

Aragonitic-walled benthic foraminifera (*Epistomina*) in the Cretaceous 'mudbelt' off southern Africa, and postmortem cross-shelf transport of tests

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(with 2 figures)

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Throughout the Early Albian to Maastrichtian period there was a widespread dominance of aragonitic-walled tests in inner neritic benthic foraminifera assemblages, of which species of the genus *Epistomina* predominate. Fifty years ago Smitter first recognized *Epistomina*-dominated assemblages from outcrops at Mzamba and in the KwaZulu Basin, and realized their stratigraphic potential. These aragonitic-walled species are believed to have inhabited the palaeo-mudbelt. The changing ornamentation characteristics of both highly ornamented and smooth-walled *Epistomina* evolving through time led Smitter to recognize their value as marker species. They are found throughout the inner neritic region in basins experiencing slow siliciclastic sedimentation in normal marine, clay-dominated environments where fluvial input is limited (Pletmos, Gamtoos, Algoa, Thekwini and KwaZulu). *Epistomina* species, and aragonitic genera in general are absent in inner neritic regions of basins experiencing hyposalinity and rapid sedimentation, where fluvial input is abundant (Bredasdorp and Orange). However, although *Epistomina*-dominated assemblages are missing in the inner neritic (partly equivalent to the mudbelt) domains of the Orange and Bredasdorp Basins, transported tests of *Epistomina* are preserved in abundance in upper bathyal claystones in the two basins. The enigma of a complete absence of *in situ* aragonitic-shelled tests in the inner neritic domain, yet an abundance of obviously allochthonous tests, transported *via* debris flows to upper bathyal environments, is discussed with regard to the development of unconformities within the stratigraphic successions of southern African Cretaceous basins.

Key words: foraminifera, benthic, test, Cretaceous, assemblage, aragonite, mudbelt.

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INTRODUCTION

Smitter (1957) recognized the chronostratigraphic significance of changing ornamentation patterns, and often rapid species turnover, in the aragonitic-walled benthic foraminifera genus *Epistomina* in the South African Cretaceous succession, during his analysis of foraminifera assemblages from outcrops in the KwaZulu Basin and at Mzamba (Klinger & Kennedy 1980). Mzamba Cliff is located about 150 km south of Durban, and well to the south of the offshore Thekwini Basin (Fig. 1). Test patterning (see Smitter 1957, fig. 20) includes sutural ribs, spiral ribs ranging the length of the spiral suture, strongly developed reticulating patterning, which may be polygonal or sub-circular, one- or two-bladed peripheral keels, and circum-apertural ribs. There are also more subtle patterns on essentially smooth-walled tests, such as limbate, straight, curved or oblique suture lines, finely-bladed peripheral keels (single or double keels), and localized fine polygonal reticulation limited to umbonal areas.

Such ornamentation patterns, whether intensely or faintly developed, were often relatively short-lived in the stratigraphic record, usually to the duration of a Stage (from 2 to 5 million years (Ma), such as *Epistomina pondensis* (Chapman), which ranges throughout the Santonian (see Makrides 1979, pl. 10, re-illustrated here as Fig. 2.). *Epistomina pondensis* would seem to have lived around southern Africa for about 2.5 Ma. It has been found in the Santonian half of the Mzamba cliff outcrop (Makrides 1979), in the Wanderfeld IV outcrop of southern coastal Namibia and in samples from below the sugar terminal, Durban (McMillan 2003, pp. 564 and 566), and in proximal borehole sections (boreholes NZA, ZD 1/71, ZG 1/72, ZH 1/74 and ZU 1/77) in the KwaZulu Basin. *Epistomina pondensis* is rare in the interval of ammonite assemblage Santonian I (Early Santonian), but abundant in the intervals of ammonite assemblages Santonian II and III (Middle to Late Santonian) in KwaZulu Basin borehole sections. Some carefully-processed samples from the Middle to Late Santonian

