Palaeont. afr., **15**, 1–21. 1973

PROBLEMATIC MICROFOSSILS FROM THE LOWER KARROO BEDS IN SOUTH AFRICA

by

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ABSTRACT

A problematic group of microfossils has recently been recovered from strata of Permian age, in the northern part of the Karroo basin in South Africa. This article attempts to present the information that is presently known about them. They have been found in a wide variety of sediments in the Lower, Middle and Upper Ecca stages, and in carbonaceous sediments in the lower part of the Beaufort series. The external morphology of the microfossils is extremely varied, but they are characterized by a regular cup-shaped organ. They closely resemble forms called *Anellotubulata* by O. Wetzel (1959), who described them from the Upper Lias (ϵ) of Germany. Other workers have recovered, but not described, similar microfossils from Permian, Triassic and Cretaceous strata in Australia. In this paper, the microfossils are referred to as anellotubulates. They are remarkable in a number of respects, the most extraordinary of which is their composition. Electron-microprobe and X-ray diffraction tests have shown the shell to consist of a non-crystalline mineral or minerals, composed mainly of iron and phosphorus, with minor calcium. It has not been possible to demonstrate clearly whether this is the original shell composition, or whether it has resulted from replacement. The available information, including that provided by associated fossils, which has bearing on the palaeoenvironment of the anellotubulates, is discussed. It is hoped that, when more information is available, these problematic microfossils will contribute towards a better understanding of the depositional environment of the sediments in which they occur.

INTRODUCTION

This study forms part of research being undertaken for a higher degree at the University of the Witwatersrand. As an employee of SOEKOR, the author initiated the project in 1970. After being transferred to other work in March of that year, the project was continued on a part-time basis. Sampling has been confined to the northern part of the Karroo basin. The sediments of the Northern Ecca facies are described in general by Haughton (1969) and Ryan (1968), and in detail by Ryan (1967). The palaeontological zones used to subdivide the Beaufort sediments in the borehole sections (fig. 75) are presumed correlatives of the fossil reptile zones (reviewed by Kitching, 1970). The names are tentatively applied on the basis of lithological similarity and stratigraphic position (J. Anderson, pers. comm.). The reptile zones are currently being re-interpreted by Kitching.

Wetzel first mentioned certain problematic microfossils from the Upper Lias of Germany in an unillustrated paper in 1959. In a report on a study of the microfossils of the Baltic Cretaceous flintstones, he recorded and illustrated (Wetzel, 1961, pl. 3, fig. 14) a single problematic microfossil in a flintstone chip that was possibly similar to the forms he had previously noted. He proposed the group *Anellotubulata* to accommodate these forms. In 1967 he described more anellotubulates from the Upper Lias of Germany in greater detail. In all he treated 14 samples of core, cuttings and outcrop from 14 different sites. The microfossils were recovered from hard black shales after they had been crushed and treated with hydrogen peroxide. He described the shell wall as consisting of a clear brown chitin-like substance. Although the anellotubulates are morphologically variable, he felt that only one species is present, but named three varieties:

Mikrocalyx pullulans forma *syringata*
Mikrocalyx pullulans forma *vermiculata*
Mikrocalyx pullulans forma *cornea*

placing them in the family *Mikrocalycidae*. He did not describe any clearly recognisable associated fossils except for fragments of fossil wood. On the basis of this association, he suggested that the anellotubulates may have lived on decaying wood, which was later transported and finally deposited in a distant environment. It is not clear whether the depositional environment of these anellotubulates was marine, freshwater or intermediate.

MATERIAL

Five hundred and thirty samples of borehole core were treated for this study. Nearly all of the samples came from the boreholes listed below.

