Lying on the continental margin of South Africa are seven major depocentres containing variable thicknesses of Cretaceous drift succession, which dates in age from Early Barremian to Late Maastrichtian, or approximately from 127 to 65 million years ago (Myr). Accumulation of these sedimentary piles was episodic, and the succession is subdivided by major and minor unconformities. A foraminiferal-based biostratigraphy is presented for this Cretaceous drift succession, reliant on integrated studies of 215 oil exploration borehole sections from all seven basins, as well as three onshore outcrop areas (Wanderfeld IV, Mzamba and Needs Camp/Igoda), and 772 Middle Albian to Late Santonian sea-floor samples from off the west coast of southern Africa. The biostratigraphic and chronostratigraphic successions of each basin are compared, and sea-level curves established where possible. It can be seen that sedimentation patterns during the Cretaceous drift succession were controlled almost exclusively by the relative availability of accommodation space, caused by sea-floor subsidence, still-stand or uplift, of different parts of the southern African continental margin. From Early Barremian to Early Cenomanian times (approximately 127 to 97.2 Myr) most of the basins subsided and uplifted in unison. From Late Cenomanian to Late Maastrichtian times (approximately 97.2 to 65 Myr) the southern African continental mass appears to have repeatedly suffered mild east–west rolling motions, which have resulted in distinctly different stratigraphic successions especially on the Atlantic and Indian margins. Thus, the Atlantic and Southern margins subsided particularly in the Early Turonian, the Late Coniacian and the Late Santonian. In contrast, the Indian Margin subsided particularly in the Late Cenomanian, the Early Santonian, and the Late Campanian. The boundary between the two regions must lie in the vicinity of East London. Each basin fill is sufficiently dissimilar from the others for these successions to have accumulated purely as a response to the tectonic regime at any given time. Except possibly for the Early Turonian Horizon ‘1’ shelf-wide forced regressive sandstone episode, no recognized events are sufficiently consistent across the seven basins for them to be attributable to global sea-level rises or falls. The global sea-level change record in the seven basins must thus be represented by relatively minor base-level changes that are entirely concealed behind the tectonically driven movements controlling the stratigraphic record described here.

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Introduction

Seven basins with Cretaceous drift infills lie on the continental margin of South Africa and southern Namibia: the Orange Basin on the Atlantic Margin, the Bredasdorp, Pletmos, Gamtoos and Algoa basins on the Southern Margin, and the Durban/Thekwini Basin and KwaZulu Basin (part of the South Mozambique Basin) on the Indian Margin (Fig. 1). All are structurally simple basins, and, despite the development and movement of the Falkland–Agulhas Fracture Zone south of the Southern Margin during the period Early Barremian to Albian, can all be considered pull-apart drift basins. No deep drilling has yet been undertaken in an eighth basin, the Port St Johns Basin, and consequently the foraminiferal assemblages of its Cretaceous drift succession remain unknown: this basin is not considered further in the present article. This study concentrates on the basins of the southern African continental plate. The investigation is based on foraminiferal analysis at roughly 10-m sample intervals throughout, on the following integrated borehole data-set: Orange (32 boreholes); Bredasdorp (96); Pletmos (33); Gamtoos (10); Algoa (30), Thekwini/Durban (4); and KwaZulu (10), as well as samples from the Wanderfeld IV, Mzamba and Igoda/Needs Camp outcrops. As a result of South Africa’s political and economic isolation in the 1980s, several of these basins have been especially densely drilled, and also studied for foraminifera in great detail, so that the confidence level for the foraminiferal biostratigraphy presented below is unusually high, in a global sense. This work was mostly undertaken during the period 1973 to 1993, while the author worked at Soekor. Subsequent work after 1993 has particularly concentrated on understanding the biostratigraphy of the Cretaceous drift succession exposed in sea-floor outcrop of the proximal Orange Basin, off the west coast of southern Africa, under the auspices of De Beers Marine. Some 736 sea-floor samples from the Cretaceous drift succession have been studied from the proximal Orange Basin, scattered across most of the sea-floor outcrop (inset, Fig. 2). Of these, 29 are interpreted from their foraminiferal assemblages and lithostratigraphy as being of Middle Albian to Early Cenomanian age, 114 of Early to Middle Turonian age, 540 of later Early to Late Coniacian age, and 53 of Late Santonian age. An additional 36 samples, of Early Santonian age have been studied from the onshore Wanderfeld IV outcrop and the surrounding area in southern coastal Namibia.

Throughout the full rifting (Kimmeridgian to Hauterivian; approximately 154 to 127 Myr) and drifting (Early Barremian to the present day; approximately 127 to 0 Myr) histories of these basins, the southern African continent has remained a unified landmass. Consequently there is much similarity in the sedimentation patterns of the seven basins (but they are
certainly not the same), and in the facies distributions of their stratigraphic successions. In addition, the history of these basins during the Cretaceous and Cainozoic drift period has been a relatively quiet one: there have been neither intense folding nor faulting episodes, nor have there been any substantial volcanic or salt diapiric episodes that could have severely disrupted bedding patterns or destroyed fossil content. As a result, the bed-by-bed stratigraphy of the basins and their fossil content remain very well preserved, and much as they were at the time of deposition.

Early use of foraminiferal biostratigraphy to subdivide the southern African Cretaceous drift successions dates from 1904 until the late 1950s, but the first biostratigraphic subdivision of borehole successions publicly available was completed only in 1958 in Angola and in 1968 in South Africa. More intensive and comprehensive studies were undertaken in the late 1960s and 1970s, and by the end of that decade a generalized view of most of the offshore succession for much of the continental margin was available in published form. However, the increasing pace of oil exploration in South Africa during the 1980s and early 1990s has meant that much borehole analysis work remains neither synthesized nor integrated into a regional model. Increased understanding of deeper water foraminifera assemblages around southern Africa has come from Deep Sea Drilling Project (DSDP) and Ocean Drilling Project Legs 25 and 26 on the Indian Margin, and Legs 40, 74, 75, and 175 on the Atlantic Margin. Only at relatively few DSDP sites around southern Africa have portions of the Cretaceous drift succession been intersected: DSDP sites 249, 361, 363, 364, 525, 527, 528, 529 and 530. The last five sites are located in the vicinity of the Walvis Ridge, while only the first two are sited off South Africa.

Improved drilling techniques on oil exploration boreholes from the 1970s to the 1990s led to markedly cleaner and considerably less contaminated cuttings samples, with a marked reduction in the amount of caved rock chips, and metal and rubber junk. In consequence, much more accurate and higher-resolution foraminiferal biostratigraphy than was possible previously has been achieved on cuttings samples, especially in densely drilled regions. Additionally, better use has been made of in situ core and side-hole core samples, as well as the four fully cored boreholes (ZA, ZB, ZC and NZA) drilled by the AngloVaal company in the mid-1960s in the KwaZulu Basin.

This article attempts to offer a concise summary and foraminifera-based biostratigraphic model of Cretaceous drift sedimentation principally of seven basins on the South African and southern Namibian continental margin. However, it is stressed that the stratigraphic successions identified in the basins, and described here, may well be entirely unlike the successions occurring outside the basins, or overlying the intervening Palaeozoic arches, as a result of different subsidence and uplift histories. Consequently, this article is not meant to present a generalized foraminiferal biostratigraphy of the entire continental margin of southern Africa. Some comments on the Angolan and Mozambiquan stratigraphic successions, as well as published details of foraminiferal assemblages from the two countries are also included for comparison with the seven basins described here in detail. West African Cretaceous and Cainozoic foraminiferal biostratigraphy, including Angolan material, has been summarized and illustrated in one compendium.
Figures 1 to 4 of the present work illustrate the areal extent of the seven basins studied, together with the locations of the borehole sections investigated, onshore outcrops and sea-floor samples discussed in the text. Figures 5 to 11 illustrate the summarized chronostratigraphy of recognized sedimentary units and unconformities in each of the seven basins, presented as Wheeler diagrams. Where possible, a sea-level curve has been established for the Cretaceous drift succession of each basin, shown as a red curve on Figs 5–11. Figure 12 illustrates the stratigraphic ranges of the great majority of the age-diagnostic or distinctive foraminifera species encountered in the Early Barremian to Late Maastrichtian succession. The species included on Fig. 12 are those which have been found to be of value firstly in establishing the age of the stratigraphic succession, and secondly in cross-correlating between the seven basins.

Additional details of the geology, stratigraphy and hydrocarbon potential of these basins are provided by refs 1–17, 58, 92. The Cretaceous foraminiferal biostratigraphy of the offshore South African basins has been detailed in several publications,4,16,25,59,79,81,92 and a summary and critical analysis of early biostratigraphic work has also been published.49 Seismic horizons referred to are the local ones of each individual basin, originally identified and defined over the years with a variety of symbols by Soekor geologists and geophysicists. Previous attempts to correlate seismic horizons between different basins have been successful only for the large-scale unconformity surfaces (see fig. 3 of ref. 92), such as 5At1, 13At1 and 15At1. The minor unconformity surfaces of the Barremian to Albian succession remain poorly correlated between basins in a seismic sense, but the increasingly refined foraminiferal biostratigraphy, as presented here, resolves some of the outstanding correlation problems. The seismic stratigraphic nomenclature developed for the Bredasdorp Basin16 has been taken here as the standard, against which the other basins are correlated, so that well-established terms such as 13At1 have also been employed in the other basins.

The seismic stratigraphic nomenclature used for the Cretaceous drift succession of the Orange Basin is an early unpublished drift succession exposed at the present-day sea floor, or subcropping beneath latest Pleistocene and Holocene deposits.

Curves’ chart,19 and the two editions of the Harland et al. volume A Geologic Time Scale,20,21 In the sections that follow, strong emphasis is placed on the thickness of identified biostratigraphic units, and the differences in thickness between one basin and another, because unit thickness remains the easiest indicator of differential basin subsidence during any given period.

A considerable literature now exists on the macrofossils and microfossils of the Cretaceous drift succession of southernmost Africa. Outcrops and short boreholes intersecting the succession of the KwaZulu Basin have been particularly intensively studied, primarily for ammonites (H.C. Klinger & W.J. Kennedy), a variety of macrofossils (M.R. Cooper), ostracods (R.V. Dingie) and nannofossils (W.G. Siesser). The dinoflagellate cysts (R. Davey, J. Benson), nannofossils (R.H. Pienaar) and a few ammonites (H.C. Klinger) have been described from the deep, fully-cored boreholes of the KwaZulu Basin. In addition, ostracods (R.V. Dingie) have been studied from the Cretaceous drift succession in one of the boreholes (Je-A1) in the Thekwini Basin, from the Mazamba outcrops, from sea-floor outcrops on the Southern Margin, and, in unpublished work, from two of the Kudu boreholes in the northern Orange Basin. Siesser has also reported on nannofossils from the Cretaceous drift succession of the Southern Margin. Except where deemed absolutely
necessary, because of of space limitations, references to these publications are excluded, and this article has been rigorously constrained to a review of the foraminiferal biostratigraphy.

The basins

An abbreviated description of each basin is given below, in order to set the Cretaceous drift successions in context. The lowest part of each basin infill is the graben fill succession, which is distinguished by major bounding faults: in all seven basins the Cretaceous drift succession overlies the graben fills unconformably. The great majority of the studied boreholes are rotary-drilled boreholes, and the microfossil results described below are based on cuttings samples, with their inherent tendency to cave downhole. As a result, the first downhole appearances of foraminifera species, which tend to be either extinction points or disappearance points due to facies changes, are usually easy to define. In contrast, the last downhole occurrences of species may not be so clear, because of caving problems. However, in general, much improved drilling techniques introduced over the past decade or so have almost eliminated the cavings problem. In addition, the high density of studied boreholes in the Bredasdorp Basin and elsewhere has greatly increased the confidence level of the stratigraphic ranges of the foraminifera species shown in Fig. 12, and listed in the text below.

Orange Basin (Fig. 5)

The Orange Basin, situated on the Atlantic Margin of South Africa and southern Namibia, is by far the largest basin of the seven. It extends from off Saldanha in the south to off Chameis in southern Namibia in the north. It was also the most energetic basin. The Orange Basin received the great majority of the drainage from the interior of southern Africa throughout the Late Barremian to Early Campanian period. Except for the Kudu area, in the northwestern part of the basin, where the Early Barremian to early Early Aptian succession is almost complete, the drift succession everywhere else in the Orange Basin appears to have started at the beginning of Late Barremian time. The mid-Barremian hemipelagic claystone interval, evident in the Kudu boreholes, in the Bredasdorp and Pletmos Basin successions, and at the base of the KwaZulu Basin drift succession, is extensively absent in the Orange Basin. This suggests that, except for the Kudu area, drift sedimentation in the Orange Basin mostly began about one million years after that of the KwaZulu Basin, and about 3.5 Myr after those of the Kudu area, the Bredasdorp and Pletmos basins. Probably because of its frequently rapid rate of sediment input and rate of subsidence, it is the only basin to contain extensively preserved fluvial/coastal plain deposits in its proximal part through most of the Cretaceous drift period (Late Barremian to Late Santonian). Thus, the hinge-line of shelfal flexure in the Orange Basin must have often been well inland of the palaeo-shoreline during the drift period, whereas the hinge-line was usually at or near the palaeo-shoreline in the other smaller basins. Any given rock unit within the Barremian to Campanian succession in most of the Orange Basin is generally over twice as thick as its contemporary equivalent in the six other basins. Thus, both the rate of subsidence and the rate of sediment input in the Orange Basin were significantly greater than in any other South African basin.
during this period. Nonetheless, the same tectonically driven controls on sedimentation existed in both the Orange Basin and the other smaller basins, so that the chronology of periods of sedimentation (caused by basin subsidence) and of periods of unconformity (caused by basin still-stand or uplift) during this period are much the same. This is despite differences in size of the basin, in rate of siliciclastic sediment input and rate of basin subsidence, in coarseness of siliciclastic sediment supply, as well as differences in lithology (localized presence of biogenic limestones and limey clays especially in the Southern Margin basins).

Initial rift faulting in the Orange Basin is aligned roughly parallel to the present coastline. In the proximal part of the basin localized half-graben infills (T to R/5At1 succession) accumulated, most of which consists of unfossiliferous fluvial red and green claystones, sandstones and pebble beds. This succession is occasioned up to at least 2500 m thick. Locally in the most proximal settings (Karreedoornvlei onshore, boreholes A-J1, Ba-A1 and Ba-A2 offshore), brown and black lacustrine claystones (from about 3 m up to 350 m thick), with high gamma characteristics and occasional organic enrichment, occur within the graben infills. The lacustrine claystones contain non-marine ostracods such as *Cypridea australis* Musacchio (first described from the Hauterivian-Barremian of the Neuquén Basin, and subsequently from time-equivalent beds of the San Juan Basin of southern Argentina), charophyte oogonia, the land-plant microfossil *Microcarapolites hexagonalis* Vangerow ('hexiseds'), and pollens and spores that support a Hauterivian age.7,99

In the distal Orange Basin is a seawards thickening wedge which up to now has been only poorly drilled: its age is unknown, although it may well be contemporaneous with the proximal graben infills. Where drilled, in O-A1, A-C1 and A-C3 boreholes in the southern Orange Basin, the seawards thickening wedge consists of volcanics.

Unconformably overlying the graben infills, basement highs of Precambrian rocks and the seawards thickening wedge, often with a strongly angular unconformity, is the Cretaceous drift succession, which may attain a thickness of 8000 m in depocentres.10 This Early Barremian to Early Campanian sedimentary succession is exclusively clastic. About 5200 m of this has been drilled in the main depocentre (borehole K-A2), but up to now the complete succession can only be studied by examining a number of borehole sections from different parts of the basin. Some of these boreholes lie in proximal settings, but as a result display much less fossiliferous sections, so that some aspects of the Barremian to Albian biostratigraphic succession still need to be resolved. The most normal marine early drift succession known is in the Kudu boreholes.10 Here, the first drift deposits are volcanics topped by shelly littoral sandstones and rare claystones, which are interpreted as being of Early Barremian (5At1 to 6At1 equivalent) age. From mid-Barremian times (6At1 onwards, variously diverse microfossil assemblages occur, which include planktonic foraminifera and radiolaria, showing that fully marine, open ocean conditions prevailed from this time throughout the distal part of the Orange Basin. The distal drift succession (as in the Kudu boreholes and borehole O-A1) includes two high-gamma hemipelagic claystone intervals rich in planktonic foraminifera and radiolaria, one of mid-Barremian age limited to the northern part of the basin (the P2 source rock: 6At1 to 8At1 equivalent), and one of later Early APTian age occurring in both the north and south (the P source rock: 13At1 to 13Arm's equivalent).

The proximal drift succession is generally characterized by evidence of substantial fluvial input throughout the Late Barremian to Early Campanian period, with widespread lignite, siderite spheres, seeds, megaspores, and distinctive agglutinated foraminifera assemblages indicative of hyposaline conditions.93,97–98,100,104 The thickest portion of the succession is of Early Albian to Early Cenomanian age, which attains 2800 m in the depocentre (borehole K-A2), and which shows signs of hyposaline influence almost to the palaeo-shelf break, usually with abundant agglutinated benthonic foraminifera but sparse planktonic and calcareous benthonic foraminifera assemblages. Massive sandstones of Early Albian to Early Cenomanian age (up to 1550 m thick in the K-A boreholes) locally developed across the palaeo-outer shelf, and these lack foraminifera except in minor interbedded claystones. Only in the generally clayier Early Albian to Early Cenomanian and Turonian to Coniacian successions deposited on the palaeo-outer shelf and upper slope, as well as the Turonian and Coniacian shelfal deposits in the far north of the basin off the Chameis to Bogenfels coast, were calcareous benthonic and planktonic foraminifera tests preserved in any numbers. The distribution of foraminiferal
Fig. 5. Interpreted chronostratigraphy and summarized lithostratigraphy of the Cretaceous drift succession of the Orange Basin. The distribution of Albian shelf sandstones is depicted as for the main depocentre (area of borehole K-A2). In the southern part of the basin most of these sandstones are of Early to Middle Albian age only. Yellow intervals mark thick or massive sandstones, single lines of stipple indicate sandstone stringers, blue intervals mark claystones (with major high-gamma claystones distinguished), and 'brickwork' symbol represents carbonates. White areas are unconformities.
assemblages rich in calcareous tests in the Orange Basin Creta-
ceous drift succession effectively defines the limits of the re-
markably extensive hyposaline facies of this basin. As an ex-
ample, the offshore limit of the Orange Basin hyposaline facies
in the Late Santonian is shown in Fig. 2.

The Middle Albian to Late Santonian part of the succession
outcrops at the present-day sea floor, or subcrops beneath thin,
latest Quaternary veneers. Of the outcrop succession, the
Middle Albian to Early Cenomanian portion consists every-
where of fluvial braidedplain quartz sands with minor brown and
black clays bearing lignite and a variety of seeds, megaspores,
‘hexiseds’, and other plant microfossils. The Early to Middle
Turonian and the later Early to Late Coniacian successions
consist mainly of fluvial white, pale grey, pink, green and red
soft clays, fluvial sands and occasional grits, and interfluve
ferricretes, interbedded with occasional thin ‘marine bands’ of
stiff dark grey clay, occurring on a fourth order cyclicly.104 The
hyposaline marine influence in the ‘marine bands’ is evident by
the occurrence of exclusively agglutinated foraminifera assem-
blages, and, in more distal settings, by calcareous benthonic
foraminifera, ostracods, *Inoceramus* prisms and oysters.294 The
Coniacian portion of the succession is particularly well exposed
on the present-day sea floor, and contains widespread carbon-
ized and silicified tree trunks and other wood debris.98,104 Two
high-gamma, poorly organic-rich hemipelagic claystone epis-
odes occur in the Early Turonian, the lower only distally at the
base of an earlier Early Turonian lowstand tract, and the
upper across the entire shelf at the base of the shelfal later Early
Turonian. The Early Turonian succession, including the two
hemipelagic claystones, is entirely missing on the palaeo-slope.
The upper, more extensive high-gamma claystone (up to about
70 m thick distally) constitutes a distinctive marker horizon
especially in the otherwise poorly fossiliferous proximal part
of the basin. There is also a substantial high-gamma claystone
event, with a concomitant foraminifera burst, in the mid-
Coniacian (on the 140/1 unconformity), which is again well
developed across the palaeo-shelf but absent on the palaeo-
slope.

The Orange Basin expanded shorewards during the Barremian
to Middle Albian period, and this part of the succession progres-
sively overlaps in an eastwards direction. Thereafter, during
the Middle Albian to Early Campanian period, the basin margin
slowly migrated offshore to the west. Maximum marine advance
occurred at the time of the mid-Early Turonian high-gamma
claystone, which lies at the base of the proximal Turonian
succession. This basal claystone accumulated slightly later in the
Early Turonian than the basal Turonian event seen widely in the
Bredasdorp and Pletmos basins. This suggests subtle differences
in the tectonic regimes governing movement of the Atlantic and
Southern margins during this time period. The only known
onshore exposure of the Cretaceous drift succession is the
Wanderfeld IV outcrop in southern Namibia, which contains
abundant planktonic and benthonic foraminifera and ostracod
assemblages indicative of an Early Santonian age.76,84 These
assemblages compare well with those of the lower half of the
Mzamba cliff type section.27

Substantial uplift at mid-Campanian time brought sediment
accumulation in this large basin to an end, and led to severe
downcutting of the previously deposited Middle Albian to Early
Campanian succession. A thin succession of Late Maastrichtian
pink, grey and white deep-water chalks is preserved on the
palaeo-upper slope (borehole O-A1), and is marked by a
particularly strong seismic character that can be recognized
along the entire length of the basin (E.A. Pegler, unpubl. data).

