Early Campanian Foraminifera of the Igoda Formation and Needs Camp upper and lower quarries, Eastern Cape, South Africa, and comparison with Mzamba and the KwaZulu Basin

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(with 3 figures, 2 tables, 1 appendix)

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Four outcrops of Late Cretaceous rocks are known in the East London region of the Eastern Cape Province, discovered at different times during the 20th century. These are at the Needs Camp upper and lower quarries, inland of East London; and at Igoda River mouth and a nearby road cutting close to the estuary, located to the south of East London, designated the Igoda Formation. All four sites contain similar foraminiferal assemblages, and the successions are interpreted as roughly coeval. The published record from the two Igoda Formation outcrops up to now consists of just one foraminifera species (*Spiroplectinella* sp.), and about 20 Cretaceous species have been reported from the Needs Camp quarries. However, examination of additional samples, as well as repeated reprocessing of previously-studied limestone samples from the four outcrops has led to the discovery of 87 species of foraminifera. Only five of these are planktic species, mainly very rare *Heterohelix globulosa* (Ehrenberg), *Hedbergella* spp., *Hedbergella* cf. *H. simplex* (Morrow), *Globigerinelloides asper* (Ehrenberg) and *Rugoglobigerina rugosa* (Plummer), the last-named indicating a Campanian-Maastrichtian age. These planktics indicate that surface waters were slightly better oxygenated, but the complete absence of keeled planktics yet diverse benthics suggests the majority of the lower water column, but not the sea-floor, was experiencing dysoxic conditions. Because of the different circumstances in the discovery of each of these outcrops, their contained foraminiferal assemblages and their interpreted foraminiferal ages and depositional environments have never before been effectively compared and contrasted. The Igoda/Needs Camp foraminiferal assemblages detailed here are compared with a greatly revised biostratigraphy for the southern African Campanian succession. The distinctive Igoda benthic assemblages, composed in the main of *Gavelinella* and *Lenticulina* species, are marked by small numbers of the age-diagnostic early Campanian (Campanian I and lowest Campanian II) benthic species, *Valvulineria* sp., and the Early Campanian (Campanian I) benthic species, thin *Dorothia* sp. The four outcrops are considered to expose parts of a somewhat siliciclastic-poor, carbonate-rich deposit. This accumulated in an inner (Needs Camp limestones) to middle (Needs Camp limey claystones) to outer neritic (Igoda limey claystones) setting on a relatively well-oxygenated sea-floor experiencing periodic inflows of inner neritic siliciclastics and shell hash. The majority of foraminifera tests preserved in these rocks have been the focus of post-depositional ferric iron precipitation, probably derived from oxidation and deterioration of pyrite, so that they are now a strong orange-red colour.

Key words: foraminifera, Needs Camp, Igoda, planktic, benthic, Cretaceous, Campanian, biostratigraphy.

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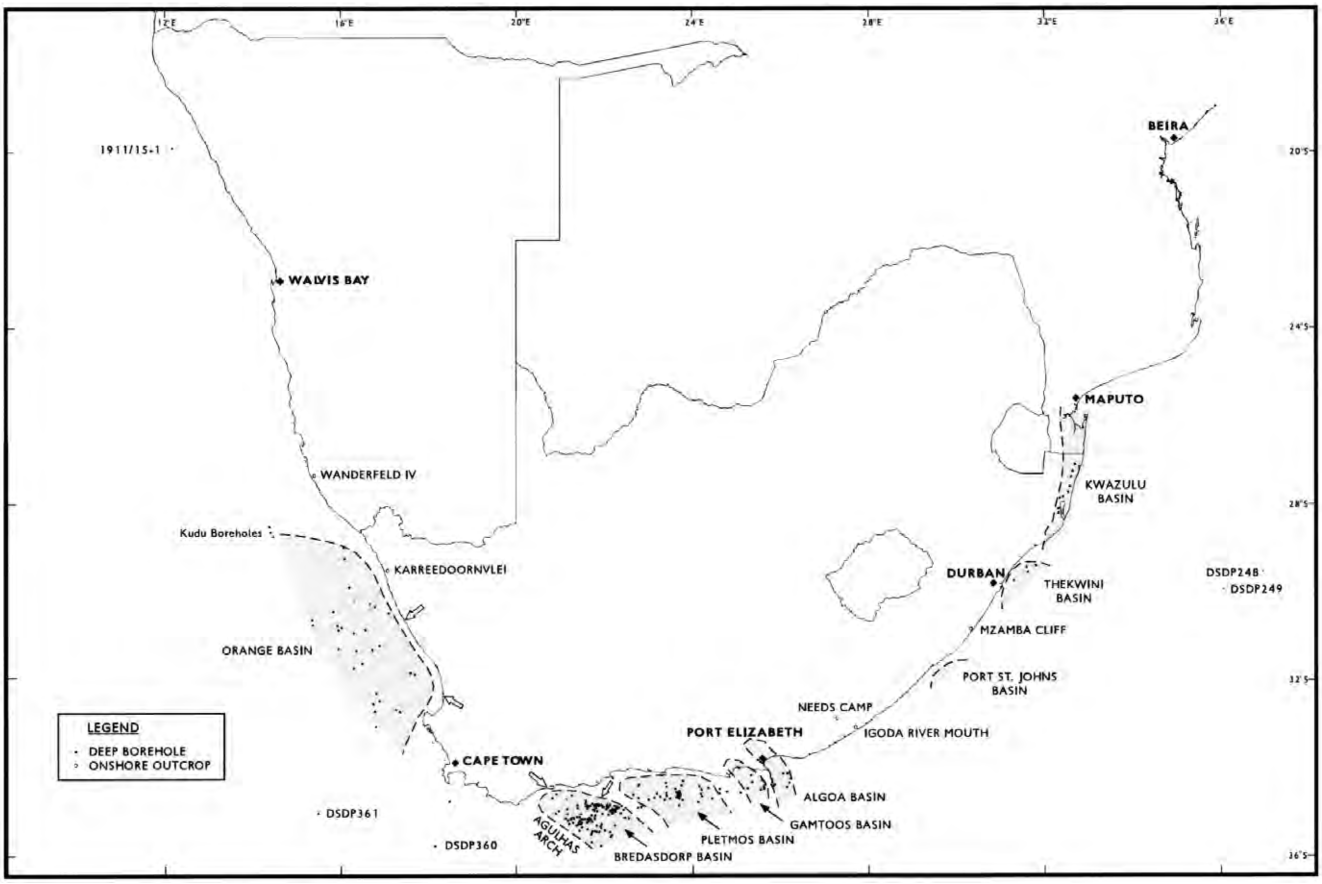

Fig. 1. Locations of Needs Camp quarries and Igoda Formation outcrops in the vicinity of East London, compared with the major Cretaceous sedimentary basins and other significant Cretaceous outcrops preserved on the South African continental margin.

INTRODUCTION

The four Igoda and Needs Camp outcrops, lying to the south and west of East London, although physically distant from the KwaZulu and South Mozambique Basins lie within the same tectonic domain as those basins (see locations in Fig. 1). Previous macrofossil and microfossil analysis of these outcrops has shown them to consist of rocks of Campanian to Maastrichtian or Late Campanian to Early Maastrichtian age (Lang 1908; Woods 1908; McGowran & Moore 1971; King 1972; Salmon 1977; Brood 1977; Klinger & Lock 1978; Siesser & Miles 1979; Dingle 1981, 1996; Siesser 1982; McMillan 2003). The Igoda Cretaceous and the Early Campanian section of the Mzamba cliff succession (Klinger & Kennedy 1980) both constitute parts of the Lower Grudja (Abdula & Salman 1995; Salman & Abdula 1996) of the South Mozambique Basin. The Lower Grudja is delimited by major unconformities and downlap surfaces at the base (Santonian to Campanian boundary) and at the top (Early to Late Maastrichtian boundary), but apparently not in between these datums. The Lower Grudja is especially distinguished by a series of sandstones with hydrocarbon reservoir characteristics, extending across much of the South Mozambique Basin (Abdula & Salman 1995; Salman & Abdula 1996), and southwards into the KwaZulu Basin, as seen in cored borehole ZC. The ZC borehole section includes a 45.7 m thick sandstone (G6 sandstone equivalent, Early Maastrichtian), with underlying thinner sandstones (each about three or four metres thick, G7, G8, G9, G10 and G11 sandstones equivalents, mostly of Late Campanian age), occurring in much the same manner as seen in the Pande gasfield in Mozambique (Abdula & Salman 1995; Singh & McLachlan 2003). Both underlying Santonian (Upper Domo claystones) section and overlying Late Maastrichtian (Upper Grudja fine sandstones, foraminiferal chalks and claystones) are distinctly finer-grained units than the Lower Grudja. The lower and upper boundaries of the Lower Grudja are defined also by planktic and benthic foraminifera turnovers, at both the Santonian–Campanian and the Early–Late Maastrichtian boundaries. There appears to be only one possible substantial turnover datum in between, at the 'blue' horizon, topmost *Loxostomum eleyi,* in the lowest Late Campanian/Campanian III. Thus, the Santonian–Campanian boundary is distinguished by the extinction of the planktic *Dicarinella asymetrica* (Sigal) and the benthic thin elongate *Textularia* sp., amongst others, and the appearance of the planktics *Globotruncanita elevata* (Brotzen), *Pseudotextularia cushmani* (Brown), *Globotruncana ventricosa* (White), *Gublerina ornatissima* (Cushman & Church) and *Rugoglobigerina rugosa* (Plummer), and the benthics *Cibicides convexus* (Reuss), *Angulogavelinella* sp., and *Praebulimina carseyae* (Plummer), amongst others (Caron 1985; McMillan 2008*b*). Likewise the Early–Late Maastrichtian boundary is marked by the disappearances of planktics *Globotruncana linneiana* (D'Orbigny), *Globotruncana tricarinata* (Quereau) and *Contusotruncana fornicata* (Plummer), and the progressive appearances of *Racemiguembelina fructicosa* (Egger), *Contusotruncana contusa* (Cushman), and *Abathomphalus mayaroensis* (Bolli) (Caron 1985; McMillan 2008*b*).This mid Maastrichtian boundary is also characterized by the disappearance of benthic species *Pyramidina* sp., *Stensioeina* sp. with incurved spiral side (equal to *Gyroidinoides quadratus martinii* of Lambert 1971), and by the progressive appearance of ornamented *Stensioeina* sp., *Oridorsalis* sp. and *Bolivinoides draco* (Marsson), amongst others. Inoceramid bivalves, and consequently their prisms, disappear at the mid Maastrichtian boundary. As a result, the age of the Needs Camp and Igoda sections are regarded as lying between the Santonian–Campanian boundary and the mid Maastrichtian boundary.

Previous publications and theses documenting the benthic and planktic foraminifera of the KwaZulu Basin succession and coeval outcrops include Chapman (1904, 1916, 1923); Smitter (1955, 1957*a*, 1957*b*) De Gasparis (1968); Lambert (1971, 1973, 1978); McGowran & Moore (1971); King (1972); Lambert & Scheibnerová (1974); Stapleton (1975); Makrides (1979); Wright (1998); and McMillan (2003, 2008*a*, 2008*b*). Ostracods have been studied by Dingle (1969*a*, 1969*b*, 1980, 1981, 1985, 1996). Calcareous nannoplankton has been detailed by Pienaar (1966, 1968, 1969); Stapleton (1975); Siesser & Miles (1979); Siesser (1982); Verhagen *et al.* (1990); Klinger *et al.* (2001); and Ovechkina *et al.* (2008). Dinoflagellate cysts and hystrichospheres have been documented by Davey (1969*a*, 1969*b*) and by Benson (1990, 1992). Publications specifically on Needs Camp and Igoda microfossils are Chapman (1916), McGowran & Moore (1971), King (1972), Siesser & Miles (1979), Dingle (1981). The description of outcrops at Needs Camp, Igoda and elsewhere have been detailed by Mountain (1946, 1962*a*, 1962*b*, 1974). Approximate coordinates for the lower quarry, Needs Camp are 33°00′58″S, 27°38′58″E; for the upper quarry, Needs Camp are 33°00′45″S, 27°36′59″E; and the main cliff at Igoda are 33°03′40″S, 27°46′00″E. A number of previous unpublished horizons recognized in the KwaZulu Basin, based on first downhole appearances of particular benthic species in the deep boreholes, were designated colours: blue, black, green, red, orange for ease of correlation across the basin: they are included in the foraminiferal biostratigraphy shown in Table 2.