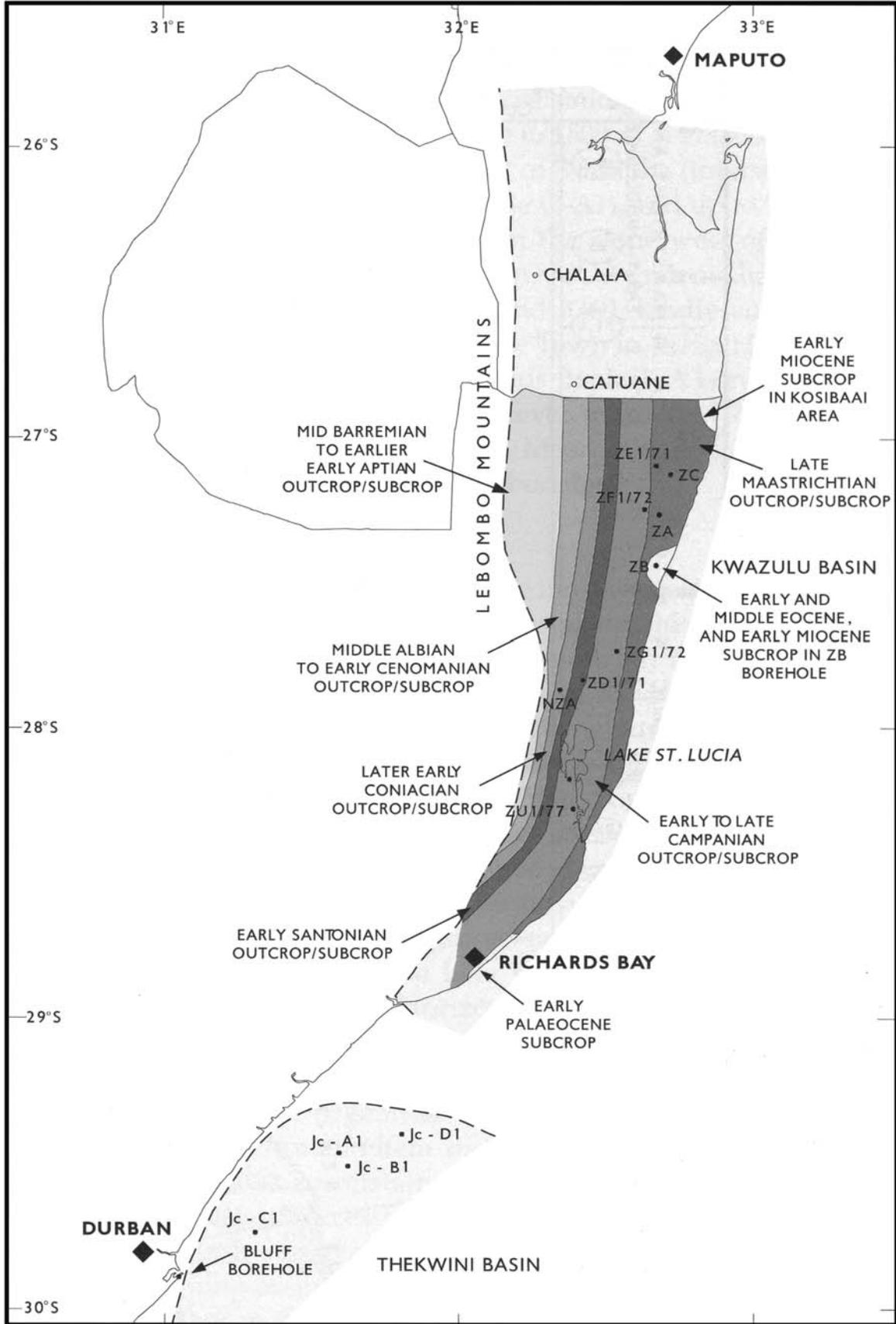


Fig. 1. The Mzamba locality is situated 150 km south of Durban. Relative to boreholes drilled in the onshore part of the KwaZulu Basin (southernmost South Mozambique Basin) and the Thekwini Basin.