Subsequent sedimentation through the Cenozoic is often
very localized, and is mostly confined to the uppermost slope.105 Based on unpublished seismic data interpreted by
Pegler, there are thicknesses of up to 1500 m of Palaeocene dark
grey claystones on the slope west of Saldanha (intersected and
foraminifera studied in borehole O-A1), and up to 1200 m of
Pliocene greenish-brown clays on the slope west of Lüderitz
(foraminifera studied in UCT/SANCOR grab or shallow core
samples 3153, 3202, 3205, 3257 and 3360, kindly supplied by
J. Rogers of the University of Cape Town in 1975). However, in
most areas on the shelf, as at Childs Bank (K-A boreholes), the
Cainozoic succession is usually never more than 250 m thick,
and proximally no more than 50 m. Most of this limited thickness
consists of Burdigalian shelfal carbonates.

Bredasdorp Basin (Fig. 6)

The Bredasdorp Basin14–16,92 is the most westerly of the South-
ern Margin basins. Of the four basins on this margin, it has the
thickest Cretaceous drift succession. An initial graben fill
succession (horizon D to 1At1) consists of very variable thick-
nesses (locally at least 800 m) of basal conglomerates, then fluvial
sandstones and red and green claystones interbedded with two
major littoral, locally shelly (comminuted oyster shell flakes and
rare whole oysters, crinoid ossicles and echinoid spines) and
microfossil-bearing (common ostracods and rare foraminifera),
glaucolitic, clean sandstones. The top of the D to 1At1 succession
is variably eroded off. This succession is regarded as being of
probable Kimmeridgian to Late Valanginian age.92 The lower
glaucolitic sandstone (horizon V sandstone) contains the
distinctive foraminifera *Tritaxia cf. fusca* (Williamson), which is
taken to suggest a latest Jurassic (Portlandian) age, based on
its occurrence in Argentina. However, in general, the limited
occurrence of foraminifera in this Bredasdorp Basin interval
greatly hinders correlation with the much more fossiliferous
time-equivalent successions in the Pletmos, Gamtoos and Algoa
basins. Abrupt uplift and erosion, then considerable subsidence
of the rifting basin during Late Valanginian times (1At1) led to
accumulation of poorly fossiliferous latest Valanginian to
Hauterivian deep marine dysoxic black claystones and turbiditic
sandstones, in which ‘brown plates’ (diagenetically formed
microscopic plates or lenses of calcite), pyritized radiolaria and
deep-water agglutinated foraminifera predominate widely.
 Locally, however, shelfal calcareous and agglutinated benthonic
foraminifera, including *Reinholdella valendisensis* (Bartenstein &
Brand) and *Dorothy australis* McMillan, and ostracod
assemblages, do occur at proximal sites. Following a major uplift
episode at 5At1 times, most of this 1At1 to 5At1 succession was
subsequently planed off, particularly in the southern, distal part
of the basin, before deposition of the drift succession.

The overlying Early Barremian basin drift succession in the
Bredasdorp Basin (5At1 to 6At1) is limited to localized
topographic lows on the break-up unconformity surface. In the
basin centre the succession generally shows a continuation of the
deep marine black dysoxic claystones and turbiditic sand-
stones facies of the 1At1 to 5At1 interval, but sediment input
directions have changed. Localized high-gamma, organic-rich
claystones of mid-Barremian age (6At1 to 8At1) are developed
especially in coarser-clastic-starved palaeo-outter shelf and
palaeo-slope settings, where hemipelagic clay accumulation
was unaffected by bed-loads of quartz sand and silt moving
across the palaeo-shelf into deep water. These hemipelagic
claystones are best developed along the flank of the Agulhas
Arch, and in the E-S/E-M/E-C area in the north of the basin. Such
claystones are absent down the basin axis, and in the F-A region
Fig. 6. Interpreted chronostratigraphy and summarized lithostratigraphy of the Cretaceous drift succession of the Bredasdorp Basin. The distribution of Albian shelf sandstones is depicted as for the basin axis, whereas on both the Agulhas Arch and Infanta Arch flanks of the basin sandstones are very limited (compare with fig. 3 of ref. 90). Yellow intervals mark thick or massive sandstones, single lines of stipple indicate sandstone stringers, blue intervals mark claystones (with major high-gamma claystones distinguished), and ‘brickwork’ symbol represents carbonates. White areas are unconformities.

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<table>
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<th>AGE (Ma)</th>
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<td>PROXIMAL COASTAL PLAIN</td>
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<td>75</td>
<td>125</td>
<td>LOWER SLOPE</td>
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</tbody>
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[Diagram details and labels are not transcribed due to the image limitations, but would depict the stratigraphic sections and their descriptions as mentioned in the text.]
in the northeast of the basin, where sandstones predominate. Substantial shelfal sandstones accumulated across much of the basin during later Barremian to earlier Early Aptian (about 9At1 to 12At1) times, and more extensively during Middle Albian to later Early Cenomanian times (these latter up to 970 m thick in borehole E-N1). There are notable organic-rich dysoxic successions on the palaeo-slope in the later Early Aptian (13At1 to 13Amfs’), and on the palaeo-shelf in the basin Early Turonian (just above 15At1), with a final major high-gamma episode in the shallow mid-Coniacian (equivalent to the 140t1 event of the Orange Basin). Substantial fluvial and sediment input into the basin, and significant subsidence of the basin appear to have ended at mid-Cenomanian times (15At1). The post-Cenomanian, Late Cretaceous succession is generally much finer-grained, and contains foraminiferal assemblages that reflect normal marine environments across the entire basin. Biogenic carbonate sedimentation prevailed distally during the Late Santonian and Early Campanian period (interval between horizons K and southern X). Overlying these is a thicker (up to 600 m in borehole F-R1), silty and sandy succession of Late Campanian to Early Maastrichtian age, partly confined to the eastern half of the basin, suggesting river input to the Southern Margin increased during this period. The full Cretaceous drift succession attains a maximum thickness of about 4000 m (boreholes E-N1, E-AA1).

Unconformably overlying the Cretaceous in the Bredasdorp Basin is a widely developed, rather uniform succession of 500–700 m of shelfal Palaeocene, Early to Late Eocene, Early Oligocene and Early Miocene (Aquitanian and Burdigalian) units, consisting of interbedded glauconitic sandstone, claystone and carbonate units. Overlying the Cretaceous and Tertiary successions is a veneer of littoral, latest Pleistocene sandstones, though locally there are red fluvial claystones and occasional conglomerates in proximal settings. An unconformity-bounded conglomerate package (equivalent of the Enon Conglomerate Formation) occurs widely at the base of the Pletmos Basin succession, and can be regarded as Kimmeridgian in age, when compared with the datable time-equivalent packages (distally foraminifera and ostracod-bearing) of the Gamtoos and Algoa basins. Like the Bredasdorp Basin, the Pletmos Basin suffered abrupt uplift then considerable subsidence at 1At1 times in the Late Valanginian. This movement resulted in the upper part of the graben fill consisting of a deep-water claystone and sandstone succession of latest Valanginian to Hauterivian age (1At1 to 5At1). The entire graben fill succession was subsequently uplifted and substantially planed off at 5At1 times (Hauterivian-Barremian boundary), especially in the southern Pletmos Basin, prior to deposition of the earliest unit of the drift succession. There are several major fault-bounded graben fill depocentres where the thickness of the Kimmeridgian to Hauterivian infill attains at least 4820 m (compounded borehole sections Gb-H1 and Gb-Gemsbok 3). This represents well over half of the entire Pletmos Basin infill.

The Early Barremian succession (5At1 to 12At1) is only developed in the northern half of the basin, principally north of the Superior Fault. Again, the mid-Barremian high-gamma claystone (12At1 to 12Ct1) forms a distinctive horizon, but, unlike in the basins to the west, it can be recognized almost basin-wide, as sand input at this time into the Pletmos Basin was much less. Somewhat more diverse foraminifera assemblages in this basin during the entire Early Barremian to earlier Early Aptian period indicate that sea-floor dissolved-oxygen levels were generally higher than in either the Bredasdorp or Orange basins during this period. The Early Barremian to earlier Early Aptian succession attains a thickness up to 1800 m in borehole Ga-W1, most of which is of Early Barremian age. There are some thicknesses of Late Barremian to earlier Early Aptian sandstone (12Ct1 to 13At1). In the main, the Pletmos Basin ended as a substantial depocentre at mid-Aptian times (13At1). Subsequent sedimentation is thinner than in the Bredasdorp Basin, parallel-bedded, and consists mostly of shelfal claystones. Essentially the same sedimentary units occur as those seen in the Bredasdorp Basin. However, no convincing Late Aptian unit (13Amfs’ to 14At1) has been recognized in this basin. The thin (up to 640 m on the palaeo-upper slope, no more than 250 m on the palaeo-shelf) Early Albian to Early Cenomanian succession consists mainly of glauconitic claystones with minimal sandstones. As with the Bredasdorp Basin the Early-Middle Turonian succession (maximum 360 m thick) is usually overstepped by the later Early Cenomanian interval in a shorewards direction, and mostly does not reach up to the sea floor. There are very thin (up to 240 m distally but usually no more than 100 m), mainly carbonate units of Late Santonian and Early Campanian age (equivalent to the K to southern X interval of Bredasdorp Basin). Again, the Late Campanian to Late Maastrichtian succession is significantly thicker (up to 350 m), and siltier and sandier than the underlying beds, and represents reactivation of clastic input from rivers entering this part of the coast. The maximum thickness of the Cretaceous drift succession is 2240 m (borehole Ga-E2, sited in a palaeo-uppermost slope setting). The overlying shelfal Cainozoic succession is almost exactly the same as that described for the Bredasdorp Basin, and is about 520 m thick.

Gamtoos and Algoa basins (Figs 8, 9)

The Gamtoos and Algoa basins are nearly identical in the styles of their basin fills. The great majority of the basin succession in both is the graben fill, which locally attains up to 4160 m (as in Algoa onshore borehole AL 1/69). This Kimmeridgian to Hauterivian graben fill succession mostly accumulated in a marine environment, and black and grey claystones and sandy glauconitic sandstones are widespread. In proximal settings, and even locally at a few distal sites, a discrete, unconformity-bounded basal package of red fluvial conglomerates (Enon Conglomerate Formation) occurs (up to 2150 m in Gamtoos onshore borehole MK 1/70), grading seawards to shelfal sandstones and claystones, then distal dysoxic deep marine sandstones and black claystones (D to DC1 interval), which is interpreted as exclusively Kimmeridgian in age. An overlying succession of extensive distal high-gamma, organic-rich black claystones is regarded as Portlandian in age (up to about 800 m thick; DC1 to P3 interval), and correlates with the locally developed onshore unit known as the Colchester Member and its equivalents (up to 400 m in the Uitenhage Trough, up to 180 m in the Sundays River Trough). In the north of both basins there are thick successions of fluvial red and green claystones and estuarine green claystones with sandstones (Kirkwood Formation; up to 2620 m thick) which grade southwards to shelfal grey claystones and sandstones, interpreted as
Fig. 7. Interpreted chronostratigraphy and summarized lithostratigraphy of the Cretaceous drift succession of the Pletmos Basin. Yellow intervals mark thick or massive sandstones, single lines of stipple indicate sandstone stringers, blue intervals mark claystones (with major high-gamma claystones distinguished), and 'brickwork' symbol represents carbonates. White areas are unconformities.
Fig. 8. Interpreted chronostratigraphy and summarized lithostratigraphy of the Cretaceous drift succession of the Gamtoos Basin. Yellow intervals mark thick or massive sandstones, single lines of stipple indicate sandstone stringers, blue intervals mark claystones (with major high-gamma claystones distinguished), and ‘brickwork’ symbol represents carbonates. White areas are unconformities.
Fig. 9. Interpreted chronostratigraphy and summarized lithostratigraphy of the Cretaceous drift succession of the Algoa Basin. Yellow intervals mark thick or massive sandstones, single lines of stipple indicate sandstone stringers, blue intervals mark claystones (with major high-gamma claystones distinguished), and ‘brickwork’ symbol represents carbonates. White areas are unconformities.
being of Berriasian to Early Valanginian age. A substantial
marine transgression at the beginning of the Late Valanginian,
evident in the north of both basins, led to the termination of the
Kirkwood fluvial facies and the initiation of shelfal interbedded
grey claystones and sandstones (lower Sundays River Forma-
tion; up to 430 m thick) across the full extent of both basins. This
mid-Valanginian transgressive event is also seen in the northern
Pletmos Basin, in offshore borehole PB-A1 at 2467 feet (752 m),
and below the Brenton Formation, at a depth of 9 m (just below
mean sea level) in an onshore Council for Geoscience shallow
borehole drilled down to total depth of 69 m, at Brenton next to
Knyasa Lagoon by J. le Roux. Uplift and erosion, then substan-
tial subsidence during the time of the Late Valanginian 1At1
unconformity led to the subsequent accumulation of the latest
Valanginian to Hauterivian (1At1 to 5At1) succession. This final
unit of the graben fill succession consists of proximal shelfal grey
claystones and thin sandstones (upper Sundays River Forma-
tion; up to 2050 m thick), and distal deep marine, dysoxic black
claystones and occasional turbiditic sandstones (only up to
680 m, due to subsequent uplift and erosion). As in the Bredas-
dorp and Pletmos basins, the distal 1At1 to 5At1 succession of
the Gamtoos and Algoa basins includes a basal high-gamma,
organic-rich claystone unit, distinguished by Reinhodella valen
disensis (Bartenstein & Brand) and Dorothia australis
McMillan in proximal settings (see fig. 3 of ref. 92). In both the
Gamtoos and the Algoa basins, the differences in areal extent and
in thickness of the five main sedimentary packages recogni-
zied in the graben fill succession (interpreted to be of
Kimmeridgian, Portlandian, Berriasian to Early Valanginian,
Late Valanginian, and latest Valanginian to Hauterivian age),
indicate that these two large and complex grabens experienced
considerable changes in size, in rate of subsidence, and in grain
size of accumulated sediment through their approximately
27-Myr life history.

Substantial uplift of the southern parts of both basins at the
end of the Hauterivian (5At1, drift-onset unconformity) led to
the formation of large cross-shelf canyon systems in both basins.
The Algoa Canyon is the larger and more complex of the two
systems. Until now, no sediments of Early Barremian to later
Early Aptian age (5At1 to 13Atms’ interval) have been found in
either basin, and it would seem that during this period these
canyons were being actively down-cut, and were conduits that
enabled all sediment reaching this part of the coast to bypass the
two basins. Because of the arrangement of the graben depo-
centres and the bounding faults, canyon downcutting into the
graben fill successions may locally reach as deep as latest
Berriasian sediments (borehole Ha-K1 in the shallower Gamtoos
Canyon). However, in the more deeply incised Algoa Canyon,
the canyon floor locally consists of rocks as late in age as
mid-Hauterivian (borehole HB-II). The distal floor of the
canyons began to infill with sediment probably from Late Aptian
times. Thus, drift sedimentation in these two basins only
commenced at about 116 Myr at earliest, much later than in any
of the five other basins. Thereafter, thick canyon-fill successions
(up to 1390 m in Algoa borehole HB-II, but only 360 m in
Gamtoos borehole HA-K1) of possibly Late Aptian, and
definitely Early to Middle Albian age accumulated. There is a
widespread post-canyon fill interval of Late Albian age in the
Gamtoos Basin (up to 60 m thick in borehole HA-K1), but this is
missing in the Algoa Basin. Post-canyon-fill sediments in the
Algoa Basin are widespread, fairly thick, Early Cenomanian
massive sandstones topped by thin claystones on the outer shelf,
the entire succession attaining 450 m in distal borehole HB-C1,
but the interval thins rapidly shorewards. In contrast, Early
Cenomanian deposits appear to be absent in the Gamtoos Basin.

Sediments of Early Turonian and later Cretaceous age in both
basins are extremely attenuated, more so even than those of the
Pletmos Basin, and indicate minimal shelf subsidence. The Early
Turonian interval consists of probable littoral silts and
sandstones, and is everywhere poorly fossiliferous. Distal inter-
sections of the Late Santonian and Early Campanian consist of
carbonates and limey claystones. At about mid-Campanian
times the northeast Pletmos Basin, the northern Gamtoos and
Algoa basins, and probably also the inshore part of the continen-
tal shelf at least as far north as East London, all subsided, which
resulted in a major marine transgression. Just prior to this trans-
gression, the entire Albian to Early Campanian drift succession
of the two basins was planed off, and then overstepped shore-
wards by post-transgression units of Late Campanian and Late
Maastrichtian age. Only these latter two units extend up to the
sea floor. Dating from probably either the Late Campanian or the
Early Maastrichtian are the onshore shelly and glauconitic
marine sandy claystones and limestones of the Igoda Formation,
at Igoda River mouth,55 the basal Needs Camp upper quarry
section,63 and the Needs Camp lower quarry.25-27 Available
foraminifera data from these onshore outcrops unfortunately do
not resolve their precise age within this time period. This latest
Cretaceous succession must originally have been extensively
distributed across the Eastern Cape coastal plain, but subse-
quent Cainozoic uplift and erosion events have reduced it to
to extremely localized remnants. The total maximum thickness
of the offshore Cretaceous drift succession occurs in the Algoa
Basin canyon (2340 m in borehole HB-II), but outside the
canyons, the succession is only up to 460 m thick. Neither in the
Gamtoos Basin nor the Algoa Basin does the Cretaceous drift
succession contain any high-gamma, hemipelagic claystone
units.

The overlying Cainozoic succession is about 500 m thick, and
consists everywhere of shelfal, parallel-bedded deposits, of
Palaeocene, Middle to Late Eocene and Early Oligocene age,
and, off the Algoa coast, Early Miocene (Burdigalian), Early to
Late Pliocene and Early Pleistocene (50-m Package equivalent)
age as well.81,92

Thekwini Basin (Fig. 10)
The Thekwin, or Durban, Basin45,57 is sited off the Durban to
Stanger coast, over the proximal Tugela Cone. Its early history is
very erratic. Up to now two northern boreholes (Jc-B1 and Jc-D1)
have intersected a graben fill succession (K. Kitchin, I.
McLachlan, pers. comm.), at least 470 m thick in Jc-B1, but in
neither case have datable microfossils (foraminifera, ostracods,
megaspores or charophyte oogonia) been found. This succes-
sion probably accumulated in a lacustrine and/or fluvial
environment.

The Early Cretaceous drift succession is very localized. In the
south off Durban (borehole Jc-C1) there is a thick succession (at
least 920 m) of outer shelf grey claystones and very minor
sandstones of Late Barremian to earlier Early Aptian age
(roughly 8At1 to 13At1). The time-equivalent interval in the
north off Stanger is much thinner, very localized (only in Jc-B1
borehole), much sandier, and is interpreted as having accumu-
lated in an innermost shelf environment. Thereafter, localized
minor subsidence occurred in the distal part of the Thekwin
Basin in Middle Albian, Early Cenomanian, Middle Turonian
and Early Santonian times. The basin only came into being as
one depocentre in mid-Campanian times. The entire basin then
began to subside rapidly, leading to the development of a thick
(up to 950 m), shallowing upward succession of Late Campanian

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Fig. 10. Interpreted chronostratigraphy and summarized lithostratigraphy of the Cretaceous drift succession of the Thekwini (Durban) Basin. Note that the Early Cretaceous stratigraphic successions in the north and the south of the basin are very different, and are depicted in separate columns. Yellow intervals mark thick or massive sandstones, single lines of stipple indicate sandstone stringers, blue intervals mark claystones (with major high-gamma claystones distinguished), and 'brickwork' symbol represents carbonates. White areas are unconformities.
to Late Maastrichtian age, consisting mainly of deep marine grey claystones. Only one high-gamma, hemipelagic claystone has been identified in the Cretaceous drift succession of the Thekwini Basin, occurring at the base of the drilled section of southern borehole Jc-C1: the claystone may well continue below total depth of this borehole.

Outcrops of the Early Santonian and Early Campanian Mzamba Formation occur along the southern KwaZulu-Natal coast10,11,12,13,14,15,16,17,18,19 and contain foraminifera assemblages closely comparable with those of the same age in the KwaZulu Basin. These sites mostly lie well south of the offshore Thekwini Basin. The type locality of the Mzamba Formation at Mzamba River mouth consists of a lower interval of Early Santonian age and an upper interval of Early Campanian age, separated by a major unconformity lying about half-way up the cliff section. Other less complete coastal exposures reveal either the lower92 or upper93 interval only, unconformably overlying Palaeozoic rocks. The Early Santonian succession also occurs in subcrop beneath latest Quaternary deposits of Durban Harbour (unpublished foraminifera data from samples collected from shallow boreholes drilled for the foundations of the Sugar Terminal, examined courtesy of A. Cooper and the University of Natal). Consequently, an Early Santonian succession is probably also present within the interval of Late Cretaceous rocks, from approximately 485 to 785 feet (148 to 239 m), intersected by the Bluff borehole drilled in 1906.26 The Early Santonian portion of the coastal Mzamba Formation correlates with the locally developed Early Santonian succession in the distal Thekwini Basin, intersected in boreholes Jc-B1 and Jc-D1, but there appears to be no offshore equivalent of the Early Campanian portion of the Mzamba Formation.

Unconformably overlying the offshore Cretaceous drift succession (maximum total thickness 1500 m) in the Jc boreholes is an unusually thick Cainozoic interval (maximum 1800 m thick) of Palaeocene, Early to Late Eocene, Early Oligocene and Early to Middle Miocene (Aquitanian to Langhian) age. Unconformably overlying the entire succession is a thin sea-floor veneer composed of an Eemian-Weichselian littoral shelly sand unit (Uloa Formation), unconformably overlain by a Holocene mud unit, which together are no more than 1 m thick in the vicinity of the boreholes studied.94

KwaZulu Basin (Fig. 11)

The KwaZulu, or Zululand, Basin2,13,14 is the southernmost portion of the large South Mozambique Basin. The South African portion of the basin is decidedly on the basin flank, and the succession is shelfal throughout, with no marked sediment depocentres. This is the only South African basin with much of the Cretaceous drift succession exposed on land in outcrops, or subcropping below a thin veneer of latest Quaternary deposits. Here, graben fills, presumably of Kimmeridgian to Hauterivian age, are very limited in time and distribution, reaching some 100 m thick in the vicinity of the boreholes studied.

