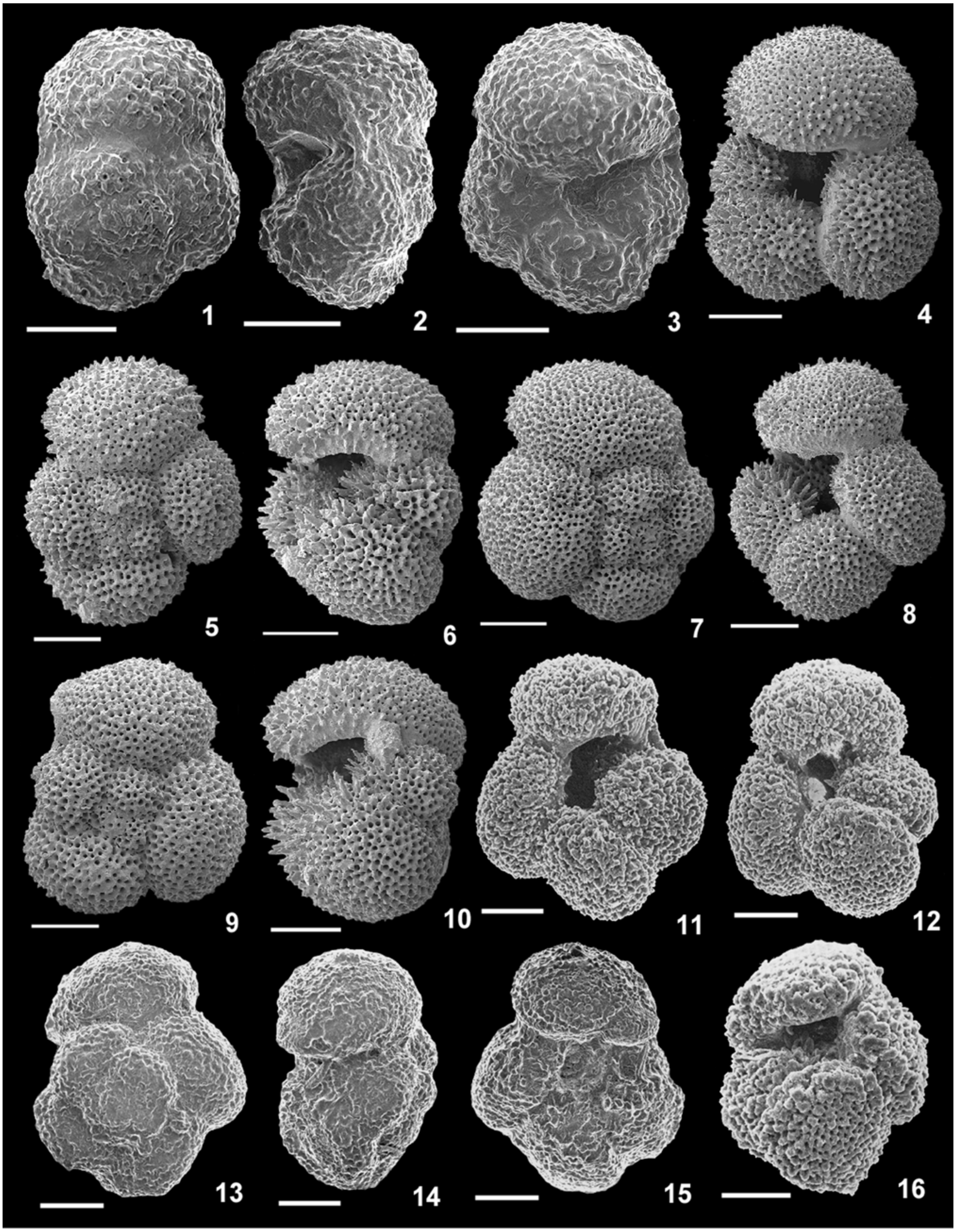

Plate 9.3 *Acarinina soldadoensis* (Brönnimann, 1952), *Acarinina angulosa* (Bolli, 1957)

Test morphology: Subcircular planconvex test, coiled in a low trochospiral with 4 1/2-5 chambers in the final whorl; chambers radially compressed and appressed with flat or slightly depressed sutures on a flat spiral side; aperture umbilical-extraumbilical, a low arch; ventral sutures straight, radial and depressed converging on a narrow, deep umbilicus; periphery subacute.

Size: Maximum diameter of holotype 0.28 mm; thickness 0.21 mm.

DISTINGUISHING FEATURES.— *Acarinina boudreauxi* is distinguished from *A. interposita* by the much tighter coil and more compressed chambers, and by having straight radial sutures on the umbilical side and an anguloconical test. *Acarinina boudreauxi* differs from *A. punctocarinata* by lacking a discontinuous muricocarina and typically being smaller; it differs from *A. bullbrooki* by its rounded profile and more slowly expanding chambers and the 4 1/2-5 (as opposed to 4) chambers in the final whorl.

DISCUSSION.— This taxon has rarely been used, but is nevertheless a distinctive form. Originally described from Zones P9 to P11 in the Arabian Sea area, it has recently been found at the same levels in Tanzanian drill cores (Pl. 9.5, Figs. 13-16). *Acarinina boudreauxi* is clearly related to the *A. bullbrooki* group, particularly the *matthewsae* morphotype described by Blow (1979) (here considered conspecific with *bullbrooki*) but appears lower/earlier in the record, and provides a possible evolutionary link for that group with lower Eocene *Acarinina pseudotopilensis*.

PHYLOGENETIC RELATIONSHIPS.— Possibly evolved from *Acarinina pseudotopilensis* and was ancestral to *A. punctocarinata* and *A. bullbrooki*.

STRATIGRAPHIC RANGE.— Ranges from the lower Part of Zone E7 to within Zone E9.

GEOGRAPHIC DISTRIBUTION.— Probably widespread; currently known only from the Indian Ocean.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY— Holotype (USNM 211386) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina bullbrooki (Bolli, 1957)

Plate 9.6, Figures 1-16
(Pl. 9.6, Figs. 1-3, 5-7: new SEMs of holotype and paratype of *Globorotalia bullbrooki* Bolli)
(Pl. 9.6, Fig. 13: reillustration of holotype of *Globorotalia* (*Acarinina*) *matthewsae* Blow)
(Pl. 9.6, Fig. 16: new SEM of holotype of *Globigerina spinuloinflata* Bandy)

Globorotalia crassata (Cushman) var. *densa* (Cushman).—Cushman and Barksdale, 1930:68, pl. 12: figs. 8a-b [Martinez Fm., Martinez, California].—Cushman, 1939:74, 75, pl. 12: figs. 20a-b [northwest Atlantic Ocean, off eastern North America].—Cushman and Renz, 1948:40, pl. 8: figs. 7, 8 [Navet Fm., Trinidad].—Bandy, 1949:80, pl. 12: figs. 4a-c [Tallahatta Fm., Clarke County, Alabama].—Hamilton and Rex, 1959:793, pl. 252: figs. 8, 9 [Sylvania Guyot, Bikini Atoll, Marshall Islands].—Todd and Low, 1960:850, pl. 259: fig. 13a-c [Eniwetok Atoll, Marshall Islands].—Saito, 1962:214-215, pl. 33: figs. 5a-11c [Haha Jima, Bonin Islands, western Pacific Ocean].—Aubert, 1962:58, pl. 2: figs. 4a-c [middle Eocene, Morocco]. [Not Cushman, 1925.]

Plate 9.3, 1-10, *Acarinina soldadoensis* (Brönnimann, 1952); 11-16, *Acarinina angulosa* (Bolli, 1957)

Acarinina soldadoensis **1-3** (holotype, USNM 370079), Zone P5, lower zone of Lizard Springs Fm., Trinidad; **4-10**, Zone E1, Bass River Borehole, New Jersey, ODP 174AX, 1167.0-1167.9 feet. *Acarinina angulosa* **11, 12** (Blow, 1979, pl. 131, figs. 4, 5), Zone E6, DSDP Hole 47.2/8/2, 71-73 cm; **16** (Blow, 1979, pl. 109, fig. 9), Zone P5, DSDP Hole 47.2/8/4, 78-81 cm, northwest Pacific Ocean; **13-15** (holotype, USNM P5037), Zone E6, Ravine Ampelu, Lizard Springs area, Trinidad. Scale bar: **1-16** = 100 μm.

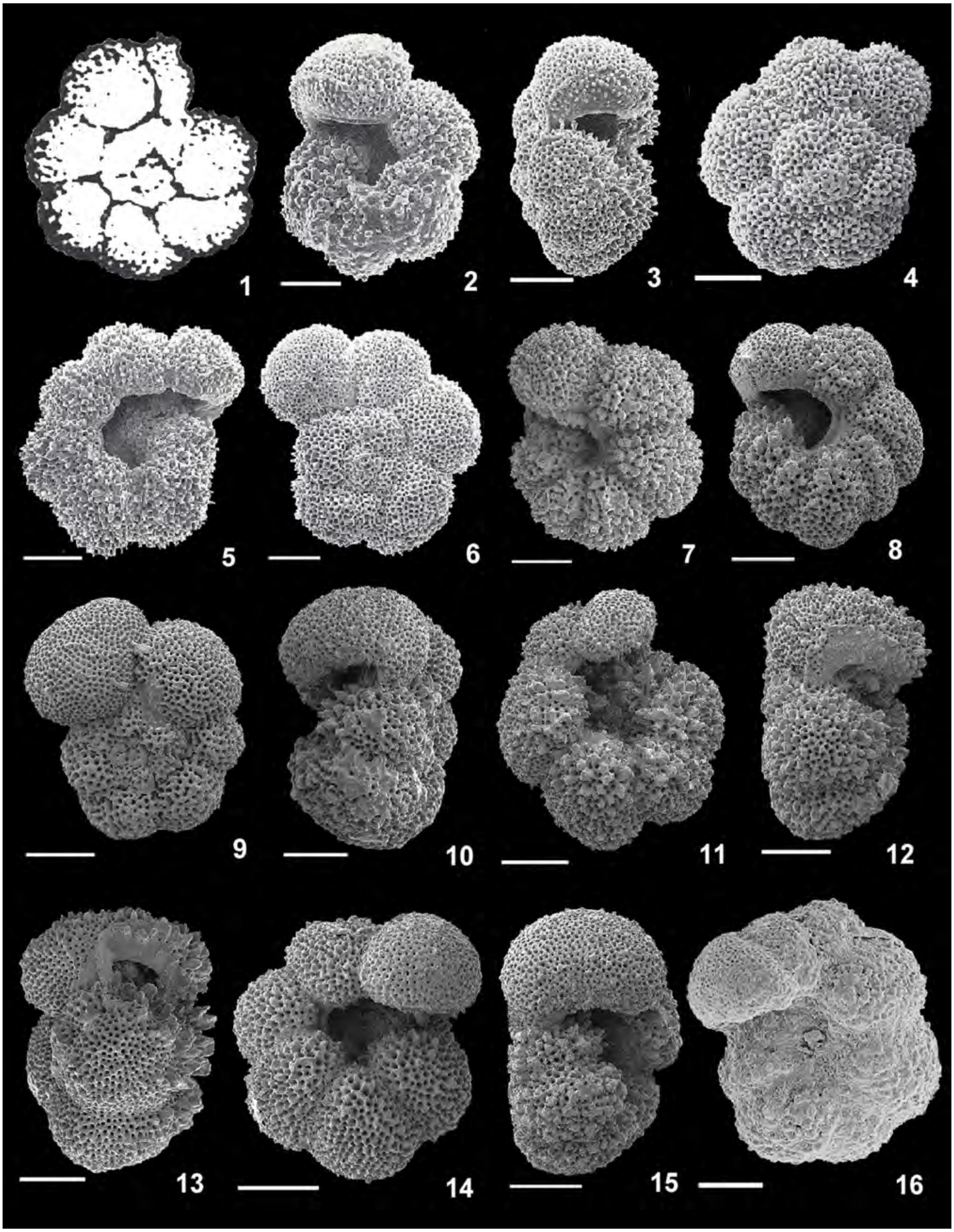

Plate 9.4 *Acarinina aspensis* (Colom, 1954)

Globorotalia (Truncorotalia) crassata (Cushman) var. *densa* (Cushman).—Cushman and Bermúdez, 1949:38, pl. 7: figs. 10-12 [Matanzas Province, Cuba]. [Not Cushman, 1925.].

Globorotalia densa (Cushman).—Pessagno, 1960:99, pl. 5: fig. 3 [south-west Puerto Rico], pl. 1: figs. 1-3 [Jacaguas Group, south central Puerto Rico]. [Not Cushman, 1925.]

Acarinina densa (Cushman).—Berggren, 1977:259, chart no. 12 (reillustration of figured specimens in literature). [Not Cushman, 1925.]

?*Globigerina decepta* Martin 1943:114, pl. 7, figs. 2a-c [lower Eocene, Lodo Fm, Fresno Co., California].

?*Globorotalia* (*Acarinina*) *decepta* (Martin).—Blow, 1979:926, pl. 149, figs. 2-6 [lower Eocene, Zone P9, KANE 9-C piston core, Endeavour Seamount, equatorial Atlantic Ocean], pl. 154, fig. 5 [middle Eocene, Zone P10, KANE 9-C piston core, Endeavour Seamount, equatorial Atlantic Ocean].

?*Globigerina spinuloinflata* Bandy, 1949:122, pl. 23: figs., 1a-c [Tallahatta Fm., Claiborne Group, Little Stave Creek, Clarke County, Alabama].—Cifelli, 1972:159, figs. 2a-c (reillustration of holotype) [lower Eocene, Tallahatta Fm., Claiborne Group, Little Stave Creek, Alabama].

?*Globorotalia spinuloinflata* (Bandy).—Bandy, 1964:6, pl. 4: fig. 19 (reillustration of holotype).

?*Globorotalia* (*Acarinina*) *spinuloinflata* (Bandy).—Jenkins, 1971:83, 84, pl. 4: figs. 99-101, pl. 5: figs. 119-122 [*G. (G.) index* Zone, Hampden Beach, lower part of Bortonian Stage, New Zealand; = tightly coiled, 4$^1/_2$ chambered form].

Globorotalia crassaformis Galloway and Wissler.—Subbotina, 1953:223 (*partim*), pl. 21: figs. 4a-c [Zone of conical globorotaliids, Green Group, Kuban River, North Caucasus]. [Not Galloway and Wissler, 1927.]

Globorotalia bullbrooki Bolli 1957b:167, pl. 38: figs. 4a-c and 5a-b (holotype) [Zone P10, Navet Fm., Trinidad].

Globorotalia (Acarinina) bullbrooki Bolli.—Blow, 1979:915, pl. 149: figs. 8 and 9, pl. 155 (*partim*), figs. 1-2, 6-8 [Zone P9-P10, KANE 9, piston core 42, Endeavour Seamount, equatorial Atlantic Ocean] (not figs. 3-5 = *A. mcgowrani*), pl. 171: figs. 1-3 and 7-9 [Zone P11, Kilwa area, Tanzania].

Globorotalia (*Acarinina*) sp. ex interc. *G.* (*A.*) *pseudotopilensis* (Subbotina) and *G.* (*A.*) *bullbrooki* (Bolli).—Blow, 1979:915, pl. 143: figs. 1-5 [Zone P8b, DSDP Hole 20C, South Atlantic Ocean].

Globorotalia (*Acarinina*) cf. *bullbrooki* Bolli.—Blow, 1979:915, pl. 187: figs. 6, 7 [DSDP Site 19, South Atlantic Ocean].

Acarinina bullbrooki (Bolli).—Huber, 1991:439, pl. 3, figs. 6, 7 [*Acarinina collactea* (AP10) Zone, ODP Site 738, Kerguelen Plateau, southern Indian Ocean].— Berggren, 1992:563, pl. 2: figs. 9,10 [*Acarinina bullbrooki / A. matthewsae* Zone; ODP Hole 748B, Kerguelen Plateau, South Indian Ocean].

Globorotalia (*Acarinina*) *matthewsae* Blow 1979:935, pl. 170: figs. 1 (holotype) –9; pl. 203: fig. 3 = detail of pl. 170: fig. 2 [Zone P11, sample RS. 24, Kilwa area, Tanzania], pl. 179: figs. 1 and 2 [DSDP Hole 21A, South Atlantic Ocean]; pl. 187: fig. 5 [Zone P12, DSDP Site 19, South Atlantic Ocean], pl. 204: figs. 1-5, pl. 205: figs. 1-6 [Sample RS. 24, Kilwa area, Tanzania].

Acarinina matthewsae Blow.—Huber, 1991:439, pl. 3, figs. 3, 4 [middle Eocene Zone AP8, ODP Hole 738B, Kerguelen Plateau, southern Indian Ocean].—Berggren, 1992:563, pl. 2, figs. 7, 8 [*Acarinina bullbrooki* Zone, middle Eocene, ODP Hole 749B, Kerguelen Plateau, southern Indian Ocean].—Pearson and others, 2004:37, pl. 2, figs. 5, 6 [middle Eocene, Zone P11, Tanzania Drilling Project Site 2, Kilwa Masoko, Tanzania].

DESCRIPTION.

Type of wall: Strongly muricate, non-spinose, normal perforate.

Test morphology: Quadrate, low-trochospiral; 4 inflated, moderately embracing, hemispherical chambers in last whorl; intercameral sutures radial, straight, depressed; umbilicus narrow to moderately wide in some (usually) younger forms, no circumumbilical rim of concentrated muricae; aperture a low, rimmed opening extending towards, but not reaching, the periphery; spiral side with lunate shaped chambers distributed in 2-2$^1/_2$

Plate 9.4 *Acarinina aspensis* (Colom, 1954)

1 (lectotype, Colom, 1954, pl. 3, fig. 16), lower/middle Eocene, Alicante, Spain; **2** (Blow, 1979, pl. 153, fig. 6), Zone E7, KANE 9-Core 42, 163 cm; **3, 5, 6** (Blow, 1979, pl. 157, figs. 1, 4, 5), Zone E8, KANE 9-Core 42, 95 cm; **4** (Blow, 1979, pl. 148, fig. 7), Zone E7, KANE 9-Core 42, 200 cm, Endeavor Seamount, equatorial Atlantic Ocean; **7-15**, Zone E7, sample 21.0907/1, Tanzania; **16** (hypotype, Bolli, 1959, USNM P5738), Zone E7, Navet Fm., Trinidad. Scale bar: **1-16** = 100 μm.

whorls; small, discrete opening(s) are observed rarely on well-preserved individuals; sutures weakly curved; edge view rounded to subangular; moderate marginal/ peripheral concentration of muricae gives impression of pseudocarina in some instances.

Size: Maximum diameter of holotype 0.43 mm, thickness 0.32 mm.

DISTINGUISHING FEATURES.— *Acarinina bullbrooki* is distinguished by its (sub)quadrate test, closely appressed and embracing chambers, rounded to subangular periphery, and weak to moderate murical concentration on the periphery. It differs from *A. praetopilensis* and related forms in having less incised sutures, generally smaller muricae, and by populations generally being approximately randomly coiled.

DISCUSSION.— Subbotina (1947, p. 129, pls. 8, 9; 1953, p. 223, pl. 21) was one of the first to recognize and illustrate the plexus of late early to middle Eocene acarininids now associated with the *bullbrooki* and *punctocarinata* group. She referred a suite of specimens (pl. 21, figs. 1a-7c) to the Pliocene-Holocene taxon *crassaformis*. The illustrated forms would appear to be referable to *A. wilcoxensis/quetra* (pl. 21, figs. 1a-c) from the *G. marginodentata* Subzone (lower Eocene); *A. decepta* (pl. 21, figs. 2a-3c; see Blow, 1979, pl. 149, figs. 1-7; pl. 154 (from the lower Eocene Zone of conical globorotaliids); *Acarinina bullbrooki* (pl. 21, figs. 4a-c) from the Zone of conical globorotaliids; *A. quetra* (pl. 21, figs. 5a-c) from the lower part of the Zone of acarininids, middle Eocene; *Acarinina primitiva* (pl. 21, figs. 7a-c) from the upper middle Eocene *Lyrolepis caucasica* Beds, Zone of thin-walled pelagic foraminifera; and an apparent morozovelloidid referable to *Morozovelloides crassatus* (pl. 21, figs. 6a-c (from the Zone of thin-walled pelagic foraminifera [~/= Zone P14]).

The status of this taxon has long remained in limbo because of the uncertainty surrounding the generic identity of the holotype of *Globorotalia bullbrooki* Bolli and its uncertain relationship with *Pulvinulina crassata* var. *densa* Cushman (see discussion in Blow, 1979). Pessagno (1961) suggested that *Globorotalia bullbrooki* Bolli should be considered a junior synonym of *densa*, based on examination of the primary types at the USNM, a viewpoint accepted by Berggren (1966, 1968, 1977). Blow (1979, p. 915) noted that although he had made a cursory examination of the holotype of *densa* during a visit the U.S. National Museum in 1965 it was not found during a subsequent visit to the museum in May 1970 and presumed to be missing, a view seemingly confirmed in a subsequent letter to Blow from the then curator Richard Cifelli that the holotype of *densa* was indeed "not in our collections and I have no knowledge of it" (letter by Cifelli to Blow, 15th September 1970). Blow (1979: 915) suggested that unless the holotype was found it would be better to consider *densa* a *nomen non conservandum*, because of its similar appearance to *decepta* Martin, *praetopilensis* Blow, and *pseudotopilensis* Subbotina and the fact that it might be referable to either *bullbrooki* or any one of these three forms. Enigmatically the holotype of *densa* (Cushman Collection 3027) was described and redrawn only two years later by Cifelli (1972). The specimen appears to exhibit a beaded peripheral keel, hallmark of a morozovellid rather than an acarininid. Although poorly preserved, we have illustrated the holotype in SEM and have assigned it (questionably) to *Morozovelloides crassatus* (see Pearson and Berggren, Chapter 10, this volume).

The holotype of *bullbrooki* (USNM P5742) has a subangular peripheral margin and lacks a peripheral muricocarina. The paratype of *bullbrooki* (USNM P5743) is somewhat smaller and has a subrounded periphery in edge view. Toumarkine and Bolli have

Plate 9.5, 1-8, *Acarinina punctocarinata* Fleisher, 1974; 9-16, *Acarinina boudreauxi* Fleisher, 1974

Acarinina punctocarinata **1-3** (holotype, USNM 211532), Zone E9, DSDP Site 220/12/5, 71-72 cm, Arabian Sea; **4-8** Zone E11, TDP Site 13/9/1, 0-11 cm, Mkazambo, Tanzania. *Acarinina boudreauxi* **9-11** (holotype, USNM 211386), Zone E9, DSDP Site 219/19/6, 51-53 cm, Arabian Sea; **12**, Zone E8, TDP 2/19/1, 90-100 cm, Tanzania; **13-16**, Zone E7, TDP 2/28/2, 16-24 cm, Tanzania. Scale bar: **1-16** = 100 µm.

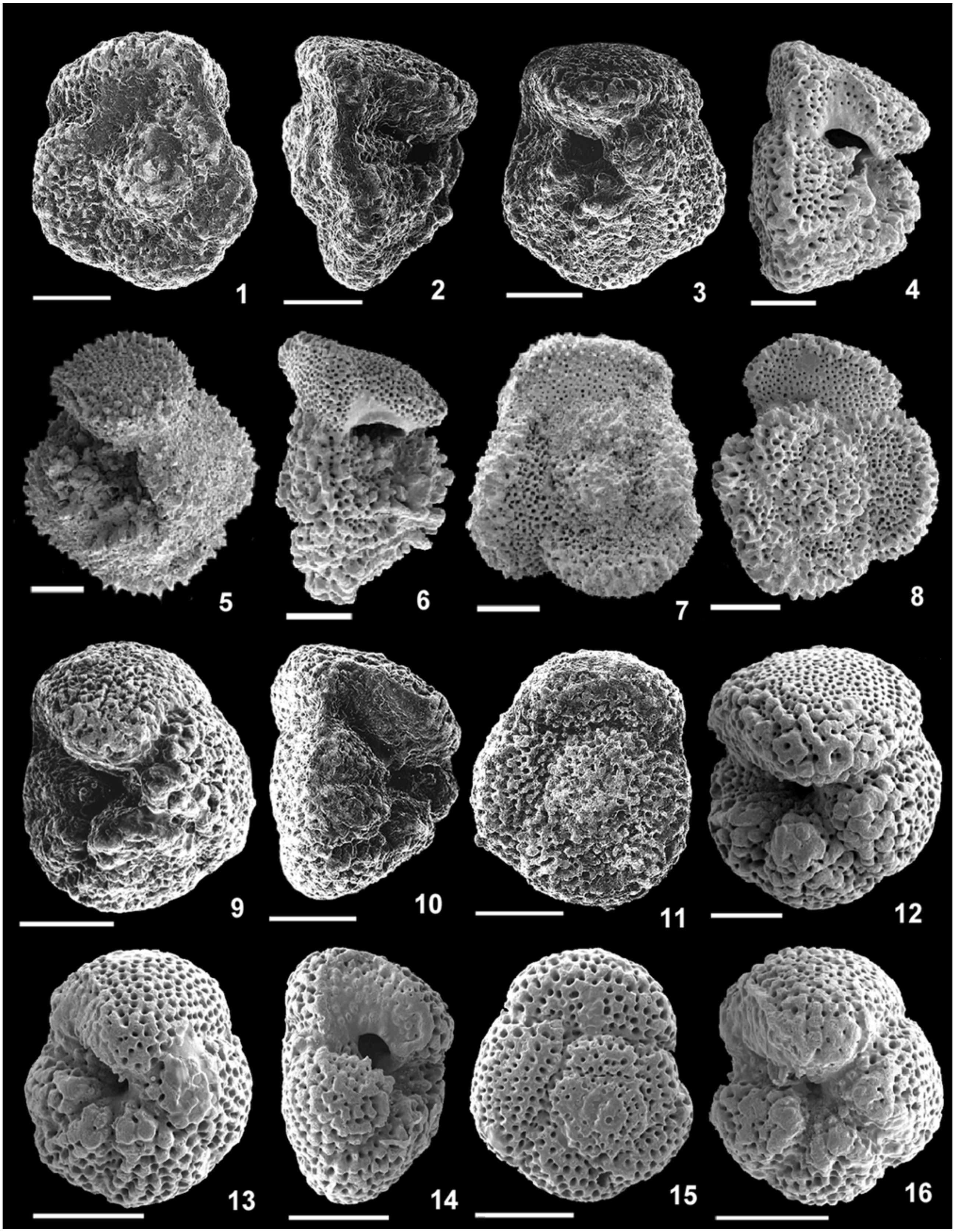

Plate 9.5 *Acarinina punctocarinata* Fleisher, 1974, *Acarinina boudreauxi* Fleisher, 1974

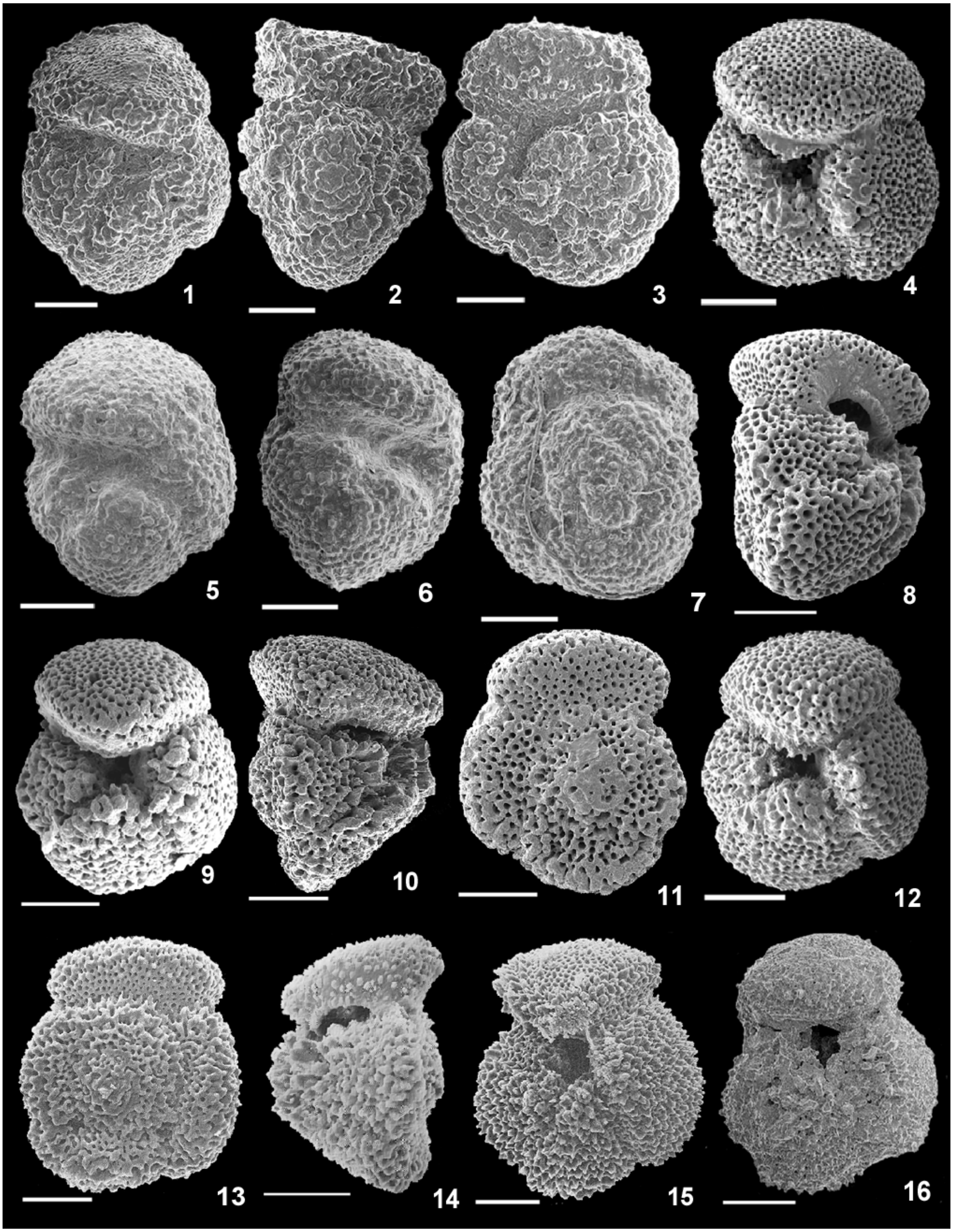

PLATE 9.6 *Acarinina bullbrooki* (Bolli, 1957)

deposited a suite of specimens of *bullbrooki* in the Cushman Collection at the USNM from Site 313 of DSDP Leg 32 which includes individuals with muricate (but unkeeled) peripheral margins varying from angulate to subangular to subrounded, reinforcing the understanding that Bolli included a wide range of variation in his concept of *bullbrooki*, an interpretation which we follow here.