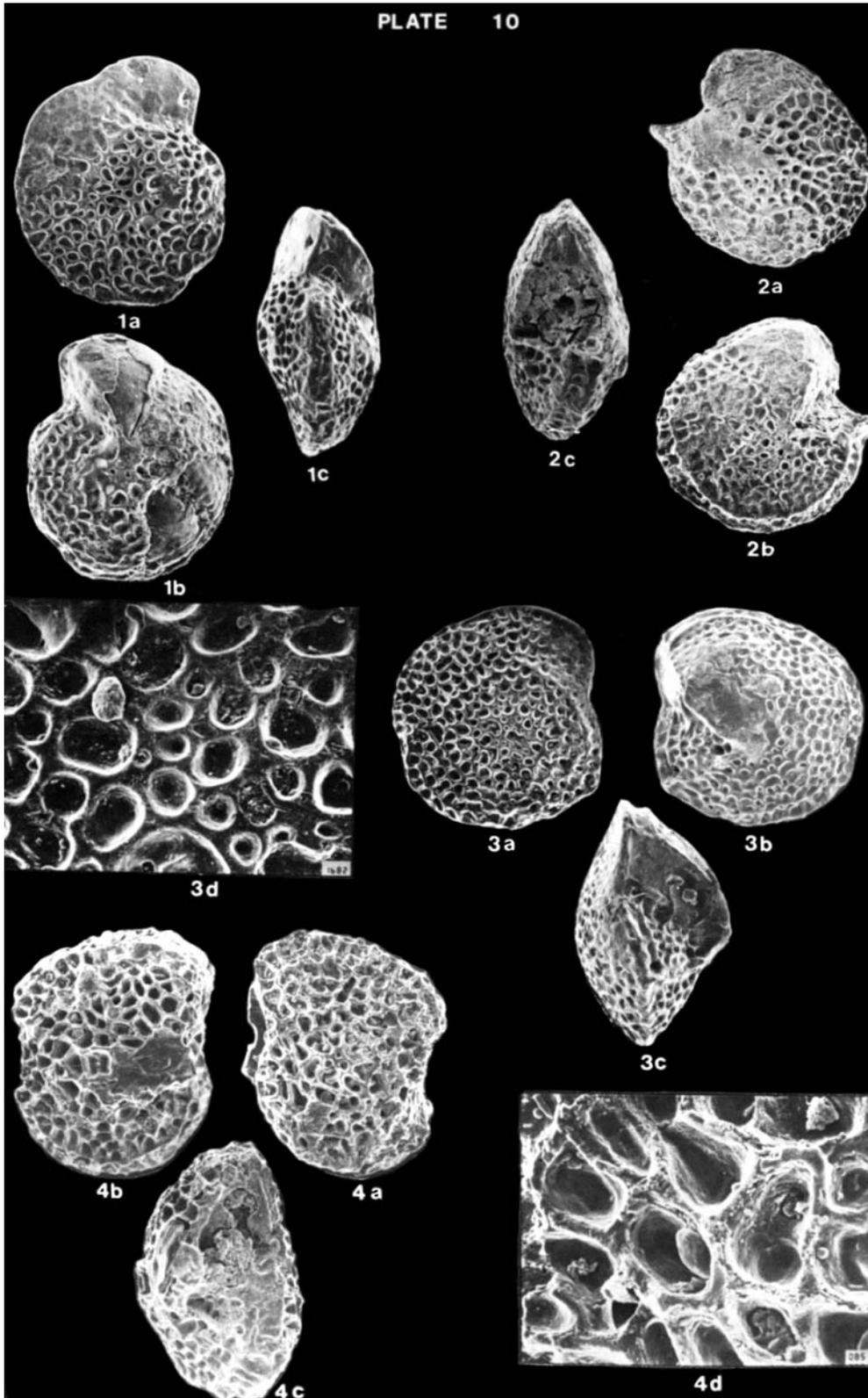


Fig. 2. Copy of the beautiful original Plate 10 from Marina Makrides' M.Sc. thesis from 1979, illustrating variety in test ornamentation in the strongly reticulated aragonitic benthic foraminifera species *Epistomina pondensis* (Chapman). All four tests illustrated are from the Mzamba Formation type outcrop at Mzamba cliff. Makrides (1979) referred the specimens illustrated as figs 1 and 3 to the species *Epistomina favosoides* (Egger), but these tests are here all allocated to the single species *E. pondensis*. The reticulation in *E. favosoides* is interpreted to be much more delicate, finer and lighter than that of *E. pondensis*. The test illustrated as fig. 1 is from bed A2; that illustrated as fig. 2 is from bed A7; that illustrated as fig. 3 from bed A3; and that illustrated as fig. 4 is from bed A7; all specimens are from the Middle to Late Santonian part of the Mzamba succession. Reproduced by courtesy of the Bernard Price Institute for Palaeontological Research, University of the Witwatersrand, Johannesburg.

succession in the lower half of Mzamba Cliff contain many hundreds of tests of this species, and it is often the dominant Santonian benthic species by far. It is especially abundant and predominant in the finest-grained, least cemented clays at Mzamba, and much less common in the sandy, carbonate-cemented units. It occurs in association with variable numbers of essentially smooth-walled *Epistomina* tests that have been referred to the species *Epistomina supracretacea* Ten Dam, *sensu lato*, which itself may occur as many hundreds of tests in some samples. It is not known if the highly reticulated tests occupied a different sea-floor environment than the smooth-walled tests, for example some were infaunal burrowers deep into the sea-floor mud, while others limited their activities to grazing on the sea-floor. It is as yet unknown if these fluctuations in abundance have any biostratigraphic, cyclical, orbital or correlation significance from one section to another. *Epistomina pondensis* appeared at or near the Late Coniacian-Early Santonian boundary, which is probably an unconformity, and became extinct at or near the Santonian-Campanian boundary, which is an unconformity, in boreholes ZD 1/71, ZG 1/72, ZH 1/74 and ZU 1/77 in the KwaZulu Basin. These boundary datums can be recognized in most boreholes drilled in the KwaZulu Basin and to some degree can also be recognized in the attenuated Thekwini Basin successions. This implies that *Epistomina pondensis* lived for about 2.5 Ma.