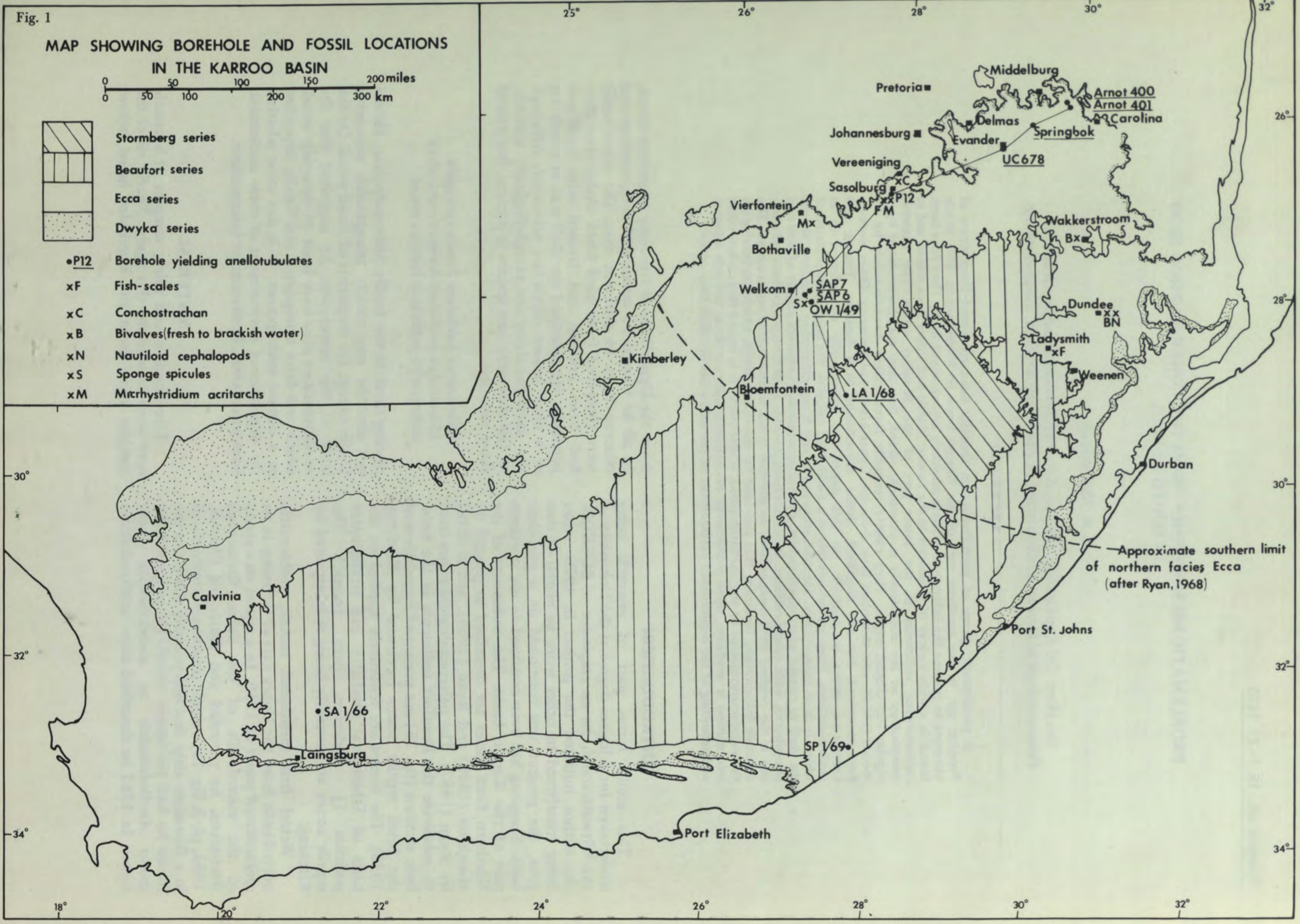


Fig. 1
MAP SHOWING BOREHOLE AND FOSSIL LOCATIONS IN THE KARROO BASIN
0 50 100 150 200 miles
0 50 100 200 300 km
Stormberg series
Beaufort series
Ecca series
Dwyka series
•P12 Borehole yielding anellotubulates
xF Fish-scales
xC Conchostrachan
xB Bivalves(fresh to brackish water)
xN Nautiloid cephalopods
xS Sponge spicules
xM Micrhystridium acritarchs
Middelburg
Pretoria
Arnot 400
Arnot 401
Carolina
Delmas
Johannesburg
Evander
Springbok
UC678
Vereeniging
xC
Sasolburg
xP12
FM
Vierfontein
Mx
Bothaville
Wakkerstroom
Bx
Welkom
SAP7
SAP6
Sx
OW 1/49
Dundee
xx
BN
Ladysmith
xF
Weenen
Kimberley
Bloemfontein
LA 1/68
Durban
Approximate southern limit of northern facies Ecca (after Ryan, 1968)
Calvinia
Port St. Johns
SA 1/66
SP 1/69
Laingsburg
Port Elizabeth
25°
26°
28°
30°
32°
18°
20°
22°
24°
34°

Their positions are indicated on the accompanying borehole logs, (fig. 75) and in figure 1.

Table 1

Borehole	*Area*	*Permission to sample core from:*
Arnot 401 Arnot 400 Springbok	Middelburg area, Transvaal	Anglo American Corporation
UC. 678	Evander goldfields, Transvaal	Union Corporation
P12	Sigma colliery, Orange Free State	Federale Mynbou
SAP6 SAP7 OW1/49	Welkom goldfields, Orange Free State	Anglo American Corporation
LA1/68	Eastern Orange Free State	SOEKOR

Fifteen additional samples were taken from glauconite-rich sediments and 16 from bioturbated sediments from 11 other boreholes in the Evander area, close to UC. 678.

During a visit to Australia in June 1971, the following people very kindly made information available on microfossils they had found that closely resemble the Karroo anellotubulates:

Dr. V. Scheibnerova, New South Wales Geological Survey, Sydney, showed the author anellotubulates? from Cretaceous sediments in Eastern Australia.