Blow (1979, p. 926-928) treated the taxon *Acarinina decepta* (Martin) in some detail, the essential features of which are listed below:

1) *Acarinina decepta* was interpreted as ancestral to *A. matthewsae* by way of intermediate morphotypes of *A. nitida;*
2) *A. decepta* is distinguished from its ancestor *A. pseudotopilensis* by a slight increase in the number of chambers in the last whorl, reduction in the tangential elongation of the later chambers and in having a more quadrate (as opposed to lobulate) peripheral outline;
3) The morphotypes *decepta* and *nitida* lie at the early end of the morphogenesis that leads from *pseudotopilensis* to *matthewsae*;
4) *A. decepta* also forms a link between *A. pseudotopilensis* and *A. cuneicamerata*;
5) *A. pseudotopilensis* evolved into the angulate *A. topilensis* without passing through a "*decepta*" intermediate stage; in similar fashion *A. pseudotopilensis* evolved into *A. bullbrooki* at stratigraphic levels prior to the "*decepta*/*nitida*" morphotypes;
6) The name *decepta* serves as a useful means of recognizing the complex of forms from which the extreme end members *matthewsae* and *cuneicamerata* differentiate from the *pseudotopilensis* rootstock.

The various illustrations provided by Blow (1979) of the taxa cited above do point to the intermediate nature of the morphology of *A. decepta*. Reference to the illustrations of Martin (1943, pl. 7) and Blow (1979, pls. 149, 154) suggest closest affinities of *decepta* with *bullbrooki* (compare Blow, 1979, pl. 149, fig. 4 with Blow, 1979, pl. 155, fig. 6, for example). In this work we have included *A. matthewsae* as a junior synonym of *A. bullbrooki*. In view of the intermediate morphologies expressed in *A. decepta* and its enigmatic affinities we include *A. decepta* here provisionally as a dubious prior synonym of *A. bullbrooki*.

Globigerina spinuloinflata Bandy, 1949 has long been considered a junior synonym of either *densa* or a senior synonym of *bullbrooki* as Bandy (1964, p. 6) pointed out. (Re)illustration / drawing of the holotype of *spinuloinflata* Bandy by Cifelli (1972) shows marked similarities with *bullbrooki*, even though Cifelli called attention to the somewhat more rounded periphery of *spinuloinflata* in edge view as did Toumarkine and Bolli (1975, p. 130). We have been able to illustrate the holotype of *Globigerina spinuloinflata* Bandy from the Tallahatta Formation of Alabama. While it is difficult to place this form, we believe it may be conspecific with *bullbrooki* as Bandy proposed, in which case it could be regarded as the senior synonym. We retain *bullbrooki*, however, in the interests of nomenclatural stability, because in contrast to *spinuloinflata*, *bullbrooki* is a well-known form with historically consistent usage in the works of Bolli and coauthors and the holotype of *spinuloinflata* is not a common or central morphotype among the middle Eocene acarininids that have historically been referred to *bullbrooki*.

Acarinina bullbrooki is a widely used taxon in middle Eocene biostratigraphy. However, its biostratigraphic utility has been somewhat compromised by uncertainty regarding its taxonomic affinities. With

Plate 9.6 *Acarinina bullbrooki* (Bolli, 1957)

1-3 (holotype, USNM P5742), **5-7** (paratype, USNM P5743), *Hantkenina aragonensis* Zone, Navet Fm, Trinidad; **4, 9-11**, Zone E9, TDP Site 2/9/CC; **8**, Zone E8, TDP Site 2/17/2, 35-43 cm; **12**, Zone E8, TDP Site 2/18/1, 20-26 cm, Kilwa, Tanzania; **13,14** *Globorotalia* (*Acarinina*) *matthewsae* Blow, 1979, (13 holotype, Blow, 1979, pl. 170, fig. 1; 14, paratype, Blow, 1979, pl. 179, figs. 1, 2), Zone E9, DSDP Hole 21A/1/4, 148-150 cm, South Atlantic Ocean; **15** (paratypes, Blow, 1979, pl. 170, figs. 3, 8), Zone E9, sample RS.24, Kilwa Area, Tanzania; **16** *Globigerina spinuloinflata* Bandy (holotype), lower-middle Eocene, Clark County, Alabama. Scale bar: **1-16** = 100 µm.

the recognition that *densa, decepta,* and *spinuloinflata* cannot be definitively placed, the biostratigraphic utility of *bullbrooki* can now be re-established.

PHYLOGENETIC RELATIONSHIPS.— Probably evolved from *A. boudreauxi* (in Zone E7).

STRATIGRAPHIC RANGE.— ZONE E7 to Zone E11.

GEOGRAPHIC DISTRIBUTION.— Cosmopolitan distribution (see synomy above).

STABLE ISOTOPE PALEOBIOLOGY.— Boersma and others (1987) and Pearson and others (1993, 2001) record this species as having isotope ratios indicative of a surface mixed layer habitat.

RESPOSITORY.— Holotype (USNM P5742) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina coalingensis (Cushman and Hanna, 1927)

PLATE 9.7, FIGURES 1-16
(Pl. 9.7, Figs. 1-3: new SEMs of holotype of *Globigerina coalingensis* Cushman and Hanna)

See Olsson and others (1999, p. 47) for synonymy list and taxonomic discussion (and also discussion, below).

DISCUSSION.— Berggren and Norris (1997) and Olsson and others (1999) discussed the gradual evolution of the *coalingensis-primitiva* lineage and included *primitiva* in synonymy with *coalingensis*. Having studied populations of *A. primitiva* in the type Hampden Beach Formation, New Zealand, we now conclude that they are not synonymous; see also under *A. primitiva*. We restrict the concept of *coalingensis* to the robust, triangular-subquadrate tests with (predominantly) globular chambers (typified by *Globigerina coalingensis* Cushman and Hanna) and its junior synonym *Acarinina triplex* Subbotina.

STRATIGRAPHIC RANGE.— Zone P4c-E7; (not to P14, = E13 of this study, as given by Olsson and others, 1999).

Acarinina collactea (Finlay, 1939)

PLATE 9.8, FIGURES 1-16
(Pl. 9.8, Figs. 1-7: new SEMs of holotype and paratypes of *Globorotalia collactea* Finlay)

Globorotalia collactea Finlay, 1939:327, pl. 29: figs. 164, 165 [middle Eocene, Hampden Beach, North Otago, New Zealand].
Globigerina collactea (Finlay).—Hornibrook, 1961, p. 149 [middle Eocene, Hampden Beach, North Otago, New Zealand].
Truncorotaloides collactea (Finlay).—Jenkins, 1965a:843-848, figs. 1-3 (holotype reillustrated).—Berggren, 1969:139, pl. 3: figs. 13-15 [Søvind Marl, Moesgaard Strand, Denmark].—Samanta, 1970:206, pl. 3: figs. 15-17 [*Orbulinoides beckmanni* Zone, Lakhpat, Cutch, western India].—Jenkins, 1971:134, 135, pl. 14: figs. 402-404 (holotype reillustrated), 405-407 (paratypes) [middle Eocene, Hampden Beach, North Otago, New Zealand].—McKeel and Lipps, 1972:82, 83, pl. 1: figs. 5a-c [lower middle Eocene upper Tyee Fm., Ulatisian Stage, Oregon Range].—Berggren, 1977:261 (reillustration of figures from the literature).—Toumarkine and Luterbacher, 1985:132, figs. 6. 7, 9 (re-illustrations from the literature; incorrect reference made to Jenkins, 1985, Chapter 7 for illustrations).—Jenkins, 1985:280, figs. 6, 10a-c (reillustration from literature).—Jenkins and Srinivasan, 1986:824, pl. 5: figs. 11, 12 [*G. aculeata* Zone, DSDP Site 592, Lord Howe Rise, south-west Pacific Ocean].—

Plate 9.7 *Acarinina coalingensis* (Cushman and Hanna, 1922)

1-3 (holotype) lower Eocene, California; **4, 9-16**, Zone E1, Bass River Borehole, New Jersey, ODP 174AX, 1145.0-1169.2 feet; **5-8**, (5-7, *Acarinina triplex* Subbotina, 1953, holotype, pl. 23, figs. 1a-c), Paleocene-lower Eocene, northern Caucasus. Scale bar: **1-16** = 100 µm.

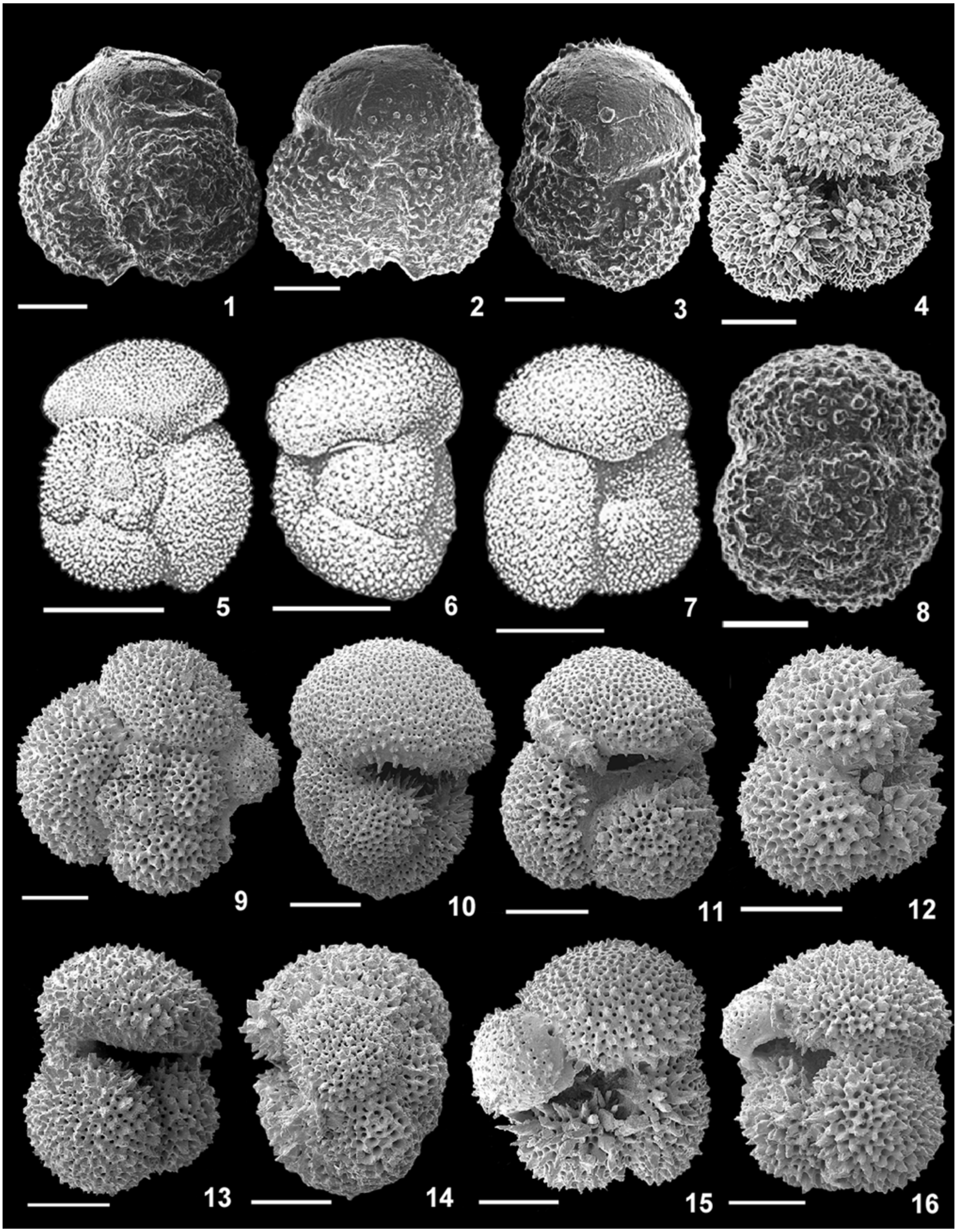

Plate 9.7 *Acarinina coalingensis* (Cushman and Hanna, 1922)

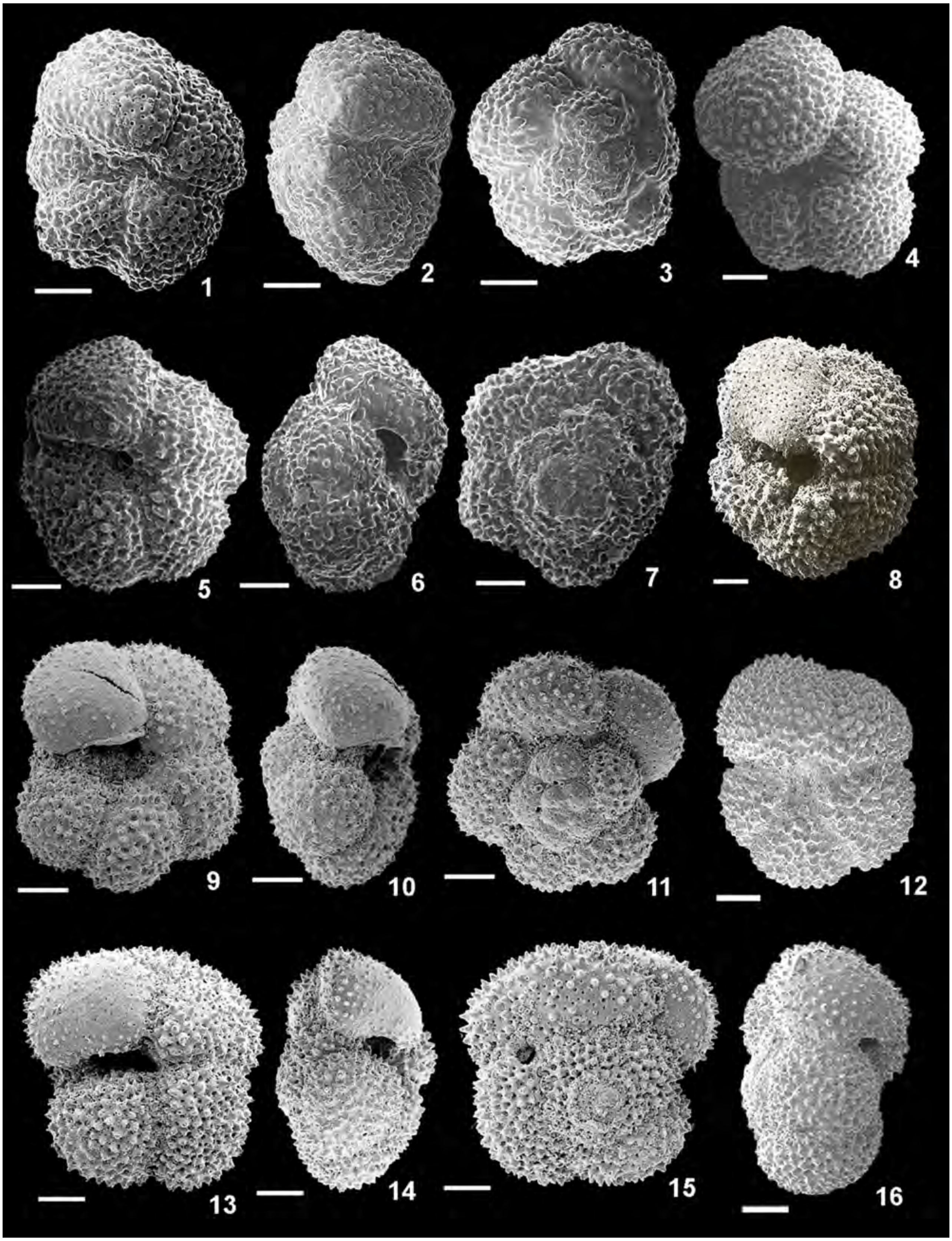

Plate 9.8 *Acarinina collactea* (Finlay, 1939)

Poore and Brabb, 1977:269, pl. 5: figs. 5-7 [Zone P13/14 equivalent, Butano Sandstone Fm., Santa Cruz Mountains, California].

Globorotalia (*Acarinina*) *collactea* Finlay.—Blow, 1979:919, pl. 172: figs. 7-9 [Zone P11, sample RS. 24, Kilwa area, Tanzania]; pl. 194: figs. 1-4 [Zone P13, Sample RS. 311, Kilwa area, Tanzania].

Acarinina collactea (Finlay).—Stott and Kennett, 1990:559, pl. 6: figs. 7,8 [Zone AP8, ODP Hole 689B, Maud Rise, Antarctic Ocean].—Huber, 1991:439, pl. 3, figs. 16, 17 [Zone AP 10, Hole 738B, Kerguelen Plateau, southern Indian Ocean].—Berggren, 1992:563, pl. 2: figs. 13-15 [middle Eocene *A. collactea* Zone, ODP Hole 748C, Kerguelen Plateau, southern Indian Ocean].—Lu and Keller, 1993:103, pl. 3: figs. 12-13 [lower Eocene Zone AP7, ODP Hole 738C, Kerguelen Plateau, southern Indian Ocean].

Truncorotaloides collacteus (Finlay).—Poore and Bybell, 1988:20, pl. 5: figs.7, 8 [*Turborotalia pomeroli* / *T. cerro-azulensis* Zone, Mansquan Fm., Core ACGS #4, New Jersey].

Acarinina rotundimarginata Subbotina, 1953:234, pl. 25: figs. 1a-c (holotype), 2a-3c [middle Eocene Zone of thin-walled pelagic foraminifera, Bura Group, Kuban River section, north Caucasus].

Truncorotaloides rotundimarginata (Subbotina).—Berggren, 1960b:53, pl. 1: figs. 19a,b [middle Eocene, approximately equivalent to Zones P10/11, Otta borehole, western Nigeria].

Globorotalia spinuloinflata (Bandy).—Bolli, 1957b:168, pl. 38: figs. 8a-c [*P. mexicana* Zone, Navet Fm., Trinidad]. [Not Bandy, 1949.]

Truncorotaloides pseudodubia (Bandy).—Berggren, 1969:155, pl. 3: figs. 10-12 [Søvind Marl, Moesgaard Strand, Denmark]. [Not Bandy, 1949.]

Not *Globigerina collactea* (Finlay).—Brönnimann, 1952:13, pl. 1: figs. 13-15 [*G. aragonensis* Zone, Ramdat Marl, Navet Fm. (= upper Lizard Springs Fm., see Bolli, 1957a:64, south-east Trinidad].—Bolli, 1957a:72, pl. 15: figs. 21-23 [*G. rex* Zone, upper Lizard Springs Fm., Trinidad].—Bolli,1957b:162, pl. 35: figs. 18a-b [*G. palmerae* Zone, Navet Fm., Trinidad].—Postuma, 1971:146, 147, text-figs. on p. 147 [*G. formosa formosa* Zone, Trinidad].

DESCRIPTION.

Type of wall: Nonspinose; normal perforate; densely muricate on both sides.

Test morphology: Test low-trochospiral, 5 subangular, essentially equal sized chambers in last whorl, separated by straight radial to weakly curved intercameral sutures; umbilicus narrow, deep; aperture a low, arched slit along the base of the last chamber; weakly convex to flat; about 12 rounded chambers in three whorls on the spiral side; sutures radial, straight to weakly curved; minute intercameral openings visible at chamber junction margins on some well-preserved specimens; rounded to subangular peripheral margin in edge view.

Size: Maximum diameter of holotype 0.18 mm, thickness 0.13 mm.

DISTINGUISHING FEATURES.— This taxon is distinguished by its small size (~0.25-0.30 mm in maximum diameter), 5-chambered and compact (involute) test. *Acarinina medizzai* is morphologically similar to, and probably descended from, *A. collactea*. The moderately muricate *medizzai* may be distinguished from *collactea* in having a smaller (generally less than 0.2 mm in diameter), lower trochospiral test and more restricted aperture.

DISCUSSION.— This is one of the most distinct and ubiquitous components of middle Eocene planktonic foraminiferal assemblages. Distinguished by its small size and compact, densely muricate test with irregularly distributed minute "openings" on the spiral side, it is a familiar and particularly common form in mid-high latitude assemblages.

This form has been thoroughly studied and documented by Jenkins (1965a) who re-examined

Plate 9.8 *Acarinina collactea* (Finlay, 1939)

1-8 (1-3, holotype, NGS TF1150/1; 4-7, paratypes, USNM 689047), upper lower Eocene, Hampden Beach section, North Otago, New Zealand; **9-11, 13-15** (same specimens), Zone AE7, ODP Hole 738B/15X/CC; **12, 16**, Zone AE7, ODP Site 1135/8R/7, 75-79 cm, Kerguelen Plateau, southern Indian Ocean. Scale bar: **1-16** = 40 μm.

Finlay's original type material. Blow (1979, p. 920) noted that the suturally-located openings on the spiral side do not appear to be functional supplementary apertures and may owe their origin to the "stand off" effect of late stage calcification preventing smooth junction of adjacent chambers owing to the development of previously calcified muricae in the intervening space(s).

The form identified by Bolli (1957a) as *Globorotalia spinuloinflata* (Bandy) is a subangular variant of the generally more rounded *collactea* and included here in the synonomy of *collactea*. In the former Soviet Union *collactea* has been identified as *Acarinina rotundimarginata* Subbotina from the middle Eocene of the N. Caucasus. We specifically exclude from *collactea* the ovate, sinistrally coiled specimens identified by Brönnimann (1952) and Postuma (1971) from the lower Eocene (Zone P6b) of Trinidad. *Acarinina collactea* is generally subcircular in outline, dextrally coiled and restricted to stratigraphically younger levels. The possible extension of this taxon into upper Eocene levels in high latitudes remains controversial.

PHYLOGENETIC RELATIONSHIPS.— Ancestry uncertain; possibly descended from *A. pentacamerata*; this morphospecies probably evolved into *A. medizzai*.

STRATIGRAPHIC RANGE.— Zone E7 to Zone E14. On the Kerguelen Plateau *collactea* disappears at a stratigraphic level possibly correlative with Magnetochron C17n (~/= to Zones NP17/18=P15; ~ 37 Ma; near the Bartonian/Priabonian = middle/late Eocene boundary; Berggren, 1992, p. 556, 557). Earlier, the record from the Søvind Marl in Denmark (Berggren, 1969) suggested extension to the Priabonian/late Eocene (*Isthmolithus recurvus* Zone =NP19/20).

GEOGRAPHIC DISTRIBUTION.— As the synonymy given above indicates, this taxon has an essentially cosmopolitan distribution, having been recorded from latitudes in excess of 50^{o} in both the northern (Denmark, NW Germany) and southern (Kerguelen Plateau and Maud Rise) hemispheres.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY— Holotype (TF 1150/1) and paratypes deposited in collections of the New Zealand Geological Survey Collection, Lower Hutt, New Zealand.

Acarinina cuneicamerata (Blow, 1979)

Plate 9.9, Figures 1-16
(Pl. 9.9, Figs. 1-4, 8: reillustration of holotype and paratypes of *Globorotalia* (*Acarinina*) *cuneicamerata* Blow)

? *Globorotalia berwaliana* Mohan and Soodan, 1969:9-10, pl. 1 a-f [Middle Eocene *Globigerinoides kugleri* - *Globigerina frontosa* Assemblage Zone, Berwali Stream, Kutch, India].

Globorotalia (*Acarinina*) *cuneicamerata* Blow, 1979:924 (*partim*), pl. 146: figs. 6-8 [Zone P9, DSDP Site 47, Shatsky Rise, north-west Pacific Ocean], pl. 153: figs. 1-4 [Zone P9, KANE 9, piston core 42, Endeavour Seamount, equatorial Atlantic Ocean], pl. 156 figs. 1, 2 (holotype), 3-4; pl. 203: fig. 5, detail of pl. 146: fig. 5 (given erroneously as detail of pl. 156: fig. 6); pl. 165: figs. 4 and 7 [Zone P10, KANE 9, piston core 42, 95 cm; Endeavour Seamount, equatorial Atlantic Ocean].

Globorotalia (Acarinina) sp. ex interc. *G. (A.). decepta* (Martin) and *G. (A.) cuneicamerata* n.sp.—Blow, 1979:924, pl. 154: figs. 6, 7 [Zone P10, KANE 9, piston core 42, 95 cm; Endeavour Seamount, equatorial Atlantic Ocean].

Plate 9.9 *Acarinina cuneicamerata* (Blow, 1979)

1-3 (1, holotype, Blow, 1979, pl.156, fig. 2; 2, 3, paratypes, Blow, 1979, pl.156, figs. 1, 3), Zone E8, KANE 9 Core 42, 95 cm; **4** (paratype, Blow, 1979, pl.153, fig. 2), Zone E8, KANE 9, Core 42, 163 cm; **13-15**, Zone E8, KANE 9 Core 42, 15 cm, Endeavour Seamount, equatorial North Atlantic Ocean; **5-7, 9-12**, (5-7, 9-11 same specimens), Zone E7/8, WHOI Piston Core 2625B, 20-30 cm, Oceanographer Canyon, western North Atlantic Ocean; **8** (paratype, Blow, 1979, pl. 146, fig. 6), DSDP Site 47/2/7, 65-67 cm, western North Pacific Ocean; **16**, Zone E8, TDP Site 2/23/1, 65-75 cm, Kilwa, Tanzania. Scale bar: **1-16** = 100 µm.

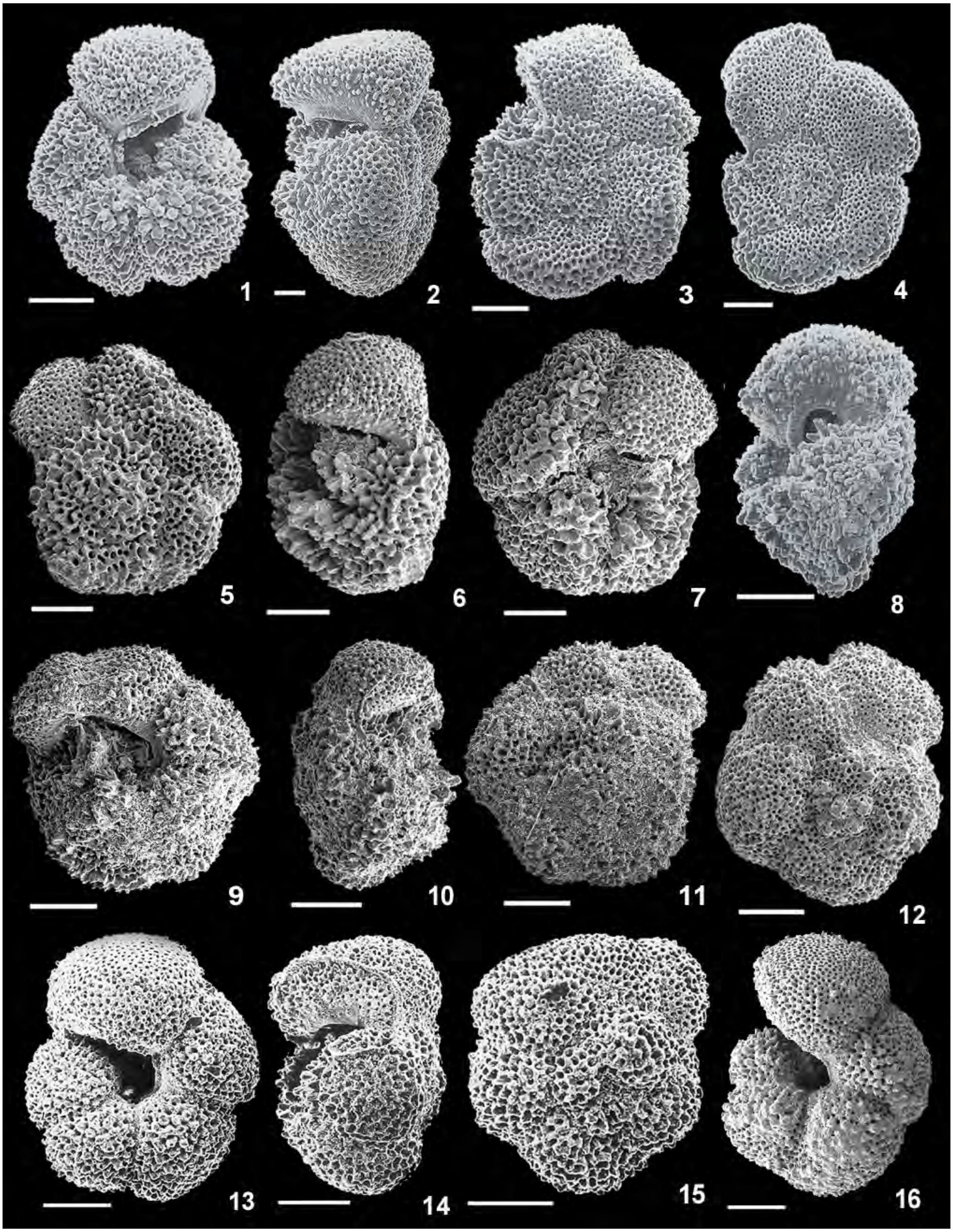

Plate 9.9 *Acarinina cuneicamerata* (Blow, 1979)

DESCRIPTION.