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Unconformably overlying the graben fill and the Jurassic Lebombo Volcanics is the Cretaceous drift succession, which attains a maximum thickness of 2000 m. Except for the area of the Bumbeni High (drilled by borehole ZB), sedimentation started across the basin in mid-Barremian times (equivalent to the 6At1 to 8At1 interval of Bredasdorp Basin) with a thin (up to 33 m in borehole ZF 1/72) basal high-gamma, hemipelagic claystone. Above this the proximal succession becomes increasingly sandy and conglomeratic up the Late Barremian to earlier Early Aptian (8At1 to 13At1 equivalent) section, and is locally topped by a cap of pink terrestrial limestone (borehole NZA). Above this is the ‘Aptian-Albian Unconformity’, as described in outcrop,5 between earlier Early Aptian and basal Middle Albian rocks. Down-dip in the distal borehole sections, intervals of Late Aptian and Early Albian age occur, which do not outcrop. Similarly, the ‘mid Cretaceous Unconformity’, occurs in outcrop1 between Early Cenomanian and later Early Coniacian rocks. However, down-dip in the borehole sections, intervals of Late Cenomanian and Early Turonian age occur, which do not outcrop. Some thin high-gamma claystones with floods of lenticular radiolarians occur in between sandstones in the topmost Late Cenomanian succession. There is a substantial basin-wide gritty and pebbly clean sandstone interval towards the top of the Early Turonian, which accumulated in a forced regressive shoreline environment. This sandstone can be correlated with the Domozandstone of southern Mozambique, the ‘11’ sandstone of the Pletmos and Bredasdorp basins, the Turonian sandstones of the Gamtoos and Algoa basins, and the 133t1 sandstones of the Orange Basin. The most complete and thickest part of the succession is the Campanian, which may attain 440 m. In general, the KwaZulu Basin appears to have subsided at a slow, steady rate through most of the Barremian to Maastrichtian period, and appears to have been a more stable basin than any of the others. In addition, although sandy and silty claystones occur widely in the KwaZulu Basin, true sandstones are rare, and except for the Late Barremian to earlier Early Aptian, Late Cenomanian, and Early Turonian intervals, are mostly confined to the basin margin.

Planktonic foraminifera from the Cretaceous drift succession of the KwaZulu Basin are generally larger-sized, and assemblages are generally more diverse, than those of all the other basins studied. This is especially so for the Late Albian to Late Maastrichtian portion of the succession, but this feature is not especially apparent for the mid-Barremian to Middle Albian interval. This suggests that for at least the Late Albian to Late Maastrichtian interval, water temperatures off the KwaZulu coast were warmer than anywhere else on the southernmost African coastline.

The overlying Cainozoic succession of the KwaZulu Basin is very limited in time and distribution, reaching some 100 m thick at most, and is composed of localized remnants that have survived subsequent planation episodes. From their open shelfal foraminiferal biofacies all the remnants must formerly have constituted much more areally extensive rock units across the KwaZulu coastal plain. These remnants consist of the following ages: Early Palaeocene (Richards Bay Formation) in the vicinity of Richards Bay (up to 50 m thick in borehole Z2*), extremely thin Early and Middle Eocene in the vicinity of Lake Sibaya (together about 1.01 m in borehole ZB), and Early Miocene in the vicinity of Lake Sibaya (10.54 m of Aquitanian and 26.83 m of Burdigalian in borehole ZB*) and Kosibaa (more than 20 m of Aquitanian and 2 m of Burdigalian in shallow borehole P110-4a.77,96 The Palaeogene and Neogene units are not found in outcrop. They are unconformably overlain by the Eemian-Weichselian forced regressive Uloa Formation, which is in turn unconformably overlain by the ?Weichselian-Early Holocene couplet of the terrestrial ‘Berea Sands’ and the estuarine Port Durnford Formation.43,44 Like the rest of the South African continental margin, the KwaZulu coastal plain was subject to post-Pliocene uplift, which removed most of the previously...
Fig. 11. Interpreted chronostratigraphy and summarized lithostratigraphy of the Cretaceous drift succession of the KwaZulu Basin. Yellow intervals mark thick or massive sandstones, single lines of stipple indicate sandstone stringers, blue intervals mark claystones (with major high-gamma claystones distinguished), and "brickwork" symbol represents carbonates. White areas are unconformities.
deposited Palaeogene and Neogene succession, and exhumed the Cretaceous drift succession. In all likelihood, older Pleistocene raised beaches can be expected to exist, equivalent to the Early Pleistocene 50-m and 30-m Packages of the west coast of South Africa, at higher altitudes than the Uloa Formation, lying on the flanks of the Early Cretaceous and Lebombo Volcanics successions. However, such raised beaches have not yet been recognized.

Foraminiferal biostratigraphy

Fine-scale foraminiferal biostratigraphic analysis of the Cretaceous drift successions in the seven basins studied has revealed that these subdivide into two distinct episodes. In the first (Early Barremian to Early Cenomanian), most basins accumulated virtually the same stratigraphic succession, and unconformities developed of much the same magnitude. In the second episode, from the base of the Late Cenomanian to the end of the Maastrichtian, a history of repeated uplifted Atlantic and Southern margins/subsided Indian Margin, or vice versa, is evident. Where possible, dating comparisons and correlations are made to the Cretaceous succession of southern England, based on the detailed foraminiferal biostratigraphy established by Hart and his co-workers. Especially useful are the range charts of the bed-by-bed distributions of foraminifera species (figs 7.4–7.17 of ref. 23), showing the relative ranges of species such as Lingulogavelinella globosa (Brotzen) and Rotalipora cashmari (Morrow). Such a correlation has been attempted, to try to establish how complete is the stratigraphic succession preserved around southern Africa. In particular, since the southern England and North Sea Cenomanian to Maastrichtian stratigraphic succession consists almost exclusively of remarkably continuous chalk lithologies, the implication is that this region suffered minimal tectonic movement during that period. Consequently, the English chalk succession is expected to be a more complete one than the mainly siliciclastic time-equivalent succession preserved around southern Africa.

The southern African Cretaceous drift succession can be divided into the following 22 units, described below. Some of these units can be further subdivided by foraminifera; I comment on subdivisions where they are regarded as of value in correlating between the seven basins. The stratigraphically defined boundary unconformities of these units in the seven basins, and first downhole foraminiferal appearances, are also given in the comments on each unit. The unconformity at the top of the Hauterivian succession (interpreted as the rift-drift or drift onset unconformity) is termed 6At1, but previously this was locally erroneously identified as 6At1, such as in ref. 101. In the following sections, species with the species name in inverted commas are informal, unpublished names, as recognized in-house in both Soekor and De Beers Marine.

Early Barremian (approximately 127–124.5 Myr)

(R to P2 in Orange Basin; 5At1 to 6At1 in Bredasdorp Basin; 5At1 to 12At1 in Pletmos Basin; absent in Gamtoos, Algoa and KwaZulu Basins; possibly present in southern Thekwini Basin.) This interval is distinguished by the marker species Reinholdella cf. valdensensis (Bartenstein & Brand) and Conorboides 'barreniana'. Planularella triaricella (Reuss) occurs only in the earlier part, and Pseudopolyphyma 'carinata' only in the later part of the Early Barremian succession in the Pletmos Basin. Because of active tectonic uplift and subsidence during this period, this succession is only locally developed, and often the 5At1 and 6At1 unconformities are compounded on the palaeo-shelf. In addition, many Early Barremian borehole sections are only poorly fossiliferous. Foraminiferal assemblages tend to be monotonous, in part because of poor sea-floor water circulation and low levels of dissolved oxygen at the time of deposition, and also because there are many sandstones. The Early Barremian interval seems to be thickest and most frequently encountered in boreholes in the northern Bredasdorp and Pletmos basins, and is generally absent or very limited in the southernmost offshore parts of the two basins. Notable shelf successions rich in foraminifera and with few sandstones occur particularly in the northern Pletmos Basin, such as in boreholes Ga-D1 and Ga-W1. Epistomina caracolla (Roemer) s.l. is common, but no in ten of, and Astacus lookardie gruyet Espsitalè & Sigal, Lenticulina nodosa Reuss, Trachammina sundaysriverensis McMillan, Citharina austroafricana McMillan, Astacus gibber Espsitalè & Sigal and conservative Lenticulina spp. occur widely in shelfal successions. Distal successions sited on the palaeo-shelf generally contain only small numbers of pyritized radiolarians, 'brown plates' and extremely low-diversity agglutinated foraminifera assemblages of Haplophragmoides species (fig. 3 of ref. 92). There are no planktonic foraminifera in this interval. In sandier successions on the palaeo-shelf, indeterminate or conservative species of Ammobaculites and Haplophragmoides predominate, as in the F-A boreholes in the northeastern Bredasdorp Basin.

Not surprisingly, the succession of volcanics and littoral and aeolian sandstones regarded as of Early Barremian age intersected in the Kudu boreholes of the northern Orange Basin is generally unfossiliferous, but occasional thin, uncedmented black shale intervals occur within the topmost sandstones that contain pyritized benthonic foraminifera: Quinqueloculina sp., Globulina sp. and Cornuspira sp. This assemblage is not very age-diagnostic, but the succession can be constrained since it uncommonly overlies the seaward-thickening wedge, and unconformably underlies dated mid-Barremian claystones. When examined on seismic sections, the Early Barremian interval in the northern Orange Basin can be seen to be limited to a narrow zone beneath the present-day outer shelf, and for the most part is too deeply buried by the overlying Cretaceous succession to be accessed in oil exploration boreholes. Closer to shore, across most of the present-day middle and inner shelf, and everywhere in the southern Orange Basin, the Early to mid-Barremian interval is missing, and there are no other boreholes in the Orange Basin that intersect this Early Barremian unit.

The entire Early Barremian to earlier Early Aptian succession is missing in the Gamtoos and Algoa basins. The easternmost boreholes of the Pletmos Basin that contain this succession show Late Barremian rocks onlapping on to the Early Barremian section in an eastwards direction, and the mid-Barremian high-gamma claystone unit is absent. This relationship is especially seen between boreholes Gb-K1 (complete section) and Gb-II (mid-Barremian hemipelagic claystone missing). Further east still, the westernmost Gamtoos Basin borehole Ha-J1 contains only a much thinner interval of Early Barremian age. The occurrence in borehole Ha-J1 is the most easterly yet known, for the Early Barremian is yet to be drilled in the Thekwini Basin (if present), and it is absent in the KwaZulu Basin.

Thickness of Early Barremian interval. Estimated to be about 800 m of volcanics, topped by aeolian and littoral shelly sandstones and interbedded rare black claystones in Kudu boreholes, but elsewhere absent in Orange Basin; up to 600 m (borehole E-L1), but tends to be absent in distal part of basin, such as in boreholes E-R1, E-D3, and F-R1, Bredasdorp Basin; up to 1300 m.
Fig. 12. Interpreted chronostratigraphic ranges of selected foraminifera species on the continental shelf and uppermost slope, occurring in the Cretaceous drift succession (Early Barremian to Late Maastrichtian) of southern Africa. The interpreted chronostratigraphic successions, including the major sequence boundaries and the most significant seismic horizons of the seven basins studied, are shown for comparative purposes. Large dots and thickened bars on particular stratigraphic ranges mark the
occurrence of local or regional highstands and associated unconformities. Shaded areas in the upper vertical columns mark uplift or tilting, while vertically lined areas indicate unconformities. High gamma claystones are marked with a symbol, while a horizontal line of dots indicates the stratigraphic level of the Horizon 1.1 sandstones.
Mid-Barremian (approximately 124.5–123.5 Myr)

Source rock locally (P2 to unnamed horizon in Orange Basin; 6At1 to 8At1 in Bredasdorp Basin; 12At1 to 12Ct1 in Pletmos Basin; absent in Gamtoos and Algoa basins; unnamed horizons in southern Thekwini Basin; basal high-gamma claystone unconformably overlying Lebombo Volcanics in KwaZulu Basin) with abundant Gorbachikella kugleri (Bolli) and rare Prachledbergella sigali (Moullade) plankton flood. Locally in some borehole intersections especially in the Pletmos Basin (Ga-A boreholes), this interval contains an agglutinated bentthic assemblage distinguished by *Verneuilina hovcheni* Crespin, *Gravellina australis*, *Trocchamminoides coronus* Loeblich & Tappan, and occasionally *Ulvigerinamina manitobensis* (Wickenden). This mid-Barremian occurrence of planktonic foraminifera is the first in the South African stratigraphic record, and they do not reappear until the later Early Aptian. This distinctive planktonic foraminifera-bearing interval is also recognized in the North Sea Early Cretaceous succession (figs 8.3 and 8.5 of ref. 24). It has been identified as representing a major expansion of the planktonic foraminifera habitat, away from the tropical Tethyan waters where they first appeared in the Jurassic, and into more temperate waters in both the northern and southern hemispheres.  

Just below the planktonic foraminifera-bearing stratigraphic level occur floods of relatively large-sized *Epistomina caracolla* (Roemer) s.l., and these are especially abundant in the organic-rich claystones of the mid-Barremian palaeo-outter shelf, in the Bredasdorp, Pletmos and KwaZulu basins. Sandier regions of the Bredasdorp Basin contain only agglutinated foraminifera (*Ammobaculites* and *Haplophragmoides* species) to this stratigraphic level, as evident in the F-A boreholes in the southern Thekwini Basin; basal high-gamma claystone conformably overlying Lebombo Volcanics in KwaZulu Basin; above basal high gamma claystone to *Astacolus gibber* Espitalié & Sigal, *Astacolus microdictyotos* Espitalié & Sigal, *Pseudopolyphyma carinata* and *Reinholdella cf. valdensis* Bartonstein & Brand only in the basal part of interval. This succession everywhere contains low-diversity foraminifera assemblages, regardless of whether lithologies are dominated by claystones or sandstones. Variable thicknesses of shelfal sandstones occur proximally in the southern Orange, Bredasdorp, northern Pletmos, southern Thekwini and KwaZulu basins, which in the Bredasdorp Basin mostly lie within the 9At1 to 12At1 interval. Distal, slope claystones are distinguished by abundant ‘brown plates’, downslope-transported blocks of *Inoceramus* prisms, fluctuating numbers of pyritized radiolarians, and rare agglutinated foraminifera. Claystones on the shelf are distinguished by low diversity nodosarid assemblages, in which *Lenticulina nodosa*, other conservative *Lenticulina* species and *Pseudodosarid* centrum (*Borenmann*) predominate. *Epistomina caracolla* (Roemer) s.l. is absent. In sandier shelf sections there are usually only variable numbers of mostly indeterminable *Ammobaculites* and *Haplophragmoides* species, sometimes with the relatively large-sized *Ammobaculites subeqaulis* Mjatljuk. Both in shallow and deep-water settings, this succession is not easy to subdivide. The presence of *Lenticulina nodosa* right to the top of the succession where clays predominate indicates an age no later than Early Aptian.

The topmost beds of the earlier Early Aptian interval, immediately below the 13At1 unconformity, on the northeast flank of the Bredasdorp Basin (E-M, E-S and F-A boreholes), are distinguished by a thin horizon of ‘ferro-ooliths’ (fig. 3 of ref. 92). These are microscopic sub-spherical or ovoid pellets distinguished by a hard thin, straw-coloured external coating, and a softer, mint-green interior. They constitute a distinctive horizon in a rather sandy, poorly fossiliferous part of the succession, and locally occur in association with *Lenticulina nodosa*. In claystones just below the ‘ferro-ooliths’ are the oldest specimens of *Conorotalites apthiensis* found on the southern African margin (fig. 3 of ref. 92). This species is similar to true *Conorotalites apthiensis* (Betenstaedt), first described from northwest Germany, but it differs by consistently displaying a completely flat dorsal side to the test. Its stratigraphic range (earlier Early Aptian to topmost Early Cenomanian) differs from the German species, and it warrants a new species name.
absent along northern margin, and thinning southwards, being 680 m in borehole Ga-H1, 475 m in borehole Ga-V1, 365 m in borehole Ga-K1, and, on the palaeo-slope in the southern part of the basin, only 320 m in borehole Ga-J1, 258 m in borehole Ga-E2, and 68 m in borehole Ga-E1, only 160 m in eastemmost borehole Ga-I1, Pletmos Basin; absent in Gamtoos and Algoa basins; variably distributed, being 890 m in southern borehole Jc-C1 and 290 m in northern borehole Jc-B1, elsewhere absent in Thekwini Basin; variable thickness because of basin topography, but up to 330 m in borehole ZF 1/72, KwaZulu Basin.

Published/illustrated foraminifera. The only published illustrations of foraminifera of this interval are from DSDP site 249, as detailed above for the mid-Barremian.75 A short list of species, including Lenticulina nodosa, from the earlier Early Aptian of Chalala in southern Mozambique has been published,39 but none is illustrated.

Later Early Aptian (approximately 118.5–116 Myr)

Source rock (P1 to P0/t1 in Orange Basin; 13A/t1 to 14At1 in Bredasdorp and Pletmos basins; absent in Gamtoos, Algoa, Thekwini and KwaZulu basins). This interval is characterized by abundant radiolaria, abundant Praehedbergella sigali (Moullade) and rare Gorbachikella kugleri (Bolli), as a strongly marked plankton flood. This succession is confined to the palaeo-slope in all basins, and has not been recorded where drilling hitherto has been limited to the palaeo-shelf. Many of the radiolaria are white, and usually well preserved either as calcite or silica infillings: dictyoanform forms predominate. Proximal successions high on the palaeo-slope (as in borehole E-N1 in Bredasdorp Basin) contain considerable numbers of one or two species of benthonic foraminifera such as Gavelina sp., but in deeper waters, assemblages consist only of planktonic elements. ‘Brown plates’ are absent in every borehole intersection. This organic-rich interval is an economically significant source rock. Microfaunal processing of samples from this interval in the Bredasdorp Basin shows abundant organic-stained tiny quartz grains (<125 µm diameter), in which the dark brown organic matter has penetrated microscopic fractures on the surface of the grains. Seismic stratigraphic work has considered this interval to represent a marine condensed section, but it represents relatively fast hemipelagic sedimentation over little time, as there is essentially no difference in foraminiferal assemblage throughout the interval. The presence of Gorbachikella kugleri indicates that this interval cannot be any later in age than mid-Aptian.

This later Early Aptian interval probably correlates with the planktonic foraminifera-bearing Atherfield Clay of southern England.22,23,63 Specimens referred to the names ‘Hedbergella heteroviva (Subbotina)’ (illustrated) and ‘Hedbergella infractacea (Glaessner)’ (not illustrated) were reported from the Atherfield Clay.39 The illustrations of the former species (pl. 2, fig. 1-2 of ref. 63) indicate that it lacks a reticulated surface ornamentation, and thus is probably referable to Praehedbergella sigali (Moullade) and Gorbachikella kugleri (Bolli) on the one hand, and Globigerinelloides algerianus and Hedbergella trocoida on the other.

Thickness of Late Aptian interval. Confined to southern palaeo-outermost shelf and uppermost slope, with maximum of about 80 m in borehole A-N1, southern Orange Basin; widely developed along central axis of the basin but absent along Agulhas and Infanta (E-M, E-S and F-A boreholes) flanks, and absent distally on most of the palaeo-slope, 23 m in borehole E-AP, 48 m in D-D1, 17 m in borehole E-C1, 124 m in borehole E-AA1, 94 m in borehole E-R1, Bredasdorp Basin; everywhere absent in Pletmos and Gamtoos basins; probably 311-m-thick interval in base of canyon fill (borehole Hb-II), Algoa Basin; absent in Thekwini Basin; confined to distal intersections on the palaeo-outershelf, being up to 123 m in borehole ZE 1/71, KwaZulu Basin.

Published/illustrated foraminifera. None.

Early Albian (approximately 112–108 Myr)

(99/t1 to below 5t1 in Orange Basin; 13A/t1 to 14At1 in Bredasdorp Basin; absent in Pletmos Basin; absent in Gamtoos Basin; probably from base of canyon to horizon I in basinal canyon fill in Algoa Basin; absent in Thekwini Basin; thin interval just above ‘Aptian-Albian Unconformity’ only in distal KwaZulu Basin, not outcropping.) This interval is distinguished by Globigerinelloides algerianus Cushman & Ten Dam, Hedbergella trocoida (Gandolfi) and Bilingulogavelinella australis Scheiibernova. This interval does not outcrop in any basin. These three distinctive species are all confined to the palaeo-shelf (even though the first two are planktonic foraminifera), and as yet there is no viable marker species that identifies this interval on the palaeo-slope. Consequently, in the distal Bredasdorp Basin this succession (13A/t1 to 14At1 interval) can be defined only using seismic sections. This succession is limited in areal extent to the palaeo-outershelf of the southern Orange Basin, the palaeo-shelf and palaeo-slope of the western and central Bredasdorp Basin, and the palaeo-outershelf of the KwaZulu Basin. A shallow-marine sandstone interval at the base of the Algoa Basin canyon-fill succession (borehole Hb-II) probably is also Late Aptian in age, but despite an intensive search, no diagnostic microfossils have been found to confirm this. Generally, diverse foraminifera assemblages of benthonic foraminifera occur everywhere, but apart from the three species listed, all others also occur in the earlier Albian succession. From Late Aptian to Early Cenomanian times diverse foraminifera assemblages predominate in all the basins studied, with a wide variety of calcareous benthonic species, indicating generally well-oxygenated sea-floor conditions all round South Africa, except proximally in the hyposaline facies off the west coast. From available sidewall core data in studied borehole sections there is no overlap in any of the South African basins between the stratigraphic ranges of Praehedbergella sigali (Moullade) and Gorbachikella kugleri (Bolli) on the one hand, and Globigerinelloides algerianus and Hedbergella trocoida on the other.