AGE OF NEEDS CAMP AND IGODA

History

Chapman (1916) concluded a Late Cretaceous age for the foraminifera identified by him from the Needs Camp lower quarry; while McGowran & Moore (1971) concluded a Campanian-Maastrichtian age for their assemblage also from the lower quarry. Lambert (in King 1972) recognized Campanian-Maastrichtian benthic foraminifera in the basal part of the upper quarry section, with King noting that larger foraminifera (*Discocyclina*), identified by C.G. Adams, were present in the same sample. This suggests that matrix from one or both of the two gastropod infills (comprising Sample 1008) processed to extract the foraminifera is not Cretaceous but instead Middle Eocene in age. It may mean that there are Cretaceous benthic foraminifera reworked into the basal *Discocyclina*-bearing Middle Eocene limestone; or it may mean that processed sample residues from the two gastropod infills were mixed together, creating an appearance of reworking; thirdly it may mean Eocene foraminifera tests are naturally falling down the quarry face and contaminating the Cretaceous section. Lock (1973) disputed King's Cretaceous date, regarding it as a date for the entire upper quarry section, and emphasized the Eocene larger foraminifera in the limestones of the upper quarry. Analysis of the smaller benthic and planktic foraminifera from the strongly-cemented and recrystallized Eocene massive limestones of the Needs Camp upper quarry shows there to be typical Eocene species, comparable with those of Pato's Kop, an outcrop sited further west close to the Fish River (Maud *et al.* 1987), also known as e'Kalikeni. McMillan (1990*b*) listed a few Late Cretaceous species from a basal glauconitic claystone below the Eocene limestone, at the base of the upper quarry section (sample 3029). No clearly Eocene, or otherwise Cainozoic foraminifera were found in sample 3029 collected by Lock, and studied by the author from this basal rock unit, in contrast to the mixed Eocene/Campanian-Maastrichtian nannoplankton assemblages detailed by Siesser & Miles (1979) from their portion of the same (?) sample. On the basis of the foraminifera studied by Lambert (in King 1972; and Lambert & De Klasz 1973) and by McMillan (1990*b*) this basal glauconitic claystone appears to be an *in situ* Cretaceous unit. None of the researchers involved in the dating of Needs Camp outcrops have actually reported a sample with both *Discocyclina* and Campanian-Maastrichtian benthic foraminifera in the same sample. The larger foraminifera *Discocyclina* occupied inner neritic environments in clear-water coastal settings, and unless transported post-mortem by debris flows, is not encountered in claystone settings reflecting turbid water regimes. Even if transported into clays by post-mortem cross-shelf current or swell processes, low sea-floor pH levels and consequent pyritization will tend to result in corrosion and destruction of most allochthonous foraminifera tests. Through the courtesy of Brian Lock about five tests of *Discocyclina* were presented to Soekor from the upper quarry massive limestone, and it can be confirmed that they are definitely of this genus.

Previous assemblages

Chapman (1916) detailed the following species from the lower quarry at Needs Camp: *Haplophragmium neocomianum, Spiroplecta anceps, S. anceps infracta, S. deflata* (all probably species of *Spiroplectinella*), *Nodosaria zippei* and *N. sulcata* (both probably species of *Pyramidulina*), *Lenticulina parallela, L. intermedia* and *L. secans, Discorbina pileolus* (an extant South American species of *Glabratella,* probably what is herein called *Angulogavelinella* sp.), *Cibicides schloenbachi* (probably what is here called ?*Rosalina* sp.), *Cibicidoides* ?*ungerianus* (possibly a *Gavelinella* species), *Anomalina ammonoides* (again probably a *Gavelinella* species), and *Pulvinulina karsteni* (either *Epistomina* sp. or *Angulogavelinella* sp.). Many of these species were illustrated. Chapman's assemblage (from one sample?) appears to lack several species now known to be common, but he was using Holocene, Cainozoic and Cretaceous taxa, which reflects both the early state of foraminiferal taxonomy in 1916, as well as the then widely held belief that many species had very long ranges. His generalized interpreted age of Late Cretaceous is therefore hardly surprising.

Smitter (1955) examined mid Santonian foraminifera from the Itongazi River mouth, and late Campanian–Early Maastrichtian foraminifera from Sandy Point, Lake St Lucia (Smitter 1957*a*). His taxonomy is strongly reliant on that of Cushman, and is often not easy to compare with that of Lambert (1971). Smitter's 1957*a* samples derive from almost the same locality as Lambert's (1971) samples 46 to 49 (now regarded as Maastrichtian a in age).

McGowran & Moore (1971) reported the following species to be abundant in the lower quarry at Needs Camp: *Spiroplectammina* aff. *laevis* (now *Spiroplectinella*), *Lenticulina* spp., *Alabamina dorsoplana, Cibicides* spp. (probably includes *Cibicides convexus*), and Gen. et sp. indet. cf. *Rotorbinella* or *Gavelinopsis* (probably *Angulogavelinella* sp. as used here). Other species include *Nodosaria vertebralis* (now *Pyramidulina*), *Dentalina* cf. *D. confluens* (probably now *Laevidentalina*), *Marginulina* cf. *M. jarvisi, Bolivina* aff. *B. incrassata* (now *B. incrassata incrassata*), *Gavelinella* aff. *G. pertusa, Gyroidinoides nitidus,* '*Gavelinella*' sp., *Cibicides* ?aff. *G. excavata,* and the planktic species *Rugoglobigerina* aff. *R. rugosa* and ?*Hedbergella* sp.

Lambert (in King 1972) listed the species from the pit dug into limestone behind the National Monument notice in the floor of the upper quarry at Needs Camp: from the matrix enclosing two gastropods (Sample 1008) were obtained *Gyroidinoides depressus, Lenticulina* spp., *Textularia laevis* cf. *cretosa* (now *Spiroplectinella*), *Quinqueloculina* spp., *Nodosaria* cf. *N. corta* (now *Pyramidulina*), *Epistomina* cf. *E. zuluensis, Eponides* sp., *Gavelinella* spp., *Gyroidinoides* cf. *G. nitidus, Quinqueloculina* cf. *Q. itongaziana,* the planktic *Heterohelix globulosa,* and supposedly the larger Eocene foraminifera *Discocyclina* from a thin section cut from one of the gastropod casts. It is clear from Lambert's comments (in King 1972, and in Lambert & De Klasz 1973), that the Cretaceous foraminifera came from sediment *encrusting* one of the gastropods, while the *Discocyclina* was identified on a thin section cut from the sediment *infilling* one of the gastropods: whether these are the same gastropod, or different ones is not clear. Consequently it is also not clear whether the Cretaceous foraminifera and shell debris is reworked into the basal Middle Eocene succession, or not. Detailed sampling and microfossil and macrofossil collecting is necessary throughout the entire upper quarry succession, rather than reliance on single samples.

Dingle (1985, pp. 153–154, table 11) examined 95 ostracods from the Igoda type section. Dominant species are of the genera *Bairdoppilata, Pondoina, Paracypris* and *Brachycythere.* On the basis of the Campanian-Maastrichtian successions of the KwaZulu Basin, Mzamba, Igoda, Agulhas Bank and Tugela offshore, and the ostracod assemblages discovered from them by Dingle (1985, pp. 163–166), he established an ostracod biozonation of this part of the stratigraphic succession. However, the biozonation was based on the ages of the ostracod species established relative to the ammonite biozonation developed by Kennedy & Klinger (1975 *et seq.*). It is difficult to establish exactly what age the Igoda ostracod assemblage implied, especially since almost half the species were described as new, and therefore provided no chronostratigraphic detail.

It is also difficult to establish an accurate age from the macrofossils (Klinger & Lock 1978) since that assemblage is a sparse one: *Baculites subanceps* Haughton; *Eupachydiscus* ?sp.; pachydiscid sp. indet.; and *Saghalinites* sp. cf. *S. cala* Forbes, which suggested a probable Late Campanian to Early Maastrichtian age to Klinger & Lock. In addition, Kennedy & Klinger (1985, pp. 166–167), in their analysis of kossmaticeratid ammonites of South Africa, redefined the level of the Campanian–Maastrichtian boundary in the KwaZulu Basin stratigraphic succession. This revision has led to Campanian IV becoming (basal) Maastrichtian a, and Campanian V becoming Maastrichtian b. This indicates that Maastrichtian a, Maastrichtian b, Maastrichtian I, Maastrichtian II and Maastrichtian III are all parts of the Early Maastrichtian succession. Maastrichtian III was previously believed to be devoid of ammonites (Kennedy & Klinger 1975), but does contain inoceramid prisms.

Additional age-indications of the Needs Camp upper and lower quarry sections, and of the Igoda Formation type section were presented by Siesser & Miles (1979) and Siesser (1982), using calcareous nannoplankton. Siesser (1982) analysed nannofossils from Needs Camp lower quarry, and on the basis of the presence of *Quadrum trifidum* concluded a Late Campanian to Early Maastrichtian age.

Present work

None of the above-named publications have yet revealed the full diversity of the Igoda-Needs Camp benthic foraminiferal assemblages (see Table 1), nor defined their place in the Late Cretaceous foraminiferal biostratigraphy of South Africa. The assemblages, usually dominated by species of *Lenticulina* and *Gavelinella,* compare closely with those detailed by De Gasparis (1968) from the Late Campanian to Early Maastrichtian succession of borehole ZA, and by Lambert (1971) from Middle to Late Campanian/ Campanian II to III (and to a lesser degree Early Maastrichtian/Maastrichtian a) age outcrops in the KwaZulu Basin. A few of the Early Campanian (Campanian I and Campanian II) foraminifera detailed by Makrides (1979) from the upper part of the Mzamba Formation at its stratotype section, for example *Praebulimina carseyae carseyae,* compare with those of Igoda-Needs Camp. In contrast to Mzamba, there is a virtually complete lack of *Epistomina* at both Igoda and Needs Camp except for very occasional tests. In part because of the absence of *Epistomina,* a middle to outer neritic depositional environment (estimated water depth between 70 m and 200 m), with minimal dysoxic character, is interpreted from the Igoda and Needs Camp foraminiferal assemblages of the limey claystones, but the limestones appear to have developed in an inner neritic setting. The Igoda assemblages are thus mostly unlike those at Mzamba (Makrides 1979; McMillan 2008*b*). These differences indicate that the Igoda-Needs Camp beds, but not the limestones, accumulated in distinctly deeper water, better oxygenated conditions than did the Mzamba beds. The Needs Camp limestones may be interpreted to have accumulated in an innermost neritic, siliciclastic-starved environment close to shore. Further differences exist with the size of Igoda/Needs Camp foraminifera tests, with occasional numbers of unusually large (up to 2 mm diameter) *Lenticulina,* as well as

Table 1. Summary list of Needs Camp/Igoda foraminifera species.

(A) Agglutinated species
1. *Haplophragmoides* sp.
2. *Triplasia* sp.
3. Thin, flat *Spiroplectinella* sp.
4. Fat *Spiroplectinella* sp.
5. *Spiroplectinella laevis cretosa* (Cushman) *s.l.*
6. *Cyclammina* sp. with coarse quartz grains
7. *Cyclammina* sp. with abundant fine quartz grains, sinuous sutures
8. Small, globular *Alveolophragmina* sp.
9. Conical *Gaudryina* sp.
10. *Gaudryina* sp. with triangular cross-section
11. *Dorothia oxycona* (Reuss)
12. Thin *Dorothia* sp.

(B) Miliolid species
13. *Quinqueloculina* spp.
14. *Quinqueloculina* cf. *Q. seminulum* (Linné)
15. *Quinqueloculina* sp. with fine quartz grains in wall.
16. Fat, wide *Triloculina* sp.

(C) Nodosariid species
17. *Dentalina* cf. *D. linearis* d'Orbigny
18. *Dentalina* cf. *D. soluta* d'Orbigny
19. Ribbed *Dentalina* sp.
20. *Laevidentalina* spp.
21. *Lenticulina* spp. (tending to be poorly ornamented, large-sized and often predominant)
22. Large, keeled *Lenticulina cultrata* (Lamarck) group
23. Large, flat *Lenticulina* sp.
24. *Pyramidulina* cf. *P. affinis* (Reuss)
25. *Pyramidulina* cf. *P. zippei* (Reuss)
26. *Lingulina carinata* d'Orbigny
27. Fat *Lingulina* sp.
28. Smooth *Marginulina* sp.
29. Ribbed *Marginulina* sp.
30. *Marginulinopsis* cf. *M silicula* (Plummer)
31. *Citharina* cf. *C. gracilana* Marie
32. *Neoflabellina* cf. *N .efferata* (Wedekind) or *N. leptodisca* (Wedekind)
33. ?*Palmula* sp. fragment
34. Smooth *Vaginulina* sp.
35. Thin *Vaginulina* sp.
36. Finely ribbed *Vaginulina* sp.
37. *Vaginulinopsis* sp.
38. Smooth *Lagena* cf. *laevis* (Montagu)
39. Smooth elongate *Lagena* cf. *L. apiculata* (Reuss)
40. Smooth *Oolina* sp.
41. *Globulina prisca* Reuss
42. *Globulina lacrima* (Reuss)
43. *Siphoglobulina* sp.
44. ?*Bullopora* sp.