Type of wall: Densely muricate, nonspinose, normal perforate.

Test morphology: Low trochospiral, 5-6 moderately inflated, strongly muricate chambers in last whorl; margins of later chambers in final whorl exhibit tendency to develop angulate and disjunct chamber separation in some individuals; sutures straight, radial, depressed to moderately incised; umbilicus wide, deep, relict apertures of ante- and penultimate chambers visible within umbilical area and bordered by distinct, circumumbilically extending apertural lip(s) connecting to the relatively broad lip of the final chamber; no circumumbilical concentration of muricae; aperture umbilical-extraumbilical, extending towards, but not reaching the periphery; spiral side weakly muricate, about 12, flattened chambers arranged in relatively involute spire of 2 whorls; minute, discrete openings observable, at suture/chamber junctions on well preserved specimens; sutures straight to weakly curved and tangential to periphery; chambers of last whorl lunate with ante- and penultimate chamber often wedge-shaped (cuneiform); in edge view umbilical side is anguloconical with rounded to subacute peripheral margin; spiral side flat.

Size: Diameter of holotype 0.41 mm.

DISTINGUISHING FEATURES.— This form is distinguished by its combination of subtriangular to wedge-shaped (cuneiform) and lunate chambers, tendency to develop laterally angulate and peripherally disjunct terminal chambers, widely open umbilicus, and densely muricate umbilical side and only weakly muricate spiral side.

DISCUSSION.— This taxon was described by Blow (1979) for predominantly 5-6 chambered (in the final whorl), loosely coiled, muricate forms that exhibit a tendency to develop laterally angulate, disjunct terminal chambers and a relatively wide open umbilicus. He drew attention to the potential confusion in distinguishing 6-8 chambered forms from the stratigraphically coeval *A. aspensis* but noted that the smoothly rounded chamber margins (absence of lateral angularity) of *aspensis* serve to distinguish it from *cuneicamerata*.

The FAD of *A. cuneicamerata* has recently been calibrated to Chron C22r at ~50.4 Ma by Hancock and others (2002) at ODP Hole 762C, Exmouth Plateau, north-west Australian margin at essentially the same (estimated) level of the FAD of (the elusive) *Planorotalites palmerae* which has been used to denote the top of Zone P8 (=Zone E6 of this paper). Accordingly the FAD of this taxon has been used to denote the base of Zone E6 in the recently revised Eocene zonation (Berggren and Pearson, 2005). The little known taxon *Globorotalia berwaliana* Mohan and Soodan may be a senior synonym.

PHYLOGENETIC RELATIONSHIPS.— Probably evolved from *Acarinina angulosa* and left no descendants.

STRATIGRAPHIC RANGE.— Zone E6 (base, by definition) to Zone E9 (lower part) (Blow 1979; Hancock and others, 2002).

GEOGRAPHIC DISTRIBUTION.— Equatorial Atlantic Ocean, Tethyan region (Egypt) and Indian Ocean.

STABLE ISOTOPE PALEOBIOLOGY.— Probably recorded by Boersma and others (1987) (as *A. pentacamerata*) with negative $\delta^{18}O$ indicating a surface water habitat. Pearson and others (2001) recorded it with the most negative $\delta^{18}O$ of a large suite of middle Eocene species.

Plate 9.10 *Acarinina echinata* (Bolli, 1957)

1-3 (holotype, USNM 5729), Zone E12, Navet Fm., Trinidad; **4, 5, 9** (same specimen), Zone AE7, ODP Hole 738C/15X/CC; **6-8, 22** (6-8 same specimen), Zone AO1, ODP Hole 744A/15H/CC, Kerguelen Plateau, South Indian Ocean; **10-12, 19-21** (same specimens), (Wade, 2004, pl. 2, figs. k-m, h-j), Zone E14, ODP Hole 1052B/5H/2, 33-36 cm; **13-18** (13, 17, 18; 14-16 same specimens), (Wade, 2004, pl. 2, figs. n-p, e-g), Zone E13, ODP Hole 1052F/13H/4, 53-56 cm, Blake Nose, western North Atlantic Ocean. Scale bar: **1-22** = 100 µm.

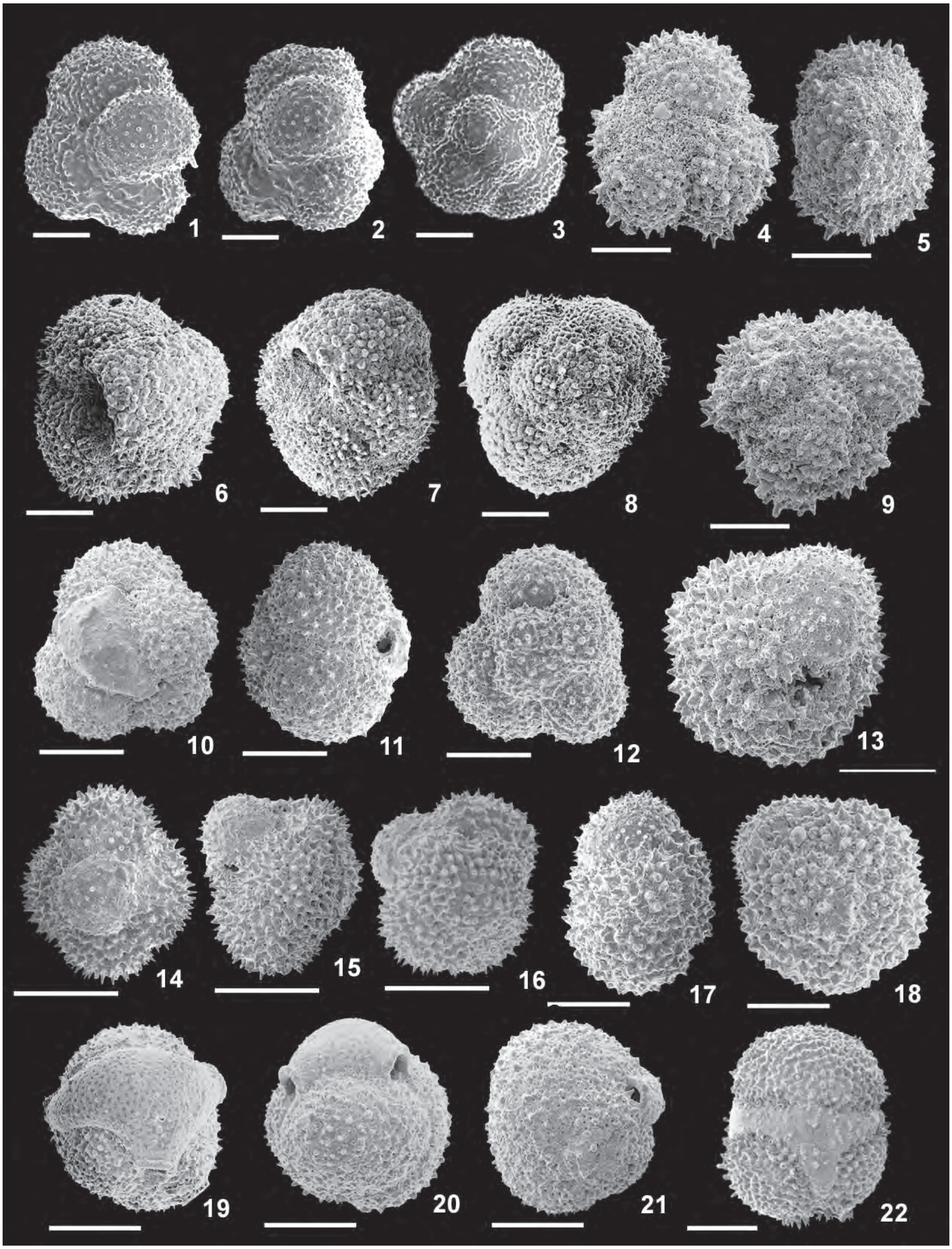

Plate 9.10 *Acarinina echinata* (Bolli, 1957)

REPOSITORY— Holotype (BP catalogue no. 60/3) deposited in the Micropaleontological collections of The Natural History Museum, London.

Acarinina echinata (Bolli, 1957)

PLATE 9.10, FIGURES 1-22
(Pl. 9.10, Figs. 1-3: new SEMs of holotype of *Catapsydrax echinatus* Bolli)

Catapsydrax echinatus Bolli, 1957b:165, pl. 37: figs. 2-5 [middle Eocene *Porticulasphaera mexicana* Zone, Navet Fm., Trinidad].—Saito, 1962:223, pl. 33: fig. 7 [middle Eocene, Hillsborough Island, Bonin Group, Japan].—Jenkins, 1971:183, pl. 21: figs. 628-631 [middle-upper Eocene, Hampden Beach, South Island, New Zealand].—Huber, 1991: 439, pl. 5: figs. 17, 20 [lower Oligocene, ODP Site 744, Kerguelen Plateau].

Acarinina echinata (Bolli).—Wade, 2004:29, pl. 2: figs. e-m [Zones P14, P15, ODP Site 1052, Blake Nose].

Not *Gobigerinita echinata echinata* (Bolli).— Blow, 1979:1334, pl. 240: fig. 7 [Zone P14, Lindi, Tanzania]. (? =*Globigerinatheka* sp.)

Not *Globigerinita echinata africana* (Bolli), Blow, 1979:1336-1337, pl. 240, fig. 8 [Zone P14, middle Eocene, Lindi, Tanzania]. (? =*Globigerinatheka* sp.)

Not *Catapsydrax echinatus* (Bolli).—Huber, 1991: 439, pl. 5, figs. 17, 20 [mid-Oligocene Zone AP13, ODP Hole 744A, Kerguelen Plateau] (?=*Globoquadrina dehiscens*).

DESCRIPTION.

Type of wall: Moderately to coarsely muricate, normal perforate, nonspinose.

Test morphology: Test compact, biconvex, peripheral outline weakly to moderately lobate, axial periphery rounded, more rarely becoming slightly subangular; chambers globular, 11-13 in adult tests increasing rapidly in size until ultimate chamber, which is usually kummerform and often connected to a variably shaped bulla that often covers the umbilicus and part or most of the umbilical sutures, 3½-4 chambers in the final whorl; umbilical sutures radial, weakly to moderately depressed, spiral sutures radial, weakly depressed to indistinct; aperture variable in size, shape, position and number depending on the characteristics of the bullate final chamber, usually a single low-arched opening directed towards the umbilicus and surrounded by a narrow lip, more rarely two or three small, low arched openings directed along umbilical sutures.

Size: Maximum diameter of holotype 0.30 mm, thickness 0.25 mm.

DISTINGUISHING FEATURES.— Characterized by its compact coiling, muricate surface texture, and presence of a kummerform or bullate final chamber and/or sutural bullae. Differs from *Acarinina medizzai* by lacking a visible umbilicus and presence of kummerform or bullate final chamber.

DISCUSSION.— Bolli (1957b) originally placed *echinata* in *Catapsydrax* because of the presence of an umbilical bulla. However, the muricate wall texture of this species is distinctly different from the cancellate spinose wall texture of the type species of *Catapsydrax* (*Globigerina dissimilis* Cushman and Bermúdez, 1937). Forms with sutural bullae (Pl. 9.10**,** Figs. 19-22) are included in this species because of their distinctly muricate test, and compact coiling. Further investigation may reveal that these forms should be differentiated from *A. echinata* s.s.

Specimens identified by Blow (1979) as *Globigerinita echinata echinata* and *Globigerinita echinata africana* have cancellate wall textures and are therefore unrelated to *Acarinina echinata*. Huber (1991, p. 439, pl. 5, fig. 17) recorded a mid-Oligocene bullate, globular, cancellate, spinose form similar to the "spinose variant" of (the lower Miocene) "*Globoquadrina*

Plate 9.11, 1-12, *Acarinina esnaensis* (LeRoy, 1953); 13-19, *Acarinina interposita* Subbotina, 1953

Acarinina esnaensis **1-3** (holotype, USNM 58002), Zone P5, Esna Shale Fm. (basal part), Maqfi section, Egypt; **4, 8, 12** (same specimen), Zone E1, Bass River Borehole, New Jersey, ODP 174AX, 1156.0-1167.9 feet; **5-7** (holotype, *Acarinina intermedia* Subbotina 1953, VNIGRI No. 4095), lower Eocene, Goryachi Kliutch Fm., Kuban River, northern Caucasus; **9-11** (same specimen), lower Eocene, Agua Fresca Shale, Magellanes Province, South Chile. *Acarinina interposita* **13-15** (paratype, VNIGRI No. 4141), lower-middle Eocene, Zone of conical *Globorotalia*, Kuban River, northern Caucasus; **16** (Stott and Kennett, 1990, pl.6, fig. 4), Zone AE4/5, ODP Hole 689B/20H/3, 35-39 cm, Maud Rise, Weddell Sea, Antarctic Ocean; **17-19** (same specimen), lower Eocene, Agua Fresca Shale, Magellanes Province, South Chile. Scale bar: **1-19** = 100 µm.

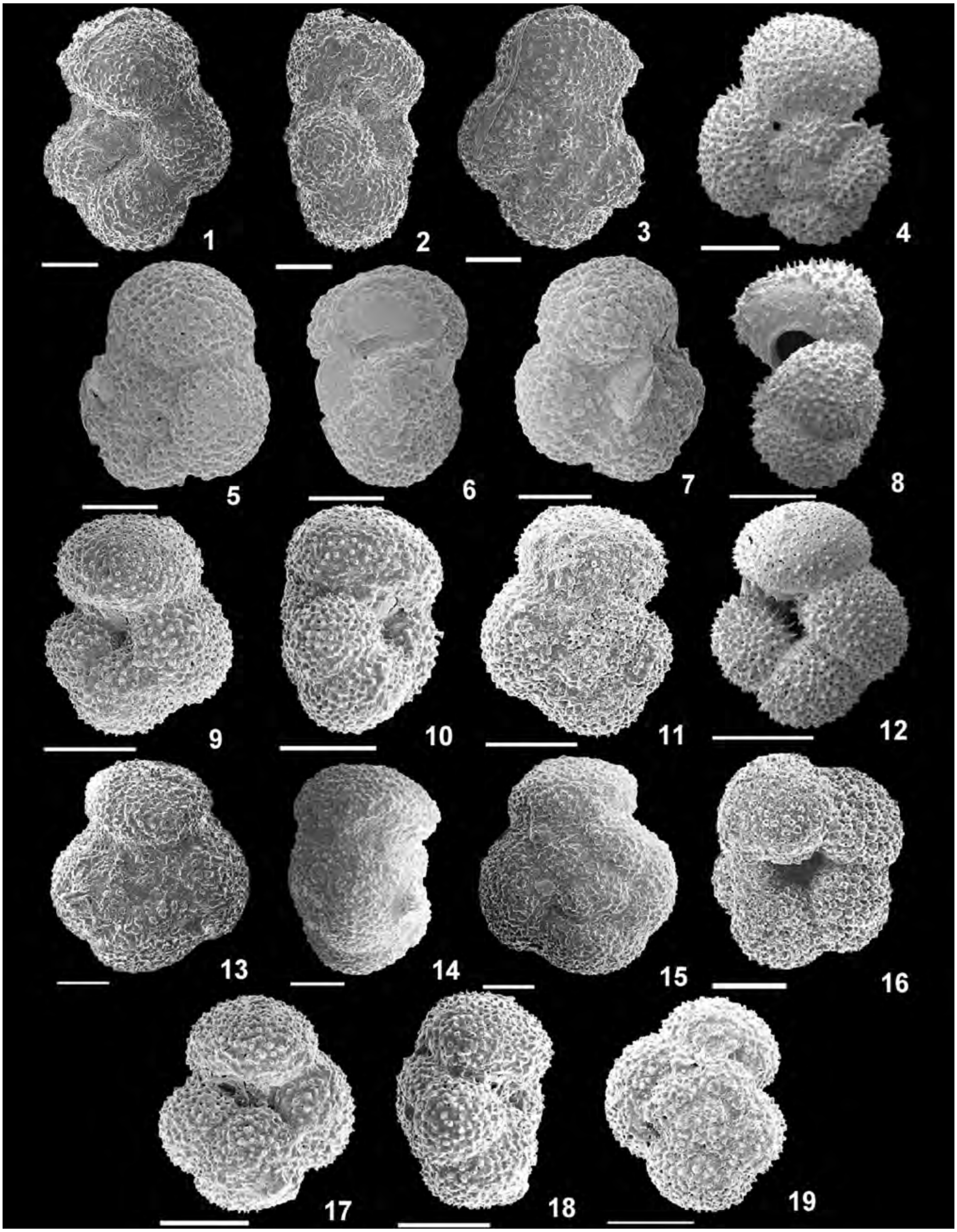

Plate 9.11 *Acarinina esnaensis* (LeRoy, 1953), *Acarinina interposita* Subbotina, 1953

dehiscens" recorded by Berggren and others (1983; pl. 1, figs. 5-10) from the lower Miocene of DSDP Site 516 on the Rio Grande Rise, South Atlantic Ocean. We view these forms as unrelated to *Acarinina echinata.*

PHYLOGENETIC RELATIONSHIPS.— May have evolved from *Acarinina pseudosubsphaerica* n.sp. during the middle Eocene. This is may be the youngest ranging species of the acarininid lineage.

STRATIGRAPHIC RANGE.— Zone E10 (Bolli, 1957b) to Zone E16 (Wade, 2004). At Blake Nose (ODP Sites 1052 and 1053) *A. echinata* ranges from middle Eocene Zone P13 (=Zone E12 of this paper) through (at least) upper Eocene Zone P15 (=E14) and Chron C16n.2n (Wade, 2004); in Trinidad, Bolli (1957b) recorded it from the *Globorotalia lehneri* through *Truncorotaloides rohri* Zone; in New Zealand this species ranges from the *Globigerina index* through the *Globigerina linaperta* Zone. May range into the Oligocene (Huber, 1991).

GEOGRAPHIC DISTRIBUTION.— This taxon has been recorded from the tropics/subtropics (e.g., Blake Nose; Trinidad) and southern middle and high latitudes (e.g., New Zealand; Kerguelen Plateau). It probably occurs at a number of other sites but may have been overlooked or recorded under a different species name.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (USNM P5729) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina esnaensis (Leroy, 1953)

PLATE 9.11, FIGURES 1-12

(Pl. 9.11, Figs. 1-3: new SEMs of holotype of *Globigerina esnaensis* LeRoy)

Globigerina esnaensis LeRoy, 1953:31 [published 27 February, 1953, before *Acarinina intermedia* Subbotina, see below], pl. 6: figs. 8-10 [Esna Fm., Farafra Oasis, Egypt].—Nakkady, 1959:461, pl. 3, figs. 2a-c [Um- El - Ghanayem section, Kharga Oasis, Western Desert, Egypt].—Gohrbandt, 1963:49, pl. 2: figs. 19-21 [Zone F, north of Salzburg, Austria].—McGowran, 1965:61, 63, pl. 6: figs. 5 (3 figs.), text-fig. 10 (20 line drawings) [Zone P5, Pebble Point Fm. and Rivernook Member of the Dilwyn Fm., Western Victoria, Australia].

Truncorotalia esnaensis (LeRoy).—Said and Kenaway, 1956:151, pl. 6: figs. 7a,b [Zone P5, Esna Shale Fm., Northern Sinai, Egypt].

Globorotalia esnaensis (LeRoy).—Loeblich and Tappan, 1957:189, pl. 61: figs. 1a-2c, 9a-c [Zone P4c, Nanafalia Fm., Wilcox Co., Alabama]; pl. 57: figs. 7a-c [Zone P4, Aquia Fm., Aquia Creek, Maryland - Virginia].—Berggren, 1960a:92, 93, pl. 5: figs. 3a-d; pl. 6: figs. 1a-c; pl. 10: figs.3a-c [Zone P7, Røsnaes Clay, Røgle Klint, Denmark].—Said and Kerdany, 1961:328, pl. 1: figs. 6a-c [Zone P5, Esna Shale, Farafra Oasis, Western Desert, Egypt].—Gartner and Hay, 1962:563-564, pl. 2: figs. 4a-c [Zone P5, Ilerdian Stage, Tremp Basin, Spain].—Said and Sabry, 1964:383, pl. 1: figs. 5a-c [Zone P5, Esna Shale, Gebel Aweina, Egypt].—Samanta, 1970:624, pl. 95: figs. 7, 8 [Zone P4c, Algal Limestone, Pondicherry Fm., Madras, South India].—El Naggar, 1966:210, pl. 21: figs. 6a-c [*Globorotalia velascoensis* Zone, Upper Awaina Shale, Egypt].

Truncorotaloides (*Acarinina*) *esnaensis* (LeRoy).—McGowran, 1965:61, pl. 3: fig. 5, text-fig. 10 [Dilwyn Fm., Wangerrup Group, Pebble Point Coastal Section, western Victoria, Australia].

Truncorotaloides (*Acarinina*) sp. aff. *T.* (*A.*) *esnaensis* (LeRoy).—McGowran, 1968, pl. 3: figs. 3-4 [*Planorotalites simplex* Zonule, Cape Range, Carnarvon basin, Victoria, Australia]; pl. 3: figs. 5,6 [Rivernook Member, Dilwyn Clay Fm., Carnarvon Basin, Victoria, Australia].

Plate 9.12 *Acarinina esnehensis* (Nakkady, 1950)

1-16, Zone E1, Bass River Borehole, New Jersey, ODP 174AX, 1167.8-1169.2 feet. Scale bar: **1-16** = 100 μm.

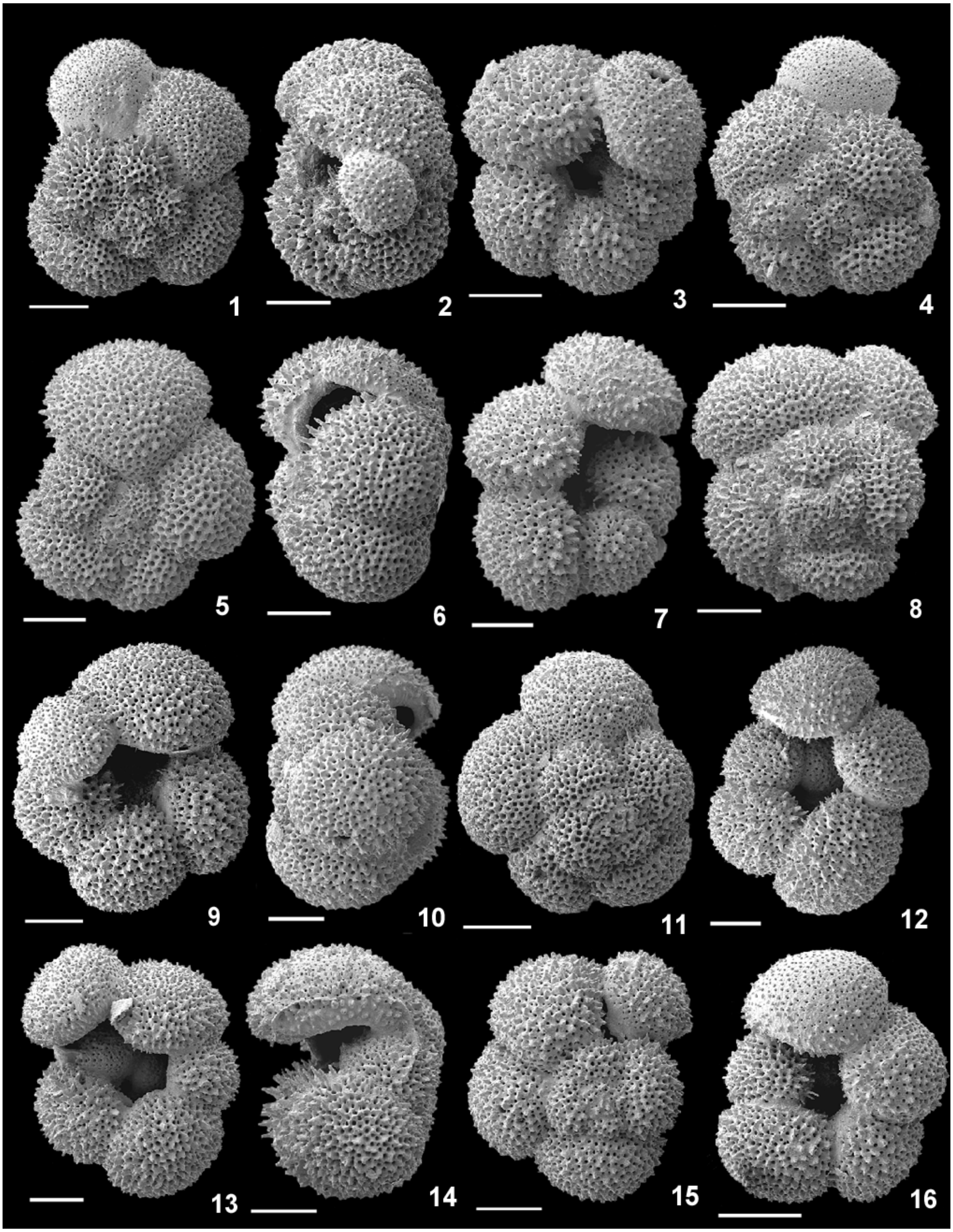

Plate 9.12 *Acarinina esnehensis* (Nakkady, 1950)

Globorotalia (*Acarinina*) *esnaensis* (LeRoy).—Jenkins, 1971:82, pl.3: figs. 84-86 [*Globorotalia wilcoxensis* Zone, Middle Waipara River, Waipawan Stage, South Island, New Zealand].

Acarinina esnaensis (LeRoy).—Berggren, 1977: 249, chart 10 (reillustrations from the literature).—Huber 1991:439, pl. 1: figs. 13-15 [Zone AP4, ODP Hole 738C, Kerguelen Plateau, southern Indian Ocean].

? *Acarinina esnaensis* (LeRoy).—Stott and Kennett, 1991:566, pl. 4, figs. 7-8 [lower Eocene *Planorotalites australiformis* (AP5) Zone, ODP Hole 689B, Maud Rise, Weddell Sea, Antarctica].

Acarinina intermedia Subbotina 1953:227 (published 19 November, 1953) (*partim*), pl. 20: figs. 14 and 15 (holotype, No. 4095) [Zone of compressed globorotaliids, Subzone of *Globorotalia crassata* and *Acarinina intermedia*, Goryachi Kliutch Fm., Kuban River section, North Caucasus]; pl. 20: fig. 16 [Zone of compressed globorotaliids, Murza Tai Range, Mangyshlak Peninsula, Lower White Series].— Shutskaya, 1970:118, pl. 24: fig. 3a-c [upper subzone of *Acarinina tadjikistanensis djanensis* Zone, Malyi Balkan, Nizhnedanatinskian Group, western Turkmenia, Kachinian Stage]; pl. 27: fig. 1a-c [*Acarinina acarinata* Zone, Tarkhankut, Crimean Peninsula].—Huber, 1991:439, pl. 2: figs. 19, 20 [Zone AP6a, ODP Site 738, Kerguelen Plateau, South Indian Ocean].

Globorotalia (*Acarinina*) *acarinata intermedia* (Subbotina).—Blow, 1979:905, pl. 199: figs. 1-4 [Zone P7, Sample RS. 80, Kilwa area, Tanzania].

Acarinina wilcoxensis wilcoxensis (Cushman and Ponton).—Stott and Kennett, 1990:560, pl. 4: figs. 1-3 [Zone A5, ODP Hole 690B, Maud Rise, South Atlantic Ocean]. [Not Cushman and Ponton, 1932.]

DESCRIPTION.

Type of wall: Muricate, non-spinose, normal perforate.

Test morphology: Low-trochospiral, subquadrate test with somewhat lobulate peripheral outline; periphery rounded to subacute; 4-4$\frac{1}{2}$ subovate to subspherical chambers in final whorl, moderately inflated; intercameral sutures radial to slightly curved on umbilical side; umbilicus small, open; 12-15 chambers on spiral side, gradually increasing in size as added; sutures distinct, depressed, straight to slightly curved in direction of coiling; wall densely muricate, particularly along periphery; aperture a long, low interiomarginal, umbilical-extraumbilical arch extending nearly to the periphery with very thin lip.

Size: Maximum diameter of holotype 0.44 mm; thickness 0.26 mm

DISTINGUISHING FEATURES.—This taxon is distinguished by its generally elongate-oval shape, with 4 rounded to subangulate, closely appressed, embracing chambers in the final whorl, narrow umbilicus, with the later chambers on the spiral side tangentially longer than radially broad.

DISCUSSION.—This taxon has had a colorful history. Originally described from the upper Paleocene (Zone P4/5) of Egypt by LeRoy (1953), it was virtually simultaneously described from the upper Paleocene of the North Caucasus by Subbotina (1953) under the name *Acarinina intermedia*, with LeRoy's taxon having (subjective synonym) seniority by 10 months. Since that time it has been recorded under a variety of names, as was already recognized over 40 years ago by McGowran (1965; see synonymy above). The synonymy of *Acarinina esnaensis* and *A. intermedia* was verified by one of us (WAB) in the course of examination of type material of *intermedia* in the collections of N.N. Subbotina at VNIGRI (in 1962 and 1977) in Leningrad/ St. Petersburg and subsequent comparison of topotype material provided by Subbotina with the holotype of *A. esnaensis* in the Cushman collections of the USNM.

