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Foraminiferal biostratigraphy of the Barremian to Miocene rocks of the Kudu 9A-1, 9A-2 and 9A-3 boreholes

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Detailed foraminifera] analyses have been undertaken of the Kudu 9A-2 and 9A-3 boreholes, and results compared with the adjacent hole 9A-1, drilled in]973-74. All three boreholes intersected much the same sequence and all bottomed in interbedded non-marine/marginal marine sediments and volcanics. Foraminifera indicate the oldest datable sediment to be of Late Barremian age, though the lowest 200 to 300 m of section in each hole contain no datable faunas. The Late Barremian to Coniacian sediments are essentially distal, having accumulated in marine environments from outermost shelf to base of slope. The Early Aptian organic-rich interval between horizons P and P] is characterised by almost exclusively planktonic assemblages of foraminifera and Radiolaria. A major mid-Aptian break (corresponding with horizon P) and a break across the Cenomanian-Turonian boundary (just below horizon N) are subcontinent-wide events recognisable off all three coasts of South Africa. Sedimentation rates increased substantially in the Santonian and an episode of shallowing upward commenced, probably due to progradation. Campanian and later deposits are all typically outermost shelf. Major breaks occur from the Early Maastrichtian to the latest Palaeocene, from the earliest Early Eocene to the latest Late Eocene, and probably also from the mid-Oligocene to the Early Miocene. Top-hole sampling is poor, but from sea-floor data, thin Holocene unconformably overlie Middle Miocene (later Langhian) deposits.

Introduction

A total of 1244 samples were examined microfaunally for the present study in an attempt to provide an age-breakdown and environmental interpretation for the Kudu 9A-2 and 9A-3 sections, and to confirm correlations to Kudu 9A-1, drilled in late 1973- early 1974. The following samples were studied from the three boreholes:

Kudu 9A-1: 430 cuttings, core and sidewall core samples.

Kudu 9A-2: 416 cuttings and core samples.

Kudu 9A-3: 398 cuttings and core samples.

Summaries of previous foraminifera-based dating work on the Kudu 9A-1 borehole section are provided by McLachlan and McMillan (1979) and Gerrard and Smith (1982). Locations of the three boreholes on the Orange Shelf are shown in Fig. 1. All depths given are driller's depths below kelly bushing. Marot *et al.* (1988) have detailed driller/loggers' depth corrections. Sidewall cores have generally been avoided in the microfaunal analysis work as they tend to upset the "smoothed" microfaunal results gained from the cuttings. Cuttings have been processed and studied for their microfaunal content at regular 10m intervals throughout all three boreholes.

Kudu 9A-1 and Kudu 9A-2 have been examined in detail, while Kudu 9A-3 has been examined at a less intensive level and correlated to the pattern of results from 9 A-I and 9A-2 (Fig. 2).

Processing methods used have been standard micropalaeontological methods. They involve the use of surfactant detergents in the disaggregation of the cuttings, and the use of surfactant detergents and a variety of crushing and sieving techniques in the case of the core samples. All samples have been processed in the recently established micropalaeontology laboratories of Soekor in Parow.

The following descriptions of the ages of the rocks intersected in the three Kudu boreholes are given from top to bottom (latest to earliest), rather than the more usual earliest to latest. This is due to the mode of study and to the use of cuttings with their inherent cavings problem. The resulting foraminiferal biozonation of the three boreholes is thus an interval zonation in the same sense as described by Hedberg (1976).

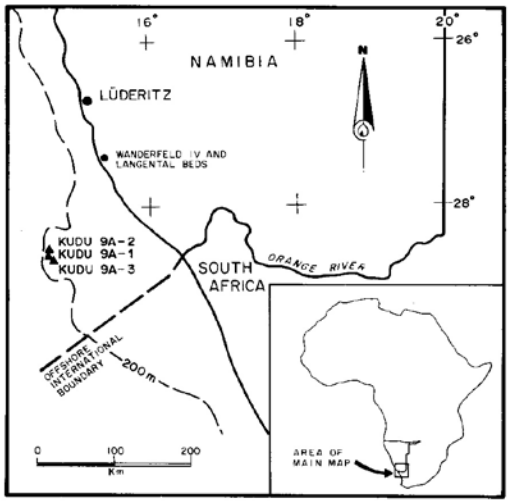

Fig. 1: Locality map of Kudu 9A-1, 9A-2 and 9A-3 on the Orange Shelf of southernmost Namibia.