Mr. P. J. Jones, Bureau of Mineral Resources, Canberra, very kindly allowed the author to take representative microfossils from two samples that he had processed in 1966, viz:

Woolamulla No. 1 well, side-wall core 50. 8 060 ft (2 457 m): Perth basin, Western Australia. Black carbonaceous micaceous siltstone (Carynginia Formation, Lower Permian). Similar forms also occur in the overlying Lower Triassic Kockatea Shale, which is a dark-grey thinly laminated micaceous shale. The samples were disaggregated by boiling in water. No associated microfaunas were found.

Baylam No. 1 well, core 9. 3 056 ft 2 in (931 m): Ipswich basin, Queensland. Age Triassic. Interlaminated sandstone and shale. The shale is black, hard and slightly pyritic, with calcareous and siliceous veins. The sample was treated with 100-volume hydrogen peroxide. The same microfossils occur in a limestone in this borehole and were extracted after treatment with 10 per cent monochloracetic acid. No associated microfaunas were found.

Treatment

Approximately 20 to 50 grams of borehole core were coarsely crushed and allowed to stand in cold hydrogen peroxide (15%) for 20 minutes. The sample was then washed through 30, 60 and 120 mesh screens and dried.

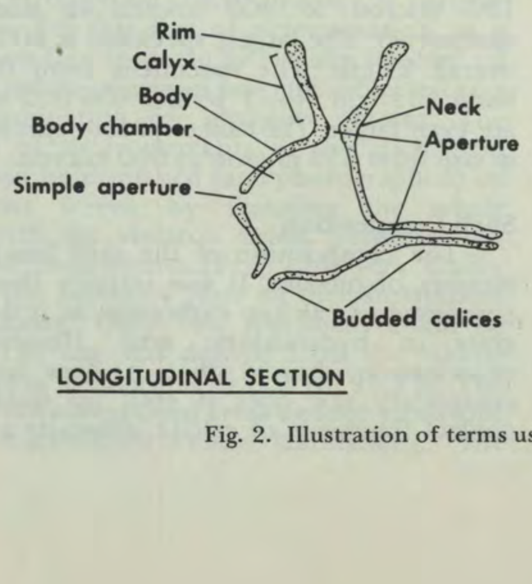
The degree of disaggregation obtained with this simple treatment was relatively low, with only 20 to 40 per cent of the sample being reduced to minus 30 mesh size. However, more involved treatments resulted in the destruction of the microfossils. It was noted that some of the samples reacted violently on the addition of hydrogen peroxide and gave off a smell of hydrogen sulphide, possibly as a result of oxidation of finely divided pyrites. Anellotubulates recovered from such samples were either badly corroded and stained by iron oxide, or the samples were barren.