By contrast, other species, like the strongly ornamented *Epistomina spinulifera polypioides* (Eichenberg) *s.l.*, illustrated by Lambert & Scheibnerová (1974), lasted for at least 20 Ma (roughly 92 to 112 Ma), from the basal Early Albian up to mid Early Turonian sediments (emended from McMillan 2003, p. 559). This species is also limited to inner neritic environments. There is a complex history of *Epistomina* ornamentation styles through nearly all the Cretaceous succession preserved in four basins (Pletmos, Gamtoos, Algoa and KwaZulu Basins) on the South African continental margin. As an indication of the complexity of this record, there are:

- 1) Early localized concentrations of smooth-walled or umbonally reticulated species mostly in outer neritic domains within the graben fills, including *Epistomina* sp. and *E. parastelligera* Hofker in the Portlandian succession of the Port Elizabeth Trough and Uitenhage Trough; and *E. caracolla* (Roemer) *s.l.* in the Late Valanginian of the Sundays River Trough.
- 2) Abundant *E. caracolla s.l.* in the mid Barremian succession of the Orange, Bredasdorp, Pletmos and KwaZulu Basins (?Faraoni Event). No *Epistomina* response to the later Early Aptian Selli Event.
- 3) Abundant *Epistomina chapmani* and *E. spinulifera polypioides* in inner neritic domain of basal Early Albian to top earlier Early Turonian succession in Pletmos, Gamtoos, Algoa, Thekwini and KwaZulu Basins. *Epistomina cretosa* Ten Dam ranges from basal Early Albian up only to top Middle Albian in most of the same basins.
- 4) Small numbers of smooth-walled *Epistomina* sp. with limited fine umbonal reticulation only in the Late Cenomanian succession of the KwaZulu Basin. No *Epistomina* response to the latest Cenomanian-earliest Turonian Bonarelli Event.

- 5) A smooth-walled *Epistomina* (*E. chapmani*) is limited to inner neritic environments in the later Early Turonian succession, only in the Pletmos Basin.
- 6) There are no *Epistomina* in the Middle Turonian succession anywhere.
- 7) Throughout the Coniacian there are localized abundances of smooth-walled *E. supracretacea s.l.* (but no ornamented species) in the inner neritic realm of the Orange, Bredasdorp, Pletmos, Algoa and KwaZulu Basins.
- 8) Small numbers of smooth and ornamented *Epistomina* occur in the inner neritic domain of the Campanian-Maastrichtian succession in most basins around southern Africa, but this facies seems to be mostly missing because of post-Cretaceous uplift and erosion. *Epistomina* here are usually smaller sized and less intensely ornamented than the Santonian species, and are generally plano-convex tests.

Epistomina pondensis is consequently the first strongly ornamented *Epistomina* in the South African stratigraphic record after a time-gap of 6.7 Ma, between 92.7 and 86 Ma.

Micropalaeontological analysis of samples from Mzamba Cliff, and re-examination of the fully-cored Anglo-Vaal borehole sections (Boreholes ZA, ZB, ZC and NZA) drilled onshore in the KwaZulu Basin indicates that frequently a dysoxic facies was developed in inner neritic environments during the Middle to Late Santonian period, characterized by dark green, grey or black silty or sandy claystones, rich in organic debris. This facies contains fragmented and comminuted shell debris, including some foraminifera tests, which have been transported by debris flows from the shoreline to inner or middle neritic depositional environments. At some proximal locations comparable later deposits have been downcut by post-Cretaceous uplift and erosion, and have not survived, especially in the Maastrichtian portion of the succession in the KwaZulu Basin.

A sharply defined, vertically aligned, Middle to Late Santonian facies boundary, preserved between this dysoxic facies and an offshore (outer neritic) well oxygenated facies distinguished by abundant keeled large *Lenticulina* spp., is comparable with vertical facies boundaries described by McMillan (2003, p. 572). It also recalls the sharply defined inshore and offshore boundaries of the Holocene mudbelt (Dale & McMillan 1998; Dale & McMillan 1999, especially fig. 7), and emphasizes that these siliciclastic accumulations on the inner continental margin are rigorously defined and controlled by energy levels in the water column. This is not about transgressions and regressions, or about fluctuations in sediment input, it is the response of too much sediment unable to occupy too little available accommodation space on the sea floor, because of prevailing energy levels in the water column. It is relevant to South Africa and to any other part of the African margin.

HOLOCENE MUDBELT

Assuming that the present is the key to the past, it is hoped that the Holocene system casts light on the Santonian system. Surrounding the African coast at the present day, locally at water depths between 70 and 130 m, is an accumulation of mixed land-derived siliciclastics and terrestrial and marine biogenic debris. This includes localized distinctive foraminifera assemblages (Dale & McMillan 1998; 1999,

fig. 7, and references therein). Siliciclastic components range in size from small boulders, cobbles, sands and silts to muds, while biogenic components include terrestrial plant debris, polychaete worm faecal pellets, comminuted molluscan and other shell, and littoral and intertidal foraminiferal tests, amongst others. Muddy sands and sandy muds are the commonest lithologies on the inshore margin of the mudbelt, as seen in the 30 m Holocene section of borehole X of the Bavenit drilling, drilled about 15 km north of the mouth of the Orange River (Dale & McMillan 2000), while silty muds and clays predominate along its offshore margin. Some of the large-sized siliciclastics (such as quartzite cobbles) are derived from reworked beaches that accumulated during Pleistocene episodes of low sea-level. Coarse gritty quartz grains with irregular surface solution pits and prominences are common. Much of the terrestrial and shoreline biogenic debris, in association with the coarser siliciclastics, has been introduced into the mudbelt by debris flows.