Cainozoic interval (sea floor to horizon L)

Early Miocene (Burdigalian and probable latest Aquitanian)

Identified in two bit samples only, at 245 and 395 m in Kudu 9A-3. Bit sample at 250 m in Kudu 9A-2, which is also probably Burdigalian, was lost after recovery. This interval is composed of foraminifera-rich limey clay, cream to off-white in colour, with bryozoans and other shell. Rare tests of *Globigerinoides lriloba* (Reuss) and *Globigerinoides immaturus* LeRoy indicate an age of Early Miocene or later: the absence of *Orbulina universa* D'Orbigny indicates these samples can not be of Middle Miocene or later age, so that a Burdigalian (later Early Miocene) age is implied. The bit sample at 395 m is a mixed sample of Early Miocene and Early Oligocene, but it lacks the earlier Early Miocene (Aquitanian) guide foraminifera *Victoriella conoidea* (Rutten) (refer to McMillan, 1989), probably as a result of the very selective recovery inherent in all bit samples. Nevertheless, the Aquitanian is probably present over the Orange Banks. Sea-floor data from the Orange Banks indicates a thin veneer of planktonic foraminifera-rich Holocene sediment unconformably overlying Early and Middle Miocene white biogenic clays (McMillan, 1987b).

Environments of deposition for the Early Miocene are middle or outer shelf. Here, as well as closer to the coast, both bit samples and sea-floor samples contain the larger foraminifera *Heterostegina costata levitesta* Papp and Kupper (refer to McMillan, 1986): their abundance indicates warm water conditions at this time. Since the great majority of the Early Miocene sediments were biogenically produced, and land-derived sediment input was at a minimum, the sea over the Orange Banks must have been exceptionally clear and the sea floor very well oxygenated.

Early Oligocene

Kudu 9A-1: cuttings 480 - ±795 m.
Kudu 9A-2: cuttings 400 - 830 m.
Kudu 9A-3: bit sample 395 m, cuttings 400 -710 m.

Indicated by the presence of the planktonic foraminifera *Globigerina eocaena* Gümbel emend. Hagn and Lindenberg, *Globigerina ampliapertura* Bolli, *Globigerina ouachitaensis* Howe and Wallace, *Eponides lisbonensis* Bandy, and large *Cibicides* spp. in abundance. An interval of the large foraminifera *Nummulites* sp. occurs from 450 to 560 m in Kudu 9A-2: the base of this interval is at 540 m in Kudu 9A-1 and at 480m in 9A-3. It is almost certain that the Early Miocene interval (probably latest Aquitanian to Langhian) lies unconformably over the Early Oligocene, with the Late Oligocene absent, as is the case widely over the South African continental shelf (McMillan, 1986, 1989).

The thickness of Early Oligocene sediments is unique to the Kudu region and indicates unusually rapid subsidence at this time when compared with generally slow rates of subsidence for the time interval elsewhere off the southern African coast: at least 430 m in Kudu 9A-2 as compared with 50 m or so at maximum on the western Agulhas Bank.

Environments would seem to have been middle to outer shelf, perhaps with a shallowing upwards. Again, the diversity and abundance of foraminifera during this interval indicates a well-oxygenated sea floor.

Late Eocene

Kudu 9A-1: ±795 - 800 m.
Kudu 9A-2: interval absent.
Kudu 9A-3: 710-±735 m.