Thickness of Early Albian interval. About 150 m in Kudu boreholes and 40 m in O-A1, absent elsewhere in Orange Basin; maximum thickness of 219 m in palaeo-uppermost slope borehole E-N1, thinned further offshore (140 m in borehole E-AA1, 123 m in borehole E-D3, 81 m in borehole E-R1, 86 m in borehole F-R1), and entirely absent on palaeo-shelf, Bredasdorp Basin; much thinner in this basin, being 47 m in borehole Ga-I1, 69 m in Ga-S1 (both sited in the southwest of the basin), and only 21 m in borehole Ga-E2 and 22 m in borehole Ga-E1, again entirely absent on the palaeo-shelf, Pletmos Basin; absent in Gamtoos, Algoa, Thekwini and KwaZulu basins.

Published/illustrated foraminifera. None.
KwaZulu Basin.) This interval is distinguished by *Involutina* sp. (only in KwaZulu Basin), *Hedbergella planispira* (Tappan), *Favusella washitensis* (Casey), and *fat Gavelinella* sp. Most of the foraminifera of this interval are essentially the same as those encountered in the Middle Albian. The Early Albian does not outcrop in the Orange, Pletmos, Gamtoos, Algoa or KwaZulu basins. It probably also does not outcrop in the Bredasdorp Basin, although it may possibly reach the present sea floor north and northwest of proximal boreholes D-C1 and D-B1. Microfossil samples from fully cored boreholes ZA, ZB and ZC in the KwaZulu Basin show that the stratigraphic ranges of *Globigerinelloides* *algerianus* Cushman & Ten Dam and *Hedbergella trocidea* (Gandolfo) do not overlap with that of *Favusella washitensis*.

The top of this interval is difficult to define in palaeo-shelf settings of the central Orange Basin and the proximal Bredasdorp Basin, because of the development of hyposaline facies on the palaeo-inner shelf, and the considerable thicknesses of widespread massive sandstones on the palaeo-outter shelf, which range through most of the Middle Albian to Early Cenomanian interval. Consequently, in central Orange Basin boreholes such as K-A2 and others nearby, and in central Bredasdorp Basin boreholes such as E-AP1 and E-N1, the top of the Early Albian is most easily defined as the first downhole appearance of diverse calcareous benthonic foraminifera assemblages just below the abrupt base of the massive sandstones. The Early Albian unit is rather limited in distribution, and frequently is absent on parts of the palaeo-uppermost slope, as in the distal Orange and Bredasdorp Basins, and extensively absent across the palaeo-shelf, as seen across the entire Pletmos Basin, the Infanta Embayment, and the E-S to F-A flank of the Bredasdorp Basin.

**Thickness of Early Albian interval.** Because of downlapping, few boreholes intersect the full succession, but it is 1116 m thick in basin depocentre borehole K-A2, 1284 m proximal borehole A-D1, and is clearly thinner in the south of the basin, being up to only 525 m in distal borehole A-N1: it is absent on the palaeo-slope (Kudu boreholes, O-A1), Orange Basin; much more areally extensive than, but similarly distributed to underlying Late Aptian interval, being 239 m in borehole E-AP1, 162 m in borehole E-N1, 251 m in borehole E-AA1, about 130 m in borehole E-R1, only 90 m in borehole E-M1, and absent in E-S and F-A boreholes on the Infanta flank, also often absent distally (boreholes E-D3, F-R1), Bredasdorp Basin; limited to distal boreholes on the palaeo-slope, being 193 m in borehole Ga-J1, 177 m in borehole Ga-E1 and 169 m in borehole Ga-E2, Pletmos Basin; Early to Middle Albian canyon fills cannot be subdivided by foraminifera in boreholes Ha-G1 and Ha-K1 in the Gamtoos Basin; confined to the lower canyon fills, not easily discriminated, probably missing in canyon flank borehole Bb-C1 and about 480 m in canyon axis borehole Hb-11, Algoa Basin; only 10 m thick and only in borehole Jc-D1, Thekwini Basin; confined to distal boreholes on the palaeo-middle and outer shelf, being a maximum thickness of about 125 m in borehole ZE 1/71 (but poor sample quality in this interval in some boreholes, and foraminifera assemblages often not representative), KwaZulu Basin. Published/illustrated foraminifera. None.

**Middle Albian (approximately 108–104 Myr)** (40t1 to 100t1/715t1 in Orange Basin, and outcrops at sea floor; unnamed horizon to just above 14t1 in Bredasdorp Basin; unnamed horizon to just above ‘14t1’ in Pletmos Basin; upper canyon fill in Gamtoos Basin; horizon III to top canyon fill in Algoa Basin; only locally present in Thekwini Basin; ‘lower’ Albian outcropping interval in KwaZulu Basin.) This interval is distinguished by *Favusella washitensis* (Casey), *Marginulinopsis pristipellis* Ludbrook on the palaeo-shelf and *Osangularia schloenbachii* (Reuss) on the palaeo-slope. There are unresolved seismic/foraminiferal correlation problems in the interval from 100t1 to 115t1 between the northern and southern Orange Basin. This interval is considered to correlate with the English lower Gault Clay/Upper Greensand succession. It is considered to equate to the Tuenza and Catumbela formations dolomites and limestones of the Kwanza and Benguela basins of the Angolan margin. As with the Early Albian, Middle Albian foraminifera assemblages are abundant, especially in the claystones distal to, and along strike of, the massive sandstones. In palaeo-slope settings, *Osangularia schloenbachii* (Reuss) (previously identified as *Osangularia californica* Dailey around South Africa) occurs in abundance with *Migros gigantica* and *Biminitina* sp. In the palaeo-mid to outer shelf massive sandstone successions of the central Orange and central Bredasdorp basins, foraminifera are usually absent, but small numbers of foraminifera and ostracods often occur in thin interbedded claystones. Shelf foraminifera assemblages include glassy *Verteulina* sp., fat *Gavelinella* sp., *Gavelinella flora*, as well as *Favusella washitensis* (Casey) and *Marginulinopsis pristipellis* Ludbrook. Other species encountered widely in the Middle Albian mostly range through-out the Albain and Early Cenomanian intervals: *Clavulina gaulinata* Morozova, *Conorotalites aptiensis*, *Textularia foeca* Reuss, *Spiropectinata annectens* (Parker & Jones), *Spiropectinata complanata* (Reuss), smooth *Dorothy oxycena* (Reuss), *Dorothy obesa* Le Calvez, *De Klasz & Brun* (identical to *Dorothia mordoviovi* Caen & Ernst), *Gavelinella pletmosiana* (identical to *Valutineria fuequina* Malumàin & Maisiuk), *Pleurostomella reussi* Berthelin, *Studiuma* sp. and *Gaudryina globulifera*. Planktonic foraminifera assemblages consist essentially of species of *Hedbergella* and *alloglobigerinelloides*, with only *Hedbergella planispira* (Tappan) and *Favusella washitensis* (Casey) being distinctive. A hyposaline palaeo-inner shelf facies marked by cyclical thin sandstones and thin black, organic-rich claystones occurs only in the proximal Orange Basin throughout the Early to Late Albian, and is distinguished particularly by abundant specimens of large black *Haplophragmoides secuies*, together with numerous more nongeneric *Haplophragmoides* spp. and *Ammobaculites* spp. The relationships of the comparable facies in the proximal Bredasdorp Basin have previously been figured (fig. 3 of ref. 92).

The planktonic species *Favusella washitensis* always becomes extinct in the southern African stratigraphic succession in association with the extinctions of a number of benthonic foraminifera, as described above and previously (fig. 3 of ref. 92). It clearly became extinct in our region well before the evolutionary appearance of *Rotaliopora appennincina* (Renz), the latter datum being regarded in southern Africa as of latest Late Albian age, and probably but not closely synchronous with the short range of *Planomalina buxtorfi* (Gandolfo), as seen in the KwaZulu Basin. *Favusella washitensis* appears to have much the same range in Brazil as in South Africa, but in northwest Europe its stratigraphic range is very different. Detailed analysis of Early Cretaceous planktonic foraminifera lineages has led to the recognition of an evolutionary series of *Favusella* species ranging from the basal Hautevitarian to the Early Cenomanian, in which the favouse ornament gradually increased through time in pattern size and intensity. On the basis of this work, all South African *Favusella* specimens examined by the author must be referred to *F. washitensis*, since their surface ornamentation is coarsely and strongly developed. None of the Hautevitarian to Aptian *Favusella* species with a finer surface ornamentation has been found in South Africa. Other authors' illustrations of *Favusella* from southern...
Africa\textsuperscript{a,b,9} are also clearly of the \textit{F. washtensis} type. Despite the lack of other confirmatory age-diagnostic planktonic species in this part of the South African stratigraphic succession, the abrupt first downhole appearance of \textit{Farussia washtensis} in the basins studied has been taken to mark the top of the Middle Albian around southern Africa. Where the Middle Albian succession unconformably overlies distinctly older rocks, principally the earlier Early Aptian interval, extensively across the northeastern flank, and locally across the Agulhas flank of the Bredasdorp Basin, the basal part of the Middle Albian is distinguished by a widely developed, thin unit which contains only agglutinated foraminifera (\textit{Ammobaculites} and \textit{Haplophragmoides} spp.). Many specimens of the latter genus are unusually large-sized, rather globular forms, and frequently badly distorted by diagenetic sediment compaction, so that this basal unit is easy to recognize. Typical thicknesses of this basal unit are seen in northeastern flank boreholes E-M1 (90 m), E-S2 (43 m), F-A10 (40 m), F-AH1 (44 m), in Infanta Embayment borehole F-K1 (42 m), and in Agulhas flank borehole E-P2 (60 m).

\textit{Thickness of Middle Albian interval.} Succession generally thinner than the Early Albian, being 735 m in depocentre borehole K-A2, 368 m in southern borehole A-N1, and much thinner on the palaeo-slope, being only 160 m in borehole Kudu 9A-2 and 141 m in borehole O-A1, \textit{Orange Basin}; much more areally extensive than the Early Albian interval, especially on the Agulhas and Infanta flanks and distally, but thickest in central basin, attaining 350 m in borehole E-AA1, 419 m in borehole E-N1, 206 m in borehole E-API, 252 m in borehole E-M1, about 130 m in borehole E-R1, 300 m in borehole E-D3, 249 m in borehole F-R1, 186 m in borehole F-AFI and 122 m in borehole F-A5, Bredasdorp Basin; developed across entire continental margin (palaeo-slope and slope), but thickest on uppermost palaeo-slope, attaining 70 m in borehole Gb-Gemsbok 1, 80 m in borehole Ga-V1, 150 m in borehole Gb-GK1, 280 m in borehole Ga-J1, 212 m in borehole Ga-E2, and 144 m in borehole Ga-E1, \textit{Pletmos Basin}; Early to Middle Albian canyon fill not subdivisible using foraminifera, being a total of 290 m in borehole Ha-G1 and 360 m in borehole Ha-K1, \textit{Gamtoos Basin}; confined to upper portion of canyon fill, being 432 m in canyon flank borehole Hb-C1 and 600 m in canyon axis borehole Hb-I1, \textit{Algoa Basin}; confined to distal part of basin, 60 m only in borehole Je-D1, \textit{Thekwini Basin}; extensively developed across palaeo-shelf, up to 130 m thick in fully cored borehole ZA, \textit{KwaZulu Basin}.

Published/illustrated \textit{foraminifera.} Many species of Middle to Late Albian foraminifera have been illustrated from the KwaZulu Basin onshore outcrops.\textsuperscript{41} In addition, 32 species of foraminifera have been listed from an outcrop at Catuane, immediately north of the South Africa–Mozambique border, and lying within the South Mozambique Basin.\textsuperscript{53} This diverse assemblage includes a wide variety of nodosariids, as well as the planktonic species \textit{Hedbergella delrioensis} (Carsey) and \textit{Hedbergella planispira} (Tappan), which confirm that the Catuane assemblage can be no older than Middle Albian. Inner shelf Middle to Late Albian aragonitic-dominated (\textit{Epistomina}) foraminiferal assemblages have been listed from two sea-floor samples (TBD 1113 and TBD 1266) recovered from off the coast at Plettenberg Bay, on the Southern Margin,\textsuperscript{48} that compare closely with those from adjacent deep boreholes drilled in the proximal Pletmos Basin. There are also well-illustrated deeper marine foraminiferal assemblages from the Middle to Late Albian of the southern Angolan offshore.\textsuperscript{45,9} from DSDP sites 363 and 364, \textit{Farussia washtensis} has been illustrated from the ‘Cenomanian’ (possibly from the underlying Middle Albian beds) of the Angolan coastal basins.\textsuperscript{8} A few species have also been listed from the Middle Albian of the northern Orange Basin, Namibia,\textsuperscript{37} and of the Southern Margin basins, South Africa (fig. 3 of ref. 92).

\textbf{Late Albian (approximately 104–99 Myr)}

(Usually 100t1 to 115t1 in Orange Basin, and outcrops at sea floor; just above 14Bt1 to 14Ct1 in Bredasdorp Basin; just above ‘14A1’ to just above ‘14B1’ in Pletmos Basin; very thin in western part, absent in eastern part of Gamtoos Basin; absent in Algoa and in Thekwini basins; present as ‘upper’ Albian outcropping interval in KwaZulu Basin.) This interval is distinguished by \textit{Planomalina buxtorfi} (Gandolfi) (only in the KwaZulu Basin), \textit{Lenticulina cf. angulosa} (Chapman) on the palaeo-shelf, \textit{Tritaxia tricarinata} (Reuss) on the palaeo-outershelf to slope, \textit{Notocorbina leanzai} Malumián & Masiuk and \textit{Autolotortus} sp., both on the palaeo-slope. \textit{Rotalipora appenninica} (Ren) occurs widely in the topmost Late Albian beds, where these are clayslates. The Late Albian interval in South Africa is considered to correlate with the English upper Gault Clay succession.\textsuperscript{22,23} Similar foraminiferal assemblages are seen in the Late Albian as previously described for the Middle Albian, but there are also distinct differences. This interval is considered to be the time equivalent of the Quissonde Formation of the Kwanza Basin.\textsuperscript{55,56} \textit{Farussia washtensis} (Carsey) is everywhere absent in the Late Albian succession of South Africa.

Where fast sedimentation, sand-rich sediment deposition and hyposaline conditions prevailed on the Early to Late Albian palaeo-inner shelf, as in the proximal Orange and Bredasdorp basins, agglutinated benthonic foraminifera (mainly \textit{Ammobaculites} and \textit{Haplophragmoides} spp.) predominate. However, where the palaeo-inner shelf experienced normal marine salinities, sedimentation rates were lower, and clay deposition prevailed, as in the proximal Pletmos and KwaZulu basins and to a lesser degree the Gamtoos and Algoa basins, there is a distinctive calcareous benthonic assemblage dominated by aragonitic-walled species. These include \textit{Epistomina chapmani} Ten Dam, \textit{Epistomina spinulifera} \textit{polypoides} (Eichenberg) (at least two morphologically very similar species, and see \textit{Epistomina} sp. in the KwaZulu Basin\textsuperscript{45}), \textit{Epistomina cretosa} Ten Dam (only in Early to Middle Albian) \textit{Reinholdella 'lambertaee} (previously identified as \textit{Pseudolamarckina} sp. in the KwaZulu Basin\textsuperscript{46}), \textit{Ceratobulimina woood Khan, Colomia cf. ‘Bolivia’ gautlin Khan and Colomia cf. \textit{austrrothocus} Taylor. There are also calcitic species in this biofacies, such as turbidite \textit{Spirillina} species and \textit{Psilocistharella} sp.. This aragonitic-dominated inner shelf assemblage ranges in age from the basal Late Aptian to the middle Early Turonian high-gamma clayslate unit, although not all of the listed species range throughout this period.

Two foraminiferal assemblages of this aragonitic type were listed by Dingle from sea-floor samples TBD 1113 and TBD 1266 recovered from off the Plettenberg Bay coast on the Southern Margin,\textsuperscript{99} identified by H. Luterbacher. The former sample contained species identified as \textit{Epistomina mosquensis} \textit{aevaedala} Espitalié & Sigal, \textit{Epistomina spinulifera} (Reuss), \textit{Epistomina aff. caracolla} (Roemer), \textit{Lenticulina} sp., \textit{Citharinella} species and \textit{Psilocistharella aff. aphiensis} (Eichenberg). The latter sample contained species identified as \textit{Epistomina mosquensis} \textit{aevaedala} Espitalié & Sigal, and \textit{Epistomina aff. caracolla} Roemer. Strongly ornamented \textit{Epistomina} specimens of the \textit{E. spinulifera} group are confined to the Late Aptian to Early Turonian part of the Cretaceous drift succession in southernmost Africa. \textit{Psilocistharella} sp. of the \textit{P. aphiensis} type are limited to the Middle Albian to Early Cenomanian part of the succession. On this basis, it is probable
that the E. aff. caracolla is in fact E. chapmani Ten Dam, and that the E. mosquensis alveolata is an unnamed Epistominella species with a reticulate surface ornamentation. These two samples are sited on the sea-floor outcrop of the Cretaceous drift succession in the proximal Pletmos Basin, and contain foraminiferal assemblages identical to those seen in adjacent deep boreholes intersecting the Middle to Late Albian interval: the Early Cenomanian portion of this succession is missing through erosion in the proximal part of the Pletmos Basin.

Agglutinated benthonic foraminifera Trinitaxis triacrinata (Reuss) defines the top of the Late Albian interval in distal palaeo-slope claystone successions, Lenticulina cf. angulosa (Chapman) does the same in palaeo-shelf claystones, and both these markers can be precisely tied together in KwaZulu Basin fully cored boreholes to the only southern African appearance of the distinctive latest Albian planktonic marker Planomalina buxtorfi (Gandolfi), which is confined to that basin. In some distal boreholes of the Bredasdorp Basin (such as borehole E-A1) and Orange Basin (such as borehole K-H1) there is a clear ‘spike’ of Rotalipora appenninica (Renz) specimens at the Late Albian–Early Cenomanian unconformity. We have not found species of age-diagnostic planktonic genera such as Schackoina, Ticinella or Bticinella anywhere in the South African Late Aptian to Albian succession (only Hedbergella and Globigerinelloides are widespread), so that fine-stratigraphic subdivision of this part of the succession using planktonic foraminifera is not yet possible. This is probably because either all our basins lay too far south of the distributions of these essentially warm-water genera, or because the great majority of our studied basins contain strongly territorially-influenced sedimentation during this period.

Thickness of Late Albian interval. Distally up to 370 m (borehole K-H1, palaeo-outmost shelf) in central basin, less in the south (258 m in borehole K-D1, 171 m in borehole A-N1), and very much less on the palaeo-slope (110 m in borehole Kudu 9A-2), Orange Basin; distally up to 330 m (borehole E-D3, palaeo-uppermost slope) in southwest, up to 210 m (borehole F-R1) in the southeast, up to 215 m in centre (borehole E-A1), but generally less on northeast flank (198 m in borehole E-M1, 164 m in borehole F-A2), Bredasdorp Basin; distally 216 m in borehole Ga-E1, 130 m in borehole Ga-J1 (both on the palaeo-uppermost slope), becoming much thinner on the palaeo-shelf, being 125 m in borehole Ga-V1 in west, 88 m in borehole Ga-AA1 in centre, and 63 m in borehole Gb-Gemsbok 1, 60 m in borehole Gb-K1 in east, Pletmos Basin; no more than 40 m in distal boreholes such as Ha-B2, Gamtoos Basin; absent in Algoa Basin and Thokwini Basin; up to 146 m in distal fully cored borehole ZC, but generally about 110 m as in borehole ZE 1/71, in KwaZulu Basin.

Published/illustrated foraminifera. See references detailed in Middle Albian section above. A few species have been listed from the Quissonde Formation carbonates of the Kwanza Basin. A few foraminifera species have also been listed from the northernmost Orange Basin, Namibia, and from the Southern Margin basins of South Africa (ref. 81 and fig. 3 of ref. 92). A few latest Albian or earliest Cenomanian planktonic foraminifera, including Rotalipora balearnaensis (Gandolfi) (now regarded as synonymous with Rotalipora appenninica), have been illustrated from DSDP site 249, off the Indian Margin. These specimens suffer from calcite crystal overgrowths.

Early Cenomanian (approximately 99–97.2 Myr)

(1151 to 1301 in Orange Basin, and outcrops at sea floor; 14C1 to 15A1 in Bredasdorp Basin; just above ‘14B1’ to 15A1 in Pletmos Basin; absent in Gamtoos Basin; top canyon fill to 15A1 in Algoa Basin; thin interval in distal northern Thakwini Basin; Cenomanian outcropping interval in KwaZulu Basin.) This interval is distinguished by Rotalipora appenninica (Renz), Rotalipora gandolfii Luterbacher & Premoli-Silva, Gavelinella ‘pletmosiana’(equivalent to Valvulinella fuequinia Malumián & Masui), Clavulinia gaultina Morozova and Conotratolites ‘aptiensis’, and, in distal Orange, Bredasdorp and KwaZulu sandstones, Triplassia sp. and Flabellammina sp. This interval is considered to correlate with the Gladcothin Marl and the ‘Chalk Marl’ of the southern English Lower Chalk succession. It is also considered to equate to the lower, carbonate interval of the Cabo Ledo Formation of the Kwanza Basin.

The Early Cenomanian can be divided into several interval biozones especially on the palaeo-middle to outer shelf in the Orange, Bredasdorp and KwaZulu basins. The top of the succession at the 15At1 unconformity is marked by the first appearance of Gavelinella ‘pletmosiana’ (identical with Valvulinella fuequinia Malumián & Masui in southern Argentina). About 30 m lower down Gaudryina ‘globularifera’ first appears, and about 20 m below that occurs Tetrasperula, a distinctive spurped, previously misidentified as ‘square scaphopod’ (fig. 3 of ref. 92). At about the Tetrasperula level is the top of the massive sandstones, marked by the unconformity designated as 1231 in the Orange Basin. The Early Cenomanian ‘top sandstones’ horizon can be recognized and correlated between the Orange Basin, the Bredasdorp Basin, the Algoa Basin and the KwaZulu Basin, and it is taken to be roughly synchronous between the four basins. The massive sandstones extended farthest offshore during the Early Cenomanian, and reached as far as the palaeo-shelf break in parts of the Orange, Bredasdorp and Algoa basins. The sillier distal sandstones on the outermost shelf are distinguished by species of Triplassia and Flabellammina. The KwaZulu Basin succession becomes sandier from the Tetrasperula horizon downwards, but the sandstones there are minor and confined to the palaeo-inner shelf, and none is massive.