DESCRIPTION OF ANELLOTUBULATES

Morphology

Figure 2 illustrates the terms used to describe the anellotubulates. They are deliberately informal, as different terms will have to be used if the microfossils can be fitted into an established fossil group. No functional or genetic associations are intended by the names used.

The external morphology of the anellotubulates is illustrated in the accompanying photographic plates. It can be seen that their shape is extremely variable. Both colonial (figs. 32–34) and individual (figs. 4–31) forms occur, but the latter are far more common. No attempt has been made to distinguish the varieties named by Wetzel (1967), as they represent only a small number of the range of forms present. Furthermore, several of his varieties may occur together on a single anellotubulate (fig. 37). It appears at present that the Karroo



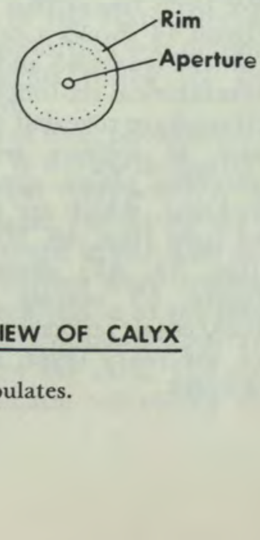


Fig. 2. Illustration of terms used to describe anellotubulates.

anellotubulates all belong to one morphologically variable species.

Typically, an individual anellotubulate consists of a hollow body chamber of irregular shape, from which the calyx extends. The surface texture is granular, and under incident light the shell is white or slightly orange. Figures 4–8 illustrate the external features of a typical individual anellotubulate.

The Calyx

This is the most characteristic feature of the Karroo anellotubulates. Calices are often found detached from the body chamber, as they may be very insecurely attached. They are most commonly cup- or cone-shaped, but tubular calices also occur. The distal rim and interior of the calyx are more finely textured than the exterior (figs. 7, 8). A small aperture connects from the base of the calyx to the body chamber (figs. 25, 44). Cup-shaped calices may be extended away from the body chamber at the end of a slender stalk. The size of the aperture varies roughly with the size of the calyx and is usually from one tenth to one third of its diameter, that is from a maximum of about 30 micron to a minimum of 2 micron. The surface area of the open distal end of the calyx (or calices in budded forms) is not directly related to body chamber size; in some individuals the ratio is large (fig. 41), in others it is small (fig. 36). Rarely a calyx appears to have ceased to function and is partly obscured by further shell deposition (fig. 42). In a few specimens a second calyx has developed from within an existing one (figs. 22, 23, 52, 54). This is perhaps a feature similar to that described as "rejuvenescence" in rugose corals (Hill, 1956, p. F245). Multiple rejuvenescence has not been observed in the Karroo anellotubulates.

The tubular calices (figs. 26–31, 36–37) often show pronounced annular (growth?) rings along their length. They are usually straight, but may be curved and twisted in an irregular way. The distal end is usually open. In one specimen (fig. 29) it has been restricted to two small lateral holes, while in others (figs. 30, 31) it has been completely plugged by shell material.

With the exception of the commonly regular circular calyx rims (figs. 6, 25, 47), only three specimens have been found that display any other symmetry. Figure 44 shows a calyx with a regular triangular outline. Figures 45 and 46 show irregular calices with symmetrical six-lobed apertures.

Thin sections have revealed some details of the calyx structure. It appears to be built up of successive concentric plates, approximately 1 to 5 micron in thickness, which are pale orange-brown in transmitted light (figs. 49, 50). Two Australian specimens (figs. 53, 62) show a similar platy structure. Figure 53 reveals that thin, clear, internal and external layers may be present on either side of the platy layer, forming a smooth surface on the calyx.