The offshore location and limits of the Holocene mudbelt (the depths of the sea-floor over which it extends), and its thickness, have been precisely controlled by the intensity of wave, current and swell energy at different levels in the water column. There is a recess on the sea floor which in South African waters is defined as the physical boundary between Cretaceous and Precambrian rocks: this recess provided most of the accommodation space on the sea floor as sea-level rose during the Holocene transgression. The recess was enlarged at times of low sea-level stand. The Holocene mudbelt accumulated during the short period of sea-level rise since the Last Glacial Maximum, as accommodation space became available on the sea-floor, but since sea-level stabilized (about 7500 years before present) sedimentation ceased, and the mudbelt has essentially 'fossilized'. This suggests that the Holocene mudbelt developed within about 14 500 years. The succession fines upwards in distal sections (Dale & McMillan 1998), but coarsens upwards in proximal sections (Dale & McMillan 2000), and the possible stratigraphic relationships are shown in Dale & McMillan (1999, fig. 7). The mudbelt is downlapping in an offshore direction, and onlapping in a shorewards direction.

Foraminifera tests which are attached in life, such as those of *Lobatula lobatula* (Walker & Jacob), indicating environments strongly subject to wave and swell activity, are commonest in the basal part of the distal mudbelt succession and become progressively rarer up section (Dale & McMillan 1998). The abundance of organic debris (especially terrestrial plant debris and marine upwelled organic debris such as diatoms) in the sediment relies on variable wind-driven upwelling for sufficient oxygen supply to the sea-floor, for consumption of this organic material by bacteria. However, frequent episodes of sea-floor dysoxia especially at the end of summer hinder the consumption of abundant organic debris, which cannot be consumed by the sparse, depleted biota. The persistently dysoxic sea-floor conditions leads to limited benthic foraminifera populations in which from one to five species occur in abundance (McMillan 1987; Dale & McMillan 1998). These include *Discamina compressa* (Goës), *Elphidium macellum* (Fichtel & Moll) *sensu lato*, *Lobatula lobatula* (Walker & Jacob), *Elphidium advenum* (Cushman), *Buliminella elegantissima* (Cushman) and *Rectuvigerina nicoli* (Mathews) (McMillan 1987). *Epistomina* species play

no part in the present-day mudbelt: around southern Africa the genus migrated into deep waters during the early Cainozoic, and now occupies upper bathyal environments (McMillan 1974). None of these Holocene benthic foraminifera species feature tests as strongly ornamented as *Epistomina pondensis*. Reworked calcareous benthic and planktic foraminifera tests are locally common, especially in the basal part of the succession, and in different localities can be of almost any age from Late Cretaceous to Early Pleistocene.

The inner neritic sea-floor (70 m and shallower) along most of the west coast of South Africa consists mostly of resistant Precambrian rocks mostly swept free of covering Holocene sediment by intensely energetic swell (O'Shea 1971). At 142 m water depth the offshore margin of the mudbelt is sharply defined. Deeper water (outer neritic and upper bathyal) sediments form a very thin (often about 0.20 m) greenish silt veneer consisting exclusively of abundant planktic and rare benthic foraminifera tests, sometimes a basal shell lag (Dale & McMillan 2000), but no mud. By contrast, in the equatorial swell and wave regime along the Sierra Leone coast, energy levels are much lower, and in consequence there is Holocene sediment cover extending continuously from waterways inland of the shoreline, including the extant beach, and down to the shelf break (Dale & McMillan 1998). Much particulate clay remains in suspension in the water column, and contributes to the nepheloid layer (Zoutendyk & Duvenage 1989), evident in water depths as great as 142 m.