Finally, only in the claystones distal of the massive sandstones, about midway through the Early Cenomanian succession, and about 150 to 200 m below (much less in the KwaZulu Basin) the Tetrasperula horizon, appear Dorothia obesa/Dorothia mordojovi and ‘Sigmomorphina’ sp. The former of these is a distinctive species that was described as Dorothia obesa Le Calvez, De Klasz & Brun in Gabon, and as Dorothia mordojovi Cañon & Ernst in southern Chile, both in the year 1974. Severe erosion of the Early Cenomanian succession occurs proximally on the palaeo-inner shelf, and even more so distally on the palaeo-outter shelf and upper slope, particularly in the Orange Basin, and to a lesser degree in the Bredasdorp and Pletmos basins. Distal claystones in the Dorothia obesa biozone may contain large numbers of the agglutinated benthonic Globospira charoides (Jones & Parker), as in the Kudu borehole sections. ‘Sigmomorphina’ sp. is a pyriform, or teardrop-shaped, polymorphinid with inflated chambers and a distinctively compressed, tapering neck leading to an elongate-ovate simple aperture: the species is limited to distal borehole intersections. The Early Cenomanian interval is mostly missing through erosion on the palaeo-slope in the Orange Basin (borehole O-A1) and in the eastern Bredasdorp Basin (F-S1, F-J1, F-V1, and F-O boreholes).

Thickness of Early Cenomanian interval. Up to 600 m thick where succession is complete in basin depocentre, on palaeo-outter shelf (K-A2 borehole), and in the south (570 m, complete succession, in borehole A-C3), down to only 93 m or less where top third of succession is missing in northernmost basin, on palaeo-upper slope (borehole Kudu 9A-3), and entirely missing (boreholes K-F1, O-A1) in distal Orange Basin; 475 m thick where succession is complete on Agulhas Arch flank of basin, on
palaeo-outer shelf (borehole E-R1), down to about 50 m where top half of succession is missing, on palaeo-outer shelf of eastern flank (F-A boreholes), Bredasdorp Basin; rarely as much as 69 m thick where top half of succession is missing, on palaeo-upper slope (borehole Ga-E2), but all other boreholes have even more incomplete successions, such as 20 m in borehole Ga-V1, 30 m in Ga-E1, 50 m in borehole Gb-Gemsbok 1, 40 m in borehole Ga-J1, and 20 m in borehole Gb-K1, Pletmos Basin; absent in Gantoos Basin; 325 m in borehole Hb-II, 456 m in distal borehole Hb-C1, 140 m in borehole Hb-K1, very poorly fossiliferous because of massive sandstones in Algoa Basin; present locally in distal boreholes Jc-B1 (30 m thick) and Jc-D1 (40 m thick) in Thekwini Basin; up to 113 m (in borehole ZE 1/71), commonly about 85 m, KwaZulu Basin.

Published/illustrated foraminifera. A few species have been listed from the lower Cape Leda Formation carbonates (Early Cenomanian) of the Kwanza Basin.99 Many species have also been listed from the northern Orange Basin, Namibia.97 The entire Early Cenomanian foraminiferal assemblage is shown as a range chart for the central Orange Basin borehole K-H1 [the Early Cenomanian interval extends from 2657 m (not 2669 m as shown) to 3110 m] off South Africa (fig. 142A and 142B of ref. 16).

Late Cenomanian (approximately 97.2–93.5 Myr) (Absent — within the 15At1 unconformity period — in Orange, Bredasdorp, Pletmos, Gantoos, Algoa and Thekwini basins; present in KwaZulu Basin only in subsurface, does not outcrop.) At the stratigraphic level of the ‘mid-Cenomanian Non-sequence’ of Hart,22,23 the basins of the Atlantic Margin and Southern Margin were uplifted, and there is no Late Cenomanian succession preserved. In contrast, the KwaZulu Basin subsided, and a succession of Late Cenomanian age accumulated, with Rotalipora cushmani (Morrow) and Lingulogavelinella globosa (Brotzen) throughout, and towards the top, lenticular radiolaria floods in several thin, high-gamma claystones interbedded with sandstones. One or two specimens possibly referable to Rotalipora greenhornensis (Morrow) also occur in this interval, but they are neither as well-formed nor as distinctive as specimens illustrated from further north in Tanzania and Madagascar. This interval is considered to correlate with the ‘Grey Chalk’ (mostly chalks) and the lower half of the overlying Plenus Marl in the English Lower Chalk succession.22,23 It is also considered to equate to most of the upper half of the Cabo Leda Formation of the Kwanza Basin,99 which consists of interbedded black claystones and pale grey carbonates or marls.

Throughout this interval, conditions in the KwaZulu Basin must have been somewhat dysoxic on the sea floor, as abundant but not very diverse, predominantly agglutinated benthonic assemblages prevail, particularly of Haplophragmoides and thin elongate Dorothyia species. Aragonitic benthonic species including Reinholdella lambertae (previously identified as Pseudolamarckina sp. in the KwaZulu Basin98), Epistominia spinulifera polytopioides (Eichenberg) and Epistominia chauymi Ten Dam occur in small numbers.

One or two samples from the cored boreholes (ZB, ZC) in the KwaZulu Basin, which probably lie immediately below the ‘mid-Cenomanian Non-sequence’ horizon, contain planktonic foraminiferal assemblages which include Rotalipora appenninica (Renz), Rotalipora gandolfii Luterbacher & Premoli-Silva and Rotalipora cushmani (Morrow), suggesting that the stratigraphic ranges of the two former species overlap very slightly with that of the last-named species.

Probable Late Cenomanian cyclical black claystones and pale grey marl beds outcrop along the coast on the shoreward flank of a small hill (9°40'20"S, 13°12'49"E), just to the east of the Cabo Leda promontory in the Kwanza Basin. These beds constitute the great majority of the upper part of the Cabo Leda Formation.26 Beds near the top of this succession contain the planktonic Schackoeina multispinata (Cushman & Wickenden), abundant Hedbergella spp., Rotalipora cf. appenninica (Renz), Hedbergella simplex (Morrow), Whiteinella aprica (Loeblich & Tappan)/W. archeocectacea Pessagno, and Rotalipora cf. montsalvensis Momord. However, benthonic foraminifera are sparse, with Lagenaammina sp. occurring in some numbers, and rare Neobulimina albertensis (Stelck & Wall) occasionally present. This Kwanza Basin assemblage remains to be published.

Thickening of Late Cenomanian interval. Absent in Orange, Bredasdorp, Pletmos, Gantoos, Algoa and Thekwini basins; up to 183 m thick in distal borehole ZC, but usually only about 90 m, as in borehole ZE 1/71, KwaZulu Basin.

Published/illustrated foraminifera. None. The Late Cenomanian succession also occurs extensively up the east coast of Africa from Mozambique northwards, but only from Tanzanian and northernmost Madagascan outcrops have foraminifera (including Rotalipora cushmani) been illustrated in published work.

Early Turonian (approximately 93.5–92 Myr) (130t1 to top of 133t1 sandstone interval in Orange Basin, and outcrops at sea floor; 15At1 to horizon ‘11’ at top of sandstone interval in Bredasdorp, Pletmos, Gantoos, Algoa and KwaZulu basins,78 absent in Thekwini Basin.) This interval is distinguished by planktonic Bodo of Whiteinella aprica (Loeblich & Tappan) and/or W. archeocectacea Pessagno, and benthonic fossils of Neobulimina albertensis (Stelck & Wall) in basal source rock units (high-gamma claystones), and in smaller numbers throughout. In the Bredasdorp and Pletmos basins, there is a high-gamma claystone unit at the base of the succession and a second, often poorer one in the middle. In the Orange Basin, the complete Early Turonian succession is only encountered on the outermost palaeo-shelf, in the two borehole sections K-F1 and A-N1. This Early Turonian interval is the ‘Zone à grandes globigerines’ of Sigal and other authors.89 Lingulogavelinella globosa (Brotzen) occurs only in the lower half of the interval, from the base of the succession up to, and including, the middle high-gamma claystone.

Early Turonian rocks extend almost to the proximal margin of the Orange Basin, usually extensively subcropping close to the present-day sea floor beneath the latest Pleistocene littoral shelly sands and the Holocene mudbelt. In contrast, shoreline deposits occur only somewhat more distally in the Bredasdorp, Pletmos, Gantoos, Algoa and KwaZulu basins, and there appears to be no Early Turonian outcrop in any of these basins. However, this succession comes very close to outcropping in the proximal Bredasdorp Basin and the western proximal Pletmos Basin. The Early Turonian succession is at its most complete and thickest on the palaeo-outer shelf, but entirely absent on the palaeo-slope. The lower half is a low stand tract, and the upper half a high stand tract in the Orange Basin; whereas both halves are high stand tracts in the Bredasdorp and Pletmos basins. On the basis especially of the distribution of Lingulogavelinella globosa, the lower half is considered to correlate with the upper half of the Plenus Marl and the nodular chalks of the Melbourn Rock in the English Middle Chalk succession.22,23 The upper half is considered to correlate with most of the Mammites nodosoides Zone of the English Middle Chalk succession.22,23 Early Turonian rocks appear to be absent (no Whiteinella) in the topmost Cabo
Leda Formation of the Kwanza Basin. Epistomina species are absent everywhere in the South African Early Turonian succession. Kneed planktonic foraminifera such as Praeglobotruncana steffani (Gandolfi) and Helvetoglobotruncana praehelvetica (Trujillo) are always rare. The unkeeled planktonic genera Hedbergella and Globigerinelloides are also rare, in contrast to their predominance in the Cenomanian and Coniacian successions, and only Whiteinella species are dominant. Benthonic foraminifera assemblages are usually poor, and show little diversity except in the basal high-gamma claystones, with Haplophragmoides spp., conservative Lenticulina spp., thin Dorothyia spp. and Praebulimina nanima (Tappan) found widely but never abundantly. Such low-diversity benthonic assemblages indicate that dysoxic sea-floor conditions were widespread almost everywhere around South Africa during this period. The top of the succession is marked by an extensive, clean, gravelly and locally pebbly, quartz sandstone (the ‘11’ sandstone), which looks distinctly wave-sorted, in the Orange (overlying seismic horizon 133t1), Bredasdorp, Pletmos, Gamtoos, Algoa and KwaZulu basins. The sandstone is usually no more than about 30 m thick in the Southern Margin basins, but is up to 80 m (borehole K-A2) in the Orange Basin. The sandstone appears to cover almost the entire Turonian palaeo-shelf of South Africa. It equates to the similarly extensive Domo sandstone interval of the South Mozambique Basin. It appears to represent a forced regressive shoreline deposit that developed in response to an abrupt major uplift of the whole southern African continent at this time. Because of the coarse clastic nature of this interval in most borehole intersections in the Gamtoos, Algoa and KwaZulu basins, typical planktonic foraminifera (Whiteinella) assemblages are very rare, and correlation can be maintained only with the benthonic foraminifera, especially using assemblages containing the Neohelvetina albiterensis, Lingulogavelinella globosa and Epistomina spinulifera polyoids association.

In clayey proximal normal marine successions, such as in the Pletmos Basin (boreholes Gb-Gemsbok 1 and Gf-F1), and in the clayey successions of the KwaZulu Basin (as in distal borehole ZB), the earlier Early Turonian interval, distinguished by the presence of Lingulogavelinella globosa, is also marked by the stratigraphically highest occurrences (first downhole appearances) of the aragonitic foraminifera species Epistomina chapmani Ten Dam and Epistomina spinulifera polyoids (Eichenberg), and by the ostracod species Majungaella nematis Grekoff. Rare specimens of Epistomina spinulifera polyoids may even occur locally in the earlier Early Turonian, above the top Lingulogavelinella globosa datum, as seen in Pletmos Basin borehole Gb-F1. In contrast, these two Epistomina species are present only in the Middle to Late Albian Gault Clay of southern England, and are absent in the carbonate facies of the Cenomanian-Turonian Lower and Middle Chalk. The stratigraphically highest occurrences of both Lingulogavelinella globosa and Majungaella nematis are within the high gamma claystone present in the middle of the Early Turonian succession. There are no ‘Brachycythe’ species in the earlier Early Turonian of South Africa, and these appear only in the later Early Turonian, after the extinction of Majungaella nematis, so that the ranges of the two ostracods in these basins appear to be mutually exclusive.

No in situ samples in any of the borehole sections studied have been found which contain Rotalipora species and Whiteinella africana/W. archaeaecreta in the same foraminiferal assemblage, and the two genera appear to be mutually exclusive in the southern African stratigraphic record. Praeglobotruncana steffani ranges down into the Early Cenomanian, and does occasionally occur in association with Rotalipora appenninica (Renz).

Thickness of Early Turonian interval. Earlier Early Turonian Low Stand Tract is 316 m thick in borehole K-F1 and 92 m in borehole A-N1, whereas the later Early Turonian succession is 563 m in borehole K-F1, 198 m in borehole A-N1, and 295 m thick in borehole K-A2, but the entire interval is absent further offshore on the palaeo-slope, as in the Kudu boreholes and O-A1, Orange Basin; this interval tends to be thin on the Agulhas flank of the basin, being 44 m in borehole D-D1, 90 m in borehole E-N1, 30 m in borehole E-R1, but becomes much thicker on the Infanta flank, being 126 m in borehole E-M1, 262 m in borehole F-A5, and a maximum of 296 m in borehole F-AFI, but the interval is absent in the most proximal boreholes such as D-A1, E-1 and E-B1, and is also everywhere absent on the upper palaeo-slope, Bredasdorp Basin; similarly confined to the palaeo-shelf, attaining thicknesses of 300 m in distal boreholes Ga-EI and Ga-J1, 240 m in borehole Ga-V1, 230 m in borehole Gb-K1, 190 m in borehole Gb-Gemsbok 1, and only 90 m in proximal borehole Ga-D1, and is overstepped by Coniacian (west) or Late Campanian (east) rocks shorewards, so that it is absent in proximal boreholes Gb-H1 and Ga-F1, Pletmos Basin; only 120 m in distal borehole Ha-B2, 100 m in Ha-H1, 90 m in Ha-A1, and is overstepped by Late Campanian rocks shorewards, so that it is absent in boreholes Ha-D1 and Ha-F1, Gamtoos Basin; 110 m in distal borehole Hb-C1, 50 m in borehole Hb-K1, and 80 m in borehole Hb-I1, and is overstepped by Late Campanian rocks shorewards, so that it is absent in proximal boreholes Hb-B1, Hb-P1, and Hb-H1, Algoa Basin; may be present proximally, but absent where drilled in the Thekwini Basin; up to 122 m in distal borehole ZB, but commonly about 70 m, as in borehole ZF 1/22, KwaZulu Basin. Published/illustrated foraminifera. The foraminiferal assemblage for the basal portion (2597 to 2657 m) of the upper (high stand) half of the Early Turonian has been published as a range chart for borehole K-H1 in the central Orange Basin (fig.142A of ref. 16). No foraminifera have yet been illustrated from the Early Turonian interval.

Middle Turonian (approximately 92–91.2 Myr) (Top of 133t1 sandstone interval to 135t1 in Orange Basin, and outcrops at sea floor; horizon ‘11’ to unnamed unconformity in Bredasdorp and Pletmos Basins; absent in Gamtoos, Algoa and KwaZulu Basins; present in distal northern Thekwini Basin.) This interval is distinguished by Praeglobotruncana steffani (Gandolfi), moderate numbers of Helvetoglobotruncana praehelvetica (Trujillo), and Neobulimina albiterensis (Stelck & Wall). It is considered to correlate with the lower nodular chalks of the basal Collignoniceras woolgari Zone of the English Middle Chalk succession. The specimens of Helvetoglobotruncana praehelvetica in the English Middle Chalk have a hispid surface ornamentation, especially on the ventral surface, but the South African specimens are characterized by a heavier, more rugose ornamentation; the significance of this difference is as yet unknown. The interval is also considered to equate to the topmost Cabo Leda Formation black claystones, distinguished by the planktonic species Helvetoglobotruncana helvetica (Bolli) and H. praehelvetica, in the Kwanza Basin. Foraminifera assemblages of the Middle Turonian are more diverse and abundant than those of the Early Turonian. A variety of keeled planktonic foraminifera occur in some numbers, and in contrast Whiteinella are rare. As well as Praeglobotruncana steffani and Helvetoglobotruncana praehelvetica, other keeled planktonic species include a large strongly convex Dicarinella species and Dicarinella cf. primitiva (Dalbiez). Except for uncertain identifications from broken or distorted tests, there are no positive records of the distinctive Middle
Turonian marker species *Helvetoglobotruncana helvetica* in any of the South African basins, and this species would seem to be confined to warmer-water settings than those that prevailed around southern Africa. However, the widespread presence of the smaller-sized species, *Helvetoglobotruncana praehelvetica*, throughout this interval likewise constrains it to the Middle Turonian. There are few diagnostic benthonic species: *Neobulimina albertensis* (Stelck & Wall) and *Prorotalia nana* (Tappan) remain significant. There is no Late Turonian succession in any of the basins, since *Helvetoglobotruncana praehelvetica* everywhere ranges up to the top of the Turonian interval (horizon 135t1), and it is the first Turonian indicator in a downhole sense. The Middle Turonian interval is the only part of the Turonian succession present on the palaeo-slope, where it locally may show some slight high-gamma character, as seen in the Kudu borehole sections. On the palaeo-slope in the Orange and Bredasdorp basins, Middle Turonian rocks unconformably overlie progressively older rocks in an offshore direction: for example in the Orange Basin, top Early Turonian in child’s Bank borehole K-A2, earlier Early Cenomanian in the Kudu boreholes, and latest Middle Albian in farthest offshore borehole O-A1.

Eighteen megadrill samples recovered from just below the sea floor directly off Chameis (De Beers Marine samples DN 3115, 3119, 3121–3123, 3129, 3130, 3138, 3141–3144, 4387–4392), in the vicinity of 28°03′24.28″S, 15°32′43.52″E, as well as two megadrill samples (De Beers Marine samples DN 1409 and 1410) from immediately off the Bogenfels rock arch, at 27°29′16.35″S, 15°18′04.01″E, have been interpreted as being of Middle Turonian age. Foraminifera assemblages from off Chameis are from variably silty stiff grey clays, and localized very waxy black silty claystone and limestone units. The Chameis assemblage reflects a dysoxic, rather hyposaline environment, since agglutinated foraminifera are predominant in all samples: thin elongate *Dorothyia* spp., *Ammobaculoides ‘turonicus’*, small and large *Haplophragmoides* spp. (small species are widespread, moderate to abundant, while large are localized, usually rare), flat *Haplophragmoides* spp., small *Ammobaculites* spp., flat *Trochammina* spp., *Bathyphoton* spp., *Spiroplectella cf. concinna* (Reuss), *Dorothyia oxyconca* (Reuss), localized *Hedbergella* spp. (abundant in the occasional limestone units), *Whiteinella aprica* (Loeblich & Tappan), rare corroded *Helvetoglobotruncana praehelvetica* (Trujillo), *Dicarinella cf. primitiva* (Dialbiez), thin *Nodosaria sp.*, *Vaginulina sp.*, and *Inoceramus primitiva* species. Further clay north, off Bogenfels, glauconitic brownish-grey claystones and *Marginotruncana praehelvetica* sp., rare *Hedbergella* spp. (*Hedbergella* spp., *Dorothyia oxyconca* (Reuss), *Gyroidinoidea nitida* (Reuss), flattened *Gyroidinoidea* spp., *Lenticulina* spp., *Whiteinella archaexecretacea* Pessagno/W. aprica (Loeblich & Tappan), moderate *Neobulimina albertensis* (Stelck & Wall), *Heterohelix globulous* (Ehrenberg), *Helvetoglobotruncana praehelvetica* (Trujillo), *Praeglobotruncana stephani* (Gandolfi), *Psilocitharella sp.*, *Citharina sp.*, rare *Haplophragmoides spp.*, *Brachycythere* sp. and *Inoceramus primitiva* species. The predominance of calcareous benthonic foraminifera in samples from the Middle Turonian succession off Bogenfels reflects normal marine conditions, and marks the northern limit of the deltaic, hyposaline facies, distributed so widely in the proximal Orange Basin.

**Thickness of Middle Turonian interval.** Thickest on the palaeo-outmost shelf, being 180 m in borehole F-A1, and only 90 m in southern borehole A-N1, 155 m in depocentre borehole K-A2, and, on the palaeo-slope, only 80 m in borehole Kudu 9A-2, Orange Basin; again thickest on the palaeo-outmost shelf, reaching 154 m in borehole F-A1, but usually much less, such as only 28 m in borehole F-A5, and thinner in distal palaeo-slope boreholes, such as 50 m in borehole F-D3, 99 m in borehole F-R1, Bredasdorp Basin; modestly absent or very thin (less than 10 m) across the palaeo-shelf, but thicker on the outermost shelf and palaeo-slope, being 60 m in borehole Ga-V1, 50 m in borehole Ga-J1 and 60 m in borehole Ga-E1, Pletmos Basin; absent in the Gaamtoos and Algoa basins; 40 m in borehole Jc-D1 and 84 m in borehole Jc-A1, Thekwni Basin; absent in KwaZulu Basin.

Earlier Early Coniacian (approximately 89–88.25 Myr) This is present only as a low stand tract in distal eastern Bredasdorp Basin and southern Pletmos Basin, but is absent over the intervening Infanta Arch. The interval is distinguished by *Dicarinella primitiva* (Dialbiez), triangular *Gaudryina ‘agulhasensis* and *Gavelinella plummerae* (Tappan). Present only in the closely set Bredasdorp borehole sections F-J1, F-V1, F-R1, F-S1 and the F-O boreholes, and the closely set Pletmos borehole sections Ga-J1, Ga-E1, Ga-E2, Ga-S1 and Ga-Z1, and possibly Ga-M1. This succession does not outcrop. The succession is considered to correlate roughly with the *Micraster cortestudinarium* and lowermost *M. coranguinum* Zones of the basal Upper Chalk of England. Some sandstones occur in this interval in proximal boreholes F-V1 and F-J1, but elsewhere there are only thin turbiditic stringers, and these do not affect foraminiferal abundance. In general, foraminifera assemblages are abundant but not very diverse, indeed are rather monotonous.