The Body Chamber

This is usually thin walled and is often filled with amorphous carbon and pyrites. In some specimens a single crystal of pyrites occupies the body chamber. The exterior of the shell may then reflect the symmetry of the pyrites due to compaction. Fractured and thin-sectioned specimens do not reveal any sign of internal partitioning (figs. 48–52). This applies also to forms with lobed bodies and to those with more than one calyx (fig. 55). The one colonial specimen (fig. 34) which was sectioned is not internally subdivided (figs. 56, 57). It is notable that numerous small calices protrude from all sides of the specimen.

The individual anellotubulates show no sign of having been detached from a larger structure and appear to represent the shell of a complete individual. The distribution of smaller calices on the bodies of some of these specimens suggests reproduction by budding (figs. 9, 12).

Size

It is difficult to define the size of these microfossils as their morphology is extremely varied, and the larger forms, especially, are often fragmentary. The most constant feature available for measurement is the prominent calyx.

The results of measurements from the four best preserved samples are shown in figure 3. The measurement used was the maximum external diameter of the calyx. There does not seem to be any correlation between calyx size and sediment grain size. Large and small calices occur in both fine-grained shales and sandstones.

The larger body chambers are relatively thin-walled and rarely survive sample preparation and picking. The smallest body chamber recovered measures approximately 20 micron across and the largest intact one 450 micron x 350 micron. Large forms with numerous small calices (fig. 34) measure up to 2 400 x 1 200 micron.

Judging from the photographs provided by Wetzel (1967), the calices of his forms range in size from 20 micron to 350 micron in diameter. They thus compare fairly well with the Karroo forms. The Australian anellotubulates are much larger. The calices of those from the Woolamulla well (8 060 ft (2 457 m)) in the Perth basin range from 100 micron to 400 micron in diameter (10 specimens). The largest specimen is 800 micron in overall length. The specimens from the Ipswich basin (Baylam No. 1 well, 3 056 ft 2 in (931 m)) are even larger. The calices of four specimens range in size from 350 micron to 600 micron.

Shell Composition

The composition of the shell has provided a number of puzzles. It was initially thought to be composed of calcium carbonate, as it does disintegrate in hydrochloric acid. However, closer examination showed that it does not dissolve completely nor does it emit gas bubbles as do control fragments of calcite, dolomite and siderite.