The earlier Palaeogene deposits of the western offshore are greatly attenuated, due in part to condensing of the sequences, but mainly to the very incomplete sedimentary record. Interestingly, the most complete sequence occurs in the most proximal of the three Kudu boreholes, 9A-3, and the least complete sequence in the most distal hole, 9A-2. It seems likely that either shelf-break erosion induced by sea-bottom water currents, or minor uplift of the outer shelf-upper slope zone was responsible. The foraminifera faunas immediately above the basal unconformity are either outer shelf or upper slope ones, and it seems that whatever process was responsible was clearly submarine.

Sediments of the Early Oligocene and Late Eocene are shelly clays or silts with abundant foraminifera. There is little change between the Early Oligocene and Late Eocene foraminifera faunas. The Late Eocene is recognised in the Kudu boreholes by the first downhole appearances of *Globigerinatheka index* (Finlay), *Globorotalia centralis* Cushman and Bermúdez and *Globorotalia cerroazulensis* (Cole). Only the latest Late Eocene is represented in 9 A -1 and 9 A - 3: there is no evidence of either *Globigerinatheka mexicana* (Cushman) (mid-Late Eocene indicator) or T*runcorotaloides rohri* Bronnimann and Bermúdez (early Late Eocene indicator).

Siesser (1977), Siesser & Salmon (1979) and McMillan (1987a) have regarded the age of the adjacent onshore Langental Beds as being of Middle or Late Eocene age on the basis of calcareous nannofossils and planktonic foraminifera. From the offshore Kudu sections, a Late Eocene age seems the more likely. The planktonic foraminifera from the Langental Beds are extremely rare, as the sequence accumulated in an innermost shelf environment, but *Globigerina eocaena*, *Hantkenina alabamensis* Cushman and *Globigerinatheka index* all occur.

Latest Palaeocene to earliest Eocene

Kudu 9A-1: 800 - 810 m.
Kudu 9A-2: interval absent.
Kudu 9A-3: ±735 -780 m.

A thin interval of foraminifera-rich clays, characterised by the age-diagnostic planktonic foraminifera *Globorotalia aequa* Cushman and Renz, *Globorotalia subbotinae Morozova* and *Globorotalia aragonensis* Nuttall. The diverse and abundant array of benthonic and planktonic foraminifera clearly indicates an outermost shelf or uppermost slope environment of deposition. This interval would appear to straddle the Palaeocene-Eocene boundary. Again, the sequence thins in an offshore direction from 9A-3 to 9A-2 for the same reasons as described above under the Late Eocene section. It seems probable that the latest Palaeocene-earliest Eocene interval equates to the episode of almost the same age known in the eastern Cape at Birbury, described by Bourdon and Magnier (1969) and Siesser and Miles (1979).

Late Cretaceous interval (horizon L to just below horizon N)

Earliest Maastrichtian

Kudu 9A-1: 810-940m.
Kudu 9A-2: 830 - 950 m.
Kudu 9A-3: 780 - 850 m.

The unconformity associated with seismic horizon L ranges in age from earliest Maastrichtian to latest Palaeocene. It is clear that the Palaeocene sea advanced over a surface of Cretaceous rocks that had been somewhat uplifted and perhaps tilted in a seaward direction at the end of the Cretaceous. This tectonic episode was responsible for erosion of what was probably a near-complete Maastrichtian sequence at the Orange Banks. Unfortunately, however, although the foraminifera faunas indicate how much of the Maastrichtian sequence is missing in the Kudu boreholes, they provide little clarity on the total thickness of sediments removed at horizon L times. Based on the thickness of the underlying Campanian, perhaps 300 or 400 m have been removed, but this is tenuous and fluctuations in sedimentation rate may be expected: a profound difference in sedimentation rates between the Campanian (about 30 m) and the Maastrichtian (350 m) of the southern offshore of South Africa has been encountered in nearly all boreholes drilled to date. There would seem, however, to be a little more erosion on the Cretaceous surface at Kudu 9A-3, where the earliest Maastrichtian is about 30 m more attenuated than at 9A-1 and 9A-2.

