HIATUS CONCRETIONS AND HARDGROUND HORIZONS IN THE CRETACEOUS OF ZULULAND (SOUTH AFRICA)

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ABSTRACT. Horizons of bored concretions, 'hardgrounds' or 'hiatus concretions' of European authors, occur at several levels in the Aptian to Coniacian marine sediments of Zululand (South Africa). They show signs of a complex burial and excavation history, are bored by lithophagous bivalves and encrusted by a variety of epizoans, while vacated borings have been secondarily occupied by nestling bivalves and other organisms. Recognition of these horizons provides insight into substrate conditions, bathymetry and diagenetic history, whilst explaining the incomplete nature of the Cretaceous succession in the area.

IN Zululand, Cretaceous rocks outcrop over a broad belt extending for 250 km south of the Mozambique border (text-fig. 1). Actual exposures are poor (less than 1% of the area), due to an extensive mantle of Tertiary and Recent sediments. The Cretaceous succession is over a kilometre in thickness, and marine horizons from Barremian to Maastrichtian have been demonstrated on macro- and microfaunal evidence at the surface, whilst a continuous marine sequence up into the Palaeocene is inferred from borehole evidence (Davey 1969, Pienaar 1969).

Recent field-work in this area (Kennedy and Klinger 1971, in preparation) has shown that the succession is far from complete, and that previous doubts as to the presence of parts of the Lower Albian, Upper Cenomanian and the Turonian are confirmed. At these levels (and at several others), horizons of winnowed, bored and encrusted concretions, sometimes rolled and incorporated into later concretions, can be recognized.

These horizons resemble the hardgrounds of the European Mesozoic described by Hallam (1969) and others, and the 'Hiatus Konkretionen' of Voigt (1968). The period of formation of these horizons in one case spanned more than a stage, whilst others developed within the duration of a single ammonite subzone.

The Cretaceous history of Zululand is outlined below, occurrences are described, and the sedimentary, diagenetic, and palaeoecological significance of the bored concretion horizons is discussed.

STRATIGRAPHIC SUCCESSION

In northern Zululand, Jurassic Lebombo Volcanics are overlain by pre-Upper Aptian to pre-Barremian coarse clastic Cretaceous sediments. These consist of interbedded conglomerates and sandstones, with log beds, and are presumably of fluviatile origin. They are followed by similar sediments with conglomerates becoming less important, trigoniid shell-pebble beds appearing and *Teredo*-bored logs abundant; these pass up into a variable series of Barremian to Aptian, or Upper Aptian, silts and shell beds, also with logs. The lowest horizons of bored concretions noted are in the Aptian.

The Albian/Aptian boundary is a non-sequence, marked by a bed of bored concretions. Above, the Albian is an expanded sequence with faunas extending up to the *Stoliczkaia*

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dispar Zone. Lithologies are usually silts, with shell beds. A number of bored concretion horizons have been recognized in the Lower Albian. The Cenomanian again consists of silts with shell beds and concretions; at the Mozambique border only the Lower Cenomanian is preserved, but at the Skoenberg, along the Mzinene River north-east of Hluhluwe, the succeeding Middle Cenomanian and part of the Upper Cenomanian are represented.

Turonian rocks are absent at the surface in Zululand. The Cenomanian/Coniacian boundary is exposed along the Mzinene River, and is a slight angular unconformity. A horizon of bored concretions with a Cenomanian fauna lies beneath a thin *Pterotrigonia* conglomerate with Coniacian *Proplacenticeras*.

South of the Mzinene, at Riverview on the north bank of the Mfolozi near Mtubatuba, this unconformity increases, and a slightly higher horizon in the Coniacian rests on Lower Cretaceous fluviatile conglomerates. At Umkwelane Hill, south of the river, the Coniacian rests first on Stormberg Basalts, and then on granitic basement.

Above this unconformity the Coniacian to Lower Maastrichtian consists of a thick sequence of silts, fine sandstones, shell-beds and concretionary layers, known chiefly from the area around Lake St. Lucia. We have seen no examples of bored concretions in this part of the succession.

LOCALITIES

Localities at which we have seen bored concretions are shown in text-figure 1. Precise latitudes and longitudes are given below.