Acarinina esnaensis is generally characterized by a relatively flat spiral side and varies from having globular to subangular chambers in peripheral edge view (compare the illustrations in McGowran [1965] with illustrations of *esnaensis* and *irrorata* and *tribulosa* in Loeblich and Tappan [1957]). Forms with an odd/ anomalous apertural modification (a vertically disposed, narrow, slit-like aperture) are included here in this taxon; compare Loeblich and Tappan (1957, pl. 61: figs. 9a-c) with Berggren (1960a, pl. 5. figs. 3a-d) from Zone P7 of the Røsnaes Clay Fm., Røgle Klint, Denmark.

The holotype specimens of *esnaensis* and *wilcoxensis* are markedly similar. However, examination of large suites of individuals reveals that there are two separate and distinct taxa involved. *Acarinina esnaensis* is generally more elongate-oval in outline, and has a narrower umbilicus than *A. wilcoxensis*.

Blow (1979, p. 906) considered *Acarinina intermedia* to have evolved from *A. acarinata* (= *nitida*) and to have been ancestral to *A. wilcoxensis* and also to the *A. pseudotopilensis*-*topilensis* s.l. lineage. The transition to *A. pseudotopilensis* was said to involve a tangential lengthening of the later chambers at the expense of their radial width concomitant with these same chambers becoming disjunct and slightly laterally angulate. Blow (1979, p. 906) pointed to (paratypic) individuals referred to, and illustrated as, *A. intermedia* by Subbotina (1953, pl. 21, figs. 9a-c and pl. 22, figs. 2a-c) as representing intermediate forms between the two taxa. These views are supported by our own observations on comparative material.

PHYLOGENETIC RELATIONSHIPS.— This taxon is ancestral to *Acarinina wilcoxensis* and may have evolved from *Acarinina nitida* in the upper Paleocene (although it was not included in Olsson and others, 1999).

STRATIGRAPHIC RANGE.— Zone P4 (upper part) to Zone E5. While this taxon has its lowest occurrence in upper Zone P4, we have found that it is particularly common and well developed within Zones P5-E2 and, in particular, within the interval of the Carbon Isotope Excursion (CIE) in the Bass River core drilled on the New Jersey Coastal Plain (basal Zone E1), where it occurs with early specimens of *Acarinina wilcoxensis*. The latter has its FAD just below the base of the CIE in Egypt.

GEOGRAPHIC DISTRIBUTION.— Widespread in low latitudes, (sub)tropical latitudes as well as in high northern (Scandinavia) and southern/austral latitudes (e.g., Kerguelen Plateau, Maud Rise).

STABLE ISOTOPE PALEOBIOLOGY.— No data available

REPOSITORY.— Holotype (USNM 58002) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina esnehensis (Nakkady, 1950)

Plate 9.12, Figures 1-16

Globigerina cretacea d'Orbigny var. *esnehensis* Nakkady, 1950:689, pl. 90: figs. 14-16 [Zone P6, upper part of Esna Shale Fm., Abu Durba, Egypt].

Muricoglobigerina esnehensis (Nakkady).—Blow, 1979:1127, pl. 109: figs. 1-7 [Zone P6 of Blow, 1979; DSDP 6/47.2/8/4, 78-81 cm; Shatsky Rise, northwest Pacific Ocean].

Globigerina gravelli Brönniman, 1952:12, pl. 1: figs. 16-18 [Zone P5, lower zone of Lizard Springs Fm., Guayaguayare area, South Trinidad].—Bolli, 1957:72, pl. 16: figs. 1-3 [*Globorotalia formosa* Zone, upper Lizard Springs Fm., Trinidad].—Hornibrook, 1958:21, figs. 21, 25 [uppermost Paleocene, Waipawan Stage, New Zealand].

Globigerina dubia Egger var. *lakiensis* Haque, 1956:174, pl. 4: figs. 2a-c [uppermost Paleocene, Laki Gorge, Pakistan].

Globigerina mckannai White, 1928.—Berggren, 1960a:68, pl. 1: figs. 4a-c and pl. 9: fig. 3a-c [lower Eocene Zone P7, Clay Quarry at Hollbecker Berg, north-west Germany]; pl. 9: fig. 2a-c [lower Eocene Zone P7, Clay Quarry at Bessenbecker Berg , north-west Germany]; pl. 9: fig. 4a-c and pl. 10: fig. 1a-c, text-fig. 7 [lower Eocene Zone P7, Røsnaes Clay, Røgle Klint, Denmark]. [Not White, 1928.]

Not *Muricoglobigerina esnehensis* (Nakkady).—Pearson and others, 1993, pl. 1:fig. 20 [middle Eocene Zone P11-P12, DSDP Site 523, Walvis Ridge, South Atlantic Ocean] (=*Acarinina pseudosubsphaerica* n. sp.).

DESCRIPTION.

Type of wall: Muricate, with strong concentration of muricae around umbilicus.

Test morphology: Low- to moderately high spired trochoid test; 5 (ranging up to 7) inflated chambers in last whorl, umbilicus open, deep and generally relatively wide; aperture low slit extending along margin of last chamber towards, but not reaching, periphery; no circumumbical muricate rim; sutures incised, radial to only slightly curved on umbilical and spiral sides of test; rounded margin(s) in edge view.

Size: Relatively large (to 0.5 mm maximum diameter); maximum diameter of holotype: 0.4 mm; thickness: 0.3 mm (Nakkady, 1950, p. 689).

DISTINGUISHING FEATURES.— This taxon is characterized by a muricate test of 5-6 (rarely 7) chambers arranged in a relatively loose (lax) coil resulting in an open and deep umbilicus, and moderate to strong lateral chamber compression (giving a subangulate appearance to the peripheral margin of some chambers). Muricae are well developed on the umbilical side but only weakly expressed (blunted) on the spiral side, the test being strongly cancellate. A small, weakly muricate chamber usually caps/bridges the junction between the first and last chambers of the final whorl and on the spiral side a smooth, virtually imperforate band (which appears to be a consistent distinguishing characteristic of this taxon) runs along the lower part of this diminutive chamber. This taxon is distinguished from *Acarinina soldadoensis* by having a greater number (5-7 vs 4) of globular (as opposed to tangentially elongate) chambers in the final whorl, straighter, radial sutures on both sides of the (generally higher spired) test and a larger, deeper umbilicus.

DISCUSSION.— As the description above indicates, clear distinction between *esnehensis* and the related taxa *mckannai*, *soldadoensis* and *gravelli* is difficult to achieve. Loeblich and Tappan (1957) expressed the view that *esnehensis* and *gravelli* are synonymous and junior synonyms of *mckannai*. As the result of a comparative examination of type material of these taxa at the British Museum (Natural History), London and the U.S. National Museum, Washington, Blow (1979, p. 1127-1128) agreed with the former view but distinguished *esnehensis* from *mckannai* on the basis of the following characters observable in *mckannai*: 1) much tighter coiling mode; 2) more "globigerine" initial coil; 3) posteriorly recurved (versus consistently radial) and more clearly incised dorsal intercameral sutures; 4) ventral intercameral sutures recurved on earlier part of last whorl to sinuous in the later part of the last whorl in addition to distinctly different stratigraphic ranges.

At the same time Blow (1979, p. 1129) was obviously at pains to distinguish consistently between *esnehensis* and *soldadoensis*, concluding that in view of the long stratigraphic persistence of transitional forms over the biostratigraphic interval of his Zone P5 (mid-part) to Zone P8b "*Muricoglobigerina esnehensis* (= *M. gravelli*) is little more than an environmentally induced ecophenotype of a basic *soldadoensis* genotype". Nevertheless, he distinguished the two forms as separate species as do we here based on the set of distinguishing characters described above.

PHYLOGENETIC RELATIONSHIPS.— *Acarinina esnehensis* probably evolved from *A. soldadoensis* in (lower) Zone P5.

STRATIGRAPHIC RANGE.— Zones P5 to Zone E6; particularly common in Zone E1 in association with the PETM excursion fauna in the Bass River section of coastal New Jersey and Egypt.

GEOGRAPHIC DISTRIBUTION.— Widespread from (sub)tropical areas (Caribbean, New Jersey, Egypt) to austral (Hornibroook, 1958) and boreal (Berggren, 1960a) regions. Probably lumped with *A. soldadoensis* in some studies and thus an understanding of its real distribution remains muted.

STABLE ISOTOPE PALEOBIOLOGY.— No data available

REPOSITORY.— Holotype and paratypes deposited in the micropaleontological collections of The Natural History Museum, London.

Acarinina interposita **Subbotina, 1953**

PLATE 9.11, FIGURES 13-19
(Pl. 9.11, Figs. 13-15: new SEMs of paratype of *Acarinina interposita* Subbotina)

Acarinina interposita Subbotina, 1953:231, pl. 23: figs. 6a-c [holotype, lower Eocene Zone of conical globorotaliids, Khieu River section, Nal'chik region, northern Caucasus]; figs. 7a-c [lower Eocene Zone of conical globorotaliids, Kuban River section, northern Caucasus].—Krasheninnikov and others, 1988:96, pl. 8: figs. 4-6 [*G. aragonensis* Zone, DSDP Site 277, Campbell Plateau].

Globorotalia (*Acarinina*) *interposita* (Subbotina).—Blow, 1979:931-933, pl. 156: figs. 7-9 [Zone P10, piston core Kane 9-C, North Atlantic Ocean].

?*Acarinina interposita* Subbotina, 1953.—Stott and Kennett, 1990:559, pl. 6: figs. 3,4 [Zone AP9, ODP Hole 689B, Maud Rise, southern South Atlantic Ocean].—Huber, 1991:439, pl. 2: figs. 13-15 [Zone AP7, ODP Site 738, Kerguelen Plateau, southern Indian Ocean].—Lu and Keller, 1993:119, pl. 2: figs. 9, 11 [Zone AP5, ODP Hole 738C, Kerguelen Plateau, southern Indian Ocean].

DESCRIPTION.

Type of wall: Densely muricate on both sides, non-spinose; normal perforate.

Test morphology: Low-trochospiral; relatively large, robust, test with embracing, appressed chambers; planoconvex, weakly lobate, circular outline, rounded periphery in edge view; 4-4$^{1}/_{2}$ chambers in final whorl, increasing slowly in size, generally globular; sutures depressed, radial, weakly curved; muricae more strongly developed on umbilical than on spiral side, short, thick muricae concentrated around umbilicus, which is narrow, deep; about 10-12 chambers in 2-3 whorls on spiral side; early chambers obscured by muricate texture, chambers of final whorl increasing slowly in size, essentially equidimensional; sutures radial, straight, only slightly depressed; muricae tend to concentrate along peripheral margin; in edge view planoconvex; profile of early chambers rounded, with flattening of ante- and/or penultimate chamber resulting in rounded margin;

peripheral margin; aperture an umbilical-extraumbilical arch, bordered by thin lip, extending almost to peripheral margin.

Size: Diameter 0.35-0.55 mm, thickness 0.20-0.25 mm.

DISTINGUISHING FEATURES.— This taxon is distinguished by its 4-4½ chambers (in the final whorl), planoconvex, distinctly muricate, test with umbilically inflated (globular) chambers; umbilical side of test distinctly inflated, accompanied by loose arrangement of chambers resulting in scalloped, lobulate peripheral margin.

DISCUSSION.— This distinctly inflated (globular) form is characteristic of lower Eocene assemblages; it is predominantly dextrally coiled throughout its range. We have observed it to appear in Zone E4 in Egypt and to grade into *A. pentacamerata* at stratigraphically higher/younger levels.

We question the high latitude records of forms cited under this name (see synonymy listing above); they do not appear to display the robust, inflated morphology characteristic of low latitude representatives, and indeed some of the forms are recorded from distinctly lower stratigraphic levels (Zone AP5 [which approximately correlates with Zone E2]) and contain only 3 chambers in the final whorl (Lu and Keller, 1993).

PHYLOGENETIC RELATIONSHIPS.— This taxon seems to have been derived from *A. soldadoensis* and evolved into *A. pentacamerata* by an increase in the number of chambers in the whorl and a change in the spire height.

STRATIGRAPHIC RANGE.— Zone E4 to Zone E6.

GEOGRAPHIC DISTRIBUTION.— Occurs commonly in the Tethys (Egypt) and in the northern Caucasus.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (No 4140) and paratype (No. 4141) deposited in micropaleontological collections of VNIGRI, St Petersburg, Russia.

Acarinina mcgowrani **Wade and Pearson, new species**

Plate 9.13, Figures 1-16

Globorotalia (Acarinina) bullbrooki (Bolli, 1957).—Blow, 1979:1043 (*partim*), pl. 155: figs. 3-5 [Zone P9-P10, KANE 9, piston core 42, Endeavour Seamount, equatorial Atlantic Ocean]. [Not Bolli, 1957.]

Acarinina pseudotopilensis (Subbotina, 1953).—Pearson and others, 1993:124, pl. 1: figs. 13-15 [Zones P11-12, DSDP Site 523, South Atlantic Ocean]. [Not Subbotina, 1953.]

Acarinina praetopilensis (Blow, 1979).—Wade and others, 2001:277: figs. 3f-3h [Zone P14, ODP Site 1051, western North Atlantic Ocean].—Wade, 2004:28, pl. 1: figs. g-h [Zone P14, ODP Site 1052, western North Atlantic Ocean]. [Not Blow, 1979.]

DESCRIPTION.

Type of wall: Densely muricate, nonspinose, normal perforate.

Test morphology: Chambers arranged in a moderate trochospiral, test compact with 2 whorls, typically 4 (but ranging from 3-4½) chambers in the final whorl, gradually increasing in size; peripheral outline weakly lobate; chambers on umbilical side, wedge-shaped or triangular, with final chamber oval in umbilical view, typically twice as long as high, and subrounded to angular in edge view; chambers densely muricate, with large, conical muricae concentrated in the circum-cameral region of the final chamber, but not fused into muricocarina; sutures distinct, deeply incised and radial; umbilical-extraumbilical aperture set in a deep umbilicus; bullae common; on spiral side chambers subrectangular or ovoid; supplementary apertures frequently occur, fringed by thin muricae; sutures incised, radial to weakly curved; sutures of both sides are commonly intruded by slender muricae; strong tendency for a preferred coiling direction, either dextral or sinistral, depending on the location and stratigraphic level.

Size: Maximum diameter of holotype 0.25-0.30mm.

ETYMOLOGY.— Named in honor of Professor Brian McGowran of University of Adelaide for his contributions to the taxonomy of Paleogene foraminifera.

DISTINGUISHING FEATURES.— *Acarinina mcgowrani* n.sp. is closely related to the middle Eocene species *A. praetopilensis* and the early Eocene species *A. pseudotopilensis.* It is distinguished from both species by its more compact test, which is densely muricate, and by having more incised sutures. Unlike *A. praetopilensis* it does not show circum-cameral fusion of muricae into an incipient circum-cameral muricocarina, and the chamber periphery is usually more rounded. The muricae are typically more conical than in other acarininids and long, slender muricae intrude into the sutures and fringe the primary and supplementary apertures. Sutures are distinct and deeply incised on both the umbilical and spiral sides, a feature that distinguishes the *pseudotopilensis – mcgowrani – praetopilensis* lineage from the co-occurring *Acarinina bullbrooki* group. Small bullae are frequently present (see holotype), and are more common than in most other acarininids.

DISCUSSION.— Despite being abundant throughout almost the whole of the middle Eocene, *Acarinina mcgowrani* n. sp. has not been formally recognized as a distinct species. Previous studies (e.g., Wade and others, 2001; Wade and Kroon, 2002; Wade, 2004; Pearson and others, 1993, 2001, 2004) have used a broad concept of either *A. praetopilensis* or *A. pseudotopilensis* to accommodate these highly muricate, compact forms. However, following study of type material from Russia, we now recognize *A. pseudotopilensis* to be a stratigraphically restricted component of early Eocene assemblages. The distinctive features of *A. praetopilensis*, as described by Blow (1979), include a circum-cameral muricocarina and angular final chamber similar to *A. topilensis*. These features also necessitate a restricted concept, hence the need for a new species.

PHYLOGENETIC RELATIONSHIPS.— *Acarinina mcgowrani* evolved from *A. pseudotopilensis* near the base of the middle Eocene and gave rise to *A. praetopilensis*.

STRATIGRAPHIC RANGE.— *Acarinina mcgowrani* characterizes almost the whole of the middle Eocene. It evolved in Zone E7 and was one of the final large acarininids to become extinct, which just preceded the extinction of *Morozovelloides* in upper Zone E13 (Wade, 2004).

GEOGRAPHIC DISTRIBUTION.— Widely distributed, but most abundant in low and mid latitudes, common in central equatorial Pacific Ocean (ODP Site 865), North and South Atlantic Ocean (ODP Sites 1051 and 1052, DSDP Site 523) and Tanzania.

STABLE ISOTOPE PALEOBIOLOGY.— Relatively negative $\delta^{18}O$ and positive $\delta^{13}C$ values indicate a mixed layer habitat. Size fraction data shows a large change in $\delta^{13}C$ through ontogeny suggestive of a symbiotic relationship like other muricate forms; Pearson and others, 1993 (recorded as *pseudotopilensis*); Wade and Kroon, 2002; Wade 2004 (recorded as *praetopilensis*).

REPOSITORY.— Holotype (USNM 528417) and paratypes (USNM 528418, 528419) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina medizzai (Toumarkine and Bolli, 1975)

PLATE 9.14, FIGURES 1-15
(Pl. 9.13, Figs. 1-4: reillustration of holotype and paratype of *Globigerina medizzai* Toumarkine and Bolli)

Plate 9.13 *Acarinina mcgowrani* Wade and Pearson new species

1-7, 9-11 (figs. 1-4 holotype, USNM 528417; figs. 5-7, 9-11 paratypes, USNM 528418, 528419), Zone P14, Sample Lin 99-17, Kitunda, Tanzania; **8, 15, 16** (figs. 8, 16 reillustration of Wade, 2004, pl. 1, figs. g, h), Zone P14, ODP Hole 1052B/14H/4, 23-26 cm, Blake Nose, western North Atlantic Ocean; **12**, Zone P12, DSDP Site 523/43/1, 123-125 cm, Walvis Ridge, western South Atlantic Ocean; **13, 14** (fig. 13 reillustration of Wade and others, 2001, fig. 3f; fig. 14 = wall texture view of fig. 13), Zone P14, ODP Hole 1051B/2H/1, 50-52 cm, Blake Nose, western North Atlantic Ocean. Scale bar: **1-3, 5-13, 15, 16** bar = 100 µm, **4, 14** bar = 20 µm.

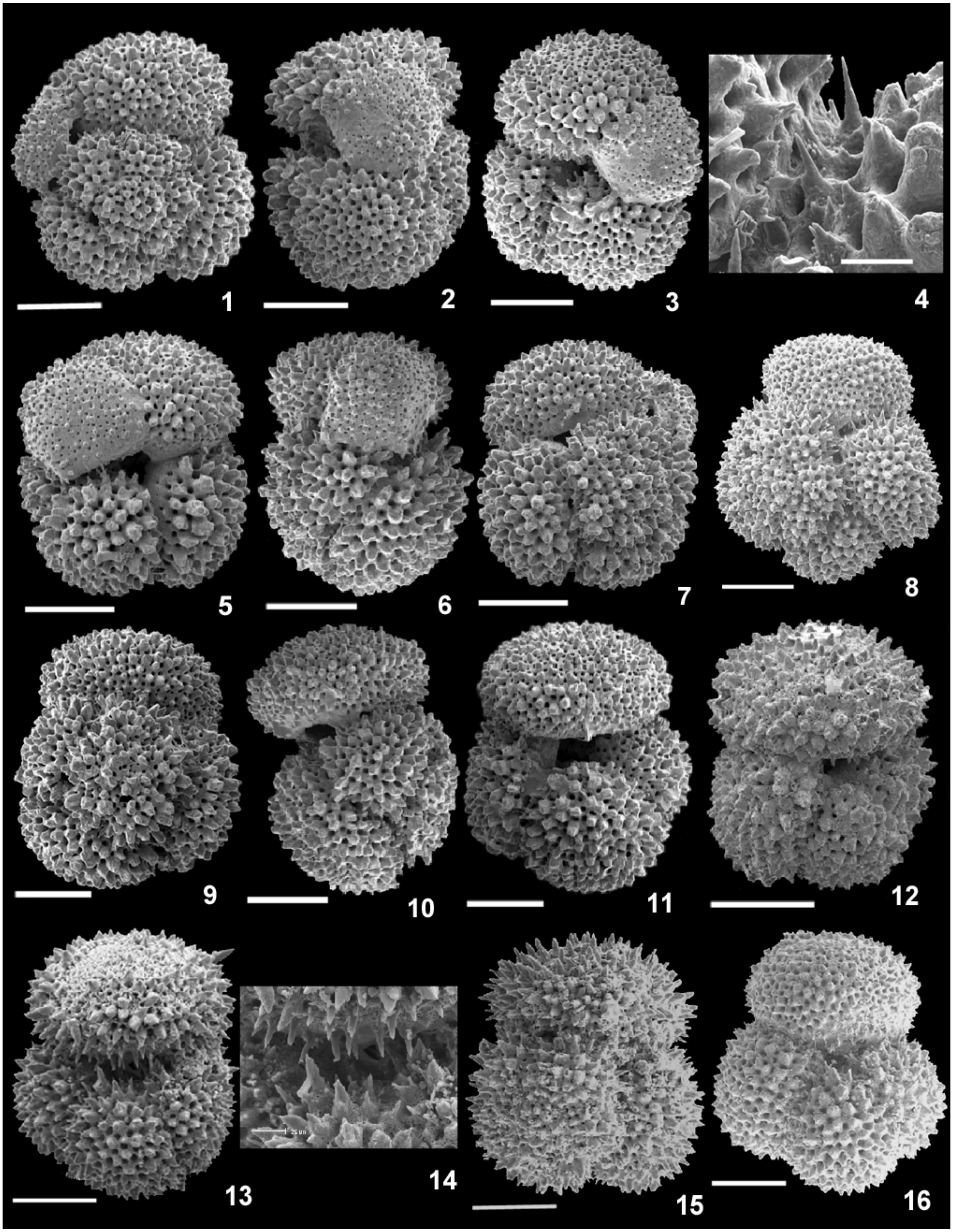

Plate 9.13 *Acarinina mcgowrani* Wade and Pearson new species

?*Acarinina rugosoaculeata* Subbotina, 1953:312-313, pl. XXV (*partim*): figs. 4a-c [upper Eocene, Don Basin, northern Caucasus]; figs. 5a-c [lower-middle Oligocene?, Kholmsk district, northern Caucasus] [Not figs. 6a-c. upper Eocene, Stalingrad region, Russia.]

Globigerina medizzai Toumarkine and Bolli, 1975:77, pl. 6: figs. 1-8, pl. 5: figs. 8, 10, 13-15, 17, 19-22 [upper Eocene, Scaglia Cinerea, Padua, Trevino, northern Italy].—Toumarkine and Luterbacher, 1985:150: figs. 41.1-6: 6, 8, 9 [upper Eocene, Scaglia Cinerea, Possagno section, northern Italy].

Acarinina medizzai (Toumarkine and Bolli).—Nocchi, and others 1991:266, pl. 4: fig. 23 [upper Eocene Zone P15, ODP Hole 703A, South Atlantic Ocean].—Spezzaferri, 1998:177, pl. 1: figs. 12a-b [middle Eocene, ODP Hole 918D, East Greenland Margin].—Wade, 2004:29, pl. 2: figs. a, b, q [Zone P15, ODP Site 1052, western North Atlantic Ocean], figs. c, d, n-p [Zone P14, ODP Site 1052, western North Atlantic Ocean].

DESCRIPTION.

Type of wall: Finely muricate, normal perforate, nonspinose.

Test morphology: Test relatively small, biconvex, quadrate to subcircular in outline, weakly to moderately lobate with a rounded periphery; chambers globular, 8-12 arranged in a low trochospire of 3-4 whorls, increasing moderately in size, 4-6 in the final whorl, rarely kummerform; umbilicus narrow in more compact specimens, shallow and broad in more evolute forms; sutures moderately depressed, radial on both sides; aperture a small and often indistinct low umbilical to slightly extraumbilical arch.

Size: Maximum diameter of holotype 0.19 mm; tests sizes range from 0.16 to 0.20 mm.

DISTINGUISHING FEATURES.— Differs from *A. collactea* by its smaller size and smaller, often indistinct aperture; differs from *A. echinata* by absence of a bulla and by presence of an umbilicus; differs from *Dipsidripella danvillensis* (Howe and Wallace) in presence of a bilamellar, rather than monolamellar, wall and more densely muricate surface ornamentation.

DISCUSSION.— This species is closely related to, and possibly synonymous with, *Acarinina rugusoaculeata* Subbotina. The latter was distinguished from *A. medizzai* by Toumarkine and Bolli (1975) on having a more umbilically positioned aperture and based on the presence of a final chamber that is larger and less detached from the previous chambers. Although Subbotina described her species as having a slit-like aperture that extends along the sutural margin, the apertural position in the holotype is not apparent from the illustration (e.g., Subbotina, 1953, pl. XXV: figs. 4a, b), and one of the other illustrated specimens that clearly does have an extraumbilical aperture and was designated as *A. rugosoaculeata* by Subbotina (1953, pl. XXV: figs. 6a, b) lacks a muricate wall texture and therefore should not be included in *Acarinina*. This ambiguity cannot be cleared up from study of Subbotina's collection since the holotype and other specimens originally assigned to *A. rugosoaculeata* have been lost (E.M. Bugrova, pers. comm., 2003). Until specimens from the type level of the *A. rugosoaculeata* holotype can be studied and compared with *A. medizzai* we have chosen to suppress *A. rugosoaculeata* in favor of recognition of the better-documented species *A. medizzai*.

PHYLOGENETIC RELATIONSHIPS.— Probably descended from *Acarinina collactea* during middle Eocene Zone P12 (=Zone E10 of this paper).

STRATIGRAPHIC RANGE.— Zone E10 to Zone E14. Toumarkine and Bolli (1975) recorded the range of *A. medizzai* from the *Globorotalia lehneri* Zone to the base of the *G. semiinvoluta* Zone (upper middle to upper Eocene). Poag and Commeau (1995) noted that in the

Plate 9.14 *Acarinina medizzai* (Toumarkine and Bolli, 1975)

1-4 (1-3, holotype, Toumarkine and Bolli, 1975, pl. 6, figs. 1, 7, 8; 4, paratype, Toumarkine and Bolli, 1975, pl. 6, fig. 3), Zone E14, sample 68/60, Italy; **5, 6** (Toumarkine and Bolli, 1975, pl. 6, figs. 2, 4), Zone E14, sample 68/59, Possagno section, Italy; **7, 11, 15**, Zone E14, ODP Hole 738B/7H/2, 90-95 cm, Kerguelen Plateau, Southern Indian Ocean; **8-10, 12-14** (same specimens), Zone E14, Atlantic City Borehole, New Jersey, ODP 150X, 1390 feet. Scale bar: **1, 4-6** = 50 µm; **7-15** = 40 µm; 2 = 10 µm; **3** = 5 µm.