(D) Buliminid species
45. *Praebulimina carseyae carseyae* (Plummer)
46. *Praebulimina kickapooensis* (Cole)
47. *Praebulimina offenbachensis* (Spandel)
48. *Bulimina arkadelphiana* Cushman & Parker
49. *Bolivina* sp.
50. *Brizalina incrassata incrassata* (Reuss)
51. Striate *Brizalina incrassata incrassata* (Reuss)
52. *Brizalina* cf.*B. incrassata* (Reuss) (smooth)
53. ?*Brizalina incrassata gigantea* (Wicher)

(E) Rotalid species
54. *Cibicidoides* spp.
55. Conical *Cibicides* sp.
56. *Globorotalites* sp.
57. *Cibicides convexus* (Reuss)
58. *Cibicides* cf. *C. convexus* with coarse perforations
59. *Nonionella cretacea* Cushman
60. *Valvulineria* sp.
61. *Spirotecta* sp.1
62. *Spirotecta* sp. 2
63. *Pullenia cretacea* Cushman
64. *Protelphidium* sp.
65. *Quadrimorphina* cf. *Q. camerata* (Reuss)
66. *Quadrimorphina allomorphinoides* Reuss
67. *Allomorphina conica* Cushman & Todd
68. *Allomorphina cretacea* (Reuss)
69. *Alabamina dorsoplana* (Brotzen)
70. *Gyroidinoides nitidus* (Reuss)
71. *Gyroidinoides* sp.
72. *Gyroidinoides depressus* (Alth)
73. *Reinholdella* sp.
74. *Epistomina supracretacea* Ten Dam *s.l.*
75. *Epistomina* cf. *E. favosoides* (Egger)
76. *Gavelinella* cf. *G. excavata* (Brotzen)
77. *Gavelinella* sp.
78. *Gavelinella/Berthelina* sp.
79. *Gavelinella* cf. *G. umbilicatiformis* Hofker
80. Flat, thick-walled *Gavelinella* sp.
81. *Angulogavelinella* sp.
82. *Osangularia expansa* (Toulmin)

(F) Planktic species
83. *Hedbergella* spp.
84. *Rugoglobigerina rugosa* (Plummer)
85. *Heterohelix globulosa* (Ehrenberg)
86. *Globigerinelloides asper* (Ehrenberg)
87. *Hedbergella* cf. *H. simplex* (Morrow)

(G) Miscellaneous microfossils
Bryozoans
Crinoid ossicles
Gastropods
Bivalves
Calcareous vagile worm tubes
Echinoid spines
Ostracods: principally *Bairdoppilata, Paracypris, Brachycythere,* ?*Pondoina.*
Sponge spicule
Sphere radiolaria

persistent numbers of unusually small tests of *Cibicides, Gavelinella, Valvulineria, Gyroidinoides,* ?*Spirotecta, Pullenia* and others, sufficiently small that it has proven difficult to keep control of these tests when manipulating them with a paint brush during picking. Such unusual test sizes are not seen in the Campanian portion of the Mzamba stratotype.

In order to establish the precise age of the Igoda and Needs Camp beds, an attempt has made to construct a much more detailed working foraminiferal biostratigraphy for southern Africa based on the benthic species for the 'difficult' base Campanian to mid Maastrichtian succession. This interval features little if any turnover in the planktic foraminifera assemblages, probably as a response to tectonically or environmentally placid continental margins of southern Africa. This time interval is marked principally by the following mainly keeled planktics which range throughout the interval: *Globotruncana tricarinata, Globotruncana linneiana, Globotruncana ventricosa, Contusotruncana fornicata, Pseudotextularia cushmani* and, intermittently from the top of the Campanian downwards, *Globotruncanita elevata.* The erratic distribution of *Globotruncanita elevata* in the later Campanian interval in the KwaZulu Basin vitiates against its use there as a robust biostratigraphic marker for the top of the Campanian, although its sharply defined appearance within about five metres above the Santonian–Campanian boundary is seen in all three deep-cored boreholes, ZA, ZB and ZC. This boundary is distinguished in the planktic assemblages by extinction of *Dicarinella asymetrica,* and, as well as appearance of *Globotruncanita elevata,* by the appearance of *Rugoglobigerina rugosa, Gublerina ornatissima, Pseudotextularia cushmani,* and *Globotruncana ventricosa,* the limited distribution of the planktic *Ventilabrella eggeri* Cushman only across the boundary interval, and considerable changes in both the species of *Hedbergella* and *Heterohelix.*

Recently three bursts in abundance of the planktic species *Contusotruncana fornicata* have been identified in the KwaZulu cored boreholes, often one of the commonest keeled planktics throughout the Campanian to Early Maastrichtian succession, which are of stratigraphic value in KwaZulu Basin biostratigraphy. The highest peak in abundance is immediately below first downhole appearance of *Loxostomum eleyi,* lower Campanian III, a second lies immediately below first downhole appearance of thin *Dorothia* sp., upper Campanian I, and the third is within the basal hemipelagic claystone overlying the downlap surface at the base of the Campanian I interval (Table 2).

Most of the benthic species utilized in the biozonation range all round southern Africa, but just a few, probably for water temperature reasons, are limited to the Atlantic, Southern or Indian continental margins. On the basis of the known foraminifera assemblages in outcrops and fully cored boreholes ZA, ZB and ZC in the KwaZulu basin, a detailed planktic-benthic foraminiferal biozonation can be established and cross-correlated with the detailed ammonite zonation developed from outcrops of the KwaZulu Basin by Kennedy & Klinger (1975 *et seq.*), as shown in Table 2. Especially relevant are the three M.Sc. theses of De Gasparis (1968) mostly on Late Campanian and Early Maastrichtian foraminifera species, of Lambert (1971), mostly on Middle to Late Campanian and Early Maastrichtian species (Campanian II and III, and Maastrichtian a), and of Makrides (1979), on the Middle to ?Late Santonian and Early to ?Middle Campanian Mzamba Formation, respectively. The M.Sc. thesis by Wright (1998) illustrates Late Maastrichtian benthic and planktic foraminifera from the 11 m of Cretaceous section in the basal part of shallow borehole P110-3, northern KwaZulu. Additional illustrations of similar assemblages of planktics and some benthics (*Bolivinoides, Stensioeina, Reussella, Neoflabellina, Gavelinella, Gaudryina* and others) from a more tropical setting have been illustrated from the Late Cretaceous succession of coastal and offshore Tanzania (Singano & Karega 2000), a volume which compares and contrasts Cretaceous foraminifera assemblages and age-diagnostic species for Angola, Namibia, South Africa, Mozambique and Tanzania (SADC). Additional comparison can be gained from examination of Australian foraminiferal zonation schemes (Apthorpe 1979; Shafik 1990, 1998; Henderson *et al.* 2000) for Late Cretaceous successions which accumulated at similar latitudes to those in the southern African basins. Comparison can also be made with the English Chalk succession (Hart *et al.* 1989) and the Campanian succession of northeast Texas (Thompson *et al.* 1991).

This zonation permits cross-correlation between various different Campanian-Maastrichtian borehole sections inside and outside the KwaZulu Basin, particularly the notable Kudu 9A-2 section (McMillan 1990*a*, with revisions) in the Orange Basin (2635 m thick Campanian section), and the ZC section in the KwaZulu Basin (523 m thick Campanian section). These borehole sections reflect a milieu of frequently rapid subsidence on the Atlantic continental margin during the Campanian, in a cooler-water setting, contrasting with generally slow subsidence on the Indian margin in a warmer water setting. Planktic and benthic assemblages are consequently more diverse on the Indian margin than on the Atlantic margin.

As a result of developing the biozonation, which has led to the identification of 22 foraminifera-based zones (Table 2), two benthic species have been identified with limited age ranges in the Needs Camp and Igoda samples: *Valvulineria* sp. and thin *Dorothia* sp., the former typical of later Campanian I and earlier Campanian II, and the latter typical of mid Campanian I and older. The Needs Camp and Igoda assemblages lack a diverse planktic assemblage, whereas the Early Campanian interval of the Mzamba Formation stratotype section at Mzamba Cliff, in beds A15 and A17 of Klinger & Kennedy (1980) and Makrides (1979) possesses diverse planktic assemblages, rich in keeled species. The implication is that the Needs Camp/Igoda Campanian is not coeval with the Mzamba Campanian.

SAMPLES

Of the nine samples reprocessed for this publication, and three samples processed for the first time, two samples 3027 and 3029 were collected from the Needs Camp outcrops in the 1970s by Brian Lock, and five samples 9590, 9591, 9592, 9593 and 9594 collected from the Igoda outcrops in the 1970s by Dr Herbie Klinger (Iziko South African Museum). All of these samples were passed to the present author by I.R. McLachlan, formerly Consultant at Soekor (Pty) Ltd and the Petroleum Agency of South Africa (PASA). An eighth sample of the Igoda Formation from the type locality was supplied by Jokl le Roux in the 1990s, and a ninth sample of the Igoda Formation cliff section was recently kindly supplied by Herbie Klinger. Two new samples were recently kindly presented to I.K.M. by Herbie Klinger from the collections of the South African Museum: one (2565: unidentified fossil fragments) was collected by S.H. Haughton from the lower quarry limestone, and the other (1727: *Pecten* matrix) was collected by J.W. Woods, but it is not clear from which quarry it derives. Both sample 1727 and 2565 are relatively well indurated shelly creamy white or yellowish limestones rich in bryozoans, and with barnacle scutes, echinoid spines and vagile calcareous worm tubes. Sample 2565 also contains numerous small blocks of inoceramid prisms. The precise stratigraphic relationships of the various samples collected at the four outcrop sites remain unclear. Work on these two samples is continuing.

Sample processing

The original two samples collected by B. Lock (Soekor laboratory processing numbers 3027 and 3029) were initially processed with 40 volumes hydrogen peroxide, but this failed to disaggregate the limestones and limey claystones effectively, and only led to small numbers of foraminifera tests being recovered. Samples 9590 to 9594

Table 2. Interval zonation of first downhole appearances (extinction points) of benthic and planktonic foraminifera compared with the ammonite zonation established by Kennedy & Klinger (1975 *et seq.*) for the Campanian to Maastrichtian succession in the KwaZulu Basin, eastern South Africa.