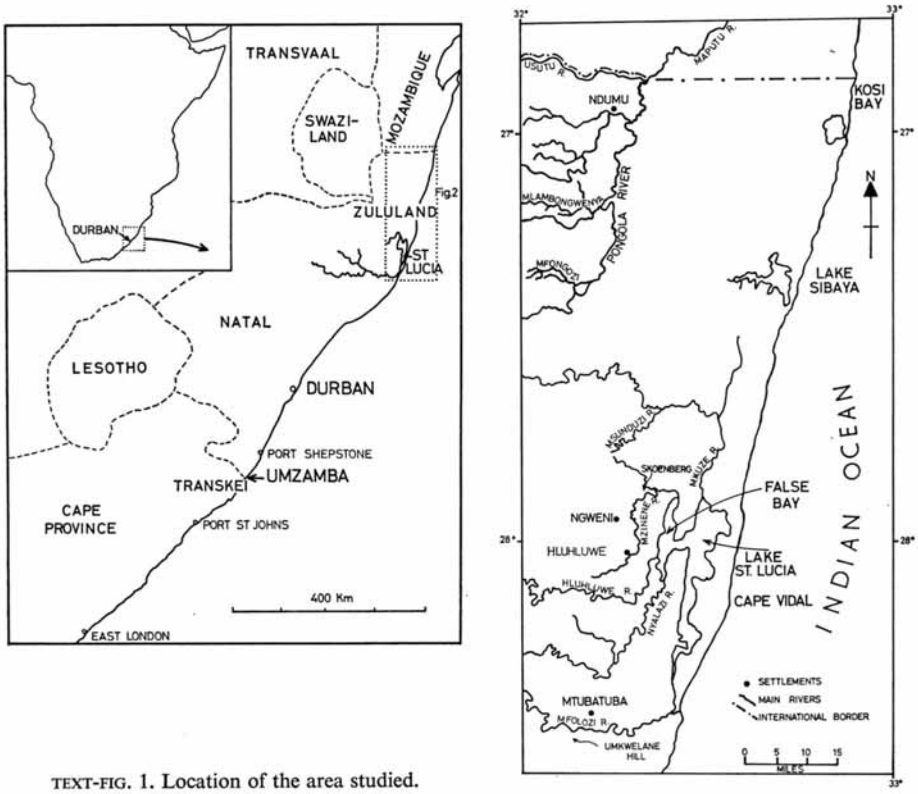
(1) *Upper Aptian* Mfongosi Spruit, 8 km north-north-east of Otobotini, exposes horizons from Lebombo Volcanics through conglomerates and sands and up into marine Aptian and Albian sediments (Haughton 1936: 286). Degraded cliffs at locality A (Latitude 27° 22′ 04″ south, Longitude 32° 09′ 03″ east) and locality B (Latitude 27° 21′ 43″ south, Longitude 32° 09′ 03″ east) on the north and south sides of the spruit (intermittent stream) approximately 700 m downstream from the old drift show Upper Aptian silts, shell beds and concretion layers. One concretionary shell bed contains bored concretions.

The sequence can be broadly interpreted as a series of small-scale sedimentary cycles: burrowed silts with a partly *in situ* molluscan fauna alternating with winnowed shell and wood beds. In the silts, infaunal bivalves are prominent; thick-shelled trigoniids, *Veniella*, *Gervillella* and oysters dominate shell beds. Silts clearly represent quieter water deposition, whilst shell beds record high energy episodes or non-sedimentation.

(2) *The Albian/Aptian boundary*. Mlambongwenya Spruit lies 20 km north-east of the Mfongosi. The boundary is exposed on the north bank, west of the drift and south of Mlambongwenya Store at locality C (Latitude 27° 10′ 59″ south, Longitude 32° 11′ 8″ east). The junction is also seen along the Mfongosi at locality D (Latitude 27° 21′ 38″ south, Longitude 32° 09′ 57″ east). At both localities there is a non-sequence at the junction. Silts below yield *Diadochoceras* and *Tropaeum*; above is a fauna rich in *Douvilleiceras*. The actual contact is a line of bored concretions, overlain by a drifted shell bed.

Along the Mzinene River, a rather similar sequence is exposed at several localities, although the actual junction is not seen.