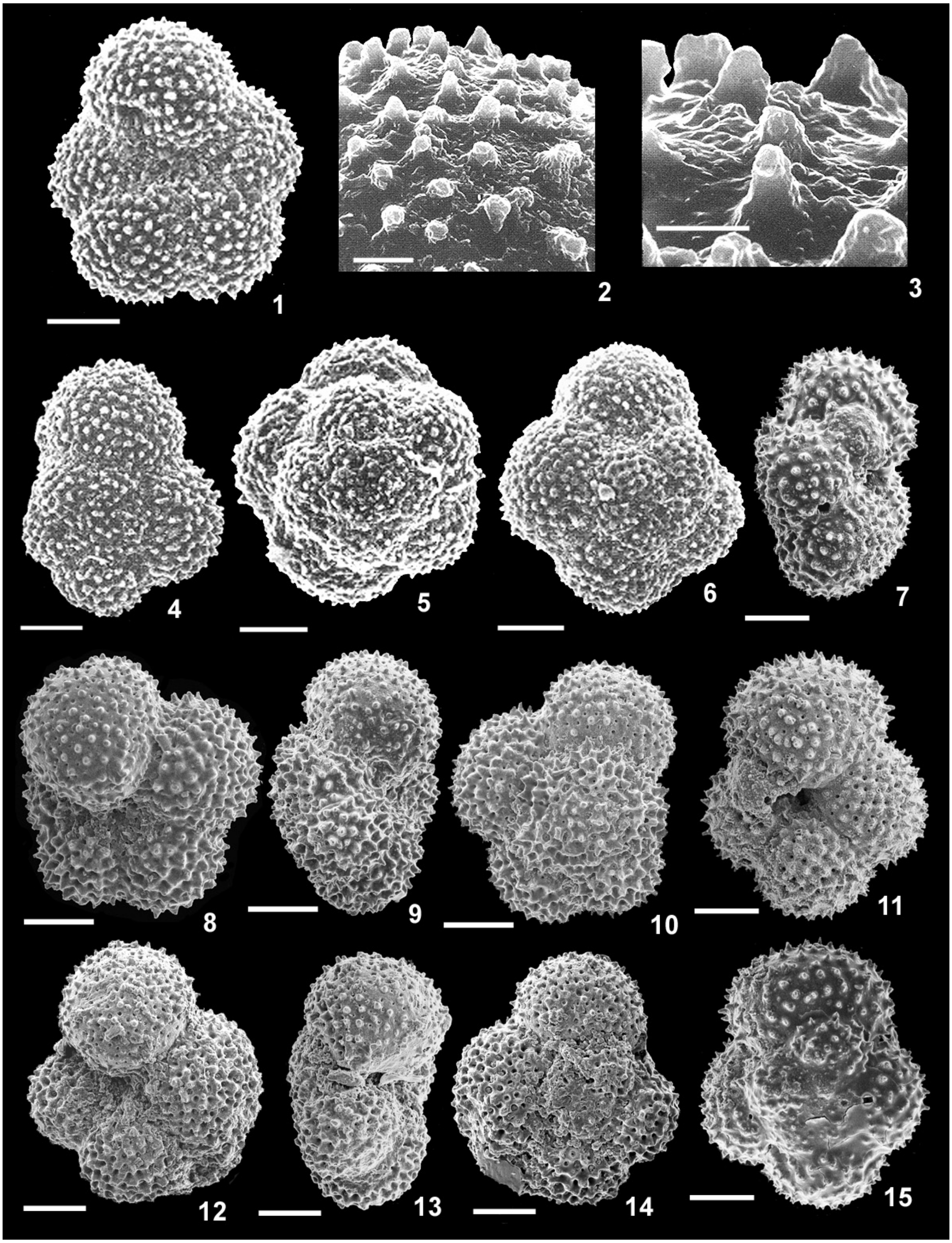

Plate 9.14 *Acarinina medizzai* (Toumarkine and Bolli, 1975)

Hammond Core, southwestern Salisbury Embayment, Maryland coastal plain, "Zone P15" was recognized by the overlap of the lower range of *Pseudohastigerina naguewichiensis* and the occurrence of *Globigerina* (*vel Acarinina*) *medizzai.* However, in ODP Hole 1053A the highest occurrence of *A. medizzai* has been recorded in Sample 1053A-3H-4, 105 cm, in Chron C16n.2n, which is stratigraphically equivalent to Zone E14 (Wade, 2004). Although Subbotina (1953) recorded muricate forms assigned to *A. rugosoaculeata* (e.g., Subbotina, 1953, pl. XXV: figs. 5a-c) in the (questionable) lower-middle Oligocene of the northern Caucasus region, no forms that are currently identified as *A. medizzai* (?=*A. rugosoaculeata*) have been recorded above Zone E14 elsewhere to our knowledge.

GEOGRAPHIC DISTRIBUTION.— This species has a cosmopolitan distribution but is often unreported, perhaps because of its small size and/or incorrect identification.

STABLE ISOTOPIC PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (C 24315) and paratypes (C 27327-27329) deposited in the Basel Museum of Natural History.

Acarinina pentacamerata (Subbotina, 1947)

PLATE 9.15, FIGURES 1-16
(Pl. 9.14, Figs. 1-3: designed neotype; 5-7: new SEMs of topotype of *Globorotalia crassa* d'Orbigny *pentacamerata* Subbotina)

Globorotalia crassa d'Orbigny *pentacamerata* Subbotina, 1936 (not described, but illustrated, pl. 3: figs. 7-9; *nomen nudum*; holotype by subsequent designation in 1947) [*Globorotalia crassaformis* Zone, Khieu River section, northern Caucasus].

Globorotalia pentacamerata Subbotina, 1947:128-129 (partim), pl. 7: figs. 15-17 (holotype by subsequent designation = 1936, pl. 3: figs. 7-9); pl. 7: figs. 12-14 [Sunzha River, northwest Caucasus].—Said, 1960:283, pl. 1: figs. 4a-c [upper Esna Shale Fm., Luxor, Egypt].—Said and Kerdany, 1961:329, pl. 1: figs. 15a-c [Ain Maqfi section, Farafra Oasis, Egypt].—Proto Decima and Zorzi, 1965:27, pl. 2: figs. 4a-5c [*G. aragonensis* Zone, Molinetto di Pederobba, western Trevigiano, Italy].—Stainforth and others, 1975:212-213, text-figs. 1-2 (reillustration from literature); figs. 4-5 [lower Eocene of northern Caucasus].—Pujol, 1983:652, pl. 5: fig. 3 [Zone P10, DSDP Hole 516F, 73/4, 148-150 cms; Rio Grande Rise, southern Atlantic Ocean].

Acarinina pentacamerata (Subbotina).—Subbotina, 1953:233 (*partim*), pl. 23: fig. 8 a,b; pl. 24: fig. 1a-c [Zone of conical globorotaliids, Kuban River section, northern Caucasus]; pl. 24: figs. 2a-c [Zone of conical globorotaliids, Gubs River section, northern Caucasus]; pl. 24: figs. 3a-5c [Zone of conical globorotaliids, vicinity of Nal'chik, Khieu River section, northern Caucasus].—Shutskaya, 1956, pl. 3: fig. 6a-c [*G. aragonensis* Zone, vicinity of Nal'chik, Cherkessk Fm., northern Caucasus].—Kraeva, in Kaptarenko-Chernoussova and others, 1963:152, pl. 31: figs. 6a-b [middle Eocene, Russian Platform, Ukraine].—Hillebrandt, 1965:344, pl. 5: figs. 10a-c [*G. palmerae* Zone, Agost, Alicante Province, Spain].—Berggren, 1969:124, pl. 1: figs. 24-26 [lower Eocene Zone P7/NP12, Hollbecker Berg, north-west Germany].—Fleisher, 1974:1013, pl. 1: fig. 9 [Zone P8, DSDP Site 220, Arabian Sea].— Snyder and Waters, 1985:443, pl. 12: figs., 12-14 [Zone P10, DSDP Site 548A, Goban Spur, north-east Atlantic Ocean].—Toumarkine and Luterbacher, 1985:116, text-figs. 17.4-5 (reillustration from literature).—Krasheninnikov and others, 1988:97, pl. 8: figs. 10-12 [*G. aragonensis* Zone, DSDP Site 277, Campbell Plateau].—Stott and Kennett, 1990:559, pl. 45: figs. 9,10 [Zone AP6b, ODP Site 690B, Maud Rise, Southern Ocean].—Huber, 1991:439, pl. 2: figs. 6-8 [Zone AP7, ODP Hole 738C, southern Indian Ocean].—Warraich, Ogasawara, and Nishi, 2000:293, fig. 17.16-18 [Zone P7, Rakhi Nala River section, Sulaiman Range, Pakistan].—Warraich and Ogasawara, 2001:27 fig. 7.1-3 [Zone P7, Dungan Fm., Rakhi Nala River section, Sulaiman Range, Pakistan].

Turborotalia (*Acarinina*) *pentacamerata* (Subbotina).—Pokorny, 1960: 1107, pl. 4: fig. 6 [lower Eocene, Czechoslovakia].—Samuel, 1972, pl. 54: figs. 1a-3c [middle Eocene, Bakony Mountains, Hungary].

Globorotalia (*Acarinina*) *pentacamerata* (Subbotina).—Hillebrandt, 1962:142, pl. 14: fig. 7a-c [Zone G, Reichenhall-Salzburg Basin, Austria].—Blow, 1979:939, pl. 135: fig. 5 [Zone P8b, DSDP Site 47, Shatsky Rise, north-west Pacific Ocean].

Acarinina pentacamerata (Subbotina) var. *camerata* Khalilov 1956:253, pl. 5: fig. 6a-c [lower Eocene, Maly Caucasus, Akhchakumia, north-east Azerbaijan].

Globorotalia (*Acarinina*) *camerata* (Khalilov).—Blow, 1979:917, pl. 135: fig. 6 [Zone P8b, DSDP Site 47, Shatsky Rise, northwest Pacific Ocean]; pl. 156: figs. 5 and 6 [Zone P10, KANE 9, piston core 42, Endeavour Seamount, equatorial Atlantic Ocean].

Globigerina soldadoensis Brönnimann-*Globigerina gravelli* Brönnimann transitional form.—Bolli, 1957a, pl. 16: figs. 10-12 [*G. formosa formosa* Zone, upper Lizard Springs Fm., Trinidad]. [Not Brönnimann, 1952.]

Globigerina mckannai (White).—Berggren 1960a:68 (*partim*), pl. 1: fig. 4 [lower Eocene, Hollbecker Berg, Germany]; pl. 9: fig. 4; pl. 10: fig. 1, text fig. 7 [lower Eocene Røsnaes Clay, Røgle Klint, Denmark]. [Not White, 1928.]

DESCRIPTION.

Type of wall: Densely muricate on both sides, normal perforate, nonspinose.

Test geometry: Low-trochospiral; generally 5 (ranging from 4$^1/_2$-6 or 7) rounded, inflated chambers, increasing gradually in size in last whorl; periphery weakly lobate; umbilicus generally small, deep with concentration of muricae around circumumbilical region; aperture a low umbilical-extraumbilical slit; 10-12 chambers arranged in 2$^1/_2$ whorls; early chambers elevated slightly above plane of final whorl; intercameral sutures weakly curved, tangential to peripheral margin in early chambers of last whorl; in edge view test is weakly biconvex, peripheral margin rounded; intercameral sutures radial, weakly retorse along rounded peripheral margin.

Size: Largest diameter 0.40-0.50 mm; thickness 0.20-0.25 mm.

DISTINGUISHING FEATURES.— Compact, strongly muricate test with 5 globular, inflated chambers in last whorl.

DISCUSSION.— The taxonomic history of *Acarinina pentacamerata* (Subbotina) is extremely complex and not without a considerable degree of uncertainty. We attempt a reconstruction here of this history in an effort to bring nomenclatural stability to a much (ab)used taxon.

1. In 1936, Subbotina mentioned and illustrated (her pl. 3, figs. 7-9) a new variety *Globorotalia crassa* (d'Orbigny) var. *pentacamerata* Subbotina. In failing to describe it, the form was instantly rendered *nomen nudum* according to the International Rules of Zoological Nomenclature, art. 25 (c), 1-2. The illustrated specimen is of a tightly coiled (involute) individual with 6 chambers in the final whorl (which may or may not be related to the *Acarinina lodoensis-broedermanni* group, cf. Blow (1979, p. 940) and was described from the "*Globorotalia crassaformis* Zone" (= probably equivalent to Zone E7 of this work). Krasheninnikov and others (1988, pl. 8, fig. 8) figured as *A. pentacamerata* a specimen from the lower Eocene of the Campbell Plateau, south-west Pacific Ocean that is virtually identical with Subbotina's (1947) strongly involute holotype figure.

2. In 1947, Subbotina formally described and illustrated *Globorotalia pentacamerata* for the first time. Three specimens were figured. The holotype (pl. 7, figs. 15-17) was recorded from the *Globorotalia crassaformis* Zone (which was considered middle Eocene in age but which is in fact probably stratigraphically equivalent to lower Eocene Zone E7 of this study). Two paratypes (her pl. 7, figs. 12-14 and pl. 9, figs. 24-26) were from the lower Eocene "*Globorotalia velascoensis* Zone" of (presumed) early Eocene age (the latter zone was subsequently termed, in 1953, the "Zone of conical globorotaliids", and is characterized by *Morozovella aragonensis* [Nuttall] and *M. caucasica* [Glaessner]). However, Subbotina (1947, 1953) consistently misidentified *M. caucasica* with *M. velascoensis* which accounts for the persistent misuse of the term *G. velasacoensis* Zone in early literature (see further discussion in Blow, 1979, p. 993-996; Berggren and Norris, 1997, p. 75-76 and under *Morozovella caucasica*, Chapter 11).

3. It is doubtful/uncertain whether the three specimens illustrated in 1947 are of the same species. The form figured on pl. 7, figs. 24-26 by Subbotina (1953) shows the distinct lateral separation of chambers peripherally which is characteristic of Bolli's (1957b) *Globigerina angulosa* (=*Acarinina angulosa*). Indeed, Subbotina's specimen is almost identical to that figured by Bolli (1957a, pl. 35, figs. 8a-c) from the *Globorotalia palmerae* Zone. There may be some question as to whether Bolli's specimen from the *G. palmerae* Zone is conspecific with that figured (Bolli, 1957a, pl. 16, figs. 4-6) from the type locality of the *Globorotalia formosa formosa* Zone of Trinidad. They are considered conspecific here.

4. The paratype specimen figured by Subbotina (1947, pl. 7, figs. 12-14) shows the characters that have subsequently come to be associated with *Acarinina pentacamerata* as elucidated subsequently by Subbotina in 1953. It is curious that Subbotina (1947, p. 128) mentions that the "specimen described was found along the Kuban River". This would presumably refer to the specimen illustrated on pl. 9, figs. 24-26 (from the Kuban River section) inasmuch as the holotype (pl. 7, figs. 15-

17) and paratype (pl. 7, figs. 12-14) were recorded from the Khieu and Sunzha Rivers, respectively.

5. In 1953, Subbotina illustrated a number of specimens which she referred to *Acarinina pentacamerata* (Subbotina) including in the synonymy the specimens illustrated in her earlier (1947) work, but making no reference to the specimens illustrated on her pl. 23, figs. 8a-c and pl. 24, figs. 1a-5c, all from the Zone of conical globorotaliids— and if we ignore/ exclude the smaller upper Paleocene forms (pl. 24, figs. 6a-8c) and the anomalous 8-chambered acarininid (pl. 24, figs. 9a-c) from the *G. marginodentata* Subzone, it would appear that we have an homogenous group of morphotypes referable to a single taxon. Blow (1979, p. 940) noted that he based his interpretation of *pentacamerata* on Subbotina (1947, pl. 7, figs. 12-14) and he represented this concept with a specimen he illustrated on pl. 135, fig. 5 from Zone P8b (=Zone E5 of this work). The specimens illustrated by Subbotina (1953) and listed above all show a close similarity to that figured by her in 1947 pl. 7, figs. 12-14. It is interesting that none conform closely, let alone remotely, to the holotype illustration of 1936/1947. One thing is clear: Subbotina (1953) did not base her concept of *A. pentacamerata* on her (earlier illustrated) holotype of the taxon.

6. The holotype and paratype specimens of *A. pentacamerata* from Subbotina (1936/1947) were missing from the micropaleontologic collections of VNIGRI (Leningrad/St. Petersburg) on the occasion of several visits there by WAB in 1962, 1963 and in the 1970s. It is possible that they were lost or destroyed during the siege of Leningrad (1941-1943). On the other hand, all the specimens illustrated by Subbotina (1953) were examined during these visits and the taxonomic statements above reflect these observations. Thus the concept of *A. pentacamerata* in the work of one of us (WAB) has been based on these specimens. The 5-7 rounded chambers, relatively wide umbilicus and weakly developed circum-umbilical shoulder distinguish this species from associated forms in the lower Eocene.

7. Inasmuch as the holotype and paratypes of this taxon have been lost and it is virtually impossible to ascertain with certainty its taxonomic identity in terms of modern nomenclature, it would appear desirable, in the interest of nomenclatural stability, to base a concept of *A. pentacamerata* on the forms illustrated by Subbotina (1953) listed above and to designate a neotype from this series. Accordingly, based on observations of the material at VNIGRI, we designate as neotype the specimen illustrated on pl. 23, figs. 8a-c (no. 3088 in the micropaleontological collections at VNIGRI) from the Zone of conical globorotaliids, Green Formation, Kuban River section, North Caucasus.

8. A relatively large, robust morphotype exhibiting more relaxed, evolute coiling exposing/ opening the umbilical region has been described as *Acarinina pentacamerata* (Subbotina) var *camerata* by Khalilov, 1956 (see also Blow, 1979, p. 917). Placed in the synonymy of *A. pentacamerata* by Berggren (1977) and Berggren and Norris (1997), we maintain this view here and view this morphology as transitional to *aspensis*.

PHYLOGENETIC RELATIONSHIPS.— Evolved from *Acarinina interposita* Subbotina and probably gave rise to *A. aspensis* (Colom) and *A. collactea* (Finlay).

STRATIGRAPHIC RANGE.— Zone E5 to Zone E7. Given the intricate taxonomic discussion above, and in the light of our selection of a neotype, it is necessary to review the range of *A. pentacamerata* as described in Subbotina's papers. Subbotina (1947) designated as the holotype of *A. pentacamerata* a specimen from the *Globorotalia crassaformis* Zone. This level is probably equivalent to Zone E7. She subsequently (1953, p. 234,

Plate 9.15 *Acarinina pentacamerata* (Subbotina, 1947)

1-3 (designated neotype, Subbotina, 1953, pl. 23, figs. 8a-c) [lower middle Eocene, Kuban River section, northern Caucasus]; **5-7** (topotype), lower Eocene *Globorotalia crassaformis* Zone, Khieu River section, northern Caucasus; **4, 8, 9-11, 13, 14** [13, 14, *Globorotalia* (*Acarinina*) *camerata* (Khalilov), Blow, 1979, pl. 156, figs. 5, 6], Zone E8, KANE 9-Core 42, 42 cm, Endeavour Seamount, equatorial North Atlantic Ocean; **15** [*Globorotalia* (*Acarinina*) *camerata* (Khalilov), Blow, 1979, pl. 135, fig. 6], Zone E6, DSDP Hole 42.2/8/1, 77-79 cm, western North Pacific Ocean; **12, 16** (Stott and Kennett, 1990, pl.6, figs. 9, 10, Zone AE3/4, ODP Hole 690B/15H/3, 110-114 cm, Maud Rise, Weddell Sea. Scale bar: **1-16** = 100 µm.

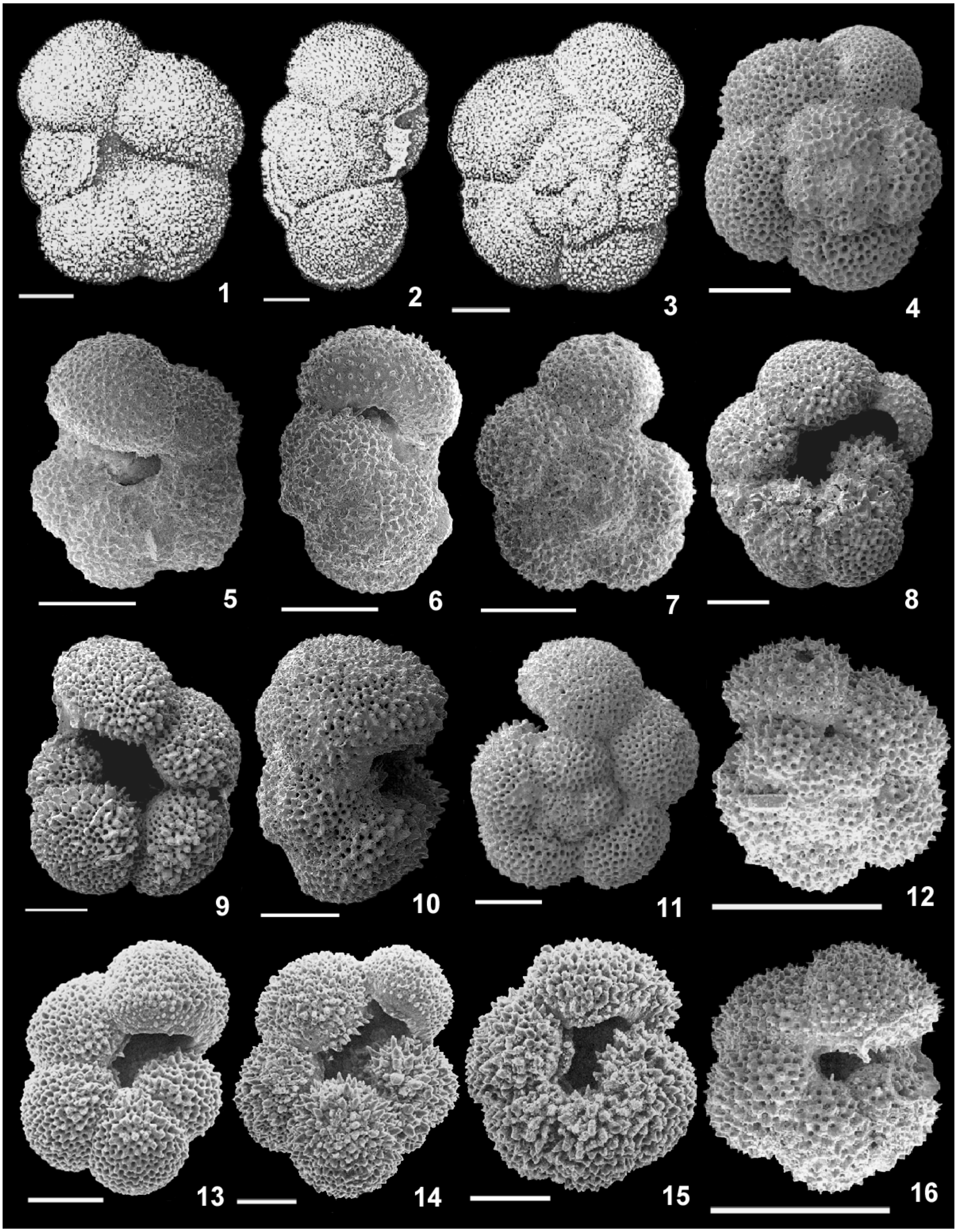

Plate 9.15 *Acarinina pentacamerata* (Subbotina, 1947)

table 3, p. 29) showed it to range from the *G. crassata* Subzone of the Zone of compressed globorotaliids (~/= Zone P5-E3) through the Zone of conical globorotaliids (~/= Zones E4-E6), but observed that this species reached its acme of development in the Zone of conical globorotaliids. However, in her chart showing the suggested phylogeny of the acarininids (Subbotina, 1953, p. 153, fig. 8) Subbotina showed *A. pentacamerata* evolving from *A. interposita* Subbotina at the base of the *G. marginodentata* Subzone (~/= Zones E4-E5) and ranging to the top of the Zone of conical globorotaliids. She mentioned (1953, p. 234) that the forms from the uppermost Paleocene of Mangyshlak Peninsula (illustrated as her pl. 24, figs. 6a-8c) differed from the lower Eocene forms in their significantly smaller size, indicating that she probably harbored some doubts/ reservations on the conspecificity of the two groups (see discussion above).

GEOGRAPHIC DISTRIBUTION.— Essentially global distribution in the early Eocene; not reliably reported from high austral latitudes.

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype and original paratypes presumed lost. Neotype (Subbotina, 1953, pl. 23, figs. 8a-c) from lower Eocene Zone of conical globorotaliids, Green Formation, Kuban River section, North Caucasus, designated here.

Acarinina praetopilensis (Blow, 1979)

PLATE 9.16, FIGURES 1-16
(Pl. 9.16, Figs. 1-3: reillustration of holotype and paratypes of *Globorotalia* (*Truncorotaloides*) *topilensis praetopilensis* Blow)

Globorotalia (*Truncorotaloides*) *topilensis praetopilensis* Blow, 1979:1043, pl. 155: fig. 9; pl. 203: figs. 1-2 (detail of pl. 155: fig. 9) [Zone P10, KANE 9, piston-core 42, 95 cm, Endeavor Seamount, equatorial Atlantic Ocean]; pl. 169: figs. 1-9 (8=holotype), pl. 207: fig. 1 (detail of. Pl. 178: fig. 9), fig. 2 (=detail of pl. 169, fig. 7), pl. 208: figs. 1-4 (=detail of pl. 169, fig. 4), pl. 208: fig. 5 (=detail of pl., 169, fig. 7) [Zone P11, Sample RS. 24, Kilwa area, Tanzania]; pl. 178: figs. 6-9, pl. 185: figs. 7-8 [Zone P11, DSDP Hole 21A, South Atlantic Ocean]; pl. 187: figs. 1-2 and pl. 208: fig. 6 (=detail of pl. 187: fig. 2) [Zone P12, DSDP Site 19, South Atlantic Ocean]; pl. 187: figs. 3-4 [Zone P12, DSDP Hole 21A, South Atlantic Ocean].

Acarinina praetopilensis (Blow, 1979).—Pearson and others, 2004:37, pl. 2: figs. 7-9 (fig. 9 =details of muricae) [Zone P11, Tanzania Drilling Project Site 2/9/CC].

Not *Acarinina praetopilensis* (Blow, 1979).—Wade and others, 2001:277: figs. 3f-3h.—Wade, 2004:28, pl. 1: figs. g-h (=*A. mcgowrani*)

DESCRIPTION.

Type of wall: Strongly muricate, nonspinose, normal perforate.

Test morphology: Low-trochospiral, sutures radial, straight, sunk (depressed) between overlapping junction(s) of juxtaposed inflated chambers; umbilicus deep and wide with no circum-umbilical muricate rim/ collar; weakly rimmed aperture extends towards (but does not reach) the periphery; 9-10 chambers in 2-2½ whorls on spiral side; chambers tangentially longer than radially broad; last chamber distinctly disjunct, cuneate or mitriform, subacute margin with profusion/ concentration of partially fused muricae; supplementary apertures usually present between the last two chambers in well preserved individuals; spiral sutures radial to weakly curved; in edge view high, angulo-conical.

Size: Maximum diameter of holotype: 0.38mm (Blow, 1979, p. 1043).

Plate 9.16 *Acarinina praetopilensis* (Blow, 1979)

1-3 (1, holotype, Blow, 1979, pl. 169, fig. 8; 2, 3, paratypes, Blow, 1979, pl. 169, figs. 4, 7), Zone E9, Sample RS.24, Kilwa area, Tanzania; **4, 6-12** (10 reillustration of Pearson and others, 2004, pl. 2, fig. 8), Zone E9, TDP Site 2/9/CC, Kilwa, Tanzania; **5, 13**, Zone E10/11, ODP Hole 865C/4H/5, 110-112 cm, Allison Guyot, equatorial Pacific Ocean; **14-16**, Zone E10/11, DSDP 523/43/1, 123-125, Walvis Ridge, eastern Atlantic Ocean. Scale bar: **1-16** = 100 µm.

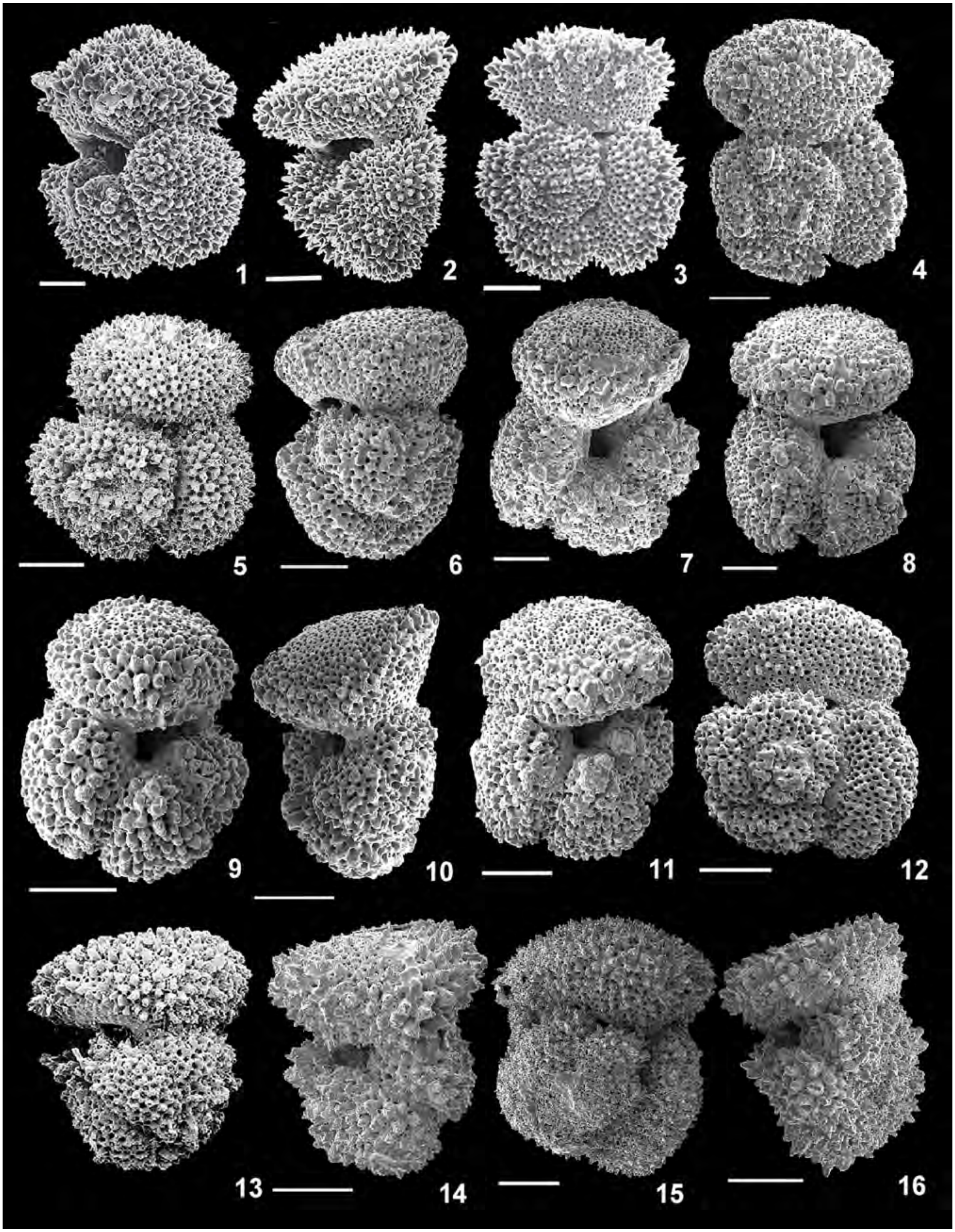

Plate 9.16 *Acarinina praetopilensis* (Blow, 1979)

DISTINGUISHING FEATURES.— Distinguished by its strongly muricate, subquadrate test, disjunct, cuneate to mitriform last chamber which bears heavy circum-peripheral concentration of partially fused muricae.