The earliest Maastrichtian interval yielded a diverse and distinctive fauna of both benthonic and planktonic foraminifera, many of the latter being large arid well formed. An outermost shelf to uppermost slope environment of deposition is indicated with a well-oxygenated water column. Age diagnostic planktonic species include Rugoglobigerina rotundata Bronnimann, *Rugoglohigerina rugosa* (Plummer), *Globotruncana arca* (Cushman), *Globotruncana tricarinata* (Quereau), *Glohotruncana linneiana* (D'Orbigny), *Globotruncanella* cf. *citae* (Bolli), *Guhlerina ornatissima* (Cushman and Church), and several species of *Heterohelix*. The absence of such later *Maastrichtian* species as *Racemiguembelina fructicosa* (Egger) and *Rosita contusa* (Cushman) is notable and these Kudu assemblages are thus clearly earlier than that described by Todd (1970) from a Vema core on the east flank of the Walvis Ridge.

Campanian

Kudu 9A-1: 940 - 1380 m.
Kudu 9A-2: 950 - 1410 m.
Kudu 9A-3: 850 -1310 m.

The Campanian sequence is essentially a continuation of the overlying earliest Maastrichtian, in terms of both its benthonic and planktonic foraminifera. The interval is distinguished by the first downhole appearance of *Globotruncana ventricosa* White, of which particularly large, typical tests occur throughout. An upper slope environment of deposition is indicated.

Santonian

Kudu 9A-1: 1380 - ?3164m.
Kudu 9A-2: 1410 - 3205 m.
Kudu 9A-3: 1310 - ?3195 m.

The later Santonian microfaunas remain much the same as the overlying Campanian. Foraminifera diversity remains high, as above, indicating well-oxygenated sea-floor conditions. The top of the Santonian is marked by the first downhole appearance of *Marginotruncana coronata* (Bolli), with subsequent scattered occurrences of *Marginotruncana angusticarinata* (Gandolfi). Occasional tests of *Globotruncanita* cf. *elevata* (Brotzen) occur between 1410 and about 1850 m in Kudu 9A-2, a genus which is typical of the latest Santonian at oldest. In this later Santonian interval, small but persistent numbers of transported shelf foraminifera occur. All of these are badly corroded, and are clearly out of place when compared to the generally excellent preservation of the *in situ* foraminifera fauna. All the transported species are aragonitic forms: *Colomia austrotrochus* Taylor, *Ceratohulimina cretacea* Cushman and Harris, *Epistomina supracretacea* Ten Dam, *Epistomina pondensis* (Chapman) and *Epistominafavosoides* (Egger).

Below about 1850 m in Kudu 9A-2, and similar depths in the two other holes, the foraminifera faunas show signs of decline in diversity. The benthonic species *Allomorphina cretacea* Reuss, "*Chilostomelloides*" sp., *Valvulineria* sp. and *Haplophragmoides* spp. become increasingly predominant, not through an increase in their own abundance, but rather through a gradual, though variable decline in the remainder of the foraminifera assemblages. Framboidal pyrite becomes increasingly common, and lignite and megaspores (both land-derived elements) begin to occur in small but consistent numbers. Poor faunas, dominated by the above microfaunal elements, but with occasional *in situ* planktonic tests of *Glohotruncana tricarinata*, *Glohotruncana linneiana, Marginotruncana coronata* and others, persist to the bottom of the Santonian interval.

The presence of *Allomorphina-Quadrimorphina-"Chilostomelloides"* - *Haplophragmoides*-dominated microfaunas clearly indicates deep waters, off the continental shelf. This is supported by the unusually large size of many of the allomorphinid tests: in South Africa the group is everywhere rare, usually absent on the continental shelf and never seen close to shore. Scattered pyritised Radiolaria occur (sphere and dictyomitroid types), as well as the planktonic foraminifera listed above.

It is believed that this sequence accumulated in a deepmarine environment, probably lower slope, and that considerable calcite dissolution of both benthonic and planktonic foraminifera occurred during this period. Although lignite is widely present, it would always seem to be a minor element in the sediments. Thus, plant debris on the sea floor would appear to have been in insufficient quantity to have caused strongly lowered oxygen levels leading to acidic bottom waters and resulting corrosion of calcite shells at the sea floor.