(3) *Lower Albian*. Bored concretions occur at several levels in the thick sequence of silts, concretions and shell beds with *Douvilleiceras* at several localities in northern Zululand. There are good exposures along the Mfongosi and Mlambongwenya, at localities C and D. To the north, we have seen loose bored concretions derived from similar horizons on the west and north banks of Qotho Pan, west of Ndumu (locality E, Latitude 26° 56′ 22″ south, Longitude 32° 12′ 48″ east and locality F, Latitude 26° 55′ 59″ south, Longitude 32° 18′ 04″ east).



TEXT-FIG. 1. Location of the area studied.

(4) *Middle/Upper Albian.* Loose bored concretions were noted in fields on the north side of Msunduzi Pan, east of Ndumu at locality G (Latitude 26° 56′ 08″ south, Longitude 32° 13′ 57″ east). They are associated with loose Middle (?) and Upper Albian fossils.

(5) *The Cenomanian/Coniacian junction.* Locality H, a degraded river cliff on the north bank of the Mzinene, 100 m due north of the farm Belvedere and north-east of Hluhluwe (Latitude 27° 52′ 45″ south, Longitude 32° 20′ 44″ east) provides the best section of this contact. The Cenomanian consists of yellow silts with concretions and shell-beds. The highest course of concretions seen is truncated, bored by lithophagids and overlain by a *Pterotrigonia* shell conglomerate with rare Coniacian *Proplacenticeras*.

THE CONCRETIONS

Lithologically, the concretions are nearly all hard, brown-weathering blue-hearted shelly calcite-cemented siltstones and fine sandstones, only rarely containing lenticles of fine conglomerate. Most are less than 30 cm long. Some are cut by calcite veins.

Concretion formation seems to have taken place at an early pre-compaction stage in diagenesis, as many included fossils and burrows are uncrushed and undistorted.

Borings

Most concretions are bored on one or several sides (Pl. 106, figs. 3–5; Pl. 108, figs. 1–2, 5). The borings themselves are from 3 to 25 mm in diameter, and when complete, may be up to 50 mm long, with a constricted aperture.

The boring organisms in every case are mytilid bivalves best referred to the Tertiary-Recent genera *Lithophaga* and *Botula*, and several species are represented, as might be expected in material ranging from Aptian to Coniacian age (Pl. 106, figs. 1a–c; Pl. 108, figs. 1a–b).

Lithophaga is a chemical borer, dissolving substrates by secretion of mucus containing a calcium complexing compound (Jaccarini, Bannister and Micallef 1968; Bromley 1970). It is thus normally restricted to calcareous substrates, as is the case with the present occurrences and other fossil records (i.e. Radwanski 1964, 1965, 1968, 1970; Hecker, Ossipova and Belskaya 1963; Roniewicz 1970; Hölder and Hollmann 1969; Purser 1969; Warme and Marshall 1969; Bromley 1970, all with bibliographies). Yonge (1955) has, however, shown that some mytilids may bore mechanically. In some cases, traces of a calcareous lining to the boring is preserved (Pl. 106, fig. 3, C). There can be no doubt that these are indeed borings, for grains and shell-fragments in concretions are truncated against the sides of the bore, as in Jurassic examples described by Purser (1969).

Borings are usually most densely developed (up to 1400 m^2) on the upper surfaces of concretions as they are found (Pl. 106, fig. 3; Pl. 108, fig. 2), and in some cases actual bioerosion due to intensive attack can be recognized. Some concretions also have borings on their edges and marginal regions of undersurfaces, showing that they stood proud of the sea-floor; yet others are bored all over, and have quite definitely been rolled and overturned.

Orientation of borings varies from normal to the surface to highly inclined.

Many borings are incomplete; the constricted aperture may be missing, or only the rounded basal termination may remain, whilst in many cases, the bivalve has been washed out. This points to quite extensive abrasion of concretion surfaces after boring (Pl. 108, fig. 2, A).

Bore fillings. The fillings of borings also give evidence of quite complex post-boring history. Where bored concretions have been enveloped in a second, later course of concretions, some have been left as voids which developed a subsequent fill of sparry calcite.

EXPLANATION OF PLATE 106

Fig. 1a–c. '*Botula*' sp. from bored concretions at the Albian/Aptian junction, locality D, Mfongosi Spruit, northern Zululand, ×1·5, BMNH LL 27575.