CRETACEOUS 'MUDBELT'

Benthic foraminifera results and sediment types from the Middle to Late Santonian portion of the Mzamba Formation type locality outcrop and contemporaneous sections from boreholes in the KwaZulu Basin, are presented as an example of a probable Cretaceous 'mudbelt', extending across the palaeo-inner shelf, which accumulated in inner neritic depositional environments. The geological setting at Mzamba Cliff is detailed by Kennedy & Klinger (1975), Klinger & Kennedy (1980), Greyling (1992), Cooper & Greyling (1996) and Krassilov *et al.* (1996). Age-diagnostic Santonian planktic foraminifera seen in the Mzamba and KwaZulu Basin successions are also known from southern coastal Tanzania (Singano & Karega 2000). All Santonian samples from the Mzamba Formation studied up to now for their foraminifera content feature fluctuating numbers of both smooth-walled and highly ornamented *Epistomina* in the benthic assemblage. Sediments are dark brown, dark grey or dark green-grey, gritty and sandy claystones with variable shell, terrestrial plant debris, locally abundant faecal pellets, and glauconite grains. The mostly dark-coloured lithologies and often low diversity benthic foraminifera assemblages imply that dysoxic conditions at the sea-floor were frequent. There is variable post-depositional carbonate cementing. The same *Epistomina*-dominated benthic foraminifera assemblage and dark coloured sediments can be recognized in the Santonian successions of proximal oil exploration boreholes drilled in the KwaZulu Basin (boreholes NZA, ZD 1/71, ZG 1/72, ZH 1/74 and ZU 1/77), from the Durban sugar terminal and from the Wanderfeld IV outcrop in coastal southern Namibia (McMillan 2003).

However, in deeper settings sediments are predominantly

grey and greenish-grey claystones, but much more shelly and carbonate-rich, and the dominant benthic foraminifera is a large-sized, strongly-compressed *Lenticulina* with a broad peripheral keel. This more distal facies, interpreted as having accumulated in outer neritic environments, is present only in the Middle to Late Santonian interval of the distal deep boreholes drilled in the basin (ZA, ZB, ZC, ZE 1/71, ZF 1/72), and is devoid of *Epistomina* species. In this distal *Lenticulina* facies the sea-floor was well-oxygenated, so that organic debris was consumed by the abundant benthos, and not preserved in the stratigraphic record.

Following McMillan *et al.* (1997) and McMillan (2003, p. 572), there is no outcrop or borehole section in which these two Santonian biofacies are interbedded, which would suggest no major sea-level rises and falls: either the entire Santonian section contains abundant *Epistomina*, or it contains abundant keeled *Lenticulina*. This argues for minor sea-level changes of perhaps no more than about 15 m during the Santonian. The *Epistomina*-dominated proximal biofacies shows many features in common with the Holocene mud belt and its benthic foraminifera assemblages, as described above (Dale & McMillan 1998).

The following characteristics argue for a mud-belt setting away from shore (about 50 to 70 m deep), usually experiencing dysoxic sea-floor conditions.

- (a) Much irregular-sized siliciclastic debris, including large irregularly shaped quartz grains, some with silvery metallized sulphide coatings.
- (b) Local abundances of polychaete worm faecal pellets, almost exactly the same dimensions as those from the Holocene mud-belt off South Africa.
- (c) Abundant molluscan shell fragments, mainly disintegrated and comminuted gastropods, bivalves, oysters and *Inoceramus* prisms, with shell often bored, flaked or rotted, and frequently infested with attached foraminifera (similar to *Stichocibicides*, but probably a new genus, new species).
- (d) Often abundant carbonized, land-derived plant stems, seeds, megaspores, and the supposed faecal pellets of certain termites, *Microcarpolithes hexagonalis* (Vangerow) (J-P. Colin, pers. comm.).
- (e) Benthic foraminifera assemblages are dominated by about 6 species occurring in abundance. *Epistomina pondensis* (Chapman), *Epistomina supracretacea* Ten Dam *s.l.*, *Gaudryina laevigata* Franke, *Rosalina* sp., *Gyroidinoides nitida* (Reuss) and *Vaginulina legumen* (Reuss) (see illustrations in Chapman 1904 and 1923; Smutter 1955; Makrides 1979) are the six commonest benthic foraminifera species in the Middle and Late Santonian succession, but their relative abundance fluctuates considerably from sample to sample. These occur together with occasional tests of genera regarded as typically deep-water (50 m or deeper?), especially *Allomorphina* and *Frondicularia*.
- (f) The only attached species is the *Stichocibicides* noted above, which, from its delicate apertural neck and thin test wall, inhabits quieter, deeper waters than the wave-break zone. There generally seems to be a complete absence of shoreline or intertidal benthic foraminifera. Do these characteristics imply that the shoreline was in the main siliciclastic starved, or, that

there was no active sedimentation at the shoreline, the line of continental margin flexure lay just offshore, between the shore-line and the mudbelt, and the shoreline was being uplifted?

- (g) The finding of two broken tests of Late Cretaceous larger foraminifera (possibly *Pseudosiderolites*, and the first South African record of this genus) in bed A7 at Mzamba Cliff, which must have inhabited a clear-water shoreline setting, changes perceptions of the variety of foraminiferal assemblages preserved at Mzamba.