DISCUSSION.— *Acarinina praetopilensis* was named by Blow (1979) for middle Eocene descendants of *A. pseudotopilensis* that show more closely appressed chambers in the last whorl leading to laterally angulate chambers and enhanced circum-peripheral concentration of partially fused muricae into a muricocarina on the last chamber.

PHYLOGENETIC RELATIONSHIPS.— Probably evolved from *Acarinina mcgowrani* n. sp. by greater lateral compression of, and concomitant concentration of partially fused muricae on, margins of last chamber, greater laxity in coiling mode and resulting larger and deeper umbilicus, and development of rimmed supplementary apertures between (at least) the last two chambers (Blow, 1979). It gave rise to *Acarinina topilensis* by developing a more distinctly lobate periphery, disjunct chamber margins on later chambers which exhibit pronounced cuneate or mitriform shape, stronger/heavier concentration of thick muricae on chambers of the last whorl, looser coiling resulting in even wider umbilicus than in *praetopilensis* and larger and greater number of supplementary apertures on spiral side.

STRATIGRAPHIC RANGE.— Zone E7 (upper part) to Zone E12.

GEOGRAPHIC DISTRIBUTION.— Widespread distribution in Tethyan and South Atlantic regions.

STABLE ISOTOPE PALEOBIOLOGY.— Relatively negative $\delta^{18}O$ and positive $\delta^{13}C$ indicate a mixed layer habitat. Size fraction data shows a large change in $\delta^{13}C$ through ontogeny suggestive of a symbiotic relationship like other muricate forms (Boersma and others, 1987; Pearson and others, 1993; recorded as *pseudotopilensis*).

REPOSITORY.— Holotype (BP Cat. NO. 64/2) deposited in the micropaleontological collections of The Natural History Museum, London.

Acarinina primitiva (Finlay, 1947)

PLATE 9.17, FIGURES 1-16
(Pl. 9.16, Figs. 1-4: new SEMs of holotype and paratype of *Globoquadrina primitiva* Finlay)

Globoquadrina primitiva Finlay 1947:291, pl. 8: figs. 129-134 [middle Eocene, *G. index* Zone, Hampden Beach Fm., South Island, New Zealand].—Hornibrook, 1953:437, pl. 1: fig. 1 (reillustration from literature).—Jenkins, 1965a:269, pl. 1: fig. 1 (outline drawing of holotype).

Globigerina primitiva (Finlay).—Brönniman, 1952:11, pl. 1: figs. 10-12 [Trinidad; Soldado and Lizard Springs Fms.].—Hornibrook, 1961:148 [middle Eocene, *G. index* Zone, Hampden Beach Fm., South Island, New Zealand].—Postuma, 1971:154, 7 figured specimens [middle Eocene Hampden Fm., Otago Province, South Island, New Zealand, lower Eocene].

Pseudogloboquadrina primitiva (Finlay).—Jenkins, 1965b:1124-1125, fig. 9, nos. 81-86 (new illustrations of holotype and paratypes) [middle Eocene, New Zealand].—Jenkins, 1971:170, pl. 18: figs. 555-557 (holotype refigured), 558-560 (paratype refigured), and 561 (other specimen) [middle Eocene, New Zealand].—Krasheninnikov and Basov, 198:840, pl. 9: figs. 4-7 [middle Eocene, DSDP Hole 512, Ewing Bank, South Atlantic Ocean].

Globorotalia (*Acarinina*) *primitiva* (Finlay)—Blow, 1979:949, pl. 143: figs. 6-9 [Zone P8b, lower Eocene, DSDP Site 20C, South Atlantic Ocean]; pl. 249: figs. 1-4 [topotypes, middle Eocene Hampden Fm., Otago Province, New Zealand].

Acarinina primitiva (Finlay).—Stott and Kennett, 1990:559, pl. 6: figs. 11,12 [Zone AP8, lower Eocene, ODP Hole 689B, Maud Rise, Weddell Sea, Antarctic Ocean].—Huber, 1991: 439, pl. 3: fig. 1 [middle Eocene Zone AP10, ODP Site 738, Kerguelen Plateau, southern Indian Ocean].—Berggren, 1992:563, pl. 2: figs. 4,5 [Zone P6-7, ODP Site 748, Kerguelen Plateau, southern Indian Ocean].—Pearson and others, 1993, pl. 1: fig. 19 [middle Eocene Zone P11-P12, DSDP Hole 523, South Atlantic Ocean].—Lu and Keller, 1993, pl 3: figs. 1,2 [lower Eocene Zone AP7, ODP Hole 738C, Kerguelen Plateau, southern Indian Ocean].—Basov, 1995:165, pl. 1: figs. 11-13 [ODP Hole 883B, Detroit Seamount, north-west Pacific Ocean; *n.b:* not recorded at this level in Table 1, p. 160].

Not *Globigerina primitiva* (Finlay).—Bolli, 1957a:71, pl. 15:figs. 6-8 [*Gt. rex* Zone, Trinidad].—Stainforth and others, 1975:215, fig. 75.1 (reillustration from Bolli and others, 1957), figs. 75.2-3 [*G. formosa formosa* Zone, Lodo Fm., California]. (=*Acarinina coalingensis*.)

Not *Globorotalia* (*Acarinina*) *primitiva* (Finlay).—Hillebrandt, 1962:141, pl. 14: figs. 2, 4 [Zone G, lower Eocene, Austria]. (=*Acarinina coalingensis*.)

DESCRIPTION.

Type of wall: Coarsely muricate, often with relatively smooth umbilical face to final chamber, normal perforate, nonspinose.

Test morphology: Robust, compact, subquadrate, strongly and bluntly muricate test; 3-4 triangular-shaped chambers in last whorl); chambers arranged at distinct right angles to each other and usually separated by distinct and incised sutures (particularly between pre-antepenultimate and antepenultimate chambers) on the umbilical side; umbilicus narrow, deep; aperture asymmetrically placed at base of last chamber, intereriomarginal, umbilical-extraumbilical; high, smooth or beaded (but not muricate) face to final chamber above aperture; chambers on spiral side tangentially longer than broad; sutures curved, generally obscured by muricate ornament; peripheral margin subangular in edge view.

Size: Maximum diameter of holotype 0.29 mm, thickness 0.26 mm.

DISTINGUISHING FEATURES.— Distinguished by triangular (broadly wedge-shaped) chambers; asymmetrically situated aperture resulting in distinct projection of umbilical face of last chamber over the umbilicus. *Acarinina coalingensis* has more rounded, inflated chambers than *A. primitiva* and lacks the straight, incised intercameral sutures on the umbilical side.

DISCUSSION.— The outward, superficial morphologic similarity of the type species *primitiva* to that of the Neogene globoquadrinid form *Globoquadrina dehiscens* led Jenkins (1965b) to create the generic name *Pseudogloboquadrina* for Eocene morphotypes, but the morphology is similar to other Paleogene acarininids and this name is unnecessary (see also Blow, 1979, p. 950).

Acarinina primitiva is the dominant acarininid in middle Eocene austral assemblages and its disappearance/extinction in the late middle Eocene (?Chron C18n) is a useful datum level for regional correlation. See discussion in Berggren and Norris (1997, p. 69), Olsson and others (1999, p. 437) and above for *A. coalingensis* for further relevant data.

PHYLOGENETIC RELATIONSHIPS.— This form descended from *Acarinina coalingensis* in the early Eocene by means of developing a more subquadrate test and concomitant sutural incision and chamber separation in the final whorl.

STRATIGRAPHIC RANGE.— Zone E6 to Zone E13. Berggren and others (2000) recorded the lowest/earliest occurrence of *A. primitiva* in association with the lowest/earliest *A. coalingensis* in Zone P4c and Chron C25r and C25n at DSDP Site 384 in the northwest Atlantic Ocean (see also compilation in Berggren and others, 1995, p. 155); we now regard these records as referable to *A. coalingensis*. The last occurrence datum has been fixed by Huber (1991) to lower Zone AP11 at Sites 738 Kerguelen Plateau, by Stott and Kennett (1990) to a level in mid-Chron C18n at ODP Site 689 on Maud Rise and by Berggren (1992) to a level within/slightly above questionable Chron 18n at Site 748, Kerguelen Plateau, which is approximately equivalent to Zone E13 in the (sub)tropics.

GEOGRAPHIC DISTRIBUTION.— Essentially temperate-high latitude (austral; South Indian Ocean and Subantarctic Ocean distribution; less commonly reported in low latitudes (Caribbean, Atlantic, Indo-Pacific).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype, New Zealand Geological Survey Register no. TF 1264.

Acarinina pseudosubsphaerica Pearson and Berggren, new species

Plate 9.2, Figures 9-16
(Pl. 9.2, Figs. 9-10, 14-15: SEMs of holotype and paratypes)

Muricoglobigerina esnehensis (Nakkady).—Pearson and others, 1993: pl. 1: fig. 20 [middle Eocene Zone P11-P12, DSDP Site 523, Walvis Ridge, South Atlantic Ocean]. [Not Nakkady, 1950.]

Acarinina aquiensis (Loeblich and Tappan).—Lu and Keller, 1995: pl. 2: figs. 24-26 [Lower Eocene Zone P9, DSDP

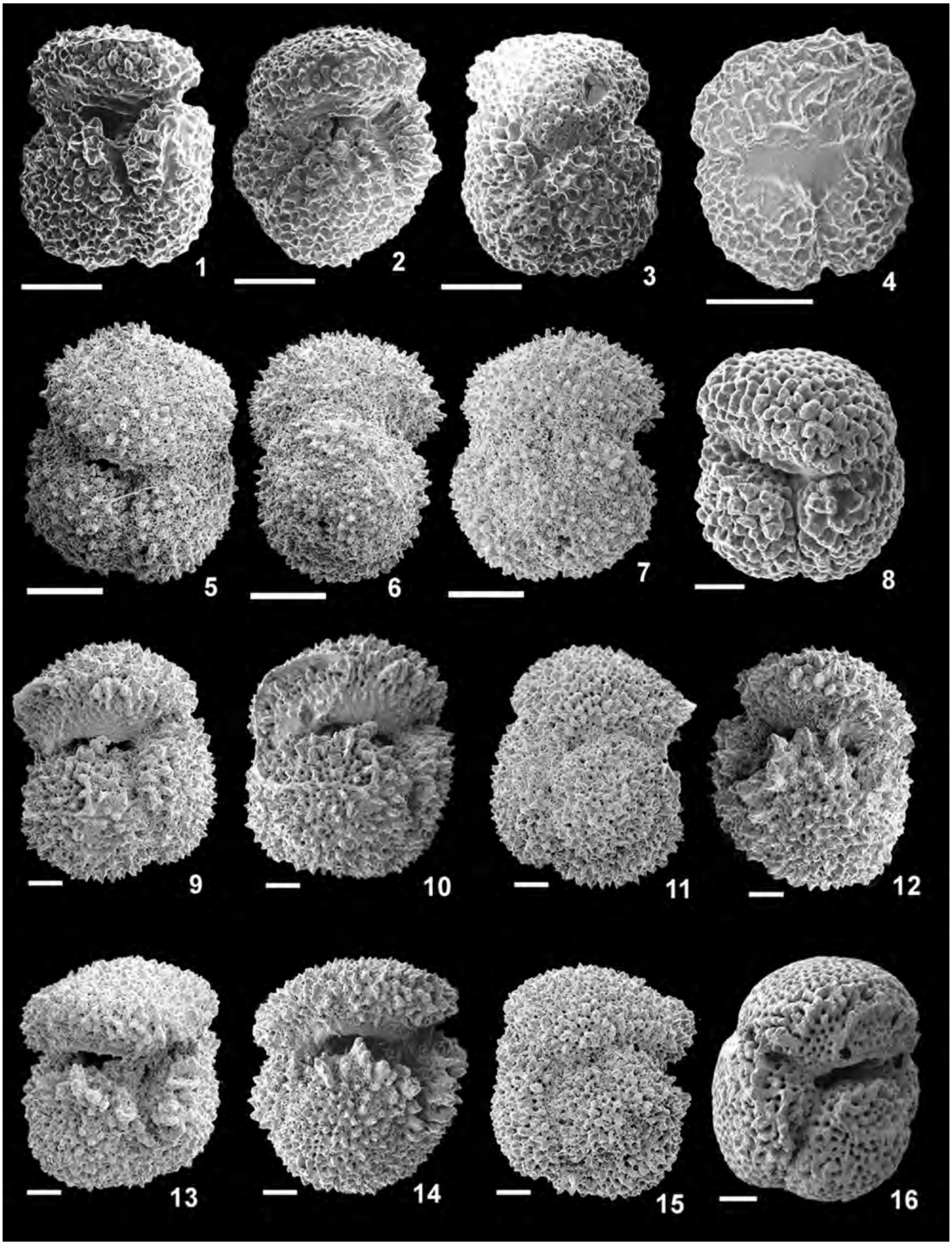

Plate 9.17 *Acarinina primitiva* (Finlay, 1947)

Site 577, Shatsky Rise, north-west Pacific Ocean]. [Not Loeblich and Tappan, 1957.]

Acarinina cf. *subsphaerica* (Subbotina).—Pearson and others, 2004:37, pl. 2, fig. 4 [middle Eocene, Zone P11, Tanzania Drilling Project Site 2, Kilwa Masoko, Tanzania]. [Not Subbotina, 1947.]

DESCRIPTION.

Type of wall: Weakly muricate, cancellate on spiral side with large, bladed muricae on umbilical side, normal perforate, nonspinose.

Test morphology: Compact subspherical test coiled in a high trochospire of about two whorls with circular, slightly lobate outline; 4-6 moderately inflated, radially compressed chambers in final whorl; dorsal sutures wide and depressed, between circular chambers; primary aperture slit-like or a low, broad arch, situated in a wide, open umbilicus, and often covered by a small, sparsely muricate final chamber.

Size: Maximum diameter of holotype 0.19 mm, thickness 0.16 mm.

ETYMOLOGY.— Named for its resemblance to the Paleocene species *Acarinina subsphaerica* Subbotina.

DISTINGUISHING FEATURES.—*Acarinina pseudosubsphaerica* n. sp. is distinguished from all other middle Eocene acarininids by its high spire, small size and subspherical shape. It is similar in morphology to the Paleocene species, *A. subsphaerica* (Subbotina), but differs from that form and *A. alticonica* Fleisher by having less closely appressed chambers and a broader umbilicus.

DISCUSSION.—Despite being a relatively common form in the lower and middle Eocene, *Acarinina pseudosubsphaerica* n. sp. has not been formally recorded. *Acarinina alticonica* Fleisher is closely related and the two species have been observed to intergrade in Zone E6/E7 (undifferentiated) of Tanzania Drilling Project Site 2 (P.N. Pearson, unpublished data). Lu and Keller (1995) recorded a first occurrence in Zone P9 (=E7) of *Acarinina aquiensis* in DSDP Site 577 (Shatsky Rise, north-west Pacific Ocean), which is regarded as conspecific here, and not referable to Loeblich and Tappan's species (which is a Paleocene form from the Aquia Formation of Virginia and Maryland probably related to/conspecific with *Acarinina subsphaerica*; see Berggren and Norris, 1997).

PHYLOGENETIC RELATIONSHIPS.—Descended from *A. alticonica*.

STRATIGRAPHIC DISTRIBUTION.—Zone E7 to Zone E10

GEOGRAPHIC DISTRIBUTION.—Probably widely distributed in tropical and mid-latitude sites.

STABLE ISOTOPE PALEOBIOLOGY.—Recorded (under the name *Muricoglobigerina esnehensis*) as a mixed layer dwelling species by Pearson and others, (1993).

REPOSITORY.—Holotype (USNM 523427) and paratypes (USNM 523427a, b, c) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina pseudotopilensis Subbotina, 1953

PLATE 9.18: FIGURES 1-16
(Plate 9.18: figs. 1-3: reillustration of holotype of *Acarinina pseudotopilensis* Subbotina)

Plate 9.17 *Acarinina primitiva* (Finlay, 1947)

1-4 (figs. 1-3, holotype, NZGS TF 1264; fig. 4, paratype, USNM 689059), lower Eocene, Hampden Beach, New Zealand; **5-7**, Zone AE7, ODP Hole 738B/5X/CC, Kerguelen Plateau, South Indian Ocean (same specimen); **8**, middle Eocene, sample PP01HB117, Hampden Beach, New Zealand; **9-15**, Zone AO1, ODP Hole 690B/13H/5, 53-56 cm, Maud Rise, Weddell Sea (9-11, 13-15 same specimens); **16**, Zone P11, Tanzania Drilling Project 2/9/CC, Kilwa Masoko, Tanzania. Scale bar: **1-16** = 50 µm.

Acarinina pseudotopilensis Subbotina, 1953:227, pl. 21: figs. 8a-c (holotype) and 9a-c [Zone of conical globorotaliids, Green Fm., Kuban River section, North Caucasus]; pl. 22: figs. 1a-3c [Zone of conical globorotaliids, Foraminiferal Beds, near Nal'chik, North Caucasus].—Berggren, 1977:250, chart no. 10 (reillustrations from the literature).—Snyder and Waters, 1985: 446, pl. 6: figs. 17-19 [Zone P7, DSDP Site 549, north-east Atlantic Ocean].—Krasheninnikov and others, 1988:95, pl. 9: figs. 1, 2 [*Globorotalia subbotinae* Zone, DSDP Site 43, Campbell Plateau, south-west Pacific Ocean]; pl. 20: figs. 5, 6 [*Globorotalia subbotinae* Zone, Koryakskoe Hills, Kamchatka, Bering Sea].—Warraich and others, 2000:193, fig. 18. 15-17 [Zone P7, Dungan Fm., Rakhi Nala River section, Sulaiman Range, Pakistan].

Globorotalia pseudotopilensis (Subbotina).—Reyment, 1960:81, 82, pl. 15: figs. 14a-c [uppermost Paleocene, Ilaro II Borehole, Nigeria]; pl. 15: 15-17, pl. 16: fig. 1a, b [lower Eocene, Otta Borehole, Nigeria].—Berggren 1960a:94-96, pl. 11: figs. 4a-c [lower Eocene, east coast island of Fehmarn, north-west Germany]; pl. 12: figs. 1a-c [Zone NP11-12, lower Eocene, Røgle Klint, Jutland, Denmark].—Stainforth and others, 1975:217, text-figs. 78: 1a-2c [reillustrations from literature], 78. 3-6 [lower Eocene, North Caucasus].—Luterbacher, 1975:65, pl. 3: figs. 4-9 [Sample 599; *G. formosa formosa* Zone, lower Eocene, Possagno Section, northern Italy].

Globorotalia (*Acarinina*) *pseudotopilensis* (Subbotina).—Hillebrandt, 1962:143-44, pl. 14: figs. 1a-c [Zone G, Reichenhall-Salzburg Basin, Germany].—Blow, 1979:955-958, pl. 110: figs. 2-9 [Zone P6, DSDP Site 47, Shatsky Rise, northwest Pacific Ocean]; pl. 113: figs. 1-6 [Zone P7, Sample RS.80, Kilwa area, Tanzania]; pl. 132: figs. 1-3a [Zone P8b, DSDP Site 47, Shatsky Rise, north-west Pacific Ocean].

Turborotalia pseudotopilensis (Subbotina).—Gohrbandt, 1963:66-67, pl. 3: figs. 13-15 [Zone F, lower Eocene, near Salzburg, Austria].

Truncorotaloides pseudotopilensis (Subbotina).—Jenkins, 1971:135, text-figs. 382-387 [*Globorotalia wilcoxensis* Zone, Middle Waipara River section, Waipawan Stage, North Island, New Zealand].

Turborotalia (*Acarinina*) *pseudotopilensis* (Subbotina).—Samuel and others, 1972:189, pl. 69: figs. 1a-c [lower Eocene *G. subbotinae* Zone, Hradisko, Hungary].

?*Acarinina pseudotopilensis* Subbotina.—Lu and Keller, 1995:102, pl. 2. figs. 16, 17 [lower Eocene, Zone P6b, DSDP 577/9/6, 53-55 cm; Shatsky Rise, north-west Pacific Ocean].

Not *Acarinina pseudotopilensis* Subbotina.—Pearson and others, 1993:124, pl. 1: figs. 13-15 [Zones P11-12, DSDP Site 523, South Atlantic Ocean] (=*Acarinina mcgowrani*).

DESCRIPTION.

Type of wall: Densely muricate, nonspinose, normal perforate.

Test morphology: Subquadrate to suboval, weakly lobulate outline; 4 inflated chambers in last whorl; umbilical sutures distinct, radial, depressed/incised, with result that chamber contact(s) are disjunct along peripheral margin in some individuals; chambers densely muricate (marked by blunt, triangular muricae), concentrated along periphery but not forming a muricocarina; umbilicus small, deep, in many individuals obscured by overhanging, rounded umbilical shoulder; aperture an umbilical-extraumbilical low arch, extending towards the peripheral margin, bordered in most individuals by a thin lip; 10-12 chambers on spiral side disposed in 2 to 3 whorls; early whorl(s) slightly elevated; chambers tangentially longer than radially broad, meeting at nearly right angles, increasing gradually in size, often assuming a subrectangular shape; final chamber strongly inflated in some individuals and assuming a markedly rectangular or even cuneate/trapezoidal shape; murical development highly variable but concentrated generally along the peripheral margin; discrete, sutural openings visible on some individuals (often obscured by muricae on overhanging edges of previous/adjacent chambers); plano-convex in edge view; spiral side slightly elevated; ventral (umbilical) margin(s) rounded to anguloconical.

Plate 9.18 *Acarinina pseudotopilensis* Subbotina, 1953

1-3 (holotype, Subbotina, 1953, pl. 21, fig. 8a-c), lower middle Eocene, Zone of conical *Globorotalia*, Kuban River, northern Caucasus, Russia; **4-8** (4, 8; 5-7 same specimens), Zone E5, sample 914, bed 11, Khieu River, northern Caucasus; **9-14** (9-11, 12-14 same specimens), Zone E5, sample 126, Novogrovgisksuite, northern Caucasus; **15, 16**, Zone E5/6, DSDP Site 98/8/1, 22-24 cm, Blake Plateau, western North Atlantic Ocean. Scale bar: **1-16** = 100 μm.

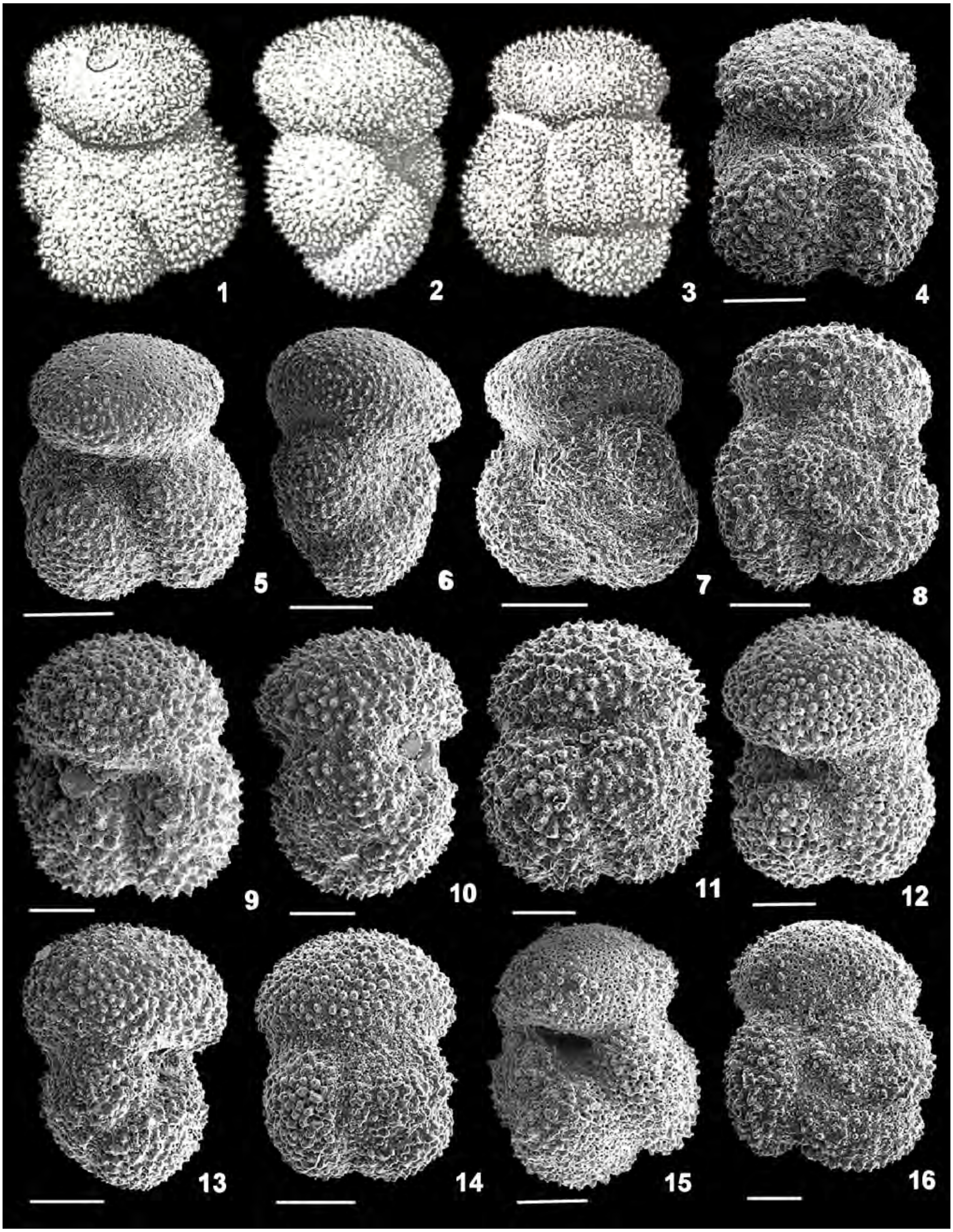

Plate 9.18 *Acarinina pseudotopilensis* Subbotina, 1953

Size: Diameter: 0.35-0.55 mm; thickness: 0.25-0.35 mm (Subbotina, 1953, p. 229); up to 0.46 mm (Berggren, 1960a, p. 94).

DISTINGUISHING FEATURES.— Distinguished from *Acarinina esnaensis* and *A. wilcoxensis* by its triangular to wedge- or cuneate-shaped chambers in the final whorl, disjunct (separation of) chamber margins and more densely muricate wall; from *A. quetra* by its less anguloconical test and lack of muricocarina.

DISCUSSION.— *Acarinina pseudotopilensis* was originally described from the Zone of compressed globorotaliids and Zone of conical globorotaliids (roughly equivalent to Zones P4-E6 of this study) in the northern Caucasus (Subbotina, 1953), although all illustrated specimens were from the Eocene part of this range. Test shape/geometry and ornament would seem to place this morphotype between *Acarinina wilcoxensis* and *A. quetra*. Blow (1979) indicated a range from Zone P6 to P10 (=E3-E8) but illustrated forms only from (his) Zones P6 to P8b (=Zones E3-E5) and it is in this (bio)stratigraphic interval that this form develops its characteristic morphology. We have not observed morphotypes referable to *pseudotopilensis* below upper Zone P5 in the course of our studies.

Blow (1979) considered that *pseudotopilensis* was the stem form of a lineage that led to *Acarinina topilensis* in the middle Eocene, and he named a new species, *praetopilensis*, for an intermediate morphology that first appears in Zone P9 (=E7 of this paper) and shows the beginnings of circum-cameral fusion of muricae that is more strongly developed in *topilensis*.

STRATIGRAPHIC RANGE.— Uppermost Paleocene / basal Eocene (uppermost Zone P5 or Zone E1) to lower Eocene Zone E7.

PHYLOGENETIC RELATIONSHIPS.— Evolved from *A. wilcoxensis* shortly after the first appearance of that species in the latest Paleocene and was ancestral to *A. quetra* in the early Eocene and *A. boudreauxi* and *A. mcgowrani* in the later part of the early Eocene.

GEOGRAPHIC DISTRIBUTION.— Widely distributed in (sub)tropical regions (Caribbean, North and South Atlantic, Indo-Pacific Oceans, Tethyan region (East, West and North Africa, North Caucasus).

STABLE ISOTOPE PALEOBIOLOGY.— Boersma and others (1987) record this species with relatively negative $\delta^{18}O$ indicating a shallow water habitat like other acarininids.

REPOSITORY.— Holotype (No. 4123) deposited in the Micropaleontological Collections of VNIGRI (Leningrad/St. Petersburg).

Acarinina punctocarinata Fleisher, 1974

PLATE 9.5, FIGURES 1-8
(Pl. 9.5, Figs. 1-3: new SEMs of holotype of *Acarinina punctocarinata* Fleisher)

Globorotalia crassaformis Galloway and Wissler.— Subbotina, 1953:223 (*partim*), pl. 21: figs. 5a-c [lower part of Zone of acarininids, Foraminiferal Beds, Green Group, Kuban River, North Caucasus]. [Not Galloway and Wissler, 1927.]

Acarinina punctocarinata Fleisher, 1974:1014, pl. 3: figs. 4-6 (holotype), 7, 8 [Zone P11, DSDP Site 220, Arabian Sea].

DESCRIPTION.

Type of wall: Strongly muricate, normal perforate, nonspinose.