Closely similar foraminiferal assemblages to those of the later Early Coniacian succession are present throughout this interval. As is the case throughout the Coniacian succession, small conservative keeled planktonics attributable to the *Dicarinella primitiva* group are the commonest datable element, and other, more time-restricted *Dicarinella* species are rare. Only in the later Late Coniacian succession do the first *Globotruncanina* and *Marginotruncana* species appear, notably *Globotruncanina linneiana* (D’Orbigny), *Globotruncanina tricarinita* (Quereau), and *Marginotruncana marginata* (Reuss). In addition, strongly convex *Dicarinella*, notably *Dicarinella concaevata* (Dialbiez) and *Dicarinella carinata* (Dialbiez), are absent from beds regarded as Coniacian, and are limited to the intervals regarded herein as Early Santonian and Late Santonian in age, respectively.

**Thickness of earlier Early Coniacian interval.** 148 m in borehole F-V1, 110 m in borehole F-J1, 159 m in borehole F-R1, Bredasdorp Basin; and 210 m in both boreholes Ga-E1 and Ga-E2, Pletmos Basin; absent in Orange, Gamtoos, Algoa, Thekwini and KwaZulu basins. Published/illustrated foraminifera. None.

Later Early Coniacian (approximately 88.25–87.5 Myr) (135t1 to 140t1 in Orange, and outcrops at sea floor in both proximal Orange and proximal Bredasdorp basins; not seismically distinguished elsewhere.) This interval is distinguished by *Dicarinella primitiva* (Dialbiez), triangular *Gaudryina ‘agulhasensis* and *Gavelinella plummerae* (Tappan), *Nodobucularia ‘conicaeinia* and *Dicarinella cf. imbriata* (Mornod), and is present in Orange, Bredasdorp, Pletmos, Algoa and KwaZulu basins. This interval has not yet been intersected in drilling in the Gamtoos Basin, but it can be expected in the most distal part of the basin. The later Early Coniacian interval is considered to correlate with part of the lower *Micraster coranguinum* Zone in the lower part of the English Upper Chalk. It is also considered to correlate with
the Coniacian Itombe Formation of the Kwanza Basin. Other species typical of this interval include Spiroplectinella cf. lucis ceretosa (Cushman), Spiroplectinella cf. concina (Reuss), Nodosaria cf. affinis Reuss, flat Hapalophragnoides sp., Ammobaculoides 'turonicus' (these last two species only in the Orange Basin), and a variety of Psilocinha, Citharina and Furdinicularia species. This interval outcrops at sea floor, as seen in borehole D-B1 in the proximal Bredasdorp Basin, near where sea-floor exposures of the Alphard Group contain dated Early Coniacian ammonites and inoceramids, and near where Dingle reported, from sea-floor sample TBD 510, the Coniacian-Santonian planktonic foraminifera Marginotruncana ex gr. marginata (Reuss).

There is a poor, thin, high-gamma claystone event recognizable at the base of this interval in all basins, marked by irregular bursts of Hedbergella species and Dicarinella species (especially D. primitiva, with few D. renzi (Gandolfi), and rare D. cf. imbricata (Mornod)) tests, and by the distinctive benthonic marker species spiky Palmula sp. Spiky Palmula sp. is a smooth, thick-walled species with well-developed thick tubercles protruding only from the proxocolar area. This basalmost assemblage with abundant Dicarinella primitiva and Hedbergella species, and also Dicarinella renzi, spiky Palmula sp. and Gavelinella plummerae, amongst others, has been recognized in sea-floor outcrop at 28°02'36"S, 15°32'52"E (De Beers Marine sample no. Dn 4397), off the Chameis coast in the northern Orange Basin. This sample lies in the only part of the Orange Basin sea-floor outcrop to expose Cretaceous rocks (Early to Middle Turonian and later Early Coniacian) that accumulated in a normal marine facies.

Thickness of later Early Coniacian interval. Again thickest in distal boreholes on the palaeo-outermost shelf, such as 220 m in borehole K-A2, 170 m in Bredasdorp borehole O-A1, 166 m in borehole A-N1, 185 m in depocentre borehole K-A2, and absent on the palaeo-slope (Kudu boreholes), Orange Basin; consistently thin across the basin, in proximal boreholes E-AP1 (50 m), and D-D1 (66 m), similarly in central basin boreholes E-AA1 (60 m) and E-N1 (50 m), in the Agulhas flank borehole E-P2 (40 m), and likewise in the Infanta flank boreholes F-A5 (70 m) and F-AF1 (60 m), but generally absent on the palaeo-slope except in the east, where it attains 210 m in borehole F-R1, Bredasdorp Basin; much the same thicknesses in boreholes Ga-N1 (60 m), Ga-V1 (80 m), Ga-D1 (proximal site, 70 m), Gb-K1 (50 m), Gb-J1 (60 m) and Ga-J1 (75 m), and only thickening on the palaeo-uppermost slope, attaining 205 m in borehole Ga-E1, Pletmos Basin; absent where drilled in Gamtoos Basin; present only distally, as in boreholes Hb-C1 (40 m), Algoa Basin; absent in Thekwini Basin; up to 130 m in distal borehole ZF 1/2, but proximally much less, as in boreholes NZA (37 m) and ZU 1/77 (20 m), KwaZulu Basin.

Published/illustrated foraminifera. Typical agglutinated hypolamine foraminifera from the later Early and Late Coniacian succession of the proximal Orange Basin have been illustrated and listed, but normal-marine foraminifera assemblages of the Coniacian remain unpublished.

Late Coniacian (approximately 87.5–86 Myr) 
(140t1 to above 150t1 in Orange Basin, and outcrops at sea floor; unnamed horizon to horizon K in Bredasdorp Basin, and outcrops at sea floor; not visibly distinguished in Pletmos Basin; absent in Gamtoos, Algoa, Thekwini and KwaZulu basins.) Marked by Dicarinella primitiva (Dalbiez), very rare Dicarinella renzi (Gandolfi), Spiroplectinella cf. concina (Reuss), Gavelinella plummerae (Tappan), Palmula orangensis' and Nodoso-bacularia 'conica'. It is not clear if the Late Coniacian outcrops to sea floor in the Pletmos Basin. The Late Coniacian interval is considered to correlate with a lower to middle portion (the topmost Coniacian portion) of the Micraster conarquimatum Zone in the English Upper Chalk succession.22,23 This interval appears to be absent in the Kwanza Basin succession of the Angolan coast.24

A well-developed, high-gamma claystone unit is present at the base of this interval in the Orange, Bredasdorp and Pletmos palaeo-shelf successions, which attains a maximum thickness of 132 m in distal Orange Basin boreholes such as K-F1, sited on the palaeo-outermost shelf. This high-gamma claystone is marked by a well-developed burst of benthonic and planktonic foraminifera (both high foraminiferal abundance and wide diversity of species), which can be easily recognized and correlated in the extensive fluvial and hypolamine facies encountered in the borehole sections of the proximal Orange Basin. It is the second strongest foraminifera burst in the proximal Orange Basin, after the mid-Early Turonian foraminifera burst, and this claystone unit appears to extend up to the present sea floor, or subcrop beneath mostly thin, latest Quaternary veneers, for a long distance from off Koingnaas in South Africa to off Chameis in southern Namibia. The equivalent basal claystone interval reaches a maximum of about 76 m, as in borehole F-A5, in the Bredasdorp Basin, and about 55 m, as in borehole Ga-A2, in the Pletmos Basin. Planktonic and benthonic foraminiferal assemblages through the Late Coniacian are generally not very diverse, although they may be abundant. Floods of Gavelinella plummerae (Fig. 13), several species of Spiroplectinella, and conservative, small-sized Gyrinoidinoides nitida (Reuss) occur widely. Pyrite, lime and plant debris are locally common, and it seems that sea-floor water circulation on the continental shelf all round southernmost Africa during the entire Coniacian was poor, and sea-floor dysoxic conditions were widespread.

There appear to be almost no samples from the topmost Late Coniacian succession in the Orange, Bredasdorp and Pletmos basins which contain planktonic assemblages that include undoubted Dicarinella primitiva, Contusotruncana fornicata and Marginotruncana corona together (the latter two essentially typical of the Early to Late Santonian), and the former and the latter two of these species are regarded as possessing virtually exclusive stratigraphic ranges.

Thickness of Late Coniacian interval. Maximum of 510 m in distal palaeo-outermost shelf borehole K-F1, 321 m in borehole O-A1, 354 m in borehole A-N1, 415 m in depocentre borehole K-A2, but only 190 m in palaeo-slope borehole Kudu 9A-2, Orange Basin; generally from 90 to 150 m on the palaeo-shelf, with maximum of 220 m (palaeo-outermost shelf borehole F-AF1), but thinner on the palaeo-slope, such as 185 m in borehole E-D3, and 110 m in borehole F-R1, Bredasdorp Basin; generally about 80–120 m, with maximum of 200 m (distal palaeo-outermost shelf borehole Ga-J1) in the Pletmos Basin; absent in Gamtoos, Algoa, Thekwini and KwaZulu basins.

Published/illustrated foraminifera. Typical agglutinated hypolamine foraminifera from the later Early and Late Coniacian succession of the proximal Orange Basin have been illustrated and listed, but normal-marine foraminifera assemblages of the Coniacian remain unpublished.

Early Santonian (approximately 86–85.2 Myr) 
(Absent, within period of unnamed unconformity above 150t1 in Orange Basin, but present onshore at Wandelfield IV outcrop; absent, within K unconformity period in Bredasdorp Basin; absent in Gamtoos and Algoa basins; present, but not visibly distinguished in Thekwini and KwaZulu basins, and present onshore at Mzamba, Durban and other coastal outcrops and subcrops.) This interval is distinguished by Sigalitidae (Sigal), Dicarinella concava (Brotzen), very rare Dicarinella
Fig. 13. Scanning electron microscope images of the calcareous benthonic foraminifera *Gavelinella plummerae* (Tappan), which are particularly diagnostic of Coniacian rocks all around South Africa. All views are of Late Coniacian specimens, obtained from sample Dn3060, from a core cutter sample (0.44–0.66 m below sea floor) taken from the base of a short vibrocore recovered at 28°19’08.31”S, 16°31’25.37”E, off the Bogenfels coast, southern Namibia. 1, Ventral view, ×65; 2, foraminal view, ×79; 3, dorsal view, ×58; 4, ventral view, ×70; 5, foraminal view, ×71; 6, dorsal view, ×85; 7, ventral view, ×57; 8, aperture view, ×57; 9, dorsal view, ×62; 10, aperture view, ×84; 11, aperture view, ×89.
primitiva (Dalbiez), Palmula ‘orangerensis’, thick-walled Epistomina pondensis (Chapman) and Gavelinella plummerae (Tappan). The interval is considered to correlate with the upper third of the Micraster coranguinum Zone and the lower part of the Uintacrinus socialis Zone (the interval bearing Dicarinella concavata) of the Upper Chalk of southern England.22,23 It is also considered to correlate with the Early Santonian N’Golomé Formation (bearing Dicarinella concavata and Sigalia deflaensis) of the Kwanza Basin.84 Samples from the Wanderfeld IV outcrop in southern Namibia contain rare examples of Dicarinella concavata, samples from the lower half of the Mzamba Formation type locality exposure contain rare examples of Sigalia deflaensis, while both Thekwini and KwaZulu basin borehole intersections contain Sigalia deflaensis, Marginotruncana coronata (Boll), and Dicarinella concavata in association.

Various comments have been made about the foraminifera of the Wanderfeld IV outcrop,44 but following intensive additional sampling and restudy of older samples, the full assemblage from this tiny exposure now amounts to the following species: ?Angulogavelinella sp., ?Dentalina sp., Dorothy acoxia (Reuss), Epistomina supracretacea Ten Dam, thick-walled Epistomina pondensis (Chapman), ?Epistomina favosoides (Egger), ?Gavelinella sp., Gyroidinoides nittida (Reuss), Globigerinelloides ehrenbergii (Barr), Dicarinella concavata (Brotzen), Globotruncanita lineinana (D’Orbigny), Marginotruncana marginata (Reuss), Dicarinella primitiva (Dalbiez), Hedbergella delrioensis (Carsey), Hedbergella cf. portsdonensis (Williams-Mitchell), Hedbergella spp., Hedbergella sp. A, Haplophragmoides sp., Lagena aculeata (Reuss), Lenticulina sp., Marginulina cf. texensis Cushman, Ramalina aculeata (D’Orbigny), ?Spirocolina sp., Cibicides sp., ribbed Nodosaria spp., Ammodiscus sp., Lagena sp., Globulina species, ?Brizalina sp., Palmula ‘orangerensis’ and a number of indeterminate cemented specimens. There is also a variety of ostracods, including ‘Brachycythere’ sp., as well as abundant dissociated inoceramus prisms, small numbers of thin elongate echioid spines with a polished surface, and vugle solitary calcareous worm tubes (seemingly not serpulids). This assemblage is taken to indicate an inner shelf environment of deposition. Preservation of microfossils is extremely variable through the outcrop, and many samples are devoid of microfossils, as a result of much calcite dissolution and reprecipitation. Keeled planktonic foraminifera are usually extremely rare. The planktonic foraminifera are dominated by the various species of Hedbergella, and the benthonics by the various species of Epistomina. Because of the calcite dissolution and reprecipitation, many of the foraminifera can only be identified to generic level. This outcrop is unique in the proximal Orange Basin succession because of the predominance of a wide variety of planktonic foraminifera species in the assemblage, whereas most other proximal foraminifera assemblages from this basin are composed exclusively of agglutinated benthonic foraminifera.

The first downhole appearance of a thin elongate Textularia species is particularly useful for identifying the top of the Early Santonian interval in the KwaZulu Basin. Other typical species occurring widely are Globotruncanita lineinana (D’Orbigny), Globotruncanica tririaritana (Quereau), Contusotruncanica fornicata (Plummer), Marginotruncanica coronata (Boll), Vaginulina egemen (Linne), and Marginulina cf. silicia (Plummer). Large-sized Vaginulina, Marginulina and ribbed Nodosaria species especially distinguish the Early Santonian portion of the Mzamba Formation22 and the proximal facies of the coeval beds elsewhere along the Indian Margin, and are absent in the Early Campanian portion.

As far as has been seen, the stratigraphic relationship of the Early and Late Santonian successions is not possible to resolve around South Africa, because each is mutually exclusive. However, northern Walvis Basin borehole 1911-15-1, sited just south of the Walvis Ridge, and studied by the author,45 drilled a Late Cretaceous succession that includes both units, and resolves their relationship. In boreholes in the Brazilian and Angolan continental margins, and in Walvis Basin borehole 1911-15-1, there is an organic-rich, possibly high-gamma, hemipelagic claystone unit at the base of the Early Santonian succession. The planktonic foraminifera abundance and diversity, and minimal fluvial influence seen in samples from the Wanderfeld IV outcrop in southern coastal Namibia46 indicate that the outcrop exposes a portion of this distinctive basal hemipelagic claystone unit. The Epistomina-rich benthonic foraminiferal assemblage at Wanderfeld IV suggests an inner shelf, normal-marine, proximal environment of deposition very similar to that of the lower half of the Mzamba Cliff outcrop.57 However, neither in the Mzamba Cliff Early Santonian succession nor in the Early Santonian interval of the KwaZulu Basin boreholes is there any marked planktonic foraminifera abundance peak, nor organic enrichment, coarse clastic starvation, lignite-starvation, or development of high-gamma claystones in a basal unit. The distinctive basal Early Santonian source rock unit thus appears to have developed only in the South Atlantic, and not in the Indian Ocean. Typical Early Santonian foraminifera, including Dicarinella concavata, occur in coastal cliff outcrops, of interbedded carbonates and some black claystone units, lying immediately southwest of Cabo Ledo village and just south of Ponta Fexe (outcrop at 9°39’46”S, 13°13’28”E), Kwanza Basin, but these assemblages remain unpublished.

**Thickness of Early Santonian interval.** Up to 4 m exposed at the surface above Namib Desert sands and in excavations at Wanderfeld IV,40 onshore proximal Orange Basin; at least 13 m in Mzamba Cliff outcrop section;46 132 m in borehole Jc-B1 and 210 m in borehole Jc-D1 in distal Thekwini Basin; averages about 125 m, but up to 195 m in borehole ZE 1/71, KwaZulu Basin; absent in offshore Orange, Bredasdorp, Pletsmos, Gaamtoos, and Algoa basins.

**Published/illustrated foraminifera.** Mzamba Cliff and Iongazi River exposure foraminifera assemblages illustrated;25-28,30,57 also foraminifera assemblages illustrated from KwaZulu Basin outcrops48 and borehole sections.59 Preliminary Wanderfeld IV outcrop foraminifera assemblage only listed.94

Late Santonian (approximately 85.2–85.3 Myr)

(Unnamed unconformity above 150t1 to Z/K1 in Orange Basin, and outcrops at sea floor; K to unnamed horizon in Bredasdorp Basin; present also in Pletsmos, Gaamtoos and Algoa basins but not seismically defined; absent in Thekwini and KwaZulu basins.) This interval is distinguished by common Contrusotruncanica fornicata (Plummer) and Gaudryina species, also Marginotruncanica coronata (Boll), Globotruncanica cf. elevata (Brotzen) (only in uppermost portion of Kudu borehole succession), 35 very rare Dicarinella carinata (Dalbiez), and also Pleurostomella subnodosa Reuss, smooth Stensioeina sp., Pseudossilina antiqua (Franke) and Bandulinea greatvalliesensis Trujillo. The interval is present only in the Orange (thickest), Bredasdorp, Pletsmos, Gaamtoos and Algoa (thinnest) basins. It is not known if this succession outcrops at the sea floor on the Southern Margin of South Africa, or is concealed by Cainozoic rocks. Foraminiferal biostratigraphy of the Late Santonian interval in the southern England Upper Chalk succession22,29 remains incomplete, so that accurate correlation with the South African succession is not yet possible. The Late Santonian
interval appears to be absent in the Kwanza Basin succession on the Angola continental margin.79

The lower part of the distal succession in the Orange Basin is characterized by a predominance of large-sized Quadrinorphina allorophinoides (Reuss), Allorophina cretacea Reuss and biseriately-arranged ‘Chilostomellaoides’ sp., present only in the zone of palaeo-shelf-margin limestonic faulting and rotated fault blocks.79 This localized dominance of these species appears to reflect rapidly sedimenting, relatively dysoxic sea floor conditions at the shelf break. More diverse planktonic and benthonic assemblages occur in the upper half of the Late Santonian succession.79 In general, Late Santonian planktonic and benthonic foraminifera assemblages are diverse, and reflect markedly improved sea-floor dissolved oxygen levels and oceanic circulation than seen in either the Turonian or Coniacian successions. Proximal Late Santonian foraminifera assemblages in the Orange Basin consist mainly of agglutinated foraminifera (variety of Miliammina, Haplophragmoides and Ammonoculatulae species, thin Dorothya sp., globular Trochammina sp. with rare Turritellitella sp.), especially in the lower part of the succession. These agglutinated-dominated assemblages show that hyposaline conditions remained predominant along most of the Atlantic Margin shoreline (Fig. 2). In addition, though, there are calcareous benthonic species, such as fat Triloculina sp., conservative Lenticulina species, Vaginula cf. gardnerae (Plummer), Nosodaria cf. zippei Reuss, Neofibulina saturalis (Cushman) and other rare nodosarids, as well as mulluscan shells such as whole oysters, oyster fragments and Inoceramus prisms, which all tend to occur more in the upper half of the succession. The widespread calcareous elements are taken to indicate a considerable decline in the abundance of plant debris, and consequently a marked raising of pH level to near neutral, as well as a concomitant increase in the levels of dissolved oxygen in coastal waters, when compared with the conditions that prevailed in the Coniacian. These hyposaline marginal marine and innermost shelf assemblages suggest an Atlantic coastline of extensive mudflats and localized channels. In contrast, such hyposaline assemblages are absent in the proximal Late Santonian of the Southern Margin basins. In the Orange Basin, there is a distinctive hemipelagic claystone unit (about 50 m thick) at the base of the distal palaeo-shelf succession (as seen in the Kudu boreholes, northern and eastern Orange Basin), which contains only unkeeled planktonics (Rugoglobigerina, Hedbergella, Heterohelix and Globigerinelloides species). The proximal Late Santonian succession of this margin consists of slightly silty grey claystones, and planktonic foraminifera, including small numbers of keeled specimens, occur as far as the landwards pinch-out of this unit. Typical benthonic species of the Late Santonian on the Southern Margin are abundant Gadrysina spp., Pleurostomella subnodosa Reuss, Heterostomella sp., Dorothya oxyconae (Reuss), Dorothya bulletta (Carsey), smooth Stensioeina sp., Osangularia cf. alata (Marsson) (often abundant in distal settings), triangular Buliminina cf. strobilae Marie, narrow parallel-sided Bolivinoides species, Pseudosigmoidina antiqua (Franke), and a wide variety of Gavelinella and Lenticulina species.