The Santonian interval is exceptionally thick by southern African standards, and it is as yet not fully clear how to account for this thickness. Rapid sedimentation during the Santonian may be a reflection of either progradation from the east or south in the L to N interval, or be a false thickness derived from the three Kudu boreholes having been drilled through the zone of growth faults. The latter alternative seems unlikely, as each of the three holes display almost identical thicknesses, which would not be the case if variable extents of faulting were encountered in the three different holes. From the faunas too, the poor foraminifera assemblages through this interval would not be expected if faulting was the cause: percolating water along fault planes would preferentially have removed the calcareous fauna, especially the thin-walled allomorphinid species.

Coniacian

Kudu 9A-1: ?3164 - 3395 m.
Kudu 9A-2: 3205 - 3445 m.
Kudu 9A-3: ?3195 - ?3405 m.

A rather condensed interval that again suffers to some degree from calcite dissolution of microfaunas. Microfaunas are very variable and many of the foraminifera tests show rather corroded surfaces. The planktonic species *Dicarinella primitiva* (Dalbiez), with the subsequent appear-ance of *Dicarinella renzi* (Gandolfi), mark the top of the Late Coniacian. The distinctive Middle Coniacian benthonic foraminifera marker, *Gavelinella plummerae* (Tappan), is also present in all three Kudu holes, but Early Coniacian markers have not been identified, probably owing to the excessive water depth at this time. Water depths are interpreted to have been base of slope during the Coniacian. Where benthonic fauna has been preserved, oxygen levels on the sea floor appear to have been somewhat higher than seen in the overlying Santonian, and lignite and megaspores considerably rarer.

The Wanderfeld IV Beds (Klinger, 1977) lie onshore, adjacent to the Orange Shelf and, though dated macrofaunally as Cenomanian, are of latest Coniacian-earliest Santonian age on the basis of the planktonic foraminifera *Dicarinella concavata* (Brotzen), *Globotruncana linneiana* and *Globotruncana tricarinata* (preliminary comment, McLachlan and McMillan, 1979, p. 172; McMillan, 1983).

Turonian

Kudu 9A-1: 3395 - 3493 m.
Kudu 9A-2: 3445 - 3525 m.
Kudu 9A-3: ?3405 - 3485 m.

The Turonian would seem to be a greatly condensed interval. Microfaunal evidence for its presence is poor, owing in part to calcite dissolution, as discussed above, and to the presence of numerous microscopic brown lumps of calcite and/or dolomite. These brown lumps appear to be a diagenetic product that may perhaps be derived from re-precipitation of the calcite of tests of foraminifera and other shelly sea-floor animals. They, and similar brown plates, occur widely in deep-marine prograding and condensed intervals around southern Africa (from latest Valanginian to Turonian) and despite their rather uncertain source, have proven a reliable facies indicator. The Turonian interval is regarded as having accumulated in a base of slope environment of deposition.

The top of the Turonian is marked by the first downhole appearance of the planktonic foraminifera *Praeglobotruncana stephani* (Gandolfi) and the subsequent occurrence of *Neobulimina albertensis* (Stelck and Wall) (see Azevedo *et al.*, 1987), but other diagnostic species of this age are rather rare. As a result, it is not yet possible to determine how complete a Turonian sequence is represented in the Kudu boreholes (see comments about the Cenomanian-Turonian unconformity below). In all three Kudu holes, the depth of horizon N lies within the Turonian and does not coincide with the microfaunal unconformity at the base of the stage. The discrepancy is a persistent one over the northern half of the explored western offshore of southern Africa, but the reason for the difference remains unclear.

Early Cretaceous interval (horizon N to Total Depth)

Cenomanian

Kudu 9A-1: 3493 - 3554 m.
Kudu 9A-2: 3525 - 3565 m.
Kudu 9A-3: 3485 - 3578 m.