Fig. 2. *Proliserpula* sp. encrusting a concretion from the Lower Albian at locality C, Mlambongwenya Spruit, northern Zululand, BMNH A 102802.

Fig. 3. Upper surface of bored concretion from the same horizon and locality as fig. 1. The surface shows numerous part-eroded *Lithophaga* crypts; some, as at C, retain traces of calcareous lining. A small caryophyllid coral is at *B*, whilst an arcid at *A* nestles in a vacated lithophagid crypt. There are also encrusting serpulids and oysters, BMNH LL 27574.

Figs. 4, 5. Vertical sections of borings in concretions from the same horizon and locality as fig. 2. Both show sections of surface oxidation zones. In 4, *A* and 5, *A* zones follow the outline of borings. In 5, *B* both boring and fill are cut, BMNH LL 27580, 27582.

Bar scales are 5 mm.

In other cases, the bore is sediment-filled whilst the lithophagid has a coarsely crystalline calcite fill. The nature of the sediment infilling of borings within the same concretion may also vary. At locality H, the Cenomanian/Coniacian contact, some borings are filled with silt (Pl. 108, fig. 2, B) whilst others are filled by the overlying conglomerate (Pl. 108, fig. 2, C). Cross-cutting relations point to two phases of filling (and perhaps burial and re-exhumation?), silt pre-dating conglomerate fill.

Secondary inhabitants. Bore infilling has not been entirely passive. In some cases, borings are crusted and lined by serpulids, oysters, and in one case a bryozoan. In some Lower Albian occurrences, eroded bores have been occupied by small non-boring bivalves (Pl. 107, fig. 3, A; Pl. 108, fig. 3). These show taxodont hinges, bear radial and concentric ornament, may have flared concentric ribs, and appear to be a species of *Barbatia* (*Acar*). These later inhabitants were presumably byssate nestlers/crevice dwellers like their recent counterparts (Kauffman 1969; Stanley 1970).

Traces of yet a third type of secondary inhabitant of borings are seen in some Upper Aptian concretions. Borings are stuffed with ovoid faecal pellets 1 mm diameter and 2 mm long. These might reasonably be interpreted as bivalve pseudofaeces, but for the fact that some lie in cylindrical vermiform burrows within the sediment filling the borings; they seem more likely to be traces of polychaetes which lived in vacated bores.

Secondary inhabitation of borings is, of course, well-known in Recent environments; Evans (1967) lists no less than 30 species which nestle in vacated *Penitella penita* bores, half of them potentially fossilisable, and there is a wide literature on the subject. Fossil nestlers have also been reported by several authors: Addicot (1963) and Radwanski (1970), pl. 2, fig. a, for instance, whilst a nestling arcid is figured by Masuda (1968, pl. 39, fig. 6) from Miocene *Pholadidea* borings in andesites.

Marginal weathering. Borings show some interesting relationships to the marginal oxidation zones of concretions. They cut the weathered zone and thus post-date it (Pl. 108, fig. 2) in some cases, whilst in others, the zone traces the outline of the bore, post-dating excavation, but pre-dating filling (Pl. 106, figs. 4, 5, A). Yet others cut both bore and filling (Pl. 106, fig. 5, B), again stressing the complex burial history of concretions.

Discussion. Apart from lithophagids, there is a singular lack of other sorts of boring organisms (i.e. Pl. 108, fig. 2). In this respect, the South African examples match certain European Middle Jurassic occurrences, but differ greatly from the diverse boring associations which Bromley (1967, 1968, 1970), Voigt (1959, 1968), Radwanski (1970), and others have documented. Lithophagids tend to occur in high densities (Radwanski 1970), and this, or narrowly defined environmental conditions, may have discouraged other borers.

Epizoans

Three groups occur commonly as cemented epizoans; bivalves, serpulid polychaetes and corals. To a degree, the presence of hard substrates is also reflected in the faunas of supra-adjacent shell beds, and these are discussed as ‘others’.

Bivalves. Two genera are represented: an *Exogyra* and an *Ostrea.* Both occur in profusion, plastering the surfaces of concretions, often to the virtual exclusion of other groups (text-fig. 2).

Exogyra occur at every growth stage from spat to 20–30 mm individuals: only lower, attached valves are preserved (Pl. 107, fig. 3).