Thus the Mzamba setting is interpreted to be within, but close to the proximal margin of a mud-belt. It was probably subject to the frequent development of a nepheloid layer (Zoutendyk & Duvenage 1989), sourced mainly by disintegrated and colloidal organic debris and the finest-grained sea-floor mud, generated by energy in the lowest part of the water column impinging on the sea-floor, and resulting in widespread turbid waters. The periodic incursions of debris flows containing much plant debris argues for moderate-sized active river systems leading to offshore low pH levels in dysoxic events. Rare larger foraminifera tests suggest the presence of localized clear-water shoreline settings away from the river mouths.

The Mzamba Santonian succession, and the Middle to Late Santonian succession in the KwaZulu Basin deep boreholes, show no sign of either shallowing upwards or fining upwards, based on the distributions of the benthic foraminifera (Makrides 1979) or the sediment types (Klinger & Kennedy 1980; Krassilov *et al.* 1996). Mzamba Cliff outcrop exposes about 13 m (Klinger & Kennedy 1980) of Middle to Late Santonian section, while at borehole ZA there is a thickness of 64 m, at ZB it is 54.8 m, at ZC it is 36.6 m, at Jc-B1 it is 132 m and at Jc-D1, the most offshore site, it is 210 m. All sections contain *Sigalia deflaensis* and/or *Sigalia* sp., and/or *Dicarinella asymetrica*, in association. This part of the Santonian forms a mainly seawards-thickening wedge, proximally primarily mixed siliciclastic and biogenic, and distally almost exclusively biogenic. By contrast, the Holocene mudbelt attains a maximum thickness of 41 m just north of the Orange River mouth (Bavenit borehole X) on the inner shelf, which thins to about 0.20 m on the middle to outer shelf, and distally consists exclusively of foraminifera shells without any mud. This 'foraminiferite' has everywhere been winnowed by sea-bottom currents that have attenuated it to a thin veneer.

The Holocene mudbelt is constrained to the recess in the sea-floor developed at the boundary between Precambrian and Cretaceous rocks. The Santonian sea-floor topography too was not level, but it is difficult to discern its morphology. No sharply-defined foraminiferal biozone marker horizons have yet been developed within the Santonian succession of the KwaZulu Basin, except for a horizon that marks (first downhole occurrence) top *Sigalia* sp. and/or top *Sigalia deflaensis*, located about 20 or 30 m below the top of the preserved Santonian succession in the onshore boreholes. Another marker horizon is provided by the top of the high gamma hemipelagic claystone, about 20 m above the base of the Middle Santonian succession. Reiterating the various outcrop and borehole sites:

- 1) Mzamba cliff: the lowest exposed Santonian consists of beds with cobbles and boulders of Table Mountain

Group (Klinger & Kennedy 1980). There appears to be no evidence of a high gamma hemipelagic claystone, or a concomitant hedbergellid plankton burst at this outcrop.

- 2) KwaZulu Basin borehole NZA intersected a plankton burst (hedbergellids and keeled planktics) between 22.8 and 30.4 m (7.6 m thick), which contains the oldest *Dicarinella asymetrica* and *Sigalia* spp. in the succession. It is presumed to equate to the comparable event in boreholes ZA, ZB and ZC. The top of this event is missing by erosion in NZA.
- 3) KwaZulu Basin boreholes ZA (503 to 521.3 m), ZB (551.8 to 570.1 m) and ZC (652.4 to 670.7 m) have the same dysoxic event (abundant hedbergellids and keeled planktics burst), which in all three sections is 18.3 m thick. It can be tied to a 20 m thick high gamma episode on the gamma ray logs for cuttings boreholes ZE 1/71 and ZF 1/72 using the Middle Santonian foraminifera assemblages (the fully cored boreholes have no electric logs).
- 4) Thekwini Basin boreholes Jc-B1 and Jc-D1 intersected Middle to Late Santonian, again distinguished by *Sigalia* spp. and *Dicarinella asymetrica*, 132m thick in the former hole and 210 m thick in the latter (McMillan 2003). This Santonian succession is entirely missing in Jc-A1 and Jc-C1. There is no Early Santonian, and there is no basal Middle Santonian hemipelagic claystone episode in Jc-B1 or Jc-D1.
- 5) The implication is that the sites without the basal hemipelagic claystone are incomplete, lacking the earliest portion of the Middle to Late Santonian succession, because of uplift of the proximal part (Mzamba) and the distal part of the margin (Jc-B1 and Jc-D1). The more complete succession on the shelf top (boreholes NZA, ZA, ZB and ZC) implies tectonic subsidence. Is this tectonic warping sufficient to compartmentalize the sea-floor, permitting access only to selected planktic foraminifera and inducing the dysoxia? However the dysoxic environments seen at Mzamba post-date the hemipelagic claystone event.