For convenience, the Cenomanian is here included in the Early Cretaceous section. A major unconformity lies across the Turonian-Cenomanian boundary, revealing a variable degree of erosion on the Cenomanian surface in the three Kudu holes. As with erosion in the Palaeogene, erosion of the Cenomanian surface has been greatest at the most distal borehole location of Kudu

9A-2, and least at the most proximal, 9A-3. Although the amount of later Cenomanian sediments eroded off is minimal due to the condensed nature of the Cenomanian interval in the Kudu area, the amount of time missing is substantial. Perhaps the upper third of the period of the stage is not represented by sediments in these boreholes.

The top of the Cenomanian in all three Kudu boreholes is marked downhole by an abrupt increase in foraminifera diversity. Because of the water depth at which these deposits accumulated, variable, but often considerable calcite dissolution of foraminifera tests has occurred. However, the quiet water and base of slope environment with, probably, a better sea-floor current circulation and consequent improved oxygen supply than that seen in the Turonian, has resulted in a very distinctive benthonic foraminifera fauna. This is composed of large numbers of *Haplophragmoides* spp., most of which have very fine-grained test walls (and are therefore archetypally abyssal), with generally smaller numbers of *Glomospira charoides* (Jones and Parker), *Ammodiscus* spp., ?*Gaudryinella* sp., *Dorothia obesa* Le Calvez, De Klasz and Brun, *Dorothia oxycona* (Reuss) and *Bathysiphon* spp., all of which are agglutinated species. Age-diagnostic planktonic foraminifera are generally rare but two characteristic of the Middle and Early Cenomanian are *Rotalipora appenninica* (Renz) and *Rotalipora gandolfii* Luterbacher and Premoli-Silva. The numbers of calcareous planktonic and benthonic foraminifera, though variable, do tend to increase down the Cenomanian interval.

Late Albian

Kudu 9A-1: 3554 - 3644 m.
Kudu 9A-2: 3565 - 3675 m.
Kudu 9A-3: 3578 - 3659 m.

The Late Albian shows a continuation of the microfaunas of the earlier Cenomanian. A wide variety of calcareous and agglutinated benthonic and planktonic foraminifera occur. The sequence is again considerably condensed and depositional environments remain abyssal/base of slope. The Late Albian shows a slight thickening seawards from Kudu 9A-3 to 9A-2.

The Late Albian is marked locally by the first downhole appearance of *Tritaxia tricarinata* (Reuss), with the corresponding disappearance of the exclusively Cenomanian Rotalipora species. Subsequently *Lenticulina angulosa* (Chapman) appears intermittently. The sequence of events is regarded as time equivalent to the Albian-Cenomanian boundary events described for the Ceara Basin of northeastern Brazil (Viviers, 1985). Some transport of shelf benthonic foraminifera tests downslope can be seen in the Late Albian interval: small numbers of very badly corroded tests of *Epistomina chapmani* Ten Dam exhibit a preservation entirely different from the *in situ* fauna.

Early Albian to Late Aptian

Kudu 9A-1: 3644 - 3809 m.
Kudu 9A-2: 3675 - 3825 m.
Kudu 9A-3: 3659 - 3848 m.

The Early Albian to Late Aptian interval is essentially a continuation of the overlying Late Albian, in terms of its fauna. Foraminifera faunas are diverse, indicate an abyssal environment of deposition, and show that the sediments accumulated at a very slow rate. The top of the interval is marked locally in southern Africa by the first downhole appearance of the distinctive calcareous benthonic species *Osangularia californica* Dailey. Horizon P is regarded as being the seismic reflection of an unconformity of mid-Aptian age. Although clear-cut changes can be seen across it in terms of depositional environment (with sea-floor oxygen levels generally lower and microfaunas correspondingly usually poorer below), its precise time span within the mid-Aptian remains unclear. Few consistent foraminifera horizons can be identified either just above or below the unconformity off the west coast of southern Africa, so that the nature of erosion on its lower surface, with the manner in which sedimentation recommenced after the break, could until now only be determined from seismic section analysis.

Early Aptian to Late Barremian (horizon P to P2 or 50 m below P2)

Kudu 9A-1: 3809 -4225 m.
Kudu 9A-2: 3825 -4312.6 m.
Kudu 9A-3: 3848 - 4228 m.