Plate 9.19 *Acarinina quetra* (Bolli, 1957)

1-3 (holotype, USNM P5070), *Globorotalia formosa formosa* Zone, upper Lizard Springs Fm., Trinidad; **4, 6, 8, 9**, Zone E6, ODP Hole 865B/9H, 62-64 cm; **10, 11**, Zone E6, ODP Hole 865B/10/1, 62-64 cm, Allison Guyot, equatorial Pacific Ocean; **5, 12-16** (Blow, 1979, pl. 123, figs. 2, 3, 6-9), Zone E5, DSDP Hole 47.2/8/3, 83-85 cm, northwest Pacific Ocean; **7**, lower Eocene, Jordan. Scale bar: **1-16** = 100 µm.

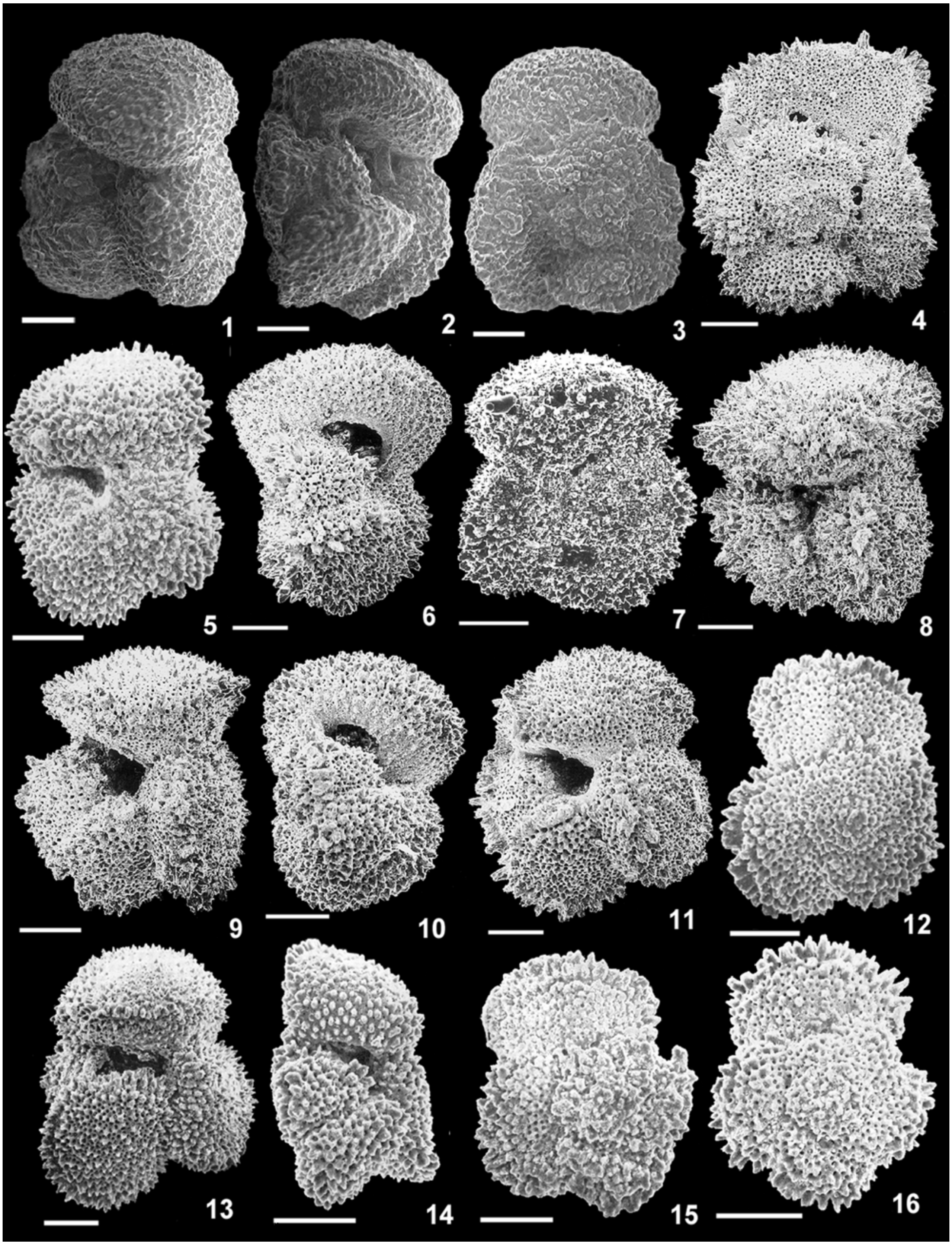

Plate 9.19 *Acarinina quetra* (Bolli, 1957)

Test morphology: Low-trochospiral, 4 inflated, wedge-shaped chambers in last whorl, distinctly longer axially than radially broad; umbilicus open, deep, and generally relatively wide; aperture a low arch bordered by distinct lip extending towards, but not reaching, the peripheral margin; short, blunt muricae concentrated on umbilical shoulders but no circumumbilical muricate rim; sutures radial to slightly curved, distinctly incised; spiral side with radial to slightly curved sutures; distinctly punctate pseudocarina formed by peripheral concentration of muricae; in edge view periphery is subacute with distinctly punctate pseudocarina.

Size: Maximum diameter of holotype 0.33 mm, thickness 0.24 mm.

DISTINGUISHING FEATURES.— This taxon is distinguished from *bullbrooki* in the tangential elongation of its chambers (giving the test a semi-rectangular vs. (sub)quadrate shape), development of wedge-shaped chambers on the umbilical side, generally more angulo-conical umbilical profile and distinct punctate pseudocarina formed by peripheral concentration of blunt, thick muricae.

DISCUSSION.— Lower middle Eocene strata are characterized by a robust acarininid with distinctly wedge-shaped chambers and a peripheral concentration of thick, blunt muricae. Fleisher (1974) denominated this morphotype *Acarinina punctocarinata*.

PHYLOGENETIC RELATIONSHIPS.— Evolved from *A. boudreauxi* (see also Blow, 1979, p. 936-937).

GEOGRAPHIC DISTRIBUTION.— Cosmopolitan distribution (from tropical to austral regions).

STRATIGRAPHIC RANGE.— Zone E7 (upper part) to Zone E11

REPOSITORY.— Holotype (USNM 211532) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina quetra (Bolli, 1957)

PLATE 9.19, FIGURES 1-16
(Pl. 9.19, Figs. 1-3: new SEMs of *Globorotalia quetra* Bolli)

Globorotalia quetra Bolli 1957a:79, pl. 19: figs. 1-3 (holotype), 4-6 (paratype) [*Globorotalia formosa formosa* Zone, upper Lizard Springs Fm., Trinidad].—Stainforth and others, 1975:221, text-figs. 80.1-6 [*G. formosa* Zone, Lizard Springs Fm., Trinidad]; 4-6 (from Bolli, 1957a, reillustrated).

Globorotalia (*Acarinina*) *quetra* Bolli.—Hillebrandt, 1962:144, pl. 14: figs. 2a-c [Zone G, Reichenhall Basin, south-west Germany].

Acarinina quetra (Bolli).—Fleisher, 1974, pl. 3: fig. 3 [Zone P8, DSDP Site 220, Arabian Sea].—Berggren, 1977: 251, chart no. 10 (reillustrations from literature).—Warraich and others, 2000:193, fig. 17.13-15 [Zone P7, Rakhi Nala section, Sulaiman Range, Pakistan].—Warraich and Ogasawara, 2001:29, figs. 7.4-6 [Zone P7, Rakhi Nala section, Sulaiman Range, Pakistan].

Globorotalia (*Truncorotaloides*) *quetra* (Bolli).—Blow, 1979:1034-1036 (note p. 1036 misprinted as 1136), pl. 122: figs. 4, 7-9 and pl. 200: figs. 5, 6 ; pl. 123: figs. 6-9, pl. 202: figs. 1-6 [lower Eocene Zone P7, DSDP Site 47, Shatsky Rise, north-west Pacific Ocean]; pl. 129: fig. 5 [lower Eocene Zone P8a, DSDP Site 47, Shatsky Rise, northwest Pacific Ocean]; pl. 132: figs. 7-9 and pl. 201: figs. 4-6 [lower Eocene Zone P7, DSDP Site 47, Shatsky Rise, northwest Pacific Ocean]; pl. 140: fig. 4 [lower Eocene Zone P8b, DSDP Site 20, South Atlantic Ocean].

Morozovella quetra (Bolli).—Snyder and Waters, 1985: 448, pl. 9: figs. 4-6 [lower Eocene Zone P6, DSDP Site 550, Porcupine Abyssal Plain, north-east Atlantic Ocean].

Plate 9.20 *Acarinina rohri* (Brönnimann and Bermúdez, 1953)

1-3 (holotype, USNM CC 172694), Eocene, marl pebble bed, Point-a-Pierre, central Trinidad; **4, 5**, Zone E10/11, ODP Hole 865B/5H/5, 29-31cm; **6-8, 10, 14**, Zone E10/11, ODP Hole 865B/5H/4, 29-31cm, **9, 13, 16**, Zone E10/11, ODP Hole 865B/5H/1, 29-31cm, Allison Guyot, equatorial Pacific Ocean; **11, 12** (same specimen), Zone E8, sample RS-24, Kilwa, Tanzania; **15**, Zone E10, TDP Site 13/15/2, 30-40 cm, Mkazambo, near Pande, Tanzania. Scale bar: **1-16** = 100 μm.

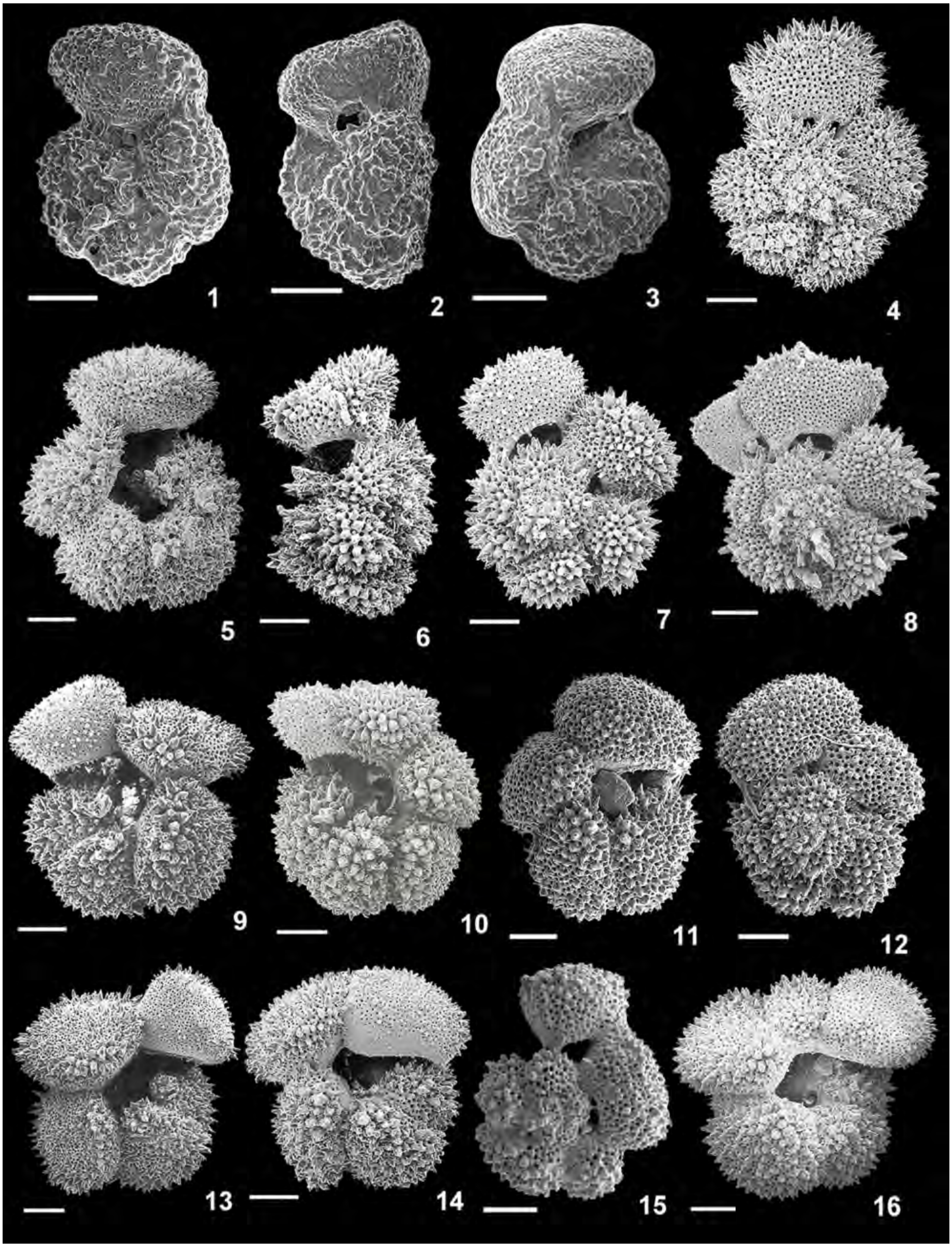

Plate 9.20 *Acarinina rohri* (Brönnimann and Bermúdez, 1953)

DESCRIPTION.

Type of wall: Moderately to strongly muricate with concentration of muricae along peripheral margin of last whorl, nonspinose, normal perforate.

Test morphology: Low trochospiral; test subquadrate, planoconvex; peripheral margin lobulate; chambers on umbilical side moderately inflated, flattened on spiral side; 4 broadly subtriangular chambers visible in umbilical view; anterior and posterior margins of last chamber flattened resulting in disjunct geometry with bordering chambers and conical apex of last chamber; sutures depressed/incised, curved to sinuous, radial; umbilicus relatively wide, deep; aperture an umbilical-extraumbilical, arch extending towards (but not to) the peripheral margin; 10-12 chambers in 2½-3 whorls on spiral side; chambers loosely disposed, meeting almost at right angles, increasing gradually in size; final chamber sometimes reduced in size; chambers lens-shaped, tangentially longer than radially broad in general, overlapping; sutures curved; discrete intercameral openings visible on some individuals (depending on preservation); planoconvex in edge view, final chamber distinctly anguloconical with high conical angle; periphery distinctly, but discontinuously, muricocarinate

Size: Maximum diameter of holotype 0.50 mm, thickness 0.38 mm.

DISTINGUISHING FEATURES.— This taxon is distinguished by its angular test whose chambers are loosely disposed sequentially to each other at ~ 90° and with a distinct, but discontinuous, peripheral muricocarina.

DISCUSSION.— *Acarinina quetra* is a distinctive form that with its cuneate chambers and peripheral concentration of muricae, bears a superficial resemblance (in some instances) to the stratigraphically younger (middle Eocene) *A. topilensis*.

PHYLOGENETIC RELATIONSHIPS.— Descended from *A. pseudotopilensis*.

STRATIGRAPHIC RANGE.— Zone E3 (upper part) to Zone E6.

GEOGRAPHIC DISTRIBUTION.— Widely distributed in (sub)tropical regions (Caribbean, Atlantic, Indo-Pacific, Tethyan/Mediterranean regions, North Caucasus)

STABLE ISOTOPE PALEOBIOLOGY.— No data available

REPOSITORY.— Holotype (USNM P5070) and paratype (USNM P5071) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

***Acarinina rohri* (Brönnimann and Bermúdez, 1953)**

PLATE 9.20, FIGURES 1-16
(Pl. 9.20, Figs. 1-3: new SEMs of holotype of *Truncorotaloides rohri* Brönnimann and Bermúdez)

?*Globigerinoides pseudodubia* Bandy, 1949: 123, pl. 24, figs. 1a-c [middle Eocene, Tallahatta Fm., Little Stave Creek, Alabama].

?*Globorotalia* (*Acarinina*) *pseudodubia* (Bandy).—Blow, 1979:951, pl. 171: fig. 4 [middle Eocene, Zone P11, Kilwa area, Tanzania, East Africa]; pl 194: figs. 5 and 6 [middle Eocene, Zone P13, Kilwa area, Tanzania, East Africa].

Truncorotaloides rohri Brönnimann and Bermúdez, 1953:818-819, pl. 87: figs. 7-9 [middle Eocene, central Trinidad].—Bolli, Loeblich and Tappan, 1957:42, pl.10: figs. 5a-c

Plate 9.21 *Acarinina sibaiyaensis* (El Naggar, 1966)

1-7, 9-16, Zone E1, Bass River Borehole, New Jersey, ODP 174AX, 1169.1-1171.2 feet; **8**, Zone E1, ODP Hole 865C/12/4, 11-18cm, Allison Guyot, central equatorial Pacific Ocean. Scale bar: **1-16** = 100 µm.

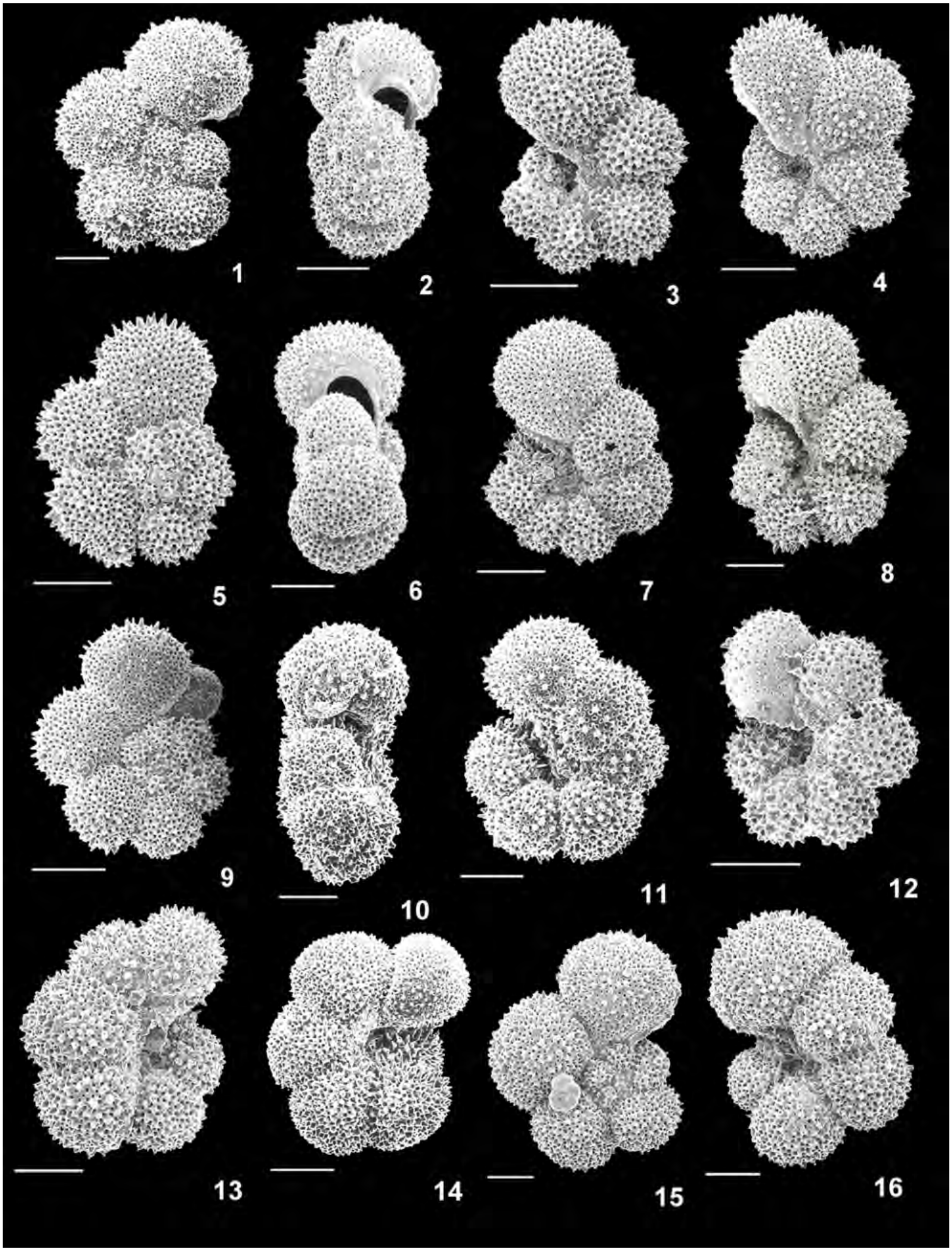

Plate 9.21 *Acarinina sibaiyaensis* (El Naggar, 1966)

[holotype reillustrated].—Bermúdez, 1961:1352, pl. 17: figs. 3a-b (4 figs.) [middle Eocene Zone P12, Guayabal Fm., Mexico].—Samanta, 1970:207, pl. 3: figs. 20-21 [middle Eocene *Orbulinoides beckmanni* Zone, *Discocyclina* biofacies, Lakhpat, Cutch, western India].—Postuma, 1971:232, illustrations on p. 233 [Trinidad].—Blow, 1979:1037: pl. 195: figs. 4-9; pl. 196: figs. 1-5; pl. 206: figs. 1-7; pl. 231: figs. 1,2 (same as pl. 195: fig. 4), fig. 4 (same as pl. 195: fig. 9) [middle Eocene Zone P13, Kilwa area, Tanzania, East Africa].

Truncorotaloides rohri var. *guaracaraensis* Brönniman and Bermúdez, 1953:819, pl. 87, figs. 1-3 [middle Eocene, Duff Road, central Trinidad].

Truncorotaloides rohri var. *piparoensis* Brönniman and Bermúdez, 1953:819, pl. 87: figs. 4-6 [middle Eocene, Duff Road, central Trinidad].

Globorotalia (*Acarinina*) *pseudodubia piparoensis* (Brönnimann and Bermúdez).—Blow, 1979:953, pl. 171: figs. 5 and 6 [middle Eocene, Zone P11, Kilwa area, Tanzania, East Africa], pl 194: figs. 7-9 and pl. 195: fig. 2 [middle Eocene, Zone P13, Kilwa area, Tanzania, East Africa], pl. 231: figs. 5 and 6 (details of pl. 194, figs. 8 and 7, respectively), pl. 232: figs. 3-6 (details of pl. 194, fig. 9)].

Truncorotaloides rohri var. *mayoensis* Brönnimann and Bermúdez, 1953:820, pl. 87: figs. 10-12 [middle Eocene of Trinidad].—Blow, 1979:1040,, pl. 196: figs. 6-9 [middle Eocene Zone P13, Kilwa area, Tanzania]; pl. 50, figs. 7, 8 (from Blow, 1969:372-373, pl. 50, figs. 7,8 reillustrated) [same sample].

Truncorotaloides haynesi Samanta, 1970:205, pl. 3: figs. 24-25 [middle Eocene *Orbulinoides beckmanni* Zone, Lakhpat, India].

?*Turborotalia* (*Acarinina*) *alteconica* Samuel, 1972:196-7, pl. 55: figs. 1-3 [Middle Eocene *Globigerapsis index* zone, Borehole Sr-1, Bakony Mountains, Hungary].

DESCRIPTION.

Type of wall: Densely muricate, normal perforate, nonspinose.

Test morphology: Low trochospiral test with about 12-13 chambers in an evolute spire, 5 (less commonly 6) rounded to subangular chambers in last whorl; final chamber usually wedge-shaped and with disjunct separation from antepenultimate chamber; sutures on umbilical side weakly curved, depressed; umbilicus narrow and relatively deep; aperture an umbilical-extraumbilical arch extending towards the peripheral margin; hemispherical to wedge-shaped chambers on spiral side separated by straight to weakly recurved, depressed sutures; distinct, rimmed supplementary apertures visible at the base of the antepenultimate and final chambers, rarely visible between earlier chambers in last whorl; subrounded to truncate in edge view; chambers on both sides of test strongly muricate.

Size: Maximum diameter of holotype 0.37 mm, thickness 0.22 mm.

DISTINGUISHING FEATURES.— *Acarinina rohri* is distinguished by its strongly muricate test, particularly the concentration of muricae on the umbilical shoulders, and around the peripheral margin, the tendency to develop disjunct separation of chambers in stratigraphically younger forms and by the development of raised imperforate rims surrounding supplementary apertures on the later chambers on the spiral side.

DISCUSSION.— The taxonomy of this morphotype is extremely complex and controversial. Several forms/taxa have been ascribed to, or differentiated from, this species over the past five decades. Below we attempt to reduce the complexity surrounding the *rohri* group to its most essential details:

1. Brönnimann and Bermúdez (1953) described *rohri* and differentiated three further varieties based on variation in chamber shape in the final

Plate 9.22 *Acarinina topilensis* (Cushman, 1925)

1-3 (holotype, USNM CC 4335), middle Eocene, Tantoyuca Fm., Vera Cruz, Mexico; **4, 6**, Zone E10/11, ODP Hole 865B/5H/1, 29-31 cm, **5, 10**, middle Eocene, ODP Hole 865C/4H/5, 110-112 cm, Allison Guyot, equatorial Pacific Ocean; **7, 8**, upper Zone E9, TDP Site 13/16/2, 30-40 cm, Mkzambo, near Pande, Tanzania; **9, 11-16**, Zone E13, Cook Mountain Fm., Couley Creek, Mississippi. Scale bar: **1-16** = 100 µm.

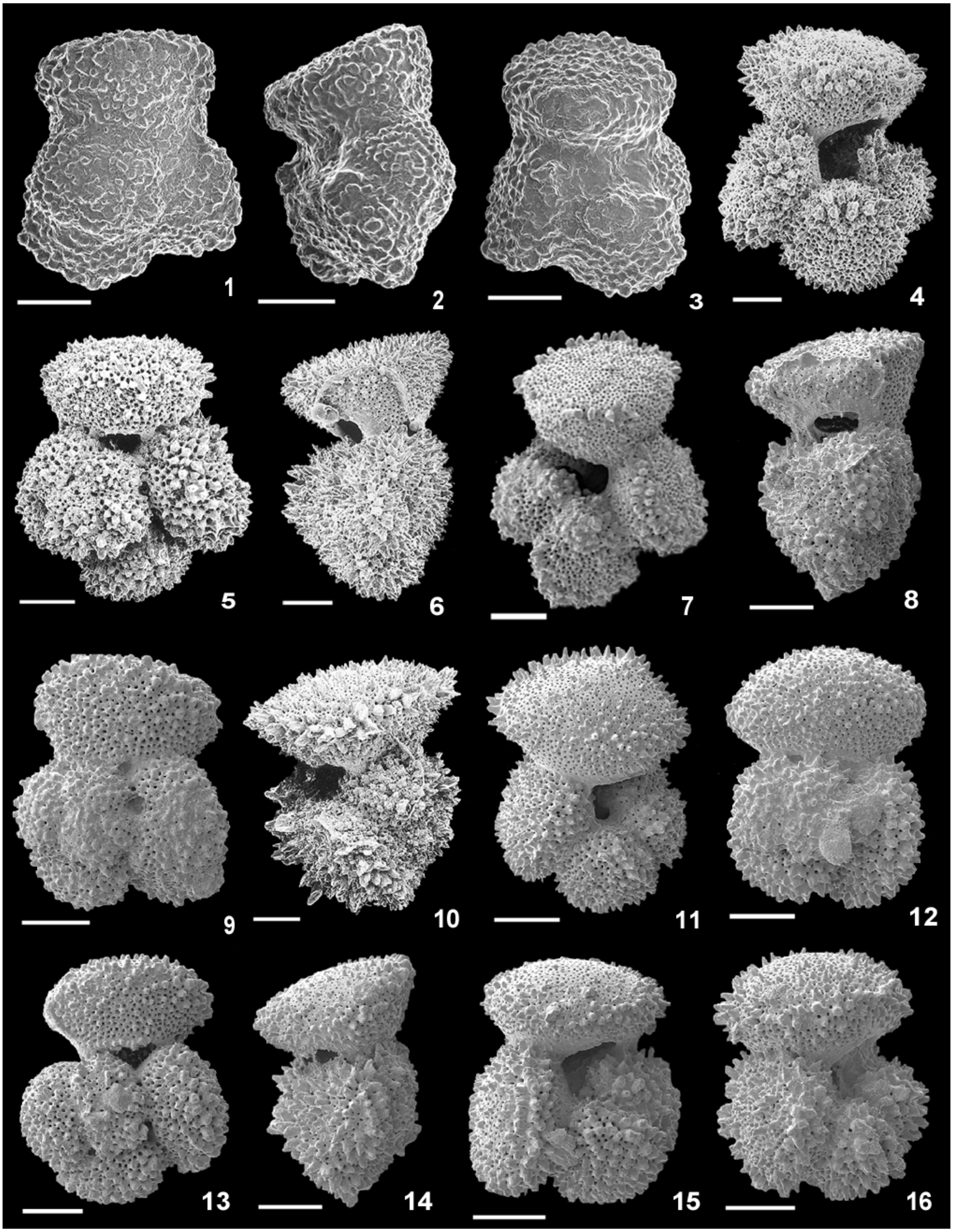

Plate 9.22 *Acarinina topilensis* (Cushman, 1925)

whorl: *guaracaraensis* (rounded), *mayoensis* (angular) and *piparoensis* (subangular; intermediate between the rounded *guaracaraensis* and the central morphotype: *rohri*). In all, 21 well preserved specimens of *guaracaraensis* were recorded, 8 of *rohri*, 5 of *piparoensis* and only 2 of *mayoensis;* no discussion of stratigraphic extent of these morphotypes was presented.