**Thickness of Late Santonian interval.** Up to 890 m in outermost palaeo-shelf sections (boreholes K-F1 and K-H1), but less in the south (up to 400 m in borehole A-C2), and markedly more in the uppermost palaeo-slope rotated fault blocks in the zone affected by listric faulting (1850 m in borehole K-B1 and 2240 m in borehole Kudu 9A-3) in the northern part of the Orange Basin; up to 326 m of carbonates on palaeo-uppermost slope (borehole F-R1), thinning fairly steadily to the basin margin, such as in boreholes F-P1 (159 m), E-D3 (125 m), E-P2 (220 m), E-A41 (200 m), E-N1 (140 m), E-AP1 (150 m), E-M1 (110 m), F-A5 (56 m) and E-C1 (60 m), Bredasdorp Basin; generally thinner across entire basin, reaching maximum in palaeo-uppermost slope boreholes Ga-J1 (70 m) and Ga-E2 (60 m), elsewhere thinner, as in boreholes Ga-V1 (50 m), Gk-B1 (40 m), Ga-D1 (50 m) and Gb-I1 (50 m), Pletmos Basin; seemingly thickening rapidly seawards, attaining a maximum in distal borehole Ha-K1 (100 m) and in Ha-B2 (70 m), but truncated rapidly shorewards, and widely absent closer to the basin margin, Gxtoos Basin; seemingly thickening rapidly seawards, attaining a maximum in distal borehole Hb-C1 (160 m), elsewhere thinner, as in borehole Hb-A1 (90 m), but truncated rapidly shorewards, and widely absent closer to the basin margin, Algoa Basin; absent in Thekewini and KwaZulu basins.

Published/illustrated foraminifera. Some species have previously been listed from the succession in the Kudu boreholes, northernmost Orange Basin.79

Early Campanian (approximately 83.5–78.5 Myr) (Z/K1 to unnamed unconformity in Orange Basin, does not outcrop; within interval between K and northern X in Bredasdorp basins. Within unnamed unconformities in Pletmos, Gxtoos, Algoa and KwaZulu basins; absent in Thekewini Basin, but present at Mzamba.) This interval is distinguished by Globotruncanita ventricosa White, Globotruncanita elevata (Brotzen) (only in KwaZulu Basin), Globorotalites michelinianus (D’Orbiny), Bolivinoides miliaris Hiltmerman & Koch, Rugoglobigerina rugosa (Plummer), Notoplanulina rakauroana (Finlay), Gublerina ornatisima (Cushman & Church), Planoglobulina acerulinoidea (Egger) (only in KwaZulu Basin) and Pseudotextularia cushmani Brown. The Early Campanian interval is present in the Orange, Bredasdorp, Pletmos, Gxtoos and Algoa basins, the upper half of the Mzamba Formation type locality outcrop, all of the Wild Coast Casino car park temporary outcrop, and in the KwaZulu Basin. The Early Campanian has proved difficult to correlate precisely with the southern English Chalk succession because of the lack diversity of the keeled planktonics in the Chalk.22,23 This Early Campanian interval is considered to correlate with the lower Teba Formation of the Kwanza Basin.79

This succession marks the last fluviatile influenced Cretaceous sedimentation in the Orange Basin, and the last of the episode of carbonate-rich sedimentation on the distal Southern Margin. Except for the agglutinated-rich foraminiferal assemblages of the hyposaline and palaeo-innermost shelf succession intersected in borehole K-E1 in the Orange Basin, benthonic foraminiferal assemblages of this age are diverse. The distinctive marker species Notoplanulina rakauroana (which is probably two morphologically similar species) was first described by Finlay from New Zealand and has also been found in contemporary beds in the Austral Basin of southern Argentina. Notoplanulina rakauroana occurs in more distal sections, in both claystone and carbonate facies, in the Orange (including the Kudu boreholes), Bredasdorp, Pletmos, Gxtoos, Algoa and KwaZulu basins, and...
especially aids correlation across the Southern Margin basins in an interval usually lacking in keeled planktonic species.

Other benthonic species typical of this interval include: Angulogavelinella corderiana (D’Orbigny), smooth Stensioinea sp., Stensioinea ‘dorsincurvata’ (synonymous with Cyrtoidinoides quadratus martini non Sliter, as described in ref. 40), Clavulina pseudoarenata (Said & Kenaway), Alabamina dorsopiana (Brotzen), Allomorpha cretacea (Reuss), Allomorpha conica Cushman & Todd, Praebulimina caseyae (Plummer), Praebulimina kickapoensis (Cole), Epistomina supracretacea Ten Dam, Epistomina favosoides (Egger), and a variety of Gavelinellae species.

The Early Campanian succession in the northern Orange Basin can be seen on seismic sections interpreted by E.A. Pegler and I.R. Stevenson to be limited to the tops of downthrown listric fault blocks at the palaeo-slope break. These listric faults were principally active during Late Santonian times. This succession is confined to the most distal borehole sections drilled up to now in the Orange Basin (Kudu boreholes, K-B1, K-E1, A-C3, A-N1 and O-A1). Most sections contain diverse agglutinated and calcareous benthonic assemblages that suggest inner shelf environments. Planktonic foraminifera assemblages are also diverse. The inner shelf depositional environment of the Early Campanian interval indicates that the shoreline moved substantially seawards between Late Santonian and Early Campanian times along the entire Atlantic Margin. Significant numbers of agglutinated foraminifera (mainly abundant Haplophragmoides and occasional Turrilina) occur in only one of the more proximal sections (borehole K-E1). Their isolated presence indicates that substantial fluvial input along this interval has declined greatly by Early Campanian times, and was substantially seawards between Late Santonian and Early Campanian times along the entire Atlantic Margin. Significant numbers of agglutinated foraminifera (mainly abundant Haplophragmoides and occasional Turrilina) occur in only one of the more proximal sections (borehole K-E1). Their isolated presence indicates that substantial fluvial input along this interval has declined greatly by Early Campanian times, and was substantially seawards between Late Santonian and Early Campanian times along the entire Atlantic Margin. Significant numbers of agglutinated foraminifera (mainly abundant Haplophragmoides and occasional Turrilina) occur in only one of the more proximal sections (borehole K-E1). Their isolated presence indicates that substantial fluvial input along this interval has declined greatly by Early Campanian times, and was substantially seawards between Late Santonian and Early Campanian times along the entire Atlantic Margin.

As with the Late Santonian interval, the distal Early Campanian succession of the Southern Margin consists of limestones and limey claystones, but distinctively lacks any keeled planktonic foraminifera. Non-keeled planktonic and benthonic foraminifera assemblages are diverse. The lack of keeled planktonic can be recognized from the Bredasdorp Basin across to the Algoa Basin; but such a feature is not evident either in the Orange Basin, nor in the KwaZulu Basin or the Early Campanian portion of the Mzamba Formation.

About 4 m of the top of the Mzamba Cliff type locality section is of Early Campanian age. Here, typical planktonic include Globotruncanina linneiana (D’Orbigny), Contusotruncanina formicata (Plummer), Globotruncanina tricarinata (Quereau) and Rugo-globigerina rugosa (Plummer), but more diagnostic Early Campanian species such as Globotruncanina elevata (Brotzen) and Globotruncanina ventricosa White, seen widely in the KwaZulu Basin borehole sections, have not yet been found here, probably because of the proximal setting. The Early Campanian age dating is thus based on the benthonic foraminifera and ammonite assemblages: a more intensive study of the planktonic foraminifera of the Mzamba cliff section is warranted. The stratigraphic position of the unconformity between the Early Santonian and the Early Campanian parts of the Mzamba Cliff exposure has not yet been established, but from the foraminifera results it must lie between the top of Klinger & Kennedy’s bed PI7 and the base of bed PI15. About 7 m of Early Campanian section was temporarily exposed in the Wild Coast Casino car park, and yielded much the same foraminiferal assemblage as that from the upper Mzamba Cliff outcrop. Again, the keeled planktonic foraminifera assemblage is limited.

Thickens of Early Campanian interval. Up to 455 m (borehole K-B1) and 420 m (borehole Kudu 9A-2) in northern shelf-break growth-fault zone, distinctly thinner in south (170 m in borehole A-N1), but interval generally absent in Orange Basin; distal carbonates are up to 385 m in southwest (borehole F-P1, palaeo-uppermost slope), up to 230 m distally in southeast (borehole F-R1, same setting), thinning shorewards (130 m in borehole E-R1, 110 m in borehole E-AA1), becoming distinctly thinner and clayier on the palaeo-middle shelf (70 m in borehole E-S3, 57 m in borehole F-A2), Bredasdorp Basin; up to about 100 m distally (borehole Ga-E1, palaeo-uppermost slope carbonates), but closer to shore about half this (boreholes Ga-J1 (50 m), Ga-AA1 (70 m), Ga-N1 (40 m), Gb-Gemsbok 1 (60 m), Gb-II (60 m), in Pletmos Basin; up to 90 m distally (borehole Ha-B2, palaeo-upper shelf) but onlapping shorewards and absent in proximal part of Gantoos Basin; up to 110 m distally (borehole Hb-C1, palaeo-upper shelf), thinning rapidly (79 m in borehole Hb-H1): onlapping shorewards and absent in proximal part of Algoa Basin; at least 4 m thick in the onshore Mzamba Cliff type section; and about 7 m thick in the Wild Coast Casino car park exposure, but absent in the distal Thekwini Basin; up to 220 m distally (borehole ZC, palaeo-upper shelf), slowly thinning shorewards (for example, 130 m in borehole ZG 1/72, KwaZulu Basin.

Published/illustrated foraminifera. Foraminifera of this age have been comprehensively illustrated from outcrops and boreholes in the KwaZulu Basin, as well as from the upper half of the Mzamba Formation. Foraminifera have also been listed from the Wild Coast Casino car park temporary exposure.

Late Campanian (approximately 76.5–72.5 Myr)
(Absent in Orange Basin; within unnamed unconformities in Bredasdorp (thin), Pletmos (thin), Gamtoos (thin), Algoa (thin), KwaZulu (moderate) and Thekwini (locally thick) basins.) This interval is distinguished by Globotruncanina ventricosa White, Globotruncanina tricarinata (Quereau), Globotruncanina linneiana (D’Orbigny), Gublerina ornatissima (Cushman & Church), Bolivinoides miliaris Hiltermann & Koch and Bulimina cf. strobilia Marie.

This succession is generally very thin across the entire Southern Margin. It contains diverse foraminifera assemblages that include many of the benthonic species also seen in the Maastrichtian rock units: Clavulina pseudoarenata (Said & Kenaway), Gaudryina laevigata Franke, Brizalina incrassata incrassata (Reuss), Angulogavelinella corderiana (D’Orbigny), Praebulimina caseyae (Plummer), Praebulimina kickapoensis (Cole), Bulimina arkadophana Cushman & Parker, Spiroplectinella laevis cretosa (Cushman), Alabamina dorsopiana (Brotzen), Allomorpha conica Cushman & Todd, Allomorpha cretacea Reuss, Quadratromphina allomorphoidea (Reuss), Quadratromphina camerata Brotzen, Epistomina supracretacea Ten Dam and deeply pitted Epistomina cf. pondens (Chapman). There are also a wide variety of Lenticulina, Nodosaria and Dentalina species, and some
Gavetinella species present. In a downhole sense, the first diverse Late Cretaceous planktonic foraminifera assemblages occur on the Southern Margin within the Late Campanian unit, since keeled planktonics especially are extremely rare in the overlying Early and Late Maastrichtian units. In contrast, Late Campanian keeled planktonic species, as listed above, are widespread and numerous. Other planktonic species not listed above include Rugoglobigerina rugosa (Plummer), Rugoglobigerina rotundata Brönnimann, Glomigerinelloides asper (Ehrenberg), Heterohelix globulosa (Ehrenberg), Heterohelix pulchra (Brotzen), and other species of this genus, as well as species of Hedbergella. More exotic species, such as Globotruncana, Pseudotextularia and Planoglobulina species, are everywhere missing on the Southern Margin at this time. Consequently, water temperatures on the Southern Margin must have been distinctly lower at this period than in the KwaZulu Basin, where planktonic assemblages are much more diverse.40

Probably dating from the Late Campanian or the Early Maastrichtian, the shelly glauconitic limestones and sandy claystones exposed onshore at Igoda River mouth46 and Needs Camp upper and lower quarries27,30,41,53. A wide variety of foraminifera occur in these rocks, and the following species are typical of all the exposures: Hedbergella spp., Rugoglobigerina rugosa, Heterohelix globulosa, Angulogavelinella corderiana, Praebulimina carsyae, finely ribbed Brizalina sp., Brizalina incrassata incrassata, Nonionella croteae Cushman and Alabamina dorsopiana. However, no keeled planktonics have been found at any of these onshore sites, so that the precise age of the Igoda Formation remains unclear. Nonetheless, the consistency of the foraminifer assemblages from all three sites confirms that the same rock unit is present at the three exposures.

It is from this time that the Thekwini Basin began to subside as one basin, although the variable thickness of the Late Campanian interval indicates distinctly differential subsidence within the basin. In all four borehole intersections in the Thekwini Basin, the Late Campanian succession consists of grey to dark grey claystones, with minimal coarse clastics. Foraminifera assemblages are generally diverse, but especially in the lower part of the succession, there are numerous Haplophragmoidea specimens, with small numbers of Bathysiphon spp., Glomospira charoides (Jones & Parker), Ammodiscus spp. and Rzehakina epigona (Rzehak), suggesting fairly dysoxic conditions on the sea floor at this time. Other species typical of this interval include Osangulina cf. alata (Marsson) (morphologically not quite the same as the Late Santonian species), Cibicides convexus (Reuss), Colonia californica Bandys, Pleurontostella subnodosa Reuss, Pullenia species and small trochosorial pullenid specimens probably referable to the genus Spiroplectinella.

Despite the thickness of the Thekwini Basin Late Campanian succession, there is no indication that fluvial input increased at this time, since the succession is so fine-grained, and the foraminifera assemblages contained there reflect normal marine conditions. Consequently, it would appear that the mid-Campanian uplift of the Orange Basin and the contiguous western portion of the southern African continent did not lead to significant river capture nor to enlarged catchment sizes of eastward-flowing rivers feeding sediment to the Indian Margin.

Thickness of Late Campanian interval. Absent in all boreholes in the Orange Basin; locally up to 384 m (borehole E-D3) on the palaeo-uppermost slope, because of ‘progradation’, but elsewhere distally much thinner (boreholes F-L1 (170 m), F-R1 (160 m)), and thinning fairly steadily shorewards (boreholes E-AA1 (100 m), F-K1 (40 m), F-A5 (50 m), E-R1 (80 m), E-M1 (50 m), E-N1 (135 m)), Bredasdorp Basin; much thinner, attaining a maximum of only 50 m in distal palaeo-uppermost slope borehole Ga-E2, thinning shorewards (boreholes Ga-I1 (30 m), Ga-V1 (40 m), Gb-K1 (30 m), Gb-I1 (20 m), Ga-N1 (20 m), and proximal borehole Gb-F1 (40 m), Plenetos Basin; much the same thickness, in distal palaeo-upper shelf borehole sections Ha-H1 (20 m), Ha-K1 (20 m), becoming slightly thicker closer to shore (borehole Ha-D1 (50 m)), Gamtoos Basin; similar thicknesses (boreholes Hb-A1 (20 m), Hb-C1 (40 m) and Hb-H1 (40 m)) in Algoa Basin; locally distinctly thicker (boreholes Jc-A1 (402 m), Jc-B1 (750 m), Jc-C1 (165 m) and Jc-D1 (240 m)), Thewkini Basin; up to 219 m distally (borehole ZC, palaeo-upper shelf), thinning only slightly shoreward before the entire interval is planed off by erosion, KwaZulu Basin.

Published/illustrated foraminifera. Foraminifera of this age have been comprehensively illustrated from outcrops40 and boreholes48 in the KwaZulu Basin. A number of sites in the Kwanza Basin (Teba Formation) and the Benguela Basin (Tchipupa Formation) in Angola yielded planktonic and benthonic foraminifera assemblages which suggest ages between Early Campanian and Early Maastrichtian.52,53,54,55–57 Most of these assemblages are only listed, and few species are illustrated in publications. The stratigraphic relationships of these different assemblages with each other, and with the assemblages from approximately time equivalent successions in the South African basins, are not yet possible to establish.

Latest Campanian to earliest Maastrichtian (approximately 72.5–71 Myr)

(Within unnamed unconformities, apparently present only in Thekwini Basin.) This interval is distinguished by Globotruncanina linniciana (D’Orbigny), Globotruncanina tricarinata (Quereau), Guliicera ornatissima (Cushman & Church) and Globotruncanina arca (Cushman). The succession consists exclusively of grey to dark grey claystones in all four borehole sections. Other foraminifera of this interval include Brizalina incrassata incrassata (Reuss), Bulimina arkeladphiana Cushman & Parker, Rugoglobigerina rotundata (Plummer), Praebulimina kickapooensis (Cole), Spiroplectinella laevis ctresis (Cushman), Heterohelix pulchra (Brotzen), Globotruncanina cf. ventricosa White, Globotruncanina cf. elevata (Brotzen), Pseudotextularia cushmani Brown, Bulimina cf. pyramidata Cushman, Quadrimorphophina allomorpho- noides (Reuss) and Contusotruncanina fornicata (Plummer). Many other species present in this interval occur also in the overlying Late Maastrichtian unit.

Thickness of latest Campanian to earliest Maastrichtian interval. Variable thickness, but generally much thinner than underlying Late Campanian unit: as in boreholes Jc-C1 (100 m), Jc-B1 (105 m), Jc-A1 (173 m) and Jc-D1 (180 m), Thekwini Basin only.

Published/illustrated foraminifera. None.

Early Maastrichtian (approximately 71–70 Myr)

(Absent in Orange Basin; unnamed unconformity to northern X, in Bredasdorp Basin (locally thick); within unnamed horizons in Plenetos Basin (thick); absent in Gamtoos, Algoa, Thekwini and KwaZulu basins.) This interval is distinguished by Globotruncanina arca (Cushman), Rugoglobigerina rotundata Brönnimann, Rugoglobigerina rugosa (Plummer), Bolivinoides draco (Marsson) and Contusotruncanina fornicata (Plummer). The top of the interval is usually most reliably marked by first downhole appearance of numbers of Gaudyrina species and a species of Pseudonodosaria. Keeled planktonics are usually very rare except in the basal part of the interval. Early Maastrichtian foraminiferal assemblages of the Southern Margin are comparable to those described below for the Late Maastrichtian, and the
interpreted environment of deposition is much the same. Across the Southern Margin, the Early Maastrichtian succession is overstepped in a westward direction by the Late Maastrichtian package, and is absent in the western Bredasdorp Basin close to the flanks of the Agulhas Arch. Similarly, it disappears in an eastward direction in the eastern Pletmos Basin, and is absent in the Gamtoos and Algoa basins. Difficulties remain in attempting to correlate this unit with the latest Campanian to earliest Maastrichtian succession recognized in the Thekwi Basin, and more work is necessary on this aspect.

Apart from the planktonic and benthic foraminifera listed above, this interval is distinguished by an unusual abundance of agglutinated foraminifera, and by the particular presence of floods of *Gaudryina laevigata* Franke in a basal unit. Although some numbers of *Haplophragmoides* spp., *Clavulinia pseudorearenata* (Said & Kenawy) and globular-chambered *Roaphax* sp. throughout the Early Maastrichtian interval. These foraminiferal assemblages with abundant *Gaudryina laevigata* are absent in the Thekwi Basin and only poorly represented in the KwaZulu Basin stratigraphic successions. Other common foraminifera of the Early Maastrichtian include *Globotruncana linneicna* (D’Orbigny) (basal part only), *Cibicides convexus* (Reuss), *Bulimina arkadelphiana* Cushman & Parker, *Angulogavelinella cordieriana* (D’Orbigny), *Praebulimina kickapooensis* (Cole), *Alabamina dorsoplana* (Brotzen), *Praebulimina carsyae* (Plummer), *Brizalina incrassata incrassata* (Reuss), *Gavelinella spp.*, *Stensioeina ‘dorsoincurvata’* (see p. 279 of ref. 40), *Epistomina supracretacea* Ten Dam and thin-walled *Epistomina pondensis* (Chapman), but most of these range through the greater part of the Campanian to Maastrichtian succession.

A distal foraminifera assemblage probably from the Middle Maastrichtian succession has been listed by Dingle96 from far off the Southern Margin, from a water depth of 1203 m (sample TBD 818). Twelve species of planktonic and two of benthic foraminifera include the species *Globotruncanita stuartii* (De Lapparent), *Globotruncanca aegyptica* Nakady, *Globotruncanella havanensis* (Vorwijk), and other less age-restricted planktonic species. There is no indication of the typical Late Maastrichtian species such as *Contusotruncana contusa* (Cushman), *Racemiguelamina fructiosa* (Egger), or *Abathomphalus mayaroensis* (Bolli), nor of the typical Early Maastrichtian species such as *Contusotruncana fornicata* (Plummer), *Globotruncanca tricornata* (Quereau) or *Globotruncanca linneicna* (D’Orbigny). This sample appears to be the only one yet recorded with a Middle Maastrichtian planktonic foraminifera assemblage from southern Africa, as at more proximal locations this part of the Maastrichtian succession appears to be missing.