Ostrea. Again vary from spat to individuals several centimetres long, occasionally with both valves (Pl. 108, fig. 2). Shape may be strongly influenced by substrate morphology: (i.e. xenomorphic, as defined by Stenzel, Krause and Twining 1957). Some are bored by bryozoans.

Serpulids. Two types of serpulid occur. A large form with a tube up to 7 mm in diameter an early planispiral coil, and a later irregular portion, is referred to the genus *Proliserpula* (Pl. 106, fig. 2; Pl. 107, fig. 1). A smaller form, with a 1 to 1·5 mm tube, coiled irregularly, meandering across concretions and forming felted coverings is referred to *Spiroserpula* (Pl. 107, fig. 1).

Corals. A small caryophyllid hexacoral occurs sparingly (Pl. 106, fig. 3; Pl. 108, fig. 4).

Distribution. Epizoans are common on concretions at the Albian/Aptian junction, and in the Lower Albian above. They also occur on Aptian concretions, but none have been noted at the Cenomanian/Coniacian junction. Associations are usually single-species dominated. Oysters plaster upper surfaces, and are well-developed on sides of concretions. They occur only sparingly on undersurfaces.

Serpulids do occur on upper surfaces, but are commonest on sides and overhung edges. They are usually the only epizoans on the undersides of many concretions, and also liked living in borings. The few corals occur on upper surfaces and sides.

These features suggest that settlement was influenced by two main factors; presence of adults, and surface orientation. This is in keeping with what we know of larval

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EXPLANATION OF PLATE 107

Epizoans on surfaces of concretions from the Lower Albian at locality C, Mlambongwenya Spruit, northern Zululand.

Fig. 1. *Proliserpula* and *Spiroserpula*, BMNH A 102801.

Fig. 2. *Ostrea* and serpulids, BMNH LL 27581.

Fig. 3. *Exogyra*, BMNH LL 27577.

Bar scales are 5 mm.

EXPLANATION OF PLATE 108

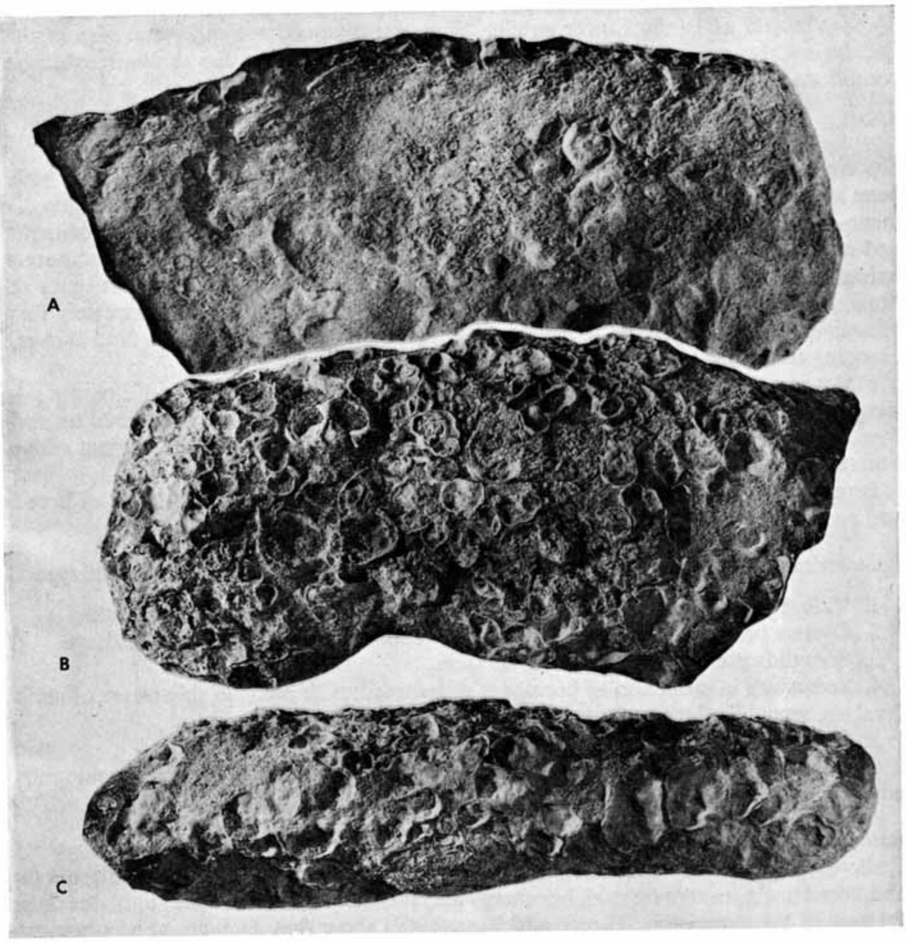
Figs. 1a–b, 2. Vertical sections of bored concretions at the Cenomanian/Coniacian junction, from locality H, on the north bank of the Mzinene River north-east of Hluwluwle, Zululand. Figs. 1a–b show internal and external moulds of '*Lithophaga*', and one specimen retaining shell. Fig. 2 shows the Cenomanian siltstone concretion below, and Coniacian shell conglomerate above. Note the lack of all but '*Lithophaga*' borings; an eroded boring at *A*, a silt-filled boring at *B*, cut by a later, conglomerate-filled boring at *C*. A section of an in-situ '*Lithophaga*' is indicated by *D*, BMNH LL 27583–5.