AN EPISTOMINA PARADOX IN THE ORANGE AND BREDASDORP BASINS

Outermost neritic to uppermost bathyal benthic foraminifera assemblages from the basal Early Albian up to the level of the mid Cenomanian disconformity in Soekor oil exploration boreholes (such as K-D1 in the distal Orange Basin, and E-D1 in the distal Bredasdorp Basin) show that widespread transport of inner neritic (mudbelt) benthic foraminifera via debris flows down to the upper slope has occurred. The transported tests consist almost exclusively of large numbers of the smooth-walled *Epistomina chapmani* Ten Dam *s.l.*, and the strongly-ornamented *Epistomina cretosa* Ten Dam and *Epistomina spinulifera polypoides* Eichenberg, *s.l.* Both these two boreholes and many others intersected distal Early Albian to mid Cenomanian successions consisting in the main of claystones, and lacking thick sandstones. They consequently contain diverse and well-preserved benthic foraminifera assemblages throughout the succession, consisting of predominant calcitic-walled benthics with smaller numbers of agglutinated-walled benthics, and of course planktics. There is little difference in benthic assemblage

composition in upper bathyal environments whether the basin is sedimenting and subsiding rapidly or slowly. However, in the proximal parts of both basins, distinguished by rapid basin subsidence, sand-rich sediments, and fast sedimentation rates, inner neritic benthic foraminifera assemblages are dominated by agglutinated-walled genera, especially by many *Ammobaculites*, *Trochammina* and *Haplophragmoides* species, as shown by McMillan *et al.* (1997, fig. 3) in the Bredasdorp Basin, and McMillan (2003, fig. 5) in the Orange Basin. Proximal depositional environments in both basins are often marked by hyposalinity, and low sea-floor pH levels occur extensively, caused by substantial terrestrial land-plant debris input. However, in this setting the mudbelt cannot be defined as a separate entity, as it cannot be separated from other proximal sedimentation, because of the overwhelming influx of siliciclastic debris flows everywhere across the shelf top.

The agglutinated-walled benthic foraminifera tests of the proximal basin do not survive transport in debris flows down to the upper slope. In contrast there is no record of *in situ* aragonitic-walled benthic foraminifera tests in inner to middle neritic environments in these two basins. Nearly all the transported inner to middle neritic benthic tests are of the three species of *Epistomina*: *E. cretosa*, *E. spinulifera polypoides s.l.* and *E. chapmani s.l.* These transported aragonitic tests are often extremely well preserved, although sometimes recrystallized, probably into calcite, or finely coated with calcite crystals. Consequently, those allochthonous aragonitic tests, transported in abundance into the deep basin, derived from the mid-Cretaceous 'mudbelt', reflect a proximal environment that is never preserved in the proximal stratigraphic sequence evident in the borehole successions.

Epistomina spinulifera polypoides is limited in southern England to the clays of the Albian Gault Clay succession, and is not seen in the overlying Cenomanian Lower Chalk limestones and chalks (Hart *et al.* 1989). This suggests that the missing proximal depositional facies in the nearshore Orange and Bredasdorp Basins is not a carbonate-dominated facies. It was, rather, a slowly-sedimenting, perhaps glauconitic and shelly, claystone accumulating in a normal marine, generally well-oxygenated environment. Dissolution of aragonite tests by sea-floor acidity due to decaying plant debris and other organic matter is not the cause of the missing aragonitic benthics in the proximal Orange and Bredasdorp Basins, otherwise there would be no aragonitic-walled tests in any basin, whether sedimenting rapidly (Orange) or slowly (Pletmos).

CONCLUSIONS

- 1) Comparison between the Holocene mudbelt and a possible Santonian mudbelt, as exposed in the lower half of Mzamba Cliff, leads to a rather inconclusive result.
- 2) The Holocene mudbelt accumulated a maximum of 30 m in 14 500 years, while the Middle to Late Santonian system accumulated a maximum of 210 m in about 2.2 Ma in borehole Jc-D1.
- 3) Holocene accommodation space was generated by fluctuations in polar glacially-driven ice volumes leading to rises and falls in sea-level of about 130 or 140 m amplitude, coupled with development of a sea-floor

recess at the Precambrian-Cretaceous boundary. Santonian accommodation space was generated by differential subsidence of parts of the continental margin: initially mostly in the inner to outer neritic realm (boreholes NZA, ZA, ZB and ZC), and later over the whole margin.

- 4) The dysoxic character of the basal Middle Santonian hemipelagic claystone in boreholes ZA, ZB and ZC, with one 18.3 m thick event of sparse benthics and floods of hedbergellid and keeled planktic foraminifera, is quite unlike the dysoxia of the Mzamba Cliff outcrop, which appears to have developed on an orbital or Milankovich basis (no dysoxia at times of accumulation of sandy carbonates).
- 5) Transport of aragonitic *Epistomina* foraminifera from the inner neritic to the upper bathyal realm in the Orange and Bredasdorp basins suggests much erosion of *Epistomina*-bearing sediments in the proximal parts of the two basins, of rock units that have subsequently been completely eroded away. This suggests much more frequent short-term unconformities exist in the stratigraphic succession than previously believed.

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