Several distinct variations in the foraminiferal faunas occur through this interval of the boreholes which, though not particularly age diagnostic, can nevertheless be utilised to correlate the three Kudu holes. Three distinct units can be recognised which reflect a wide range of depositional environments, particularly notable being variations in sea floor oxygen supply.

The highest of the three units lies between horizons P and P1:

Kudu 9A-1: 3809 - 3968 m.
Kudu 9A-2: 3825 - 3978 m.
Kudu 9A-3: 3848 - 3998 m.

It is characterised by an abundance of planktonic foraminifera, mainly of the species *Hedbergella sigali* Moullade, with some *Globuligerina hoterivica* (Subbotina), which provide a date of mid-Aptian at latest. Radiolaria, all preserved as pyritised casts, are also abundant: spherical morphotypes predominate, with scattered dictyomitroid and other morpho types. The dominance of planktonic tests and the scarcity of benthonic forms clearly implies a very poorly oxygenated sea floor at this time. With a lack of animal and bacterial activity on the sea floor, organic debris, whether from land or sea, or of plant or animal origin, has been preserved in abundance.

The second highest unit lies in the upper half of the P1 to P2 interval:

Kudu 9A-1: 3968 -4067 m.

Kudu 9A-2: 3978 -4137 m.

Kudu 9A-3: 3998 - 4088 m.

This unit is characterised by a scarcity of benthonic and planktonic foraminifera but a variable, often abundant, number of pyritised sphere and dictyomitroid Radiolaria. Diagenetically formed lumps and plates of dark brown calcite occur: these have already been described for the Turonian. Sea-floor oxygen levels must have remained low throughout this time period, but the diagenetic ally formed brown plates suggest that the extant fauna is merely a remnant of an original more diverse deposited fauna.

The third unit lies from midway between P1 and P2, to just below P2:

Kudu 9A-1: 4067 -±4225 m.

Kudu 9A-2: 4137 - 4312.60 m (core 2).

Kudu 9A-3: 4088 - 4228 m.

This third unit is distinguished by a much more substantial benthonic foraminifera fauna, dominated by species of *Lenticulina*, with the species *Lenticulina nodosa* (Reuss) (mid-Aptian to Early Valanginian) being particularly important. Radiolaria, chiefly pyritised spherical morphotypes, occur in fluctuating numbers and confirm a relatively deep-marine environment of deposition, upper slope or outer shelf, for this unit. The greater diversity of benthonic foraminifera clearly indicates sea-floor oxygen values to have been higher than in the overlying two units.

Shale samples processed from core I and the top of core 2 in Kudu 9A-2 have yielded diverse foraminifera faunas that contain numbers of *Gavelinella* sp. This genus of benthonic foraminifera is also found in isochronous sequences of the southern offshore of South Africa which are dated as earliest Barremian to Early Aptian in age. There, *Gavelinella* tends to decline in abundance down the sequence, generally being absent in the Early Barremian. Species of *Gavelinella* are never seen in the Hauterivian in South Africa. For this reason, the oldest datable sediments of the Kudu boreholes, based on the micro faunas from the top of core 2, Kudu 9A-2, are regarded as being of Late Barremian rather than Early Barremian age.

A microfauna which occurs at 4312.60 m in core 2 of Kudu 9A-2 may be considered a basal assemblage of the third unit and marks the lowest occurrence of relatively deep-marine environments. The sample contains abundant spherical Radiolaria, with occasional planktonic foraminifera (*Hedbergella sigali*), together with a diverse benthonic foraminifera fauna dominated by species of *Lenticulina*, and with *Epistomina* cf. *hechti* Bartenstein, Bettenstaedt and Bolli. The presence of glauconite and discrete coarse quartz grains, together with much shell, may argue for transport of shallow-marine debris to an outermost shelf environment.

Undatable interval (About P2 to T.D.)

This lowest unit consists of the shelly sands, aeolian sands, volcanics and rare shales that lie from just below P2 to Total Depth:

Kudu 9A-1: ±4225 - 4453 m.