Fig. 3. Arcid bivalve nestling in eroded '*Lithophaga*' crypt, Lower Albian, locality C, Mlambongwenya Spruit, northern Zululand, BMNH LL 27579.

Fig. 4. Encrusting caryophyllid coral. Horizon and locality as for fig. 3, BMNH LL 27579.

Fig. 5. Calcite-lined '*Lithophaga*' boring, from the Upper Aptian of locality A, Mfongosi Spruit, northern Zululand, BMNH LL 27573.

Bar scales are 5 mm.



TEXT-FIG. 2. *A*, lower surface; *B*, upper surface; *C*, side of *Ostrea* encrusted concretion from the Lower Albian at locality C, Mlambongwenya Spruit, northern Zululand. Note occurrence of oysters on all surfaces. 8MNH LL 27581, × 1 approx.

settlement in the living organisms (Johnson 1964) and matches some other fossil occurrences (e.g. Hallam 1969, fig. 4); although markedly different from others (e.g. Cope 1968).

Other epizoans. Shell beds above bored concretions at several localities contain bivalves which might have utilized them for attachment, in particular large *Gervillella*. These also occur in other shell beds, where they presumably utilized dead shells for attachment. At Mlambongwenya Spruit, however, brachiopods occur in the matrix of bored concretions in the Lower Albian. Since brachiopods are otherwise rare in the Zululand Cretaceous, their presence in all probability reflects the unusual substrate conditions.

CONCLUSIONS

Sedimentary history. Uncrushed fossils and burrows show concretion formation to have been an early diagenetic event, probably occurring only a little distance below the sediment—water interface. After formation, erosion has removed unconsolidated sediment and exposed concretions on the sea floor to form a hard substrate—a discontinuous hardground; they have then been encrusted and subjected to the boring activities of lithdomous bivalves. In some cases, concretions have been winnowed completely free of sediment, so that epizoans extend over the sides and base, or have been flipped over, exposing the underside to attack by borers.

Following this, the history of a concretion may follow one of several directions—simple re-burial, incorporation into a later course of concretions, or re-exhumation and renewed boring, as recorded in a series of differing sedimentary fills to successive generations of borings.