Benthic Foraminifera species	Planktic Foraminifera species	Ammonite Assemblage Zone	Typical Ammonite species	Age/stage	Benthic Foraminifera Zone number	Diagnostic horizon colour	Sequence boundary type	Lithology features	Macrofossil zones
Top Cretaceous: top Late Maastrichtian	Top Cretaceous: top Late Maastrichtian	No Ammonite zonation eroded off	None	Top Late Maastrichtian	Biozone 1			Top foraminiferal chalks	
Top *Angulogavelinella* sp.	Top *Abathomphalus mayaroensis*	No Ammonite zonation	None	Top Late Maastrichtian	Biozone 1				
Top *Pseudouvigerina cristata*	Top *Gansserina gansseri*	No Ammonite zonation	None	Top Late Maastrichtian	Biozone 1				
Top *Brizalina incrassata incrassata*	Top *Contusotruncana contusa*	No Ammonite zonation	None	Late Maastrichtian	Biozone 1				
Top *Bolivinoides draco*	Top *Racemiguembelina fructicosa*	No Ammonite zonation	None	Late Maastrichtian	Biozone 1				
Top *Allomorphina conica*	Top *Pseudotextularia cushmani*	No Ammonite zonation		Late Maastrichtian	Biozone 1				
Top *Heterostomella* sp. #1	Top *Globotruncana ventricosa*	No Ammonite zonation		Late Maastrichtian	Biozone 2				
Osangularia cf. *O. expansa*	Base *Abathomphalus mayaroensis*	No Ammonite zonation		Earlier Late Maastrichtian	Biozone 2				
Top ornate *Stensioeina* sp.		No Ammonite zonation		Earlier Late Maastrichtian	Biozone 3			Base foraminiferal chalks	
		No Ammonite zonation		Earliest Late Maastrichtian				Top siliciclastics with limestones	*Agerostrea ungulata*
Base *Oridorsalis* sp.	Base *Contusotruncana contusa*				Biozone 4				Smooth *Eubaculites* sp.
	Base *Racemiguembelina fructicosa*			Base Late Maastrichtian					*Discoscaphites* sp.
Top *Pyramidina* sp.	Top *Globotruncana tricarinata*	Maastrichtian III — Top Lower Grudja		Top Early Maastrichtian	Biozone 5: Top 'glossy foraminifera tests'	Green #1			
Top *Stensioeina* sp. with incurved spiral side	Top *Globotruncana linneiana*	Maastrichtian III	No ammonites, only inoceramids	Early Maastrichtian	Biozone 5		Downlap-onlap surface	True inoceramids extinction	
Top *Heterostomella* sp. #2	Top *Contusotruncana fornicata*	Maastrichtian III	No ammonites, only inoceramids		Biozone 5		Sediments rich in inoceramid prisms		
Top *Spiroplectinata laevis cretosa*		Maastrichtian III	No ammonites, only inoceramids		Biozone 6		G Key Bed limestone		
Top *Quinqueloculina* sp. with quartz grains in wall		Maastrichtian III	No ammonites, only inoceramids	Early Maastrichtian	Biozone 6				
Top *Globorotalites michelinianus*		Maastrichtian II	abundant coarsely ornamented *Eubaculites*	Earlier Early Maastrichtian	Biozone 7				
Top spreading *Carpenteria* sp.									
Top *Bolivinoides miliaris*		Maastrichtian I	Smooth *Eubaculites* spp.						

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Table 2 (continued)

Benthic Foraminifera species	Planktic Foraminifera species	Ammonite Assemblage Zone	Typical Ammonite species	Age/stage	Benthic Foraminifera Zone number	Diagnostic horizon colour	Sequence boundary type	Lithology features	Macrofossil zones
Top globular *Alveolophragmina* sp.							G6 sandstone about 50m thick		
Top *Pseudonodosaria manifesta* #2		Maastrichtian b	Giant *Bostrychoceras* abundant						
Top *Pyramidulina* cf. *P. affinis* floods		Maastrichtian a	*Saghalinites cala* + *Pachydiscus* common						
Top *Tritaxia* sp.		Maastrichtian a	*Saghalinites cala* + *Pachydiscus* common		Biozone 8				
Top *Cyclogyra* sp.		Maastrichtian a	*Saghalinites cala* + *Pachydiscus* common	Base Early Maastrichtian	Biozone 8		Conformable surface		
Top *Bulimina strobila* #1		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common	Top Late Campanian	Biozone 9				
Dorothia bulletta #1	Top rare *Globotruncanita elevata* (KwaZulu Basin only)	Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 9				
Notoplanulina rakauroana		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 9	Turquoise	Conformable surface		
Base *Pyramidulina* cf. *P. affinis*		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common						
	Praeglobotruncana citae	Campanian III	Nodose *Baculites* + giant *Pachydiscids* common				G7 sandstone: approx. 10 feet thick		
	Lowest *Planoglobulina* spp.	Campanian III	Nodose *Baculites* + giant *Pachydiscids* common				G8 sandstone: approx 10 feet thick		
Bulimina arkadelphiana		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 10		G9 sandstone : approx 10 feet thick		
Reappearance of *Cibicides convexus* #2		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 11	Black #1			
Dorothia bulletta #2		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 11		G10 sandstone: 2 very thin ssts.		
'*Reussella*' *szajnochae*		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 11				
smooth *Colomia* sp.		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 12				
Bolivinopsis sp.		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 13				
Top abundant *Gaudryina* spp.		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 14				
Pleurostomella subnodosa		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 15				
Bandyella greatvalleyensis		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 15				
Nonionella cretacea		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 16				

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Table 2 (continued)

Benthic Foraminifera species	Planktic Foraminifera species	Ammonite Assemblage Zone	Typical Ammonite species	Age/stage	Benthic Foraminifera Zone number	Diagnostic horizon colour	Sequence boundary type	Lithology features	Macrofossil zones
Allomorphina cretacea		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 16				
Top narrow *Bolivinoides* sp.		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 16				
Loxostomum eleyi		Campanian III	Nodose *Baculites* + giant Pachydiscids common		Biozone 16	Blue	Major unconformity surface		
Thin *Bolivinoides* sp.	*Contusotruncana fornicata* burst #1	Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 16	juvenile *Trigonia* rock			
Base *Angulogavelinella* sp.	Top *Globotruncanita elevata* — Kudu/ Orange Basin	Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 17				
Base *Bolivinoides miliaris*		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common		Biozone 17		G11 sandstone: 2 very thin ssts.		
Pullenia cretacea		Campanian III	Nodose *Baculites* + giant *Pachydiscids* common	Late Campanian	Biozone 17				
Ribbed *Marginulina* sp.		Campanian II	*Menabites* (*Australiella*) spp. common	Middle Campanian	Biozone 18	Orange			
Marginulinopsis sp.		Campanian II	*Menabites* (*Australiella*) spp. common	Middle Campanian	Biozone 18				
	Base *Globotruncanita elevata* — Kudu	Campanian II	*Menabites* (*Australiella*) spp. common	Middle Campanian		*Hoplitopla-centiceras*			
Pseudosigmoilina antiqua		Campanian II	*Menabites* (*Australiella*) spp. common	Middle Campanian	Biozone 19	*Metaplacenticeras subtilstriatum*			
Bulimina strobila #2		Campanian II	*Menabites* (*Australiella*) spp. common	Middle Campanian	Biozone 20				
Unconformity		Campanian I	*Submortoniceras woodsi* abundant	Early Campanian	Biozone 21	Red - Top dysoxic in Kudu boreholes	Disconformity — conformable		
Gavelinella sp. cf. smooth *Stensioeina*		Campanian I	*Submortoniceras woodsi* abundant	Early Campanian	Biozone 21				
Thin *Dorothia* sp.	*Contusotruncana fornicata* burst #2	Campanian I	*Submortoniceras woodsi* abundant	Early Campanian	Biozone 22		Much clayier, less sandy from here		
Lenticulina cf. *A. microdictyotos*		Campanian I	*Submortoniceras woodsi* abundant	Early Campanian	Biozone 23	Green # 2			
Bulimina strobila #3		Campanian I	*Submortoniceras woodsi* abundant	Early Campanian	Biozone 24				
Top *Ventilabrella eggeri*	*Contusotruncana fornicata* burst #3	Campanian I — Base Lower Grudja	*Submortoniceras woodsi* abundant	Early Campanian	Biozone 25				
Thin *Textularia* sp.	Base *ventricosa*, *elevata, cushmani, ornatissima, rugosa*	Santonian III -Top Upper Domo Shales	*Hauericeras gardeni* abundant	Top Late Santonian	Biozone 26	Base dysoxic in Kudu boreholes	Onlap-downlap surface		
Base *Ventilabrella eggeri*		Santonian III	*Hauericeras gardeni* abundant	Late Santonian	Biozone 27				
Dicarinella asymetrica		Santonian III	*Hauericeras gardeni* abundant	Late Santonian	Biozone 28				

Continued on p. 142

Table 2 (continued)

Benthic Foraminifera species	Planktic Foraminifera species	Ammonite Assemblage Zone	Typical Ammonite species	Age/stage	Benthic Foraminifera Zone number	Diagnostic horizon colour	Sequence boundary type	Lithology features	Macrofossil zones
Allomorphina cretacea #3		Basal Santonian II							
Top *Heterohelix sphenoides* + *Sigalia deflaensis*		Santonian II	Abundant *Texanites stangeri*	Top Middle Santonian	Biozone 29				
Top *Dorothia bulletta* #4		basal Santonian II	Abundant *Texanites stangeri*						
Base *Dicarinella asymetrica*		Base Santonian II	Abundant *Texanites stangeri*	Top Early Santonian	Biozone 30				
Base *Heterohelix sphenoides* + *Sigalia deflaensis*		Base Santonian II	Abundant *Texanites stangeri*	Top Early Santonian	Biozone 30				
Top *Dicarinella concavata*		Santonian I	*Texanites oliveti* + other *Texanites* spp.	Top Early Santonian	Biozone 31				
Smooth-keeled *Palmula* sp.		Earliest Santonian I							

Texanites stangeri to read *Plesiotexanites stangeri*

were initially treated with hydrogen peroxide, then later with the quaternary ammonium detergent Tinegal PAC (manufactured by Ciba-Geigy), but again only a few foraminifera were extracted from the carbonate-cemented samples. The subsequent construction by Ian McLachlan of a case-hardened steel pestle and mortar for the Soekor laboratory led to these seven samples being reprocessed. The more cemented samples were successfully crushed, and a considerable assemblage of foraminifera recovered. More recently these samples have been crushed further, and more foraminifera recovered. The Jokl le Roux sample was treated in the same manner, but severe calcite overgrowths on the foraminifera test surfaces led to work on this sample being discontinued. The Igoda Formation limestone sample recently kindly supplied by Herbie Klinger was crushed with a pair of pliers, four or five times, with all released foraminifera being picked after each episode of crushing. The development of 'acetolysis' in France, using dilute vinegar (acetic acid) to extract microfossils from indurated limestones steeped in dilute acid (no bubbling) for about a month, has been successfully attempted on sample 2565. Results are ongoing.

PALAEOENVIRONMENTAL MODEL

Analysis of the distinctly sparse Needs Camp/Igoda foraminifera assemblages, the predominance of smooth-walled forms in both the foraminifera and the ostracods, the predominance of species of *Gavelinella* and *Lenticulina,* and the unusual test sizes all lead to the suspicion that this is a stressed association, with severe environmental limitations on its growth patterns. The unusually large-sized *Lenticulina* tests, up to 2 mm diameter, indicate that some tests were growing senile and not reproducing at the asexual portion of their life cycle, with no halt to the steadily increasing size of senile individuals unable to reproduce. The unusually small size of other tests (some *Gavelinella* spp., *Nonionella cretacea, Gyroidinoides* spp., for example) suggests some species experienced substantial juvenile mortality for some unclear reason. The absence of keeled planktic species, and the rarity of heterohelicids, hedbergellids and globigerinelloidids suggests only a few near-surface-dwelling plankton inhabited the water column in this region. The presence of a wide variety of benthic species, despite their comparative sparsity, nonetheless indicates normal salinity at the sea-floor, and dysaerobia at the sea-floor was not excessive. However, the frequency of broken and deteriorated foraminifera tests (evident also in Chapman's illustrations of 1916), especially large-sized rectilinear nodosarid tests such as of the genera *Pyramidulina, Laevidentalina, Dentalina, Marginulina* and others, probably indicates that a substantial portion of the assemblage is derived from debris flows sourcing inner neritic shell hash. It is possible that the apparent sparsity in the *in situ* portion of the assemblages was caused by diminished or minimal food supply, but how induced is not clear.

The 1.5-m-thick limestones of the lower quarry at Needs Camp are rich in bryozoans, echinoid debris, brachiopods, corals and bivalves (Lang 1908; Brood 1977), and blocks of inoceramid prisms. Brood interpreted the bryozoans to have lived in a 'shallow water, reasonably high energy environment'. This limestone appears to mark a wave or swell-dominated environment close to shore with water clear enough to be acceptable to corals, and possibly also to larger foraminifera. The macrofossil assemblage suggests either a wave-dominated bioherm or a carbonate-rich debris flow. It will be interesting to find out what microfossils are present in the limestones, in contrast to what has been found in the limey claystones and clayey limestones, and studied in the past.

CAMPANIAN BENTHIC FORAMINIFERA SPECIES

Notes are provided here describing the stratigraphic significance of certain benthic species. Some benthic and planktic species from Igoda are illustrated in Figs 2 and 3. An attempt is made to integrate taxonomic names from several sources, and combine them with what has been seen in the oil exploration deep boreholes by the present author. The aim is to commence integration of the benthic foraminifera biozonation with the planktic foraminifera and ammonite biozonations (Kennedy & Klinger 1975 *et seq.*), and, if possible, with the ostracod biozonation (Dingle 1969*a*, 1969*b*, 1980, 1981, 1985, 1996), dinocyst (Davey 1969*a*, 1969*b*; Benson 1990, 1992) and calcareous nannofossil studies (Pienaar 1966, 1968, 1969; Siesser & Miles 1979; Siesser 1982; Verhagen *et al.* 1990; Klinger *et al.* 2001; Ovechkina *et al.* 2008). However, the complexity of correlating bio-events even just across the Campanian–Maastrichtian boundary (Burnett *et al.* 1996) makes this a daunting task.