**Thickness of Early Maastrichtian Interval. Absent in Orange Basin; up to 360 m distally (borehole F-R1) on palaeeo-uppermost slope, thinning a little shorewards (boreholes F-L1 (230 m), F-K1 (250 m), F-A5 (250 m), E-M1 (170 m)), but completely missing across southwestern third of basin (absent in boreholes E-D3, E-R1, E-AA1 and E-N1, for example), Bredasdorp Basin; decidedly thinner, up to 140 m distally (borehole Ga-E2) on the palaeeo-uppermost slope, and of similar thickness closer to shore (boreholes Ga-J1 (100 m), Ga-V1 (150 m), Ga-N1 (150 m), but thinning to the east, as in borehole Gb-K1 (70 m)), but completely absent in the northeast and east (boreholes Gb-F1, Gb-H1), Pletmos Basin. From the interval thicknesses and the distribution of offshore foraminifera facies, it seems likely that the main fluvial input point for this succession was somewhere along the Mosselbai portion of the coast. This interval is absent in the Gamtoos, Algoa, Thekwini and KwaZulu basins. Published/illustrated foraminifera. None.**

**Late Maastrichtian (approximately 66.5–65 Myr)**

(Present only in distal Orange Basin (as thin chalks), between unnamed horizon to L/22At1; from Northern X to L/22At1, and widespread (moderately thick clastics) in Bredasdorp Basin; between unnamed horizon and L/22At1, and widespread (moderately thick clastics) in Pletmos Basin; between unnamed horizon and L/22At1, and widespread (thin clastics) in Gamtoos, Algoa, Thekwi and KwaZulu basins.) Interval distinguished by *Contusotruncana contusa* (Cushman), *Pseudotextularia elegans* (Rzehak), *Abathomphalus mayaroensis* (Bolli), *Racemiguelamina fructiosa* (Egger), *Globotruncanita stuartii* (De Lapparent), *Bolivioides draco* (Marsson) and ornate *Stensioeina sp.* *Abathomphalus mayaroensis* and *Racemiguelamina fructiosa* have been found only in the southern distal Orange Basin (borehole O-A1), in the Thekwi Basin, and in the KwaZulu Basin in both shallow and deep boreholes.95,96

The Late Maastrichtian succession is instantly recognizable in the Orange, Gamtoos, Algoa, Thekwi and KwaZulu basins especially because of its exotic and ornate planktonic foraminifera, as listed above, as well as its wide variety of calcareous and agglutinated benthonic foraminifera. Such species as *Bolivioides draco* (Marsson), *Brizalina incrassata incrassata* Wiech (only in Thekwi and KwaZulu basins), *Brizalina incrassata incrassata* (Reuss), *Bulimina arkadelphiana* Cushman & Parker, *Cibicides convexus* (Reuss), *Praebulimina kickapooensis* (Cole), *Praebulimina carsyae* (Plummer), *Gavelinella spp.*, *Stensioeina ‘dorsoincurvata’* (see p. 279 of ref. 40), *Epistomina supracretacea* Ten Dam and thin-walled *Epistomina pondensis* (Chapman), *Epistomina cf. favosoides* (Egger), and a variety of *Gavelinella* species, as well as *Inoceramus* prisms, first appear downhole in this succession. *Osangularia expansa* (Toulmin) appears to be one of very few benthonic species present both in the Late Maastrichtian and the Palaeocene succession. There is a nearly absolutely planktonic and planktonic foraminiferan species turnover at the Maastrichtian-Palaeocene boundary (equivalent to seismic Horizon L or 22At1) in all borehole sections in all seven basins studied to date, and this boundary is evidently marked by an unconformity of considerable time span all round South Africa. Locally around the margin of the Bredasdorp Basin, such as on the flanks of the Agulhas Arch (boreholes E-Q1, E-P1), the Late Maastrichtian succession was eroded away before deposition of the Palaeocene. This particularly suggests that uplift of the Agulhas Arch97 began during latest Cretaceous times, although most uplift occurred during the Palaeocene to Early Oligocene period.

On the Southern Margin (Bredasdorp and Pletmos basins) the Late Maastrichtian succession is less easy to define, since unusual, not especially age-restricted, foraminiferal assemblages prevailed. Here, the benthonic foraminifera are diverse, but often dominated by the agglutinated species *Clavulinia pseudorearenata*, while the planktonic foraminifera are extremely limited, generally to non-keeled *Rugoglobigerina rugosa* (Plummer), *Rugoglobigerina rotundata* Brönnimann and conservative *Heilberella* species. Only along the eastern margin of the Agulhas Arch (westernmost Bredasdorp Basin boreholes), and in the easternmost Pletmos, Gamtoos and Algoa Basin borehole sections do scattered keeled planktonic foraminifera occur, principally *Globotruncanita stuartii* and *Contusotruncana contusa*, as well as rare *Pseudotextularia elegans*. The lack of diverse planktonic foraminifera assemblages over most of the Bredasdorp and Pletmos basins appears related to the rather thicker and sandier
Late Maastrichtian succession found here. Salinities and dissolved oxygen levels on the sea floor at this time were unaffected, as is evident from the diverse calcareous benthonic assemblages. Could there have been freshwater dilution of the surface waters alone?

**Thickness of Late Maastrichtian interval.** Present only on palaeo-upper-slope (51 m in borehole O-A1), absent everywhere on the palaeo-shelf, **Orange Basin**; up to 200 m distally on palaeo-uppermost-slope (borehole E-D3), thinning only slightly shorewards (boreholes F-R1 (190 m), F-L1 (170 m), F-K1 (170 m), E-R1 (130 m), F-A5 (150 m), E-AA1 (120 m), E-N1 (110 m), MgA-B1 (120 m), Bredasdorp Basin; slightly thinner, with maximum thickness of 170 m at palaeo-shelf break (borehole Ga-J1), thinning shorewards (boreholes Ga-E2 (140 m), Ga-V1 (110 m), Ga-N1 (130 m), Gb-K1 (80 m), Gb-F1 (90 m), and Gb-B1 (60 m), Pixelmos Basin; up to 140 m thick on palaeo-upper-slope shelf (borehole Ha-H1), much the same elsewhere (boreholes Ha-K1 (120 m), and, more proximally, Ha-D1 (120 m), <i>Gamtoos Basin</i>; up to 200 m thick on palaeo-upper-slope (borehole Hb-C1), thinner closer to shore (boreholes Hb-A1 (110 m) and Hb-F1 (120 m)), Algoa Basin; comparable thicknesses (boreholes Jc-A1 (73 m), Jc-B1 (100 m), Jc-C1 (100 m) and Jc-D1 (110 m)), <i>Thekwini Basin</i>; up to 133 m distally on palaeo-upper-slope shelf (borehole ZC), but interval disappears rapidly westwards because of subsequent uplift and erosion, KwaZulu Basin.

Published/illustrated foraminifera. Illustrated foraminifera assemblages are from KwaZulu Basin shallow and deep borehole sections, and deeper water assemblages from the Walvis Ridge.

### Conclusions

**Sedimentation pattern**

Sedimentation patterns that developed during accumulation of the drift Cretaceous succession were primarily controlled by the relative availability of sea-floor accommodation space, generated by tectonic uplift or subsidence, on different parts of the South African continental margin. From Early Barremian to Early Cenomanian times most of the basins subsided and uplifted in unison. Both the time-spans of accumulated sedimentary packages and of the intervening unconformities are clearly closely similar from one basin to the next. Only the early history of the Thekwini Basin seems different, because of its episodic, slow rate of subsidence, and this basin can arguably only have come into existence in the mid Campanian. From Late Cenomanian to Late Maastrichtian times the southern African continental mass appears to have repeatedly suffered mild east–west rolling motions, which resulted in distinctly different stratigraphic successions on the Atlantic Margin, together with the Southern Margin, as compared with the Indian Margin. The axis of these movements must have lain in the vicinity of East London. These differences in the Cretaceous drift stratigraphic successions of the seven basins are illustrated in the Wheeler diagrams presented as Figs 5–11.

Thereafter, during the Cainozoic, only localized tectonic instability occurred, confined to particular small portions of the continental margin. Typical of Cainozoic events are the Early Palaeocene uplift and later Oligocene subsidence of the Agulhas Arch, the Middle Eocene (Bartonian) subsidence and uplift of the Chamsis to Bogeniefs continental shelf (including the onshore Langenthal and Buntfeldschuh beds) in southern Namibia; and the Late Campanian to Maastrichtian (Igoda Formation, both Needs Camp quarries, earlier Early Eocene (Birbury, Spanish Reeds), and Middle Eocene (Kalikeni/ Pato’s Kop and Needs Camp upper quarry) subsidence episodes (and intervening uplift episodes) of the coastal Eastern Cape.

On a global scale, the EXXON sequence stratigraphic model has viewed all basin sedimentation as a response to lateral processes (transgressions and regressions) across the continental margin, whereas here it is viewed as a response to vertical processes (uplift and subsidence) affecting the Late Jurassic to Paleocene margin. Only in the South African Pleistocene and Holocene succession (50-m Package and later sedimentary units) do lateral processes control sedimentation, in response to sea-level changes driven by major polar glacial advance and retreat.

**Unconformities**

The presence of unconformities developed at least across most of the continental margin (shelf top and upper slope), evident in all oil exploration borehole sections examined so far, as well as in Deep Sea Drilling Project and Ocean Drilling Project boreholes drilled in the deep ocean, indicates clearly that these unconformities are not reflections of rising or falling sea level, caused, for example, by polar ice retreat and advance, but are rather reflections of tectonic activity that may influence entire ocean basins. For example, age-equivalent unconformities to those described herein (particularly 13At1, 13Am’s and 15At1) can be recognized in the Early and mid-Cretaceous succession of DSDP site 361 in the Cape Basin, as well as in the Austral, San Jorge and Neuquén basins of Argentina, the North Falkland Basin and the Falkland Plateau Basin. Some of these basins contain marine infills, others contain non-marine infills.

Consequently, it becomes apparent that three conditions must prevail at any time and on any part of the sea floor: (1) Tectonically driven uplift leads to development of an unconformity, as the sea floor is eroded down, and sediment is not deposited but is transported into deeper water. (2) No uplift or subsidence leads to development of a hardground crust on the sea floor, and sediment is not deposited but is transported into deeper water. (3) Subsidence of the sea floor leads to development of a sediment package, sediment is deposited, and there is essentially no throughput of transported sediment into deeper water. Such a threefold subdivision is also applicable for continental land surfaces. A stability datum must exist from the highest mountain-top on the continent down to the lowest trench on the ocean floor. Uplift of any part of the datum surface leads to erosion and down-wasting of the uplifted part. Still-stand leads to development of a hardground, calcrite, silcrete or gravel-covered surface: eroded sediment bypasses this region and is not deposited. Subsidence of any part of the datum surface leads to sedimentation in that part, whether of marine, fluvial or aeolian sediment.

The EXXON sequence stratigraphic model argues that sedimentation across the continental margin is a response to rises or falls in global or ‘relative’ sea level. Consequently, the most complete stratigraphic record, with the fewest unconformities, would be expected on the outermost shelf and the continental slope, and the least complete record on the innermost shelf. However, the most distal boreholes drilled up to now around South Africa clearly possess more incomplete stratigraphic records than those sited closer to shore. The most nearly complete records are evident in boreholes intersecting the palaeo-outershelf succession. It thus seems likely that tectonic movement is more muted over the inner part of the continental margin, which overlies thick continental crust, but is accentuated further offshore, where the underlying crust is very much thinner. This probably explains the often very incomplete stratigraphic successions evident in some DSDP and ODP deep
The presence of some major unconformities whose time-span clearly increases in an offshore direction, such as 15A1 unconformity (mid-Cenomanian to Early Turonian) in the Orange Basin, and 5A1 unconformity (latest Hauterivian to earliest Barremian) in the Southern Margin basins, suggests again that these unconformities are driven solely by tectonic forces, and they are not a response to perceived global sea-level rise or fall. Similarly, a maximum marine advance in the mid-Early Turonian of the Orange Basin does not correlate with a maximum marine ‘advance’ in the earliest Early Turonian of the Southern Margin basins, or with a substantial marine retreat in the Early Turonian of the KwaZulu Basin.1,81

**Progradation**

Deep suspicion must be directed towards sedimentary packages perceived from seismic sections to be prograding out from the continent across the margin. Prograding build-outs can develop only if there is a coarse elastic bed-load (in either silticlastic or bioclastic regimes) moving out across the continental margin into deep water. Such migrating sediment bodies will certainly accumulate diachronously as they build out across the continental margin. On the shelf top, these will display shallowing upwards and coarsening upwards characteristics. However, most supposed ‘prograding’ systems studied microfaunally by the author around southern Africa also contain significant proportions of fine-grained claystones, which must have accumulated as a rain of clay particles settling out of suspension on to the surface of the continental margin, and thus must drape that surface. ‘Prograding’ systems of this type consequently reflect differential sediment loading of the continental margin, as a response to the differential subsidence, still-stand or uplift of the margin both areally and through time.

High-resolution analysis of the benthonic foraminifera assemblages from numerous closely spaced borehole intersections through mixed claystone and sandstone ‘prograding’ systems in the seven basins studied shows no sign of major sea-level change. For example, Orange Basin borehole K-A3, sited just a few kilometres inshore of boreholes K-A1 and K-A2, contains numerous siderite spheres and sparse foraminifera assemblages (agglutinated benthonic species predominates), throughout the hyposaline, marginal marine Late Santonian succession. In boreholes K-A1 and K-A2, siderite spheres are missing, and foraminifera assemblages are decidedly more diverse (calcareous benthonic species predominate), throughout the succession, indicating a consistently stronger and more nearly normal marine influence. Thus, the boundary between these two facies must always have remained within the short distance between boreholes K-A1 and K-A3. Subsidence rate and sediment infill rate must have been virtually exactly equal. Comparable examples occur in the Albian, Turonian and Coniacian successions of the Orange Basin (see Albian facies boundaries shown in Fig. 5). These biofacies boundaries can be independent of sandstone distributions across the continental margin, but often styles of sandstone deposition duplicate microfossil biofacies, as is seen in the Albian to Early Cenomanian succession of the Orange Basin.

In a similar vein, the sharply defined foraminiferan biofacies boundary evident in the Middle Albian to Early Cenomanian succession in the Pletmos Basin, between the inner palaeo-shelf aragonitic facies (Epistomina-dominated assemblage) and the middle to outer palaeo-shelf calcitic/agglutinated facies (mixed foraminiferan assemblage), is a vertical boundary (fig. 3 of ref. 92). This facies boundary shows no sign of significant lateral movement towards shallower or deeper waters throughout its roughly 10-Myr history. Foraminiferas assemblages from boreholes on either side of the facies boundary are clear-cut (either the aragonitic biofacies or the calcitic/agglutinated biofacies) across the full length of the Pletmos Basin. Although not all of the given examples are associated with seismically identified ‘progradation’, the widespread occurrence of vertically aligned facies boundaries within the Cretaceous drift succession argues strongly against all these Cretaceous sedimentary packages being lateral ‘build-outs’ from the shoreline. As a result, before it can be concluded that a particular sedimentary unit is prograding, its lithology must be known. True progradation cannot occur in claystone, chalk or limestone successions that accumulated from a rain of pelagic micro-debris, even if seismic bed-patterns suggest the opposite.

**Marine condensed sections**

Hemipelagic claystone beds occur rarely in the stratigraphic succession. They are easily recognizable beds, on the basis of their unusually fine-grained, often organic-rich lithology, high-gamma electric log response, and their often benthos-poor, plankton-rich microfossil assemblages, and they can be rapidly used in correlating within and between basins. Exxon terminology has designated these rock units as ‘marine condensed sections’, and it has been concluded that they accumulated over a long period. However, none of the Cretaceous drift succession studied around southern Africa contains any rock units that can be reliably considered as ‘marine condensed sections’: that is, contain a series of robustly age-diagnostic foraminifera or other microfossils occurring through the unit that lead one to believe it represents a long time period with minimal sedimentation. Relative foraminiferan abundances have been used by some authors to identify and correlate marine condensed sections between boreholes. However, so many environmental, depositional and diagenetic parameters are involved in the proportion of skeletons from any living population that survive the fossilization process, that such correlations should more honestly and simply be deemed relative foraminifer abundance curves, and left at that.

Hemipelagic claystones, often with high-gamma and organic enrichment features, and frequently possessing source rock potential, are limited in time and space, as has been indicated above, to coarser-clastic-starved regions of these basins, generally on parts of the outer shelf or upper slope. They accumulate where there is no bed-load of quartz sand migrating across the sea floor into deeper water. Hemipelagic claystones usually form in the aftermath of major tectonic uplift, erosion, and then subsidence episodes of the continental margin, and especially overlie the 1A1t, 5A1t, 6A1t, 13A1t, 15A1t and 140t unconformities. It is clear that their accumulation is a response to the decline in coarse clastic bed-load reaching the coast and migrating across the continental margin, following tectonic disruption (uplift and subsidence) of the continental interior and its drainage pattern, with the bed-load at this time being largely trapped in newly formed lakes and other depressions in the continental interior.

In basins that have experienced considerable disturbance during such a tectonic episode, subsequent rapid sedimentation frequently onlaps against structural highs composed of distinctly older rocks. In this situation, the hemipelagic claystones ring the structural highs, but do not accumulate in the structural lows, as the latter will fill with, or be conduits for, turbiditic sandstones. These migrating sands introduce better-oxygenated waters into the deep basin from the basin margin, so that organic
debris associated with the sands in the structural lows tends to be consumed by bacteria and larger animals able to survive in the better-oxygenated regime. Thus, the organic-rich hemipelagic claystones constitute a distinct sedimentary facies, confined to the coarser-clastic-bypassed flanks and tops of distal structural highs, to bypassed parts of the outermost shelf and uppermost slope, and also to bypassed distal flanks of the basin (as in the case of the Bredasdorp Basin). As a consequence, hemipelagic claystones sometimes show substantial diachronity as they accumulate against, around and over structural highs.

Tectonic disruption of the continental margin tends to lead to an irregularly surfaced or ‘corrugated’ sea floor, with resultant poor sea-bottom water circulation and dysoxic sea-floor conditions. Such dysoxic conditions lead in turn to high concentrations and good preservation of organic debris. Microfossil assemblages accumulate that are rich in surface planktonic elements, where dissolved oxygen levels remain high (floods of planktonic foraminifera and radiolaria), and usually very poor in benthonic elements (either low diversity agglutinated or aragonitic benthonic foraminifera floods). Subsequently, as the surface depressions of the continental interior and the continental margin are infilled with sediment, and smoothed out, coarser clastic bed-load again reaches the sea. Siltsstones and sandstones then begin to accumulate on a margin once again with good sea-bottom water circulation and prevailing euxsic sea-floor conditions, and diverse planktonic, calcareous and agglutinated benthonic foraminifera assemblages are able to develop once more. In such well-oxygenated sea-floor conditions, organic debris (except lignite) is consumed by the diverse benthos, and is not preserved for the stratigraphic record.

The incomplete stratigraphic record

The repeated tilting of southern Africa during the Late Cenomanian to Late Maastrichtian period was first recognized from integration of foraminifera data obtained from 215 exploration boreholes in the seven basins during the period 1990 to 1993. At first, we believed that this implied the cessation of river output during uplifted or still-stand margin episodes, but it is clear that this cannot be true. Even at times of no sediment accumulation, sediment outflow was not hindered, and only its deposition across the uplifted margin was prevented. Consequently, there is no sedimentary record available during times of uplift to provide any indication of those features that are of crucial interest in both diamond and oil exploration: the position of shorelines and river mouths, or the lithology and grain size of sediment being transported. In addition, uplift of the continental margin had no direct bearing on the grain size of eroded siliciclastic debris available for transportation, a feature that was presumably controlled primarily by the intensity and location of uplift episodes in the continental interior. Thus, all Cretaceous drift successions on the southern African continental margin, at whatever location, sit proximally or distally, consist of episodes of sedimentation, and are incomplete records. Hence, our understanding of the stratigraphic history of South Africa must also remain incomplete, and limited to those periods that are represented by datable preserved sediment.

Sea-level curves

Because the Cretaceous drift succession of each of the seven basins studied has subsequently been uplifted and eroded down, most shoreline deposits of Barremian to Maastrichtian age, if they ever existed, have been destroyed. Only in the Orange Basin are extensive fluvial (coastal plain) and shoreline deposits preserved, and consequently it is in that basin that a sea-level curve is perhaps easiest to construct. In particular, detailed examination of the proximal Turonian to Coniacian stratigraphic succession in the Orange Basin has shown that it consists of numerous fourth-order fluvial-estuarine-innermost shelf cycles distinguished by thin ‘marine bands’ and very much thicker fluvial intervals, which are now exposed at the present-day sea floor. It is probable that similar fourth-order cyclical records exist for the Middle Albian to Early Cenomanian and Late Santonian successions in the proximal Orange Basin, but these records are not so easily accessible in vibrocoring of the present-day sea floor. However, despite these detailed, localized sea-level change records, even in the Orange Basin the presence of unconformities of considerable time-span means that any sea-level curve constructed must necessarily remain incomplete. Impartial and dispassionate sea-level curves can only be derived for those portions of the stratigraphic succession that are represented by preserved sediment, and, one hopes, contain preserved shoreline deposits. If shoreline deposits have been eroded away, analysis of the foraminiferal assemblages from a dip line of boreholes across each basin margin can define the areal and vertical distribution of each foraminiferal biofacies, and can provide indications of the marine water depth gradient that was prevalent at any particular time. It is thus possible, with some caution, to project approximate positions for palaeo-shorelines, despite their having been subsequently eroded away. Seismic dip sections may also provide projected pinch-out positions for particular rock units, and these two methods can be cross-checked. However, both methods are obviously ‘best-guess’, and conclusions clearly must be regarded in that light.

Each basin fill is sufficiently dissimilar from the others that it must be concluded that these successions accumulated purely as a response to the local tectonic regime at any given time. Except for the sea-level changes interpreted from the Early Turonian ‘11’ sandstone episode seen in most basins, and the fourth-order cyclocities in the Turonian-Coniacian succession of the Orange Basin, no other recognized events are sufficiently consistent across the seven basins for them to be solely attributable to global sea-level rises or falls. The global sea-level change record in the seven basins must thus be represented by minor base level changes that are entirely concealed behind the tectonically driven movements evident in the stratigraphic record and described herein. As a consequence, seismically derived ‘global sea-level curves’ for the Cretaceous must instead be suspected of being tectonic intensity (or tectonic change) curves, for they have nothing to do with actual sea-level change through time. As indicated, because of subsequent uplift and erosion, most rock units of the Cretaceous drift succession lack preserved shoreline deposits, so that the pinch-out position of each unit, although evident today on seismic sections, has no value in establishing a sea-level curve. Other rock units accumulated only in deep water, for example because of synchronous uplift of the shelf and subsidence of the slope, and the shorewards pinch-out of these units likewise has no value in establishing a sea-level curve.

Economic significance

The economic significance of the arrangement of stratigraphic packages around South Africa described above can yet be understood only in a simplistic manner. Coarse siliciclastic output through time has economic significance both in the development and distribution of reservoir sandstones in hydrocarbon exploration, as well as in the development and distribution of diamond placers. It is evident from the data presented above that the present-day drainage pattern in southern Africa, with
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