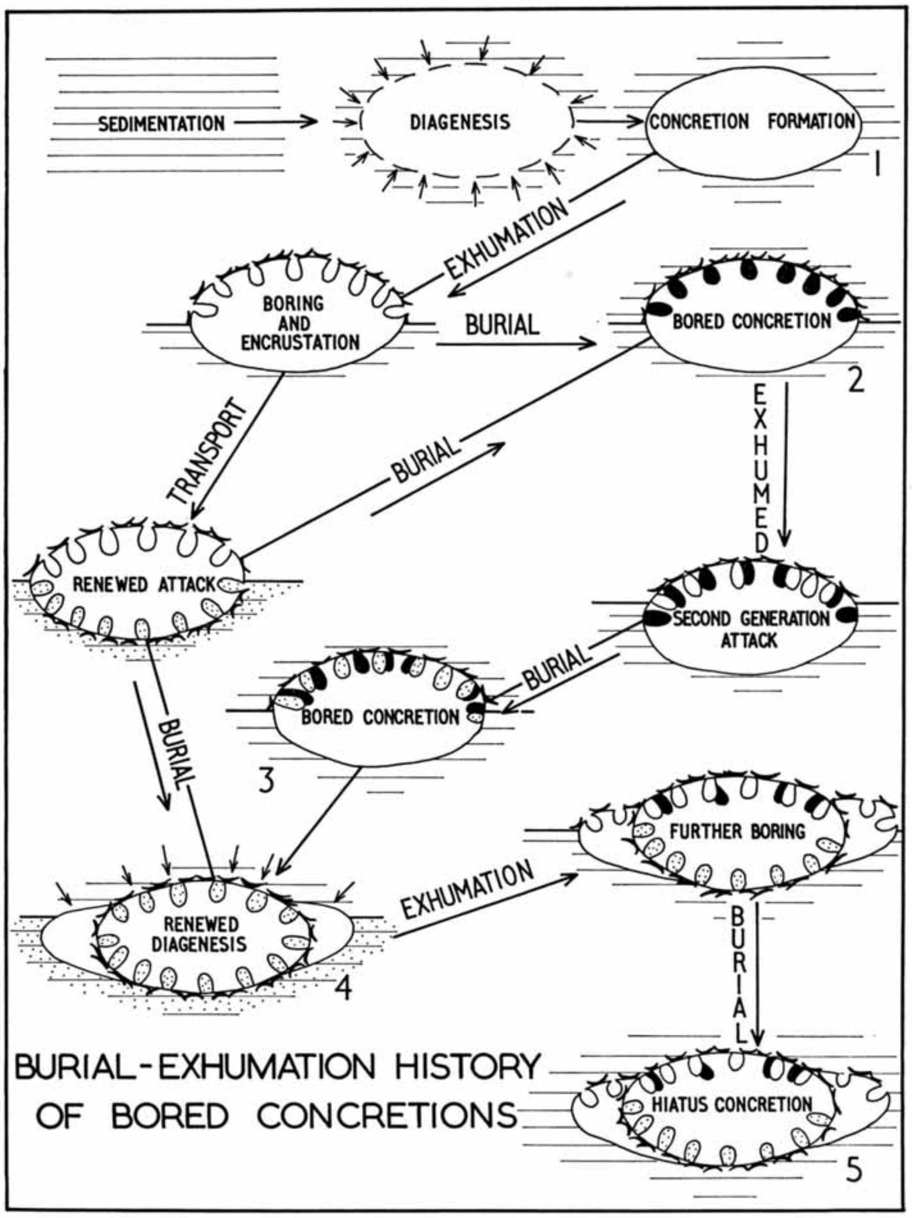
Permutations of these and other processes produce a whole series of types of bored and encrusted concretion, as we have tried to summarize in text-fig. 3.

Palaeoecology. From our descriptions and figures the following conclusions emerge:

1. '*Lithophaga*' preferred boring in the upper surfaces and sides of concretions.
2. Oysters prefer the tops and sides of concretions but also grow beneath them.
3. Serpulids prefer sides and lower surfaces.
4. Secondary inhabitation of borings is widespread, with recognizable traces of arcid bivalves, serpulids, bryozoans, and perhaps polychaete worms.
5. Encrustation usually post-dates boring.
6. Hard substrates provided attachment sites for byssate bivalves and brachiopods now found in the overlying sediments.

Bathymetry. The general facies association of the marine Zululand Cretaceous suggests shallow water, with depths probably never greater than a hundred metres. Hardgrounds and bored horizons represent higher energy and probably shallower water episodes than the rest of the succession. Turner and Boss (1962) show that *Lithophaga* occurs most abundantly intertidally or in depths of a few metres. It is a common down to 10 m and more, and occurs only occasionally at greater depths, with dead shells recorded from water depths of up to 250 m. The bored horizons described here thus indicate depths of perhaps only a few metres, and probably no more than 10–30 m.

Chronology. From the biostratigraphic data available at present, it is clear that the concretion formation, excavation and re-burial history of the bored concretion horizons took place in some cases within only part of a single ammonite subzone, a period of the order of a few hundred thousand years (Upper Aptian and Lower Albian occurrences). On the other hand, at least one occurrence (the Cenomanian/Coniacian contact) represents the duration of more than a stage: several million years.