Alabamina dorsoplana (Brotzen, 1936) or ***Alabamina australis australis*** Belford, 1960

Fig. 3.15–17

Illustrated and described by De Gasparis (1968, p. 117, pl. 13, figs 9, 9a, 9b) and by Makrides (1979, p. 53, pl. 7, figs 1a–c), it is not especially stratigraphically useful, since it occurs at five different but closely-spaced horizons in the Campanian. It seems to be more common in deeper waters than shallow. Its full range around southern Africa (McMillan 2003) is throughout the Late Coniacian to top Late Maastrichtian, but in the KwaZulu Basin (ZC) and the northern Orange Basin (9A-2) it is particularly limited to the Early to earliest Late Campanian succession, usually in small numbers. It occurs in moderate numbers in most samples from Needs Camp and Igoda. It is also present in the Early Campanian succession at Mzamba Cliff (Makrides 1979). The Australian species was described from the Santonian Toolonga calcilutite and the Gingin chalk by Belford (1960), but on the basis of the planktic assemblage this age is in doubt.

Allomorphina conica Cushman & Todd, 1949

The test morphology of this species is not typical of the genus *Allomorphina*. This species ranges in the KwaZulu Basin from mid-late Santonian up to mid to late Maastrichtian, but its range at any one site is clearly facies controlled, and it ranges further up section the deeper water the section studied. Identified as *Tosaia*? sp. by De Gasparis (1968, p. 72, pl. 7, fig. 10) and as *Allomorphina conica* by Lambert (1971, p. 259, pl. 11, fig. 3a–c, text-fig. 142a–c). Originally described from the Upper Cretaceous of southeastern Trinidad by Cushman & Todd (1949). McMillan (2003) records the range of this species around southern Africa as mid Santonian to Late Campanian, but it ranges intermittently up to Late Maastrichtian in the KwaZulu Basin. Extremely rare tests of *Allomorphina conica* occur at both Needs Camp and Igoda.

Allomorphina cretacea (Reuss, 1858)

This species is the archetypal Late Cretaceous dysoxic benthic marker species around southern Africa, with localized abundances as in the Early Campanian/Campanian I ‘dysoxic’ section in the Kudu boreholes off southernmost Namibia. Tests from deep water are often large and glassy, with clear calcite infillings, but since they are thin-walled most tests become badly compressed or crushed through diagenetic compaction processes, so that most tests are of little interest under the scanning electron microscope. The tests of *Allomorphina cretacea* at Needs Camp and Igoda are very rare, and most are either crushed or broken because of the thin test wall. Lambert (1971, p. 260, pl. 11, figs 4a–c, text-figs 143a–c) illustrated tests from KwaZulu Basin outcrops below the ‘blue’ horizon (top *Loxostomum eleyi*) with rather more elongate than globular chambers, and the rare tests in the Igoda/Needs Camp outcrops are of the same morphology. Makrides (1979, p. 52, pl. 7, figs 3a–c) illustrated more nearly globular tests from Mzamba.

Angulogavelinella sp.

This species warrants a new name. In Soekor internal reports and in McMillan (2003) the name *Angulogavelinella cordieriana* (D’Orbigny) was used, but this is incorrect since the aperture is developed exclusively along the interior margin of the last-formed chamber, extending as an elongate linear slit from near the test umbilicus to near the periphery. No South African tests display an areal, arcuate aperture extending across the terminal face of the last-formed chamber, as is typical of *Osangularia* and *Angulogavelinella* species. The umbilicus is filled with a prominent flat-topped glassy plug, tests tend to be plano-convex, with the spiral side conical and the umbilical side usually flat, giving tests of this species the appearance of a miniature child’s spinning top in side view. Tests are coarsely perforate on the umbilical surface, but on the spiral side are either extremely finely perforate, or are imperforate. No comparable species is known elsewhere in the world, and it is an endemic. This species occurs in variable, small numbers in most of the studied samples from Needs Camp and Igoda. Described and illustrated by Lambert (1971, p. 274, pl. 12, fig. 1a–c, text-fig. 150a–c) under the name *Osangularia expansa,* a distinctly different benthic species. This species is abundant and widely distributed all round southern Africa through the Campanian-Maastrichtian succession, and like *Cibicides convexus* displays abrupt changes in sparsity or abundance. Like *Cibicides convexus* it ranges from the basal Middle Campanian to the top Late Maastrichtian.

Bolivina sp.

Fig. 3.2–3

Unusual test morphology, not a true *Bolivina, Brizalina* or *Bolivinita* as the sub-circular aperture is developed on a terminally-sited short neck. Otherwise, this narrow, parallel-sided species, with biserial chamber arrangement throughout, rectangular cross-section to the test, and fine, vertically aligned striations on the early part of the test, looks somewhat like a species of *Bolivinita.* It occurs rarely in the Needs Camp and Igoda Formation outcrops, but moderate numbers occur in the Early and earlier Late Campanian succession in the KwaZulu Basin, especially in distal borehole ZC. It is common from the base of the Campanian up to the 'blue' horizon (first downhole occurrence of *Loxostomum eleyi*) in the earlier Late Campanian, but very rare examples occur even higher in the Late Campanian and earliest Maastrichtian. In general it does not occur in offshore borehole sections of this age, it is absent in the Orange and Bredasdorp Basins, and it seems to be most frequent in the KwaZulu Basin. This species has not been previously recognized but possibly *Bolivina* sp. A, detailed by Lambert (1971, p. 175, pl. 6, figs 10a–b, text-figs 97a–c) is at least partly synonymous.

Brizalina incrassata incrassata (Reuss, 1858)
Fig. 3.4–6

Although referred either to *Brizalina* or *Bolivina,* this species is morphologically unlike the Cainozoic members of either genus. Again illustrated by Lambert (1971, p. 183, pl. 6, figs 13a–b, 14a–b, text-figs 100a–c, 101a–c), this distinctive species is also limited to the Campanian-Maastrichtian succession all round southern Africa. There are moderate numbers in some Igoda samples. There is a larger-sized, wider variant, *Brizalina incrassata gigantea* Wicher, mainly limited to the Late Maastrichtian succession of the KwaZulu Basin and Thekwini Basin, and not found in contemporary beds of the southern offshore basins. The absence of *B. incrassata gigantea* emphasizes a Campanian rather than Maastrichtian age for the Igoda and Needs Camp sections.

Bulimina strobila (Marie, 1941)

The Campanian–Maastrichtian boundary was identified in the offshore Thekwini Basin on the basis of topmost *Bulimina strobila* (McMillan & Dale 2000), but this datum is not as widely defined in the onshore KwaZulu Basin. There is thus a possibility of miscorrelation of the boundary between the two basins, since *Dorothia bulletta* #1 and *Bulimina strobila* occur at slightly different stratigraphic levels close to or at the Campanian–Maastrichtian boundary in the KwaZulu Basin. *Bulimina strobila* is marked by an elongate test, chambers triserially arranged throughout, with a rounded-triangular cross-section and lobulate test margin. Lambert (1971, p. 189, pl. 6, fig. 16a–b) illustrated a very good example of this species from her sample 48, collected from near to the Kennedy & Klinger (1975) Site 113, now interpreted as Maastrichtian a in age. However, all the other illustrations she gives are of a distinctly different species (Lambert 1971, p. 189, pl. 6, fig. 17a–b, text-figs 103a–b), which is recognizably *Pseudouvigerina cristata* (Marsson), sharply triangular in cross-section, bicarinate at each margin, with a small sub-circular aperture on a short phialine neck. *Bulimina strobila* was originally described by Marie from the Late Campanian *Belemnitella mucronata* zone of France.

Cibicides convexus (Reuss, 1851)

Illustrated by Lambert (1971, p. 253, pl. 10, figs 7a–c, text-figs 139a–c) from KwaZulu Basin outcrops, and known widely through the Campanian-Maastrichtian succession all round southern Africa, this species displays a number of age-constrained appearances, disappearances and reappearances. Notably the species abruptly reappears in some numbers in the mid part of the Late Campanian succession, and consequently defines the 'black' horizon. Although only present in small numbers in the Igoda-Needs Camp outcrops, their presence implies an earlier Late Campanian or earlier age for these rocks. In total, *Cibicides convexus* ranges from basal Middle Campanian (about 30 feet above the Early–Middle boundary) up to top Late Maastrichtian.

?*Cyclammina* spp.

At several levels in the Early Middle and Late Campanian succession of the KwaZulu cored boreholes ZA, ZB and ZC, there are a variety of small agglutinated-walled tests referable to the genus *Cyclammina* or similar genera. Some are globular, deep-water *Haplophragmoides* or *Alveolophragmina* species, since they clearly possess interiomarginal, arched slit-like apertures, but others, larger in size, may prove to be juvenile *Cyclammina* spp. None display convincing cribrate apertures, as demanded in the description of *Cyclammina.* Most possess finely depressed, sinuous intercameral sutures that are typical of this genus, and the test wall is constructed of uniform very fine-grained quartz particles. One *Cyclammina* species ranges through most of the Early Campanian upper portion of the Mzamba Cliff outcrop (McMillan 2008*b*). It remains unclear what stratigraphic value these apparently short-lived foraminifera possess, if any.

Dorothia bulletta (Carsey, 1926) **#1**

This parallel-sided *Dorothia* with a strongly globular pair of last-formed chambers, and rapidly increasing width of the initial multiserial part of the test, has not been recognized by Lambert (1971), De Gasparis, Makrides or Wright. However the species occurs over four short intervals in the boreholes, the topmost being at and just below the Campanian–Maastrichtian boundary; secondly from 'black' horizon

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Fig. 2. Benthic and planktic foraminifera species of Needs Camp and Igoda. All illustrated specimens are from the Formation stratotype section at Igoda River mouth (Klinger & Lock 1978). **1**, *Alveolophragmina* sp., side view, sample 9591, magnification ×52, SAM-PQ-MF-2364. **2**, *Alveolophragmina* sp., apertural view, sample 9591, ×51, SAM-PQ-MF-2365. **3**, *Spiroplectinella laevis cretosa* (Cushman) *sensu lato,* side view, sample 9591, ×152, SAM-PQ-MF-2366. **4**, *Spiroplectinella laevis cretosa* (Cushman) *sensu lato,* apertural view, sample 9591, ×133, SAM-PQ-MF-2367. **5**, *Gaudryina* sp., side view, sample 9591, ×92, SAM-PQ-MF-2368. **6**, Thin *Dorothia* sp., side view, sample 9591, ×130, SAM-PQ-MF-2369. **7**, Thin *Dorothia* sp., side view, sample 9591, ×143, SAM-PQ-MF-2370. **8**, *Quinqueloculina* sp., side view, sample 9591, ×112, SAM-PQ-MF-2371. **9**, *Pyramidulina* cf. *P. affinis* fragment, side view, sample 9590, ×85, SAM-PQ-MF-2372. **10**, *Pyramidulina* cf. *P. zippei* fragment, side view, sample 9590, ×88, SAM-PQ-MF-2373. **11**, Ribbed *Dentalina* sp. fragment, side view, sample 9591, ×85, SAM-PQ-MF 2374. **12**, *Laevidentalina* sp., side view, sample 9591, ×43, SAM-PQ-MF-2375. **13**, *Laevidentalina* sp., side view, sample 9591, ×50, SAM-PQ-MF-2376. **14**, Narrow *Citharina* sp., side view, sample 9591, ×86, SAM-PQ-MF-2377. **15**, *Lagena* cf. *L. laevis,* side view, sample 9591, ×220, SAM-PQ-MF-2378. **16**, *Lagena* cf. *L. laevis,* side view, sample 9591, ×169, SAM-PQ-MF-2379. **17**, smooth *Vaginulina* sp., side view, sample 9591, ×69, SAM-PQ-MF-2380.