2. Blow (1979, p. 951-953 and 1036-1041) differentiated the *rohri* complex into two distinct, but phylogenetically related groups: *guaracaraensis* and *piparoensis* were assigned to *Acarinina* (lacking distinct rimmed dorsal true supplementary apertures, degree of lateral angulation of chambers, degree of development of typical disjunct chambers and the organization of circumcameral/circumperipheral muriococarina typical of *Truncorotaloides* (as typified by *rohri*); while *rohri* and *mayoensis* (with the characters listed above) were placed in *Truncorotaloides*. The taxon *guaracaraensis* was placed in synonymy with *Globigerinoides* (vel *Acarinina*) *pseudodubia* Bandy (1949).
3. Blow (1979, p. 952-955) presented the case for derivation of *rohri* from *Acarinina bullbrooki* by way of the evolution / transition from *A. pseudodubia* to *piparoensis*: increased number of chambers in final whorl (4 to 5), gradual tendency to develop more laterally angulate and disjunct chamber geometry in last one or two chambers.

In our view a much more likely ancestor for *rohri* is *Acarinina topilensis*, with which it shares several characters to the exclusion of *A. bullbrooki*, including the sinistal coiling bias, more incised sutures, supplementary apertures and heavily muricate test. We have not differentiated from *rohri* the 'transitional' morphotypes illustrated by Blow of *pseudodubia* and *piparoensis*, preferring to illustrate the wide degree of variation we ascribe to *rohri* and its morphologic end-member *mayoensis*, which we include here in the synonymy of *rohri*.

The essentially neglected and rarely recognized taxon *Globigerinoides pseudodubia* Bandy may be a senior synonym of *Acarinina rohri* (for a dissenting view see Blow, 1979, p. 951 who considered it a senior synonym of *G.* (*A.) guaracaraensis*). We include this form provisionally as a questionable senior synonym of *A. rohri*.

The taxon *Turborotalia* (*Acarinina*) *alteconica* was described by Samuel (1972) as a high-spired variant of *rohri*. Similarly *Truncorotaloides haynesi* of Samanta seems to be a large, more openly coiled variant of *rohri*.

PHYLOGENETIC RELATIONSHIPS.—Evolved from *Acarinina topilensis* via intermediate/transitional morphotypes ascribed to the *pseudubia-piparoensis* group (Blow, 1979, p. 951-955).

STRATIGRAPHIC RANGE.—Zone E10 to Zone E13.

GEOGRAPHIC DISTRIBUTION.—Widely distributed in (sub)tropical areas, Caribbean, Spain, Aquitaine, North Africa, Middle East, India.

STABLE ISOTOPE PALEOBIOLOGY.—No data available.

REPOSITORY.—Holotype (CC No. 172694) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Plate 9.23 *Acarinina wilcoxensis* (Cushman and Ponton, 1932)

1-3 (holotype, USNM CC16232), lower Eocene, Wilcox Group, Alabama; **4-7, 9-11** (5-7, 9-11 same specimens), Zone E3/4, WHOI Piston Core 2625B, 20-30 cm, Oceanographer Canyon, western North Atlantic Ocean; **8, 12** (same specimen), Zone E3, Pen River, Coffee County, Alabama; **13-15** (same specimen), Zone E3, Bashi Fm., Butler County, Alabama; **16**, Zone E6, ODP Hole 865B/10H/4, 62-64 cm, Allison Guyot, equatorial Pacific Ocean. Scale bar: **1-16** = 100 µm.

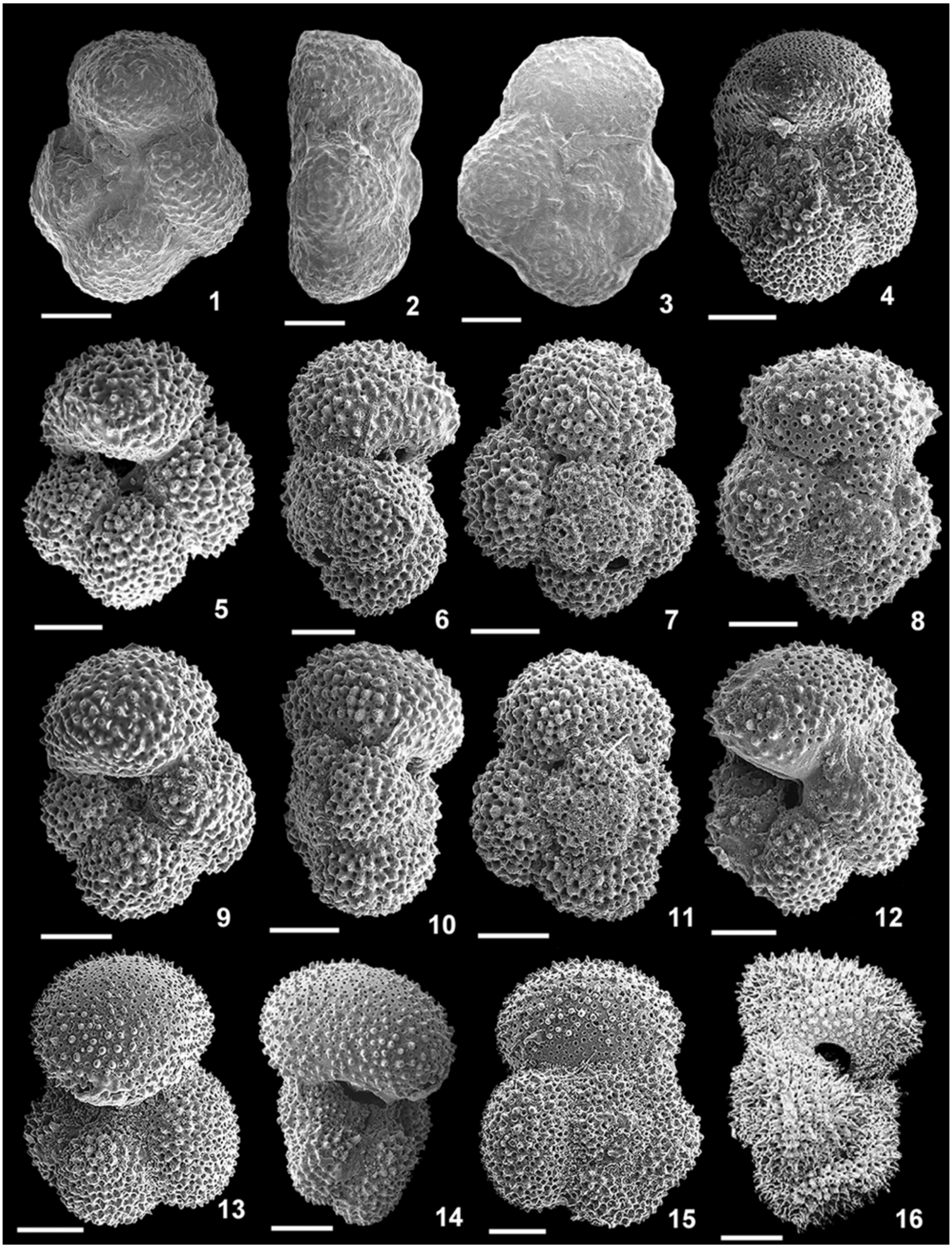

Plate 9.23 *Acarinina wilcoxensis* (Cushman and Ponton, 1932)

Acarinina sibaiyaensis (El Naggar, 1966)

PLATE 9.21, FIGURES 1-16

Globorotalia sibaiyaensis El Naggar, 1966:235, pl. 23: fig. 6a-c [*G. aequa*/*G. esnaensis* Subzone, *G. velascoensis* Zone, Gebel Owaina section, Egypt].
Acarinina sibaiyaensis (El Naggar).—Kelly and others, 1996:424, fig. 2-1a-b [upper Zone P5, from within carbon isotope excursion of the Paleocene-Eocene Thermal Maximum, ODP Hole 865C, Allison Guyot, equatorial Pacific Ocean].—Kelly and others, 1998:159, figs. 5c, 9d-e [upper Zone P5, from within carbon isotope excursion of Paleocene-Eocene Thermal Maximum, ODP Hole 865C, Allison Guyot, equatorial Pacific Ocean].— Pardo and others, 1999:44, pl. 2: figs. 19-20.[Zone P5b, Kaurtakapy, Kazakhstan].
Acarinina aff. *sibaiyaensis* (El Naggar).—Pardo and others, 1999:44, pl. 2: figs. 17-18 [Zone P5b, Kaurtakapy, Kazakhstan].

DESCRIPTION.

Type of wall: Muricate, nonspinose, normal perforate.

Test morphology: Planoconvex; generally umbilico-convex, although some specimens approach being planispiral; peripheral margin round to subround; chambers inflated, subtriangular to round on both umbilical and spiral sides; approximately 12-14 chambers arranged in 3 whorls; gradual increase in chamber size throughout; sutures depressed and radial; primary aperture circular, arch-like opening with lip to well-developed flange, umbilical-extraumbilical position extending to peripheral margin.

Size: Maximum diameter of holotype 0.29 mm, minimum diameter 0.19 mm, thickness 0.17 mm; our observations suggest that this form is typically <0.35 mm in maximum diameter.

DISTINGUISHING FEATURES.— Diagnostic characteristics are the relatively large (5-9) number of chambers in final whorl, and the test coiled in a very low trochospiral (approaching planispiral) mode.

DISCUSSION.— This form, together with *A. africana* and *Morozovella allisonensis*, constitute an assemblage of small, morphologically distinct taxa that are characteristic of the temporally short (~200 kyrs) Paleocene Eocene Thermal Maximum.

PHYLOGENETIC RELATIONSHIPS.— Kelly and others (1996) suggested that this taxon evolved from *Acarinina soldadoensis*, but it shows much greater similarity with *A. esnehensis* which we suggest was the ancestor. Further flattening of the test produced the *africana* morphology (Kelly and others, 1998).

STRATIGRAPHIC RANGE.— Zone E1, restricted to carbon isotope excursion of the PETM.

GEOGRAPHIC DISTRIBUTION.— Widely distributed throughout the (sub)tropics and temperate regions; common in the central equatorial Pacific (ODP Site 865), found in New Jersey Coastal Plain (Bass River), North Atlantic Ocean (ODP Site 1051), and also present in Tethyan sections of Europe (Alamedilla, Spain) and North Africa (Egypt).

STABLE ISOTOPE PALEOBIOLOGY.— Inferred depth-habitat primarily shallow mixed-layer; carbon isotope signature exhibits strong covariance with shell size; overall stable isotopic signature is analogous to that of modern, symbiotic species (Kelly and others, 1998).

REPOSITORY.— Holotype (P. 45628) and paratype (P. 45629) deposited at The Natural History Museum, London; hypotype (USNM 494822) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina soldadoensis (Brönniman, 1952)

PLATE 9.3, FIGURES 1-10
(Pl. 9.3, Figs. 1-3: new SEMs of holotype of *Globigerina soldadoensis* Brönnimann)

DISCUSSION.—A full synonymy list and discussion of this species was given by Olsson and others (1999).

STRATIGRAPHIC RANGE.—Zones P4c to E7; particularly common in mid-Zone P5 (=Zone E1 of this paper) in association with the Paleocene-Eocene Thermal Maximum excursion fauna at Bass River, New Jersey Coastal Plain.

Acarinina subsphaerica (Subbotina), 1947

DISCUSSION.— A full synonymy and discussion of this taxon was given in Berggren and Norris (1997) and

Olsson and others (1999). This form was used to delineate subzone P4a of Zone P4 by Berggren and others (1995). However, subsequent investigations have shown that *subsphaerica* has its highest common occurrence within the mid-part of the range of *Globanomalina pseudomenardii* (i.e., Zone P4) while ranging sporadically up into Zone P6a (=Zone E3 of this work) (Quillévéré, 1999). However, there remains, as pointed out by Blow (1979, p. 961) a distinct stratigraphic gap between the HO of *subsphaerica* (which Blow ascribed to lower Zone P5) and the LO of its dorso-conical homeomorph *alticonica* (in Zone P8b) and an even larger gap to the LO of *pseudosubsphaerica* as differentiated and delineated here in Zone E7 (=Zone P9 of Berggren and others, 1995).

STRATIGRAPHIC RANGE.— Base of Zone P4 to P4a/b (highest common occurrence); sporadic to Zone E3.

Acarinina topilensis (Cushman, 1925)

PLATE 9.22, FIGURES 1-16
(Pl. 9.22, Figs. 1-3: new SEMs of holotype of *Globigerina topilensis* Cushman)

Globigerina topilensis Cushman, 1925:7, pl. 1: figs. 9a-c [middle Eocene, Tantoyuca Fm., Vera Cruz, Mexico].—Howe, 1939:84, pl. 12: figs. 1-3 [middle Eocene, Claiborne / Cook Mountain Fm., Louisiana].—Weiss, 1955:309, 310, pl. 2: figs. 16, 17 [middle Eocene, Chira Fm., Verdun-Chira Group, north-west Peru].—Hamilton and Rex, 1959:792, pl. 252: figs. 17, 21 [middle Eocene, Sylvania Guyot, Marshall Islands, west Pacific Ocean].

Truncorotaloides topilensis (Cushman).—Bolli, 1957b:170, pl. 39: figs. 13-16b [middle Eocene *Porticulasphaera mexicana* Zone, Navet Fm., Trinidad].—Saito, 1962:215-216, pl. 33: figs. 8a-c [middle Eocene, Haha-Jima, Bonin Islands, western Pacific Ocean].—Samanta, 1970, pl. 3: figs. 22-23 [middle Eocene *Orbulinoides beckmanni* Zone, Lakhpat, India].—Postuma, 1971:234, figures on p. 235 [middle Eocene Navet Fm., Trinidad].—Jenkins, 1971:136, text-figs. 388-391 [middle Eocene *Globigerapsis index* Zone, Hampden Beach section, South Island, New Zealand].—Samuel, 1972:201, pl. 55: figs. 4a-5c [middle Eocene, Bakony Mountains, Hungary].—Toumarkine, 1975:738, pl. 743: figs. 12 [middle Eocene *Globorotalia lehneri* Zone, DSDP Site 313, South Atlantic Ocean].—Stainforth and others, 1975:234, text-figs. 91. 1a-4 (reillustration of Bolli, 1957b, pl. 39: figs. 13-16c).—Berggren, 1977:262-263, chart no. 12 (reillustration of specimens from literature).—Pujol, 1983:642, pl. 5: figs. 10-11 [middle Eocene Zone P11-12, DSDP Hole 516F, Rio Grande Rise, South Atlantic Ocean].—Snyder and Waters, 1985:443, pl. 5: figs. 13-15 [middle Eocene Zone P13, DSDP Hole 548A, north-east Atlantic Ocean].—Miller and others, 1991 [upper Eocene Zone P15 (reworked), DSDP Site 612, New Jersey continental slope, north-west Atlantic Ocean].

Pseudogloborotalia topilensis (Cushman).—Bermúdez, 1961:1348-1349, pl.16: fig. 12 [middle Eocene, Oriente Province, Cuba].

Globorotalia topilensis (Cushman).—Aubert, 1963:60-61, pl. 4: figs. 5a-c [middle Eocene, Sidi-Ameur-el-Hadi, Northern Morocco].

Globorotalia (*Truncorotaloides*) *topilensis* (Cushman).—Blow, 1979:1041-1043, pl: 193: figs. 1-9 and pl: 207: figs. 3, 4 [middle Eocene Zone P13, Sample RS. 311, Kilwa area, Tanzania].

Truncorotaloides libyaensis El Khoudary, 1977:330, pl. 2: fig. 1 [middle Eocene, Libya].—Toumarkine and Luterbacher, 1985:132, figs. 32.4-6 (re-illustration of type series); 32. 4-6; 33.8-9 [middle Eocene, Beni Mazar, Nile Valley, Egypt, from Boukhary, Toumarkine and Khalifa, 1982].

DESCRIPTION.

Type of wall: Strongly muricate, nonspinose, normal perforate.

Test morphology: Subquadrate, lobulate peripheral outline; 3½-4½ chambers on umbilical side, increasing rapidly in size, laterally angulate, ante- and penultimate chamber(s) strongly flattened along peripheral margin giving distinctly cuneate or mitriform shape; sutures strongly incised, radial and straight to weakly curved depending on degree of compression of adjacent chambers resulting in disjunct/incised chamber separation; umbilicus narrow, deep; aperture a raised, umbilical-extraumbilical arch bordered by a thin lip; approximately 10 chambers in 2-2½ whorls on spiral side; chambers elongate, lunate/semicircular, last chamber often wedge shaped/cuneate; sutures curved, depressed; peripheral margin marked by concentration of (on some individuals large, blunt) muricae; "supplementary" apertures, bordered by raised rims, visible along spiral suture margin(s); planoconvex in edge view; early chambers of last whorl subrounded to subacute, (pen)ultimate chambers strongly anguloconical.

Size: Maximum diameter of holotype 0.34 mm, thickness 0.24 mm.

DISTINGUISHING FEATURES.— Distinguished by its distinctly inflated, anguloconical, 'truncorotaloid' chambers and strongly compressed, angulate and disjunct (ante)penultimate chamber(s) rimmed by thick, blunt circum-cameral muricocarinae and sutural "supplementary" apertures on spiral side.

DISCUSSION.— Originally described from the middle Eocene of Mexico, this taxon has since been shown to have an essentially global (sub)tropical distribution. With its distinctly angulo-conical test, disjunct (ante)penultimate chamber margins, wedge/cuneate shaped and strongly muricate terminal chamber(s), "supplementary" apertures along spiral sutural margins and relatively short stratigraphic range, it is one of the most distinctive middle Eocene taxa.

The main question regarding this taxon is its ancestry which bears in turn upon the limits of variability and stratigraphic range of possible ancestral morphotypes. Blow (1979, p. 1043-1045) created the taxon *G. (T.) topilensis praetopilensis* (said to have evolved from *Acarinina pseudotopilensis*) and viewed it as directly ancestral to *topilensis*. Differentiation was made primarily on the basis of the more involute coiling pattern, smaller umbilicus, less well developed murical ornament along the peripheral margin of the later chambers, and less well developed/pronounced chamber separation in the (ante)penultimate chambers.

Pearson (1990) and Pearson and others (1993, p. 124) viewed the evolution of this taxon in a similar fashion except that *pseudotopilensis,* rather than Blow's *praetopilensis*, was viewed as the direct ancestor of *topilensis.* Reference to Pearson and others (1993, pl. 1, figs. 13-15) shows that their concept of *pseudotopilensis* is closer to Blow's (1979, pl. 178, figs. 6-9; pl. 169, figs. 1-7, 9, and, in particular, 8 [=holotype] *praetopilensis* and/or *Acarinina mcgowrani* n. sp., are distinctly different from Subbotina's (1953, pl. 21, figs. 8a-c [=holotype], 9a-c; pl. 22, figs. 1a-2c) *pseudotopilensis* from the Zone of conical globorotaliids (=Zones P6b-8 of Berggren and others, 1995). Pearson (1990) made the observation that the strongly anguloconical (truncorotaloid) character of the last chamber arises only in fully adult specimens (being absent in smaller size fractions) so that when the last chamber is lost or broken this taxon is indistingushable from "*pseudotopilensis*". (We would agree except that we believe it is with *praetopilensis* that differentiation should be made.) The taxon *pseudotopilensis* has its FAD in Zone E1 and does not range into stratigraphic levels as high as Zones P11-12 (=E9-11) from which "*pseudotopilensis*" of Pearson and others (1993) was illustrated.

PHYLOGENETIC RELATIONSHIPS.— Evolved from *Acarinina praetopilensis* in E10 and gave rise to *A. rohri*.

STRATIGRAPHIC RANGE.— Zone E10 to mid Zone E12.

GEOGRAPHIC DISTRIBUTION.— Widely distributed in the Caribbean, North and South Atlantic, Indo-Pacific and Tethyan/Mediterranean regions; rare in North Caucasus sections.

STABLE ISOTOPE PALEOBIOLOGY.— Oxygen and carbon isotope evidence suggests a mixed layer habitat (Pearson and others, 2001). Boron isotope data (Pearson and Palmer, 1999) supports this interpretation.

REPOSITORY.— Holotype (USNM CC 4335) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Acarinina wilcoxensis (Cushman and Ponton, 1932)

PLATE 9.23, FIGURES 1-16
(Pl. 9.23, Figs. 1-3: new SEMs of holotype of *Globorotalia wilcoxensis* Cushman and Ponton)

Globorotalia wilcoxensis Cushman and Ponton, 1932:71, pl. 9: figs. 10a-c [lower Eocene Bashi Fm., Hatchetigbee Group, Alabama].—Cushman, 1944:15, pl. 2: figs. 14, 15a, b [Bashi Fm., Hatchetigbee Group, Alabama].—Hamilton, 1953:231, 232, pl. 2: fig. 7 [lower Eocene, mid-Pacific guyots].—Weiss, 1955:19, pl. 6: figs. 7-9 [lower Eocene, Pale Greda Fm., north-west Peru].—Bolli, 1957a: 79, pl. 19: figs. 7-9 [lower Eocene, *Globorotalia rex* Zone, lower Lizard Springs Fm., Trinidad].—Berggren, 1960a:97-100, pl. 13: figs. 3a-4c [lower Eocene, Røsnaes Clay Fm., Røgle Klint, Denmark].—El Naggar, 1966:250, pl. 23: figs. 5a-c [*Globorotalia velascoensis* Zone, Upper Owaina Shale Fm., Egypt].—Postuma, 1971:220, figs. on p. 221, [lower Eocene Bashi Fm., Hatchetigbee Group, Alabama].—Stainforth and others, 1975:243, text-figs. 98.1 (refigured); 98.2-5 [lower Eocene *Globorotalia formosa* Zone, Lodo Fm., California].

Truncorotalia ? wilcoxensis (Cushman and Ponton).—Gohrbandt, 1963:64, 65: pl. 4: figs. 1-3 [Zone F, North of Salzburg, Austria].

Truncorotaloides (*Acarinina*) *wilcoxensis* (Cushman and Ponton).—McGowran, 1968: pl.3: fig. 1 [Bashi Marl Member, Hatchetigbee Fm., Ozark Alabama].

Truncorotaloides wilcoxensis (Cushman and Ponton).—Steineck, 1971, text-fig. 5 [lower Eocene, California].

Acarinina wilcoxensis (Cushman and Ponton).—Berggren, 1971, pl. 5: figs. 4, 5 [Zone P6, DSDP Site 20C, South Atlantic Ocean].—Tjalsma, 1977: 496, pl. 3: fig. 12 [lower Eocene Zone P6, DSDP Site 36, South Atantic Ocean].—Berggren, 1977:250, 251, chart no. 10 (literature illustrations refigured).—Lu and Keller, 1993:102, pl. 2: figs. 14, 15 [lower Eocene Zone P6, DSDP Site 577, Shatsky Rise, north-west Pacific Ocean].—Warraich and Ogasawara, 2001:33, figs. 8.4-6 [Zone P5, Dungan Fm., Sulaiman Range, Pakistan].

Globorotalia (*Acarinina*) *wilcoxensis wilcoxensis* Cushman and Ponton.—Blow, 1979:964-968, pl. 112: figs. 4, 5 [lower Eocene Zone P7 = Zone E3 of this paper, type locality of Bashi Fm., Alabama]; pl. 113: figs. 7-9, pl. 114: figs. 1 and 6, and pl. 200: figs. 1-5 [lower Eocene Zone P7, Kilwa area, Tanzania]; pl. 122: figs. 1, 2 and pl. 199: figs. 5, 6 [lower Eocene Zone P7 = Zone E3 of this paper, Shatsky Rise, north-west Pacific Ocean]; pl. 132: fig. 4 [lower Eocene Zone P8b, DSDP Site 47, Shatsky Rise, north-west Pacific Ocean]; pl. 140: figs. 5-8 [lower Eocene Zone P8b, DSDP Hole 20C, South Atlantic Ocean].

Morozovella wilcoxensis (Cushman and Ponton).—Snyder and Waters, 1985:446, pl.10: figs. 3-5 [lower Eocene Zone P6, DSDP Site 549, north-east Atlantic Ocean].

Globorotalia berggreni El Naggar, 1966:200, 201, pl. 23: figs. 7a-c [upper Paleocene *Globorotalia velascoensis* Zone, Upper Owaina Shale Fm., Gebel Owaina, Egypt].

Globorotalia (*Acarinina*) *wilcoxensis berggreni* El Naggar.—Blow, 1979:968-970, pl. 112: figs. 6 and 7 [lower Eocene Zone P7, Bashi Fm., Alabama]; pl. 114: figs. 7, 9 and 10, and pl. 115: figs. 1, 2 [lower Eocene Zone P7, Kilwa area, Tanzania, East Africa]; pl. 122: figs. 3, 5 and 6, pl. 123: fig. 1, and pl. 132: fig. 5 [lower Eocene Zone P7, DSDP Site 47, Shatsky Rise, north-west Pacific Ocean].

Acarinina wilcoxensis berggreni El Naggar—Stott and Kennett, 1990: 560, pl. 4: figs. 5, 6 [lower Eocene Zone AP6, ODP Hole 689B, Maud Rise, South Atlantic Ocean; shown as Zone AP 8 in figure 2].

DESCRIPTION.

Type of wall: Densely muricate (both sides), normal perforate, nonspinose.

Test morphology: Plano-convex, elongate-oval, equatorial outline moderately lobulate; chambers subangular to low conical, inflated on umbilical side; 4 chambers in final whorl, increasing rapidly in size; sutures depressed, radial, weakly curved; umbilicus narrow, deep; aperture an umbilical-extraumbilical arch, bordered by thin lip, extending almost to peripheral margin; on spiral side about 10-12 chambers in 2½-3 whorls; chambers, lens-shaped to semi-circular, increasing rapidly in size and overlapping previous chambers; intercameral sutures depressed, curved; sutural openings (apparently caused by secondary calcification over the projecting edges of previously calcified chamber margins) present on well-preserved individuals, often obscured by thickened, hollow muricae; muricae tend to concentrate along peripheral margin but test remains non-carinate; in edge view test is planoconvex; profile of early chambers rounded, with flattening of ante- and/or penultimate chamber resulting in subacute margin; peripheral margin distinctly muricate but not carinate.

Size: Maximum diameter of holotype 0.38 mm, thickness: 0.22 mm.

DISTINGUISHING FEATURES.— This taxon is distinguished by its (sub)quadrate, 4-chambered (in the final whorl), planoconvex, distinctly muricate, test with subrounded to (later) subacute axial outline.

DISCUSSION.— This taxon, described originally from the Bashi Formation (Zone P6a) of the U.S. Gulf Coast, is the stem form of the early Eocene radiation of the *pseudotopilensis-quetra* group. Berggren (1960a, 1968) considered that *wilcoxensis* evolved from the late Paleocene form *Acarinina esnaensis* (LeRoy), itself a senior synonym of *Acarinina intermedia* Subbotina, a view maintained here, while Blow (1979, p. 965) considered *esnaensis* a junior synonym of *wilcoxensis*. *Acarinina esnaensis* (and *A. intermedia*) were originally described from stratigraphic levels within/correlative to Zone P4, not the lower Eocene as implied by Blow (1979). *Acarinina wilcoxensis* may be differentiated from the morphologically similar *esnaensis/intermedia* by its larger size, more elongate/oval shaped test and more acute axial periphery.

Admittedly the holotype individuals of *esnaensis* and *wilcoxensis* (see Plates 9.11 and 9.23 of this paper) are markedly similar. However, the species concept of this taxon is based on a broader consideration of the variation exhibited by individuals from levels within Zone E3-4. The illustration of Bolli (1957a, pl. 7-9) of *wilcoxensis* may be taken as exemplary and demonstrates the (predominantly) subquadrate, somewhat more anguloconical character of *wilcoxensis*;

esnaensis generally is more elongate and has a subrounded periphery in edge view.

Acarinina wilcoxensis berggreni (El Naggar) was described from Zone P5 in Egypt and said to differ from *esnaensis* in its "compressed test, smaller size, fewer chambers in the last whorl, subrounded to subacute periphery, much narrower umbilicus and peculiar aperture". Blow (1979, p. 968-970) considered *berggreni* to be characterized by having distinctly flattened terminal chamber(s) on the spiral side, axially subangulate periphery in terminal chamber(s), and peripheral concentration (but not fusion) of muricae and to represent a transition to/morphologic link between *wilcoxensis* sensu stricto and *quetra* (with its disjunct, laterally angulate chambers). Blow (1979, p. 968) included Bolli's (1957a) illustration of *wilcoxensis* (with subacute periphery) in *berggreni*, thus providing a clear illustration of his concept of the taxon. Blow (1979) indicated that *wilcoxensis* appeared only marginally earlier/lower (mid-Zone P6, = basal Zone E3) than *berggreni* (base Zone P7, = upper part of Zone E3), although El Naggar (1966, p. 201) indicated that the first appearance of *berggreni* overlapped with the terminal part of the range of *Globorotalia velascoensis* (i.e., within the Zone E1-E2 interval).

Stott and Kennett (1990, p. 560), on the other hand, distinguished *wilcoxensis* and *berggreni* in Maud Rise (Subantarctic) assemblages, but viewed *wilcoxensis* as the morphotype with greater axial angularity and flattened spiral surface (Blow, 1979). The morphologic differences between these two forms are viewed as those of degree not kind and *berggreni* is included in the synonymy of *wilcoxensis* here.

PHYLOGENETIC RELATIONSHIPS.— Evolved from *Acarinina esnaensis* and is the ancestor of the *Acarinina pseudotopilensis-quetra* group.

STRATIGRAPHIC RANGE.— Uppermost Zone P5 (just below the PETM event) to Zone E5.

GEOGRAPHIC DISTRIBUTION.— Widely distributed in (sub)tropical areas (Caribbean, Atlantic, Indo-Pacific, Tethyan/Mediterranean province); present also in austral areas of the South Atlantic (Maud Rise) and Indian Ocean (Kerguelen Plateau).

STABLE ISOTOPE PALEOBIOLOGY.— No data available.

REPOSITORY.— Holotype (USNM CC16232) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

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