Kudu 9A-2: 4312.60 (core 2) - 4539 m. Kudu 9A-3: 4228 - 4520 m.

Microfaunas of this lowest unit proved extremely difficult to extract, principally because of the variable, but often intense calcite cementation of the various rock types intersected. Though thin black silty claystone intervals occur in the cored interval (cores 2 to 6) of Kudu 9A-2, these would appear to be absent in Kudu 9A-1, and only rarely developed, if at all, in Kudu 9A-3. Lignite, hexagonal incertae sedis, pyrite, shell fragments (mostly indeterminate) and ooliths occur in the sandstones and siltstones of the interval in variable numbers. The only black shale sample to have been effectively disintegrated by microfaunal processing was at 4391.18 m in core 6, Kudu 9A-2. This yielded calcareous worm tubes in abundance with pyrite, possible bivalve shell shards, and a possible ostracod and indeterminate agglutinated foraminifera. Samples from the Kudu 9A-3 cores proved to be somewhat more cemented, but two samples in core 5, at 4348.05 m and 4348.01 m, yielded small numbers of pyritised benthonic foraminifera, notable of which are *Quinqueloculina* sp., *Globulina* sp., and *Cornuspira* sp. The latter two of these species effectively indicate an environment no shallower than innermost shelf. The three species provide little indication of age, though *Cornuspira* and *Quinqueloculina* together suggest an age no older than Valanginian in a South African context.

Further down the section, in the sands and silts between the volcanic intervals, only core 11 of Kudu 9A-3 intersected fine-grained silty sediments, grey-green and often finely laminated, in a thin interval at 4460.60 m. Unfortunately, however, samples from this interval proved entirely devoid of microfauna and macrofauna, even though they were successfully disaggregated.

Conclusions

To date only the three Kudu boreholes which comprise the present study have been drilled off the coast of Namibia, at the northernmost end of the Orange Basin. Though the ages and major sequence boundary unconformities intersected in the Kudu holes are closely comparable to those seen in the Orange Basin boreholes, the depositional environments and rates of sedimentation differ profoundly between the two. Comparison of the Kudu microfaunas with faunas from further afield has revealed few reliable correlations. There are some basic similarities with the microfaunas of the Cuanza Basin (Wissink, 1956; Rocha and Ferreira, 1957; Ferreira and Rocha, 1957; Hoppener, 1958; Hanse, 1965; ,Meijer, 1972,1975; Rocha, 1973) and presumably also the Moçamedes Basin of the southern Angola coast, but little detailed work has been published. Some comparison can also be made between the Kudu holes and Deep Sea Drilling Project (DSDP) hole 361, particularly in the Early Aptian-Barremian occurrence of *Lenticulina nodosa* (Reuss) at both locations, but intensive calcite dissolution through almost the entire Late Cretaceous at Site 361 precludes any detailed foraminiferal correlation for that part of the sequence. Little similarity can be seen between the abyssal foraminifera of the Middle Eocene to Early Pliocene sequence intersected at DSDP Site 360 (Boltovskoy, 1981; Cameron, 1978; Jenkins, 1978) and of the Eocene-Palaeocene sequence of DSDP Site 361 (Proto Decima and Bolli, 1978; Toumarkine, 1978), both far to the south in the Cape Basin, with the mainly outer shelf species of the Kudu boreholes. Little similarity is evident too between the shallow-marine foraminifera of the West African basins (detailed by Kogbe and Me'hes, 1986) and the Kudu faunas, though some general similarities in the sedimentation history of the two regions are evident from mid-Aptian times onward. Some of the planktonics illustrated by Salmon (1979) from the Early Miocene and Middle Eocene of piston cores from the Central Terrace and Agulhas Passage in the southwest Indian Ocean are in common with those of the Miocene and Oligocene-Eocene of Kudu holes.

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FORAMINIFERAL BIOSTRATIGRAPHY CORRELATION OF BOREHOLES KUDU 9A-1, KUDU 9A-2 AND KUDU 9A-3.

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