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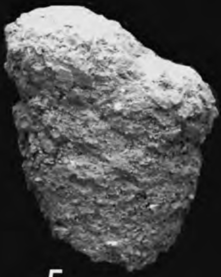

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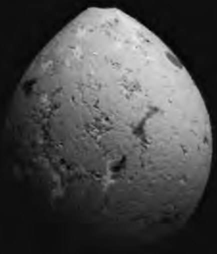

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(reappearance *Cibicides convexus*) down to just below 'blue' horizon (top *Loxostomum eleyi*) in the basal Campanian III; thirdly in the basal Campanian I; and fourthly across the hemipelagic claystone event at the Early Santonian–Middle Santonian boundary.

Dorothia oxycona (Reuss, 1860)

Fig. 2.1–2

Identified by De Gasparis (1968, p. 20, pl. 2, fig. 6) and by Lambert (1971, p. 70, pl. 1, figs 1a–b, text-figs 34a–b). Described by Reuss from 'Westphälischen Kreideformation', with a range of Albian-Senonian. Conical siliciclastic agglutinated-walled *Dorothia* tests occur widely in the Late Cretaceous succession preserved around southern Africa, but display little stratigraphic value, and are never abundant. This name covers a wide array of conical forms, but their taxonomy in southern Africa is poorly-defined, and their true stratigraphical ranges remain undetermined. There are small numbers in some of the Igoda samples.

Epistomina* cf. *E. favosoides (Egger, 1893)

One or two cemented and poorly preserved *Epistomina* tests, elegantly ornamented with a fine pitting over the entire exterior. This ornamentation is more strongly developed than the widely spaced, fine punctation of true *Epistomina favosoides* and rather looks like a miniature version of the coarse reticulation developed on the Santonian *Epistomina pondensis* tests (Lambert 1971; Makrides 1979; McMillan 2008*a*). It is very close to the *Epistomina* sp. of Makrides (1979, p. 65, pl. 9, figs 3a–c), which is limited to the Early Campanian portion of the Mzamba Formation.

Epistomina supracretacea Ten Dam, 1948 ***sensu lato***

One or two poorly-preserved casts of smooth-walled *Epistomina,* attributed to this species. It is presumed that they have been introduced into the assemblage via debris flows sourcing shelly detritus from inner neritic environments, in proximal beds that have not survived. Sutures on the umbilical side are straight, radiate and lightly limbate, and on the spiral side limbate, oblique and curved. Compare the smooth *Epistomina* tests illustrated by Smitter (1957*b*), Lambert (1971) and Makrides (1979).

Gavelinella stephensoni (Cushman, 1938)

With an unusually strongly compressed test, this species has a wide, low, flat umbonal boss on umbilical side, and prominent convex dome on spiral side, composed of initial one or two whorls of test. Described by Cushman (1938). See De Gasparis (1968: *Anomalinoides* (*Cibicides*) *stephensoni*; p. 119, pl. 13, figs 11, 11a, 11b; possibly also 12, 12a, 12b) and Lambert (1971: *Gavelinella stephensoni*: p. 292, pl. 13, fig. 3a–c, text-figs 159a–c, 160a–c. De Gasparis (1968) found this species in the topmost Late Maastrichtian sample at 282' in borehole ZA. In contrast, Lambert (1971) found it abundant in her samples 43, 42, 44 (Campanian II and basal Campanian III), but absent in her higher sample 45 (higher Campanian III) and her Maastrichtian a samples 48, 47, 49, 46.

Globorotalites michelinianus (D'Orbigny, 1850)

This distinctive species, with a glassy, trochospiral, conical test, flat spiral side and steeply tapering umbilical side, and flat terminal face to the last-formed chamber, with an elongate, interiomarginal slitlike aperture, occurs widely in the Campanian all round southern Africa. It generally occurs with *Notoplanulina rakauroana.* The species is most common off the southern and western coasts, where tests tend to be larger, whereas it is rarer, with smaller test size off the east coast in the KwaZulu and Thekwini Basins. These exclusively Campanian southern African tests are slightly morphologically different from *Globorotalites michelinianus* tests found in the Chalk of northwest Europe (Hart *et al.* 1989), and possess a different stratigraphic range. Small-sized *Globorotalites* tests occur at Igoda, but they are too small to confidently refer them to this species.

Loxostomum eleyi (Cushman, 1927)

Tests of this distinctive, small-sized, strongly compressed, biconcave form, with a flat test periphery and two peripheral keels, are limited to a short interval below 'blue horizon'in the lower part of the Late Campanian (Campanian III). Described by Cushman (1927), this species was recorded by Lambert (1971, p. 257, pl. 11, figs 2a–b, text-figs 141a–b). At the top of the interval characterized by *Loxostomum eleyi* there is a considerable benthic foraminifera turnover, perhaps attaining 50% of the assemblage. There is also a burst in the keeled planktic species *Contusotruncana fornicata,* a burst of *Gaudryina* spp., and a burst of *Gavelinella stephensoni,* amongst other species. The very short stratigraphic range of *Loxostomum eleyi* in the South African Cretaceous basins contrasts strongly with the long range in the English Chalk succession, more or less continuously from early Coniacian to Late Campanian (Hart *et al.* 1989).

***Marginulinopsis* sp.**

This unusually ornamented, J-shaped species, with

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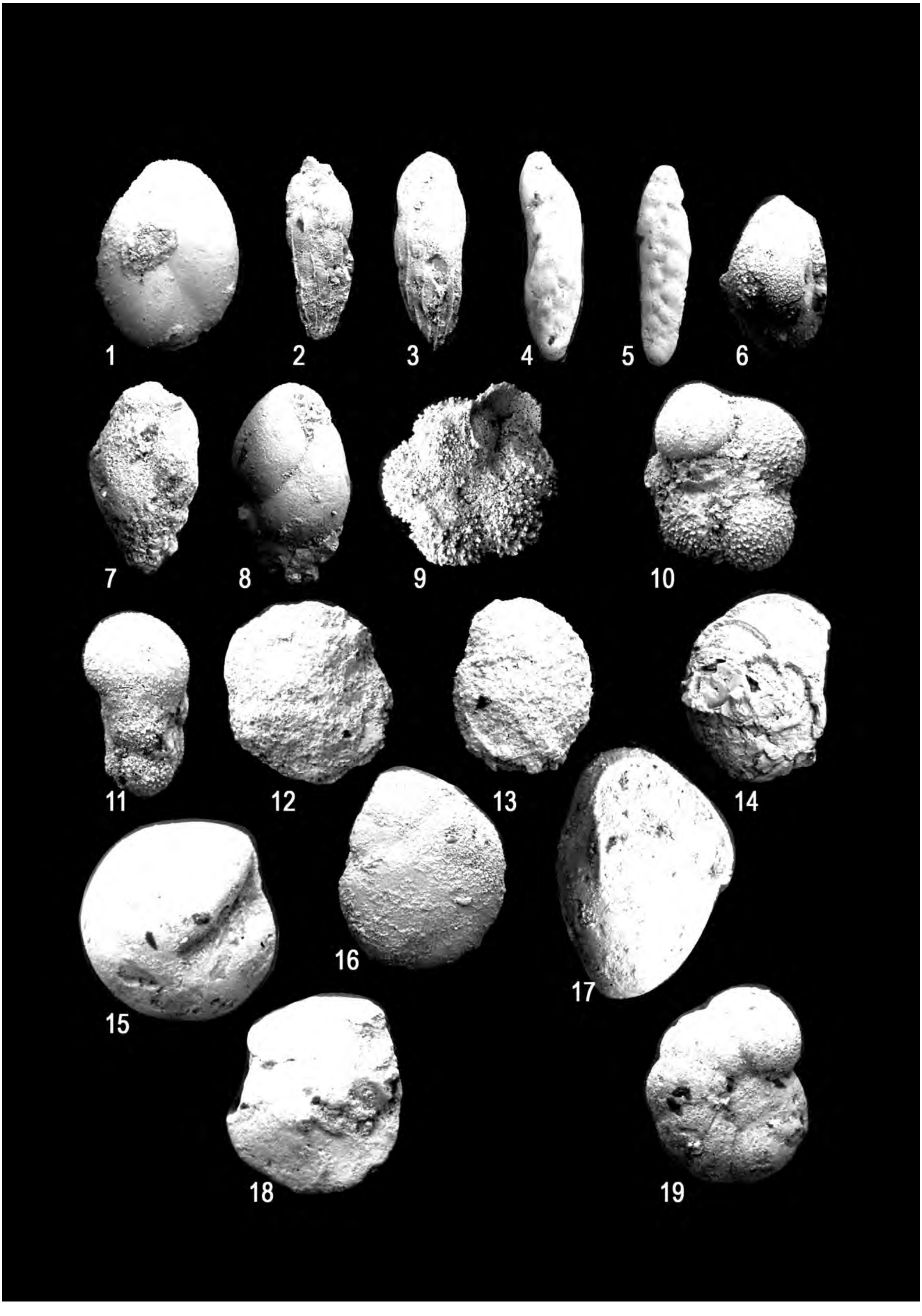
Fig. 3. Benthic and planktic foraminifera species of Needs Camp and Igoda. All illustrated specimens are from the Igoda Formation stratotype section at Igoda River mouth (Klinger & Lock 1978). **1**, *Globulina lacrima* D'Orbigny, side view, sample 9591, magnification ×81, SAM-PQ-MF-2381. **2**, *Bolivina* sp., side view, sample 9591, ×105, SAM-PQ-MF-2382. **3**, *Bolivina* sp., side view, sample 9591, ×119, SAM-PQ-MF-2383. **4**, *Brizalina incrassata incrassata* (Reuss), side view, sample 9591, ×55, SAM-PQ-MF-2384. **5**, *Brizalina incrassata incrassata* (Reuss), side view, sample 9591, ×53, SAM-PQ-MF-2385. **6**, *Brizalina incrassata incrassata* (Reuss), apertural view, sample 9591, ×136, SAM-PQ-MF-2386. **7**, *Praebulimina carseyae carseyae* (Plummer), side view, sample 9591, ×148, SAM-PQ-MF-2387. **8**, *Praebulimina carseyae carseyae* (Plummer), side view, sample 9591, ×162, SAM-PQ-MF-2388. **9**, *Hedbergella* sp., umbilical view, sample 9591, ×314, SAM-PQ-MF-2389. **10**, *Hedbergella* sp., umbilical view, sample 9591, ×216, SAM-PQ-MF-2390. **11**, *Globigerinelloides asper* (Ehrenberg), apertural view, sample 9591, ×466, SAM-PQ-MF-2391. **12**, *Epistomina* cf. *E. favosoides* (Egger), umbilical view, sample 9591, ×256, SAM-PQ-MF-2392. **13**, *Epistomina* cf. *E. favosoides* (Egger), spiral view, sample 9591, ×250, SAM-PQ-MF-2393. **14**, *Reinholdella* sp., spiral view, sample 9591, ×150, SAM-PQ-MF-2394. **15**, *Alabamina dorsoplana* (Brotzen), umbilical view, sample 9591, ×107, SAM-PQ-MF-2395. **16**, *Alabamina dorsoplana* (Brotzen), spiral view, sample 9591, ×107, SAM-PQ-MF-2396. **17**, *Alabamina dorsoplana* (Brotzen), apertural view, sample 9591, ×241, SAM-PQ-MF-2397. **18**, *Osangularia expansa* (Toulmin), umbilical view, sample 9590, ×142, SAM-PQ-MF-2398. **19**, *Gavelinella gyroidinaeformis* Hofker, spiral view, sample 9591, ×133, SAM-PQ-MF-2399.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distinctively ribbed exterior, appears to be similar to *Marginulinopsis* sp. B of Graham & Church (1963, p. 40, pl. 4, figs 15a–b). It is not clear if these are the same species. *Marginulinopsis* sp. has particular stratigraphic value, in that it is one of very few benthic foraminifera species in Campanian assemblages that is limited to the Middle Campanian (Campanian II), and it is certainly the most distinctive. The glassy test is compressed, and the proloculus is ornamented with a looped rib on both sides, with two ribs ranging the length of the test periphery. There are consequently six surface ribs that continue up the test, and fade away on the last-formed chamber. The aperture is terminal, subcircular, and developed on a short, stout neck. A ribbed *Marginulina* sp. also occurs at the same stratigraphic level in the South African basins. Found widely, in the Kudu boreholes (McMillan 1990*b* and amendments), as well as in Walvis Basin borehole 1911/15-1 (McMillan 1994), and in KwaZulu Basin boreholes ZA, ZB and ZC.