TEXT-FIG. 3. Burial-exhumation history of bored concretions.

Case 1: normal concretions.
Case 2: exhumed and bored, with or without transport.
Case 3: re-exhumation, with complex boring history.
Case 4: incorporation into a second concretion layer.
Case 5: exhumation, renewed attack and formation of 'hiatus concretions'.

Stratigraphic significance. Bored concretion horizons are a few tens of centimetres in thickness in a sequence of over a kilometre of rather uniform sedimentary facies. Location and recognition of these horizons provides an explanation of the long suspected absence of Lower Albian, uppermost Cenomanian and Turonian sediments in this part of South Africa. They also indicate (by virtue of their wide extent) tectonic and erosional events on a regional scale.

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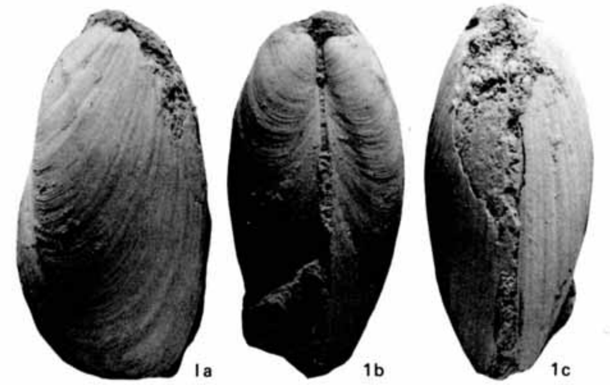


2

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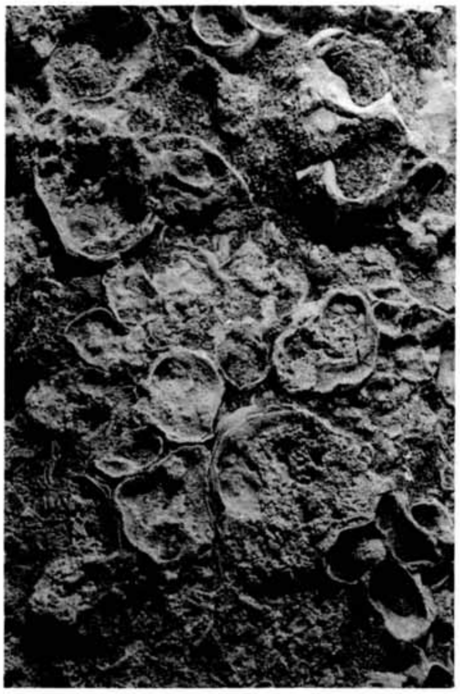
4



5

KENNEDY and KLINGER, Hardgrounds


1

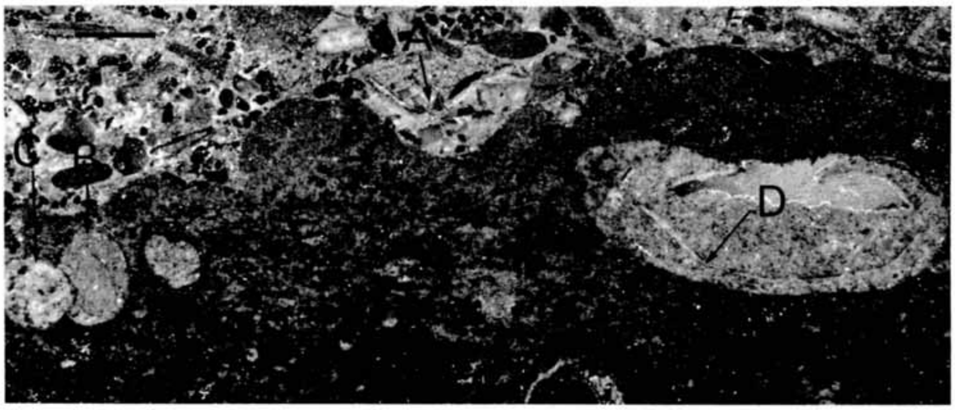

2


3

KENNEDY and KLINGER, Hardgrounds

1a

1b



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KENNEDY and KLINGER, Hardgrounds