Nonionella cretacea Cushman, 1931

This distinctive benthic foraminifera, the only one of the genus encountered in the Late Cretaceous around southern Africa, is typical of deeper-water environments, and seems limited to the Middle Campanian and the earlier part of the Late Campanian. Ranges up from 'red' horizon (Early–Middle Campanian boundary) up to 'black ' horizon. Identified by Lambert (1971, p. 266, pl. 11, figs 7a–c, text-figs 146a–c). Described by Cushman (1931) from Campanian to Maastrichtian Marlbrook Marl of Blevins, Arkansas.

Notoplanulina rakauroana (Finlay, 1939) and ***N. australis*** Malumián & Masiuk, 1976

Notoplanulina rakauroana, described from the Piripauan (Santonian-Campanian) of New Zealand (Finlay 1939, p. 326, pl. 29, fig. 154–156), and the morphologically similar *Notoplanulina australis* Malumián & Masiuk, described and illustrated by Malumián & Masiuk (1976) from the Santonian to Campanian Cabeza de León Formation of the Austral Basin of southernmost Argentina, both occur in the South African stratigraphic record, and together constitute one of the most distinctive markers for the Campanian–Maastrichtian boundary, their last occurrence equating to seismic horizon X south in Bredasdorp Basin. The Argentinian species have been re-illustrated by Malumián (1990, pl. 17, figs 2a–d, 3a–c). These two species are common and widespread in the cooler water, outer neritic and upper bathyal environments of the Atlantic and southern margins, but are either very rare or absent in the Thekwini and KwaZulu Basins on the warmer-water Indian Margin of South Africa. The flat discoidal tests are distinctive, with a prominent curved *Osangularia*-like, interiomarginal to areal, slit aperture. Although these species have not been found during the course of the present study, their presence to the west is significant, since with their help the Campanian–Maastrichtian boundary can be easily defined over an extensive region with one marker species.

On Tierra del Fuego Island, the *Notoplanulina rakauroana* zone is defined as Coniacian to Early Campanian in age (Malumián & Masiuk 1976), but in South Africa it is much shorter. McMillan (2003, fig. 12) regarded its range as Early Campanian in South Africa, but following re-examination of KwaZulu Basin benthic foraminifera assemblages and their relationship to dated ammonite assemblages, it is now taken to be limited to the Late Campanian (Campanian III).

Praebulimina carseyae carseyae (Plummer, 1931)

Fig. 3.7–8

Illustrated by De Gasparis as *Caucasina fusiforma* and *C. fusiforma* morph. D (De Gasparis 1968, p. 113, pl. 13, figs 4–5), as *P. carseyae* by Lambert (1971, p. 166, pl. 6, figs 4a–b, text-figs 92a–d), and similarly by Makrides (1979, p. 34, pl. 4, figs 3a–b), this species ranges from the base Campanian up to top Maastrichtian, and it is widespread all round southern Africa. However, it is facies controlled, and its range differs greatly from one borehole section to the next. There is also a large-sized variant, *Praebulimina carseyae gigantea* mainly in the Early and Late Maastrichtian succession in the KwaZulu Basin, which is not seen in any of the other Cretaceous basins of southern Africa. Makrides (1979) records small numbers of *Praebulimina carseyae* in the upper, Campanian half of the Mzamba cliff outcrop.

Praebulimina kickapooensis (Cole, 1938)

Identified by De Gasparis (1968, p. 112, pl. 13, figs 2, 2a, 3) from Early Maastrichtian of borehole ZA as *Fursenkoina* sp. A, and as *Fursenkoina* sp. A morph. B; identified as *Praebulimina kickapooensis* by Lambert (1971, p. 168, pl. 6, figs 5–6, text–figs 93a–b) from the Late Campanian; identified similarly by Makrides (1979, p. 35, pl. 4, figs 4a–b) from the Early Campanian of the Mzamba Formation. This species ranges intermittently throughout the Campanian and Maastrichtian all round southern Africa. Its proportions vary a good deal from place to place: KwaZulu Basin tests are much thinner and less elongate, while those from the Kudu boreholes are substantially larger and stockier tests. See comments from Lambert (1971, p. 169). Originally described from Late Campanian of Texas; Sliter (1968) considered its full range as Coniacian to Maastrichtian. In South Africa it ranges from mid Santonian to top Maastrichtian (McMillan 2003, p. 554).

Pyramidulina* cf. *P. affinis (Reuss, 1845)

Fig. 2.9

This species, with large, elongate and rectilinear tests, strongly ornamented chambers with well-developed thick vertically-aligned ribs, and often with constricted septal necks, occurs in floods in the latest Late Campanian and the earliest Early Maastrichtian of the KwaZulu Basin. All tests from Needs Camp/Igoda are broken into segments, in both Chapman's original (1916) study and the present one, and almost certainly constituted part of the shell debris derived from inner neritic environments, transported into deeper water by debris flows. Their stratigraphic range is limited to within the interval of thick sandstones in the Early Maastrichtian (G6 Sandstones), as a result of which, because of the sandstone porosity, and tendency to conduct percolating acidic fluids, tests are corroded and very poorly preserved. Strongly ribbed rectilinear nodosarids are now included in the genus *Pyramidulina,* and no longer in *Nodosaria.* Cushman (1946, p. 70, pl. 25, figs 8–23) illustrated fine examples from the Gulf Coast, and Makrides (1979, p. 25, pl. 3, figs 4a–b) figured specimens from the Mzamba Formation.

Reussella szajnochae (Grzybowski, 1896)

This distinctive triserial species, with strongly developed marginal ribs, test triangular in cross-section, is the best-known species of a group of Campanian-Maastrichtian '*Reussella*', which although nominally morphologically similar to the true *Reussella* (Early Eocene to present day) species, are quite distinct. Loeblich & Tappan (1988) make no mention of the Cretaceous forms, but it is felt that their aperture construction is distinct enough to warrant a separate genus. Eocene and later *Reussella* develop plastogamic pairs, and display radiating groove and rib patterns around the aperture, but so far as can be seen the Cretaceous forms do not. Several species occur in the English Chalk succession (Hart *et al.* 1989), some of which are long-ranging, but in South African basins this genus is limited to only one species with a very short range occurring just below 'black' horizon in lowest Campanian III. These highly ornamented tests are also known from coastal Tanzania (Singano & Karega 2000) and Australia (Belford 1960, p. 66, pl. 16, figs 16–19).

Spiroplectinella laevis cretosa (Cushman, 1933) ***sensu lato***

Fig. 2.3–4

Again detailed by Lambert (1971, p. 82, pl. 1, figs 11, text-figs 41a–b), this species is probably diachronous in its distribution, climbing up section in an offshore direction. In the KwaZulu Basin cored boreholes ZA, ZB and ZC, *Spiroplectinella laevis cretosa* appears first downhole in the latest Campanian. Its evolutionary appearance seems to be within the Mid to Late Santonian, but there are earlier Campanian samples rich with similar, but more slender *Spiroplectinella* tests, as at Igoda/Needs Camp: this Igoda form is a subtly different species to the species in KwaZulu Basin.

Valvulineria **sp.**

This small distinctive species with its subglobular test is considered to be a probable new genus and new species. It is distinguished by a high spiral of trochospirally arranged, sub-globular chambers, increasing steadily in size as added. The chambers tightly encircle the umbilicus, which is virtually closed. There are about five or six chambers in the final whorl. The most singular aspect of the test is the development of a projection of the final chamber over the umbilicus, reminiscent of species of *Nonionella,* but in this species the projection ends with a distinct, low, elongate unornamented slit, which is taken to be the aperture. This species locally occurs in considerable numbers, as in the Kudu 9A-2 section drilled offshore southern Namibia. The species appears to be at its most prolific in outer neritic environments characterized by dysoxic or near dysoxic sea-floor conditions. The rare presence of tests of this species at Igoda emphasizes the distinctly early Campanian age of the Igoda succession. A marked unconformity at the Campanian I/Campanian II boundary in the KwaZulu Basin boreholes equates to the 'Top anoxic' datum at 2300 m in Kudu 9A-2, and the appearance of a diverse benthic assemblage above this boundary, in response to more oxidized sea-floor conditions, it appears that *Valvulineria* sp. is one of the first species to occur in abundance in the later Early and early Middle Campanian/Campanian I and II succession. *Valvulineria* sp. occurs in association with *Globotruncanita elevata* in Kudu 9A-2 (McMillan 1990*a* and additions). In the Kudu holes its stratigraphic range is from below the 'top anoxic' datum up to between top *Loxostomum eleyi* and top *Marginulinopsis* sp. that is, from mid Early Campanian (mid Campanian I) to basal Late Campanian (high Campanian II to basal Campanian III). *Valvulineria* sp. occurs only rarely in the KwaZulu Basin fully cored borehole ZA in the same interval, and is not widely distributed enough in the basin for it to constitute a useful datum.

CORRELATION

Depths are given in feet because the cores were originally measured out in feet, and for help in relocating particular samples. Depths given are measured from Kelly bushing datum, a short distance above land surface. Depths and thicknesses are accurate for borehole sites, but faulting may intensively bias thicknesses elsewhere. Fully cored KwaZulu Basin boreholes ZA, ZB and ZC have been analysed for their foraminiferal content on numerous occasions. Datums of the top Cretaceous succession can be recognized in these boreholes at the following depths. 'Tops' or extinction points are mostly used for correlation. Note that the Late Maastrichtian interval is severely attenuated to 23.47 m in ZA, whereas it is 75 m thick in ZC, as a result of Cainozoic uplift and planation.

ZA Borehole

This borehole is located at Mseleni, KwaZulu Province, at 27°18′15″S, 32°36′47″E. Top of coring, and probable top of Cretaceous section: 215′ (probably equals top of Late Maastrichtian interval). Highest sample studied by De Gasparis (1968) is at 282′, which is still Late Maastrichtian, based on *Contusotruncana contusa* and *Racemiguembelina fructicosa.* Total thickness of Late Maastrichtian is 77′ or 23.47 m. Next De Gasparis sample at 292′ is top Early Maastrichtian, with first appearance of planktics *Globotruncana linneiana, G. tricarinata* and *Contusotruncana fornicata,* and benthics *Pyramidina* sp. and *Stensioeina* sp. with depressed spiral side, and inoceramid prisms. Top Late Campanian at 600′, with first appearance of *Dorothia bulletta* #1 and *Pyramidulina* cf. *P. affinis* bursts. Thickness of Early Maastrichtian: 308′ or 93.9 m. Top *Loxostomum eleyi* at 990′. Top Middle Campanian at 1080′ with first appearance of *Marginulinopsis* sp. Thickness of Late Campanian: 480′ or 146.3 m. Top Early Campanian at 1170′ with first appearance of *Gavelinella* cf. smooth *Stensioeina* sp. Thickness of Middle Campanian: 90′ or 27.43 m. Top thin *Dorothia* sp.: 1260′. Top *Lenticulina* cf. *A. microdictyotos*: 1320′. Top *Ventilabrella eggeri*: 1350′. Top Late Santonian at 1500′ with first appearance of *Dicarinella asymetrica.* Thickness of Early Campanian: 330′ or 100.6 m.

This portion of the Cretaceous succession in borehole ZA has one important ammonite identification of *Metaplacenticeras subtilstriatum* (Klinger & Kennedy 1990), at a depth of 1148′ or 350 m. This datum lies immediately above the foraminiferally interpreted Early Campanian–Middle

Campanian boundary at 1170′. Klinger & Kennedy (1990) interpreted this ammonite occurrence, based on Japanese records, as in 'the lower part of the Upper Campanian'.

ZB borehole

Borehole is located on southern shore of Lake Sibaya, inland of Gobey's Point, at 27°25′30″S, 32°43′40″E. Foraminifera species utilized in ZB are generally the same as in ZA. Top coring: 240′. Top Late Cretaceous (Top Late Maastrichtian): 361′, with *Abathomphalus mayaroensis*. Top Early Maastrichtian (Top *Pyramidina* sp.): 550′. Total thickness of Late Maastrichtian: 189′ or 57.62 m. Top Late Campanian (Top *Dorothia bulletta* #1): 790′. Total thickness of Early Maastrichtian: 240′ or 73.17 m. Top *Loxostomum eleyi*: 1320′. Top Middle Campanian (Top *Marginulinopsis* sp.): 1450′. Total thickness of Late Campanian: 660′ or 201.21 m. Top Early Campanian (Top *Gavelinella* cf. smooth *Stensioeina* sp.): 1540′. Total thickness of Middle Campanian: 90′ or 27.43 m. Top thin *Dorothia* sp.: 1570′. Top *Lenticulina* cf. *A. microdictyotos*: 1600′. Top *Ventilabrella eggeri*: 1660′. Top Late Santonian (Top *Dicarinella asymetrica*): 1690′. Total thickness of Early Campanian: 240′ or 73.17 m.

ZC borehole

Borehole located 8 miles south-southwest of Maputa town, with coordinates 27°05′30″S, 32°43′40″E. Foraminifera species utilized in ZC are generally the same as in ZA, but some benthics are missing in the deeper-water environment. Top coring and top Cretaceous (Top Late Maastrichtian) (Top *Abathomphalus mayaroensis*): 364′. Top Early Maastrichtian (Top *Pyramidina* sp.): 610′. Total thickness of Late Maastrichtian: 246′ or 75.0 m. Top Late Campanian (Top *Pyramidulina* cf. *affinis* floods): ?980′. Total thickness of Early Maastrichtian: 370′ or 112.8 m. Top *Loxostomum eleyi*: 1510′. Top Middle Campanian (Top *Marginulinopsis* sp.): 1730′. Total thickness of Late Campanian: 750′ or 228.65 m. Top Early Campanian (Top *Gavelinella* cf. smooth *Stensioeina* sp.): 1840′. Total thickness of Middle Campanian: 110′ or 33.53 m. Top thin *Dorothia* sp.: not known, depositional facies too deepwater. Top *Lenticulina* cf. *A. microdictyotos*: not known, depositional facies too deepwater. Top *Ventilabrella eggeri*: 2000′. Top Late Santonian (Top *Dicarinella asymetrica*): 2080′. Total thickness of Early Campanian: 240′ or 73.17 m.

CONCLUSIONS

By carefully piecing together the microfossil content of available outcrops and borehole sections the complex biostratigraphic history of southern Africa is gradually revealed. Cross-correlation of ostracod, calcareous nannofossil, dinocyst, foraminifera, inoceramid bivalves and ammonite biostratigraphy results in a more robust chronostratigraphic history of southern Africa. The publications on the planktic and benthic foraminifera found preserved in Late Cretaceous rocks in southern Africa reveal a high-resolution biostratigraphy, distinctive not only because of its detail, but also because it is based on the distribution through time of beautifully constructed and ornamented microscopic animal shells. By developing similar biostratigraphies for the other southern Gondwanide continental fragments of Chile and Argentina, Australia, New Zealand, Antarctica, India and Madagascar, their correlation with southern Africa through time can be determined.

This article summarizes the occurrence of 87 species of benthic and planktic foraminifera from four lithologically differing outcrops at Needs Camp and Igoda, in the vicinity of East London, using a variety of careful sample processing techniques. The Campanian succession of the Indian continental margin of southern Africa, virtually complete in the KwaZulu Basin (Early to Late Campanian or Campanian I to Campanian III), can be divided into 22 intervals on the basis of the benthic and planktic foraminifera assemblages and their distributions. Present at Igoda and at Needs Camp are two distinctive calcareous benthic species, *Valvulineria* sp. and thin *Dorothia* sp., the former limited to the later Campanian I and earlier Campanian II, and the latter limited to the mid to early Campanian I and earlier (Santonian), which define these four outcrops as exposing rocks of Early Campanian/Campanian I age. However, because the Early to Middle Campanian section in the upper half of the Mzamba Formation stratotype section (Makrides 1979) contains a diverse planktic assemblage which includes a variety of keeled species, there seems little doubt that the Igoda/Needs Camp successions, almost devoid of planktics, represent a different portion of the Early Campanian/Campanian I succession, and are not coeval.

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Appendix 1. Early Campanian foraminifera assemblages from Igoda and Needs Camp, collector's initials indicated.

Sample 9594 (off-white slightly shelly, slightly cemented sandy limestone); Mountain's (1974) road cutting P1: moderate numbers, badly cemented foraminifera (HK).

Dorothia oxycona (moderate)
Flat *Gavelinella* sp.
Alabamina dorsoplana
Fat ?*Gavelinella* sp.
Fat, wide *Triloculina* sp.
Large, flat *Lenticulina* sp.
Pyramidulina cf. *P. affinis*
Smooth *Vaginulina* sp.
Smooth elongate *Lagena* sp.
Thin *Vaginulina* sp.
Gaudryina sp.
Spiroplectinella laevis cretosa s.l.
Vaginulinopsis sp.
Angulogavelinella sp.
Gavelinella spp.
Lenticulina spp.
Hedbergella sp.
Indeterminate cemented benthics
Bryozoans
Crinoid ossicles

Sample 9593 (shelly rather cemented sandy limestone); Igoda Cliff fossil zone: moderate numbers of foraminifera (HK).

Gastropods
Quinqueloculina spp.
Bolivina sp.
Thin, flat *Gavelinella* sp.
Conical *Cibicides* sp.
Praebulimina carseyae carseyae
Angulogavelinella sp.
Hedbergella sp.
?*Cibicidoides* sp.
Dorothia oxycona
Alabamina dorsoplana
Flat, thick-walled *Gavelinella* sp.
Lenticulina spp.
Large *Lenticulina* spp. (many)
Spirotecta sp. 2
Gyroidinoides nitidus
Smooth *Marginulina* sp.
Cibicides convexus
Pyramidulina cf. *P. affinis* (large rounded longitudinal ribs)
Epistomina cf. *E. favosoides*
Epistomina supracretacea s.l.
Gavelinella spp.
Indeterminate benthic foraminifera

Sample 9592 (white sandy clay); Igoda Cliff, bottom of cliff: no foraminifera (HK).

Sample 9591 (brownish shelly, glauconitic and sandy clay); Igoda Cliff, ?5m from top of section: abundant foraminifera (HK).

Hedbergella spp.
Globulina lacrima
Bryozoans
Gastropods
Alabamina dorsoplana
?*Epistomina supracretacea s.l.* (few)
Angulogavelinella sp.
Smooth *Vaginulina* spp.
Bivalve
Praebulimina kickapooensis
Large, keeled *Lenticulina* spp. (few)
Brizalina incrassata incrassata
Brizalina incrassata ?*gigantea*
Echinoid spines
Gavelinella spp. (moderate)
Spirotecta sp. 2
Flat, thick-walled *Gavelinella* sp.
Lenticulina spp. (moderate)
Quadrimorphina cf. *Q. camerata*
Gyroidinoides nitidus
Spiroplectinella laevis cretosa s.l.
Quinqueloculina spp. (fragments)
Quinqueloculina cf. *Q. seminulum*
Cibicides convexus
Globorotalites sp.
?*Bullopora* sp.
?*Rosalina/Gavelinella* sp.
?*Palmula* sp. (fragment)
Laevidentalina spp.
Thin *Dorothia* sp.
Cyclammina sp.
Sponge spicule
Thin *Spiroplectinella* sp.
?Sphere radiolaria (rare)
Rugoglobigerina rugosa
Smooth *Lagena* sp.
Quinqueloculina sp.with quartz grains in test wall
Nonionella cretacea
Gaudryina sp.
?*Bulimina arkadelphiana*
Bolivina sp.
Pyramidulina cf. *P. affinis* (coarse rounded longitudinal ribs)
Small, fat *Alveolophragmina* sp.
Osangularia expansa
Ribbed *Dentalina* sp.
Praebulimina carseyae carseyae
Gavelinella cf. *G. umbilicatiformis* Hofker
Reinholdella sp.
Thin, ribbed *Citharina* sp.
Smooth *Marginulina* sp.
Epistomina cf. *E. favosoides*
Globigerinelloides asper
Dentalina cf. *D. soluta*
Dentalina cf. *D. linearis*
Haplophragmoides sp.
Cibicides cf. *C. convexus*
Indeterminate cemented benthic foraminifera

Sample 9590 (glauconitic and sandy clay); Igoda Cliff top: few foraminifera (HK)

Flat, thick-walled *Gavelinella* sp.
Large *Lenticulina* sp.
Angulogavelinella sp.
Pyramidulina cf. *P. affinis* (coarse rounded longitudinal ribs)
Cibicidoides sp. (?*in situ*)
Fat *Spiroplectinella* sp.
Alabamina dorsoplana
Osangularia expansa
Brizalina incrassata incrassata
Gyroidinoides depressus
Indeterminate cemented benthic foraminifera

Sample 3027 (cream, shelly glauconitic sandy limestone); Igoda River mouth (BL)

Large *Lenticulina* spp.
Flat, thick-walled *Gavelinella* sp.
Angulogavelinella sp.

Appendix 1 (continued)

Dorothia oxycona
Haplophragmoides sp.
Smooth *Vaginulina* sp.
Alabamina dorsoplana
Thin, flat *Spiroplectinella* sp.
Thin, flat *Gavelinella* sp. (moderate)
?*Quinqueloculina* sp.
Gyroidinoides nitidus
Allomorphina conica
?*Hedbergella* sp.
Marginulinopsis cf. *M. silicula*
Badly cemented indeterminate benthic foraminifera

Sample 3029 (washings from glauconitic clay, below base of limestone in upper quarry Needs Camp) (BL)

Striate *Brizalina incrassata incrassata*
Angulogavelinella sp.
Flat, thick-walled *Gavelinella* sp.
Nonionella cretacea
Thin, flat *Gavelinella* sp. (some)
Gyroidinoides nitidus
Hedbergella sp.
Praebulimina carseyae carseyae
Quinqueloculina spp.
Brizalina incrassata incrassata (smooth-walled)
Indeterminate cemented benthic foraminifera (moderate)

Sample Lm-2 (cemented limestone); Igoda River, Igoda Formation: badly recrystallized foraminifera) (J. le Roux).

Ostracods
Dorothia oxycona
Lenticulina spp.
Pyramidulina sp.
Gavelinella spp.
Alabamina dorsoplana
?*Spiroplectinella laevis cretosa s.l.*
Bolivina sp.
Flat, thick-walled *Gavelinella* sp.
Hedbergella spp.
Nonionella cretacea
Angulogavelinella sp.
Dentalina cf. *soluta*
Siphoglobulina sp.
Gaudryina sp.
Quinqueloculina spp.
Indeterminate cemented benthic foraminifera (many)

Sample Klinger-2009

Haplophragmoides sp.
Alveolophragmina sp. (globular test, simple aperture)
Cyclammina sp. (small, lenticular test, sinuous sutures)
Conical *Gaudryina* sp.
Triangular *Gaudryina* sp.
Dorothia oxycona
Spiroplectinella laevis cretosa s.l.
Triplasia sp.
Quinqueloculina spp.
Quinqueloculina cf. *Q. seminulum*
Quinqueloculina sp. with fine quartz grains in test wall.
Triloculina sp.
Pyramidulina cf. *P. affinis*
Pyramidulina cf. *P. zippei*
Thin test, ribbed *Citharina* sp.
Citharina cf. *C. gracilana*
Laevidentalina spp.
Lenticulina spp. (mostly smooth, many large, up to 2 mm diameter)
Lenticulina cultrata group
Flat *Lenticulina* sp.
Lagena cf. *L. sulcata*
Lagena cf. *L. apiculata*
Smooth *Marginulina* sp.
Ribbed *Marginulina* sp.
Marginulinopsis cf. *M. silicula*
Smooth *Vaginulina* sp.
Finely ribbed *Vaginulina* sp.
Neoflabellina leptodisca or *N. efferata*
Globulina cf. *G. prisca*
Globulina lacrima
Praebulimina kickapooensis
Praebulimina carseyae carseyae
Praebulimina offenbachensis
Lingulina carinata
Fat *Lingulina* sp.
?*Ceratobulimina* sp.
Reinholdella sp.
Epistomina cf. *E. favosoides*
Epistomina supracretacea s.l.
Brizalina incrassata incrassata
Bolivina sp.
Elongate, smooth *Lagena* sp.
Cibicides cf. *C. convexus*
Cibicides convexus
Thin *Lingulina* sp.
Valvulineria sp.
Dentalina cf. *D. soluta*
Gavelinella cf. *G. umbilicatiformis*
Ribbed *Dentalina* sp.
Gavelinella cf. *G. excavata*
Flat, thick-walled *Gavelinella* sp.
Gyroidinoides nitidus
Gyrodinoides depressus
Allomorphina conica
Allomorphina cretacea
Quadrimorphina cf. *Q. camerata*
Globorotalites sp.
Angulogavelinela sp.
Nonionella cretacea
Pullenia cretacea
Spirotecta sp. 1
Spirotecta sp. 2
Alabamina dorsoplana
Heterohelix globulosa
Rugoglobigerina rugosa
Hedbergella spp.
Globigerinelloides asper
Hedbergella cf. *H. simplex*