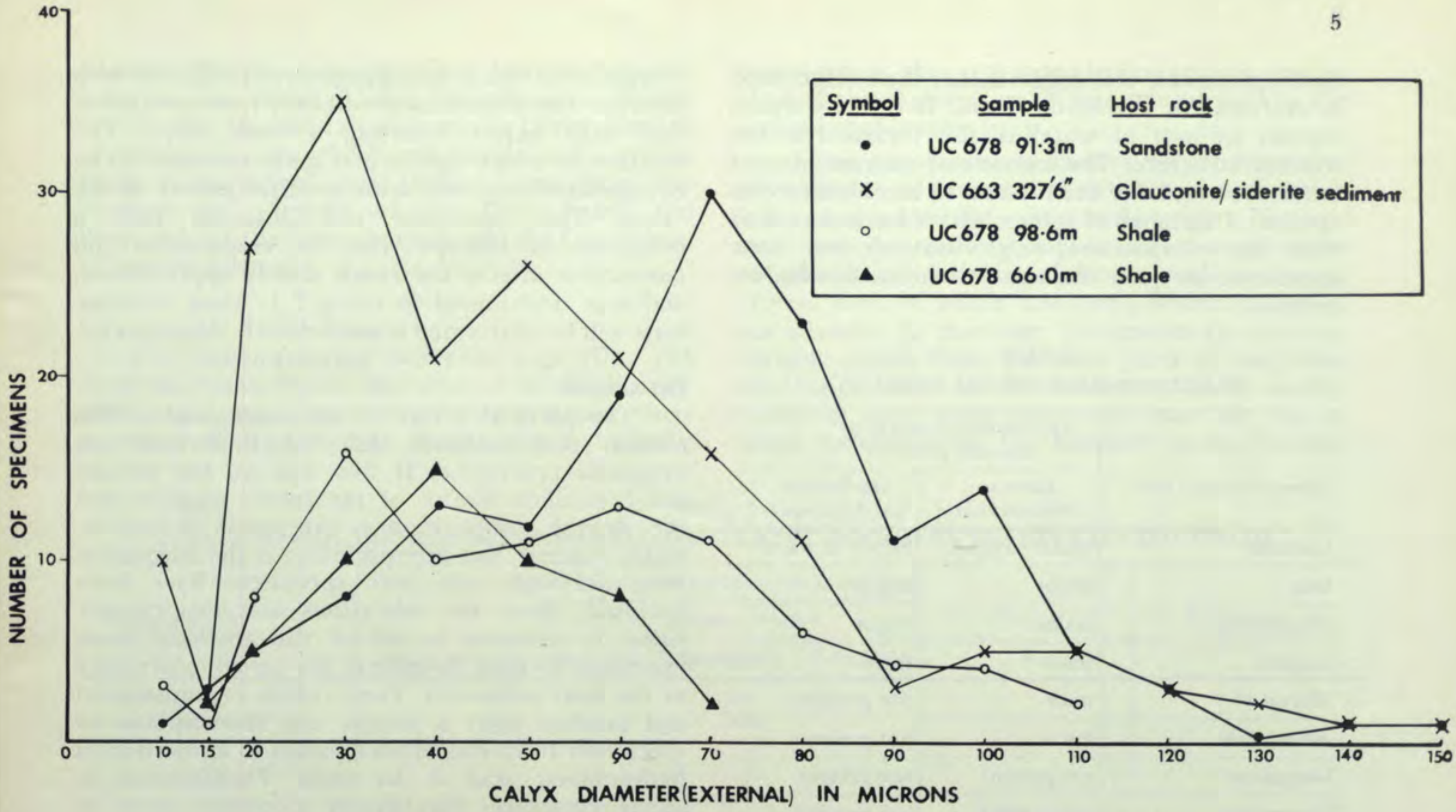


Fig. 3. Size distrubution of thecae in selected samples of Karroo anellotubulates. Only these four samples contained sufficient material in a good state of preservation.

It was concluded that the mineral was not a carbonate. The response of the anellotubulates to immersion in hydrochloric, hydrofluoric and sulphuric acid is alike. The shell rapidly becomes translucent and collapses, but leaves a colourless residue that suggests that the shell may be bimineralic. The response in nitric acid is similar but much slower. The possibility of it being apatite was then considered, but the problem of confirming this composition then arose. Using wet microchemical chemical tests, it is difficult to establish reliably the chemical composition of such small quantities of material. Furthermore, the danger of contamination by adherent mineral particles from the sedimentary matrix is high.

Electron Microprobe

The electron-probe micro-analyser is particularly suitable for this sort of determination, as a contamination-free spot can be visually selected on a polished surface of a specimen and subjected to a detailed examination for elements present. The distribution of these elements in the microfossil shell can then be displayed (and photographed) on a fluorescent screen by scanning the whole specimen with the electron beam. Johannesburg Consolidated Investments (Pty) Ltd. very kindly carried out the necessary tests on their instrument in Johannesburg. Only two specimens could be examined. The one was derived from the Middle Ecca sediments in borehole U.C. 678. 91,3 m. The sample is a medium-grained cross-bedded sandstone with carbonaceous-micaceous laminations. The main minerals present are quartz, feldspar, muscovite, biotite and carbon. Hydrogen peroxide was used to disaggregate the sample. In external appearance the specimen was very similar to figure 11. The body chamber is filled with amorphous carbon, within which there is some pyrites (fig. 58). The other specimen was from Australia from 8 060 ft (2 457 m) in the Woolamulla well (see p. 3). The enclosing sediment was a black carbonaceous, micaceous siltstone. The sample was disaggregated by boiling in water.

The two microfossils were mounted in separate resin stubs and ground on bonded carborundum laps until good longitudinal sections were obtained. A final polish was obtained using 0 to 1 micron diamond paste, and the surface was then coated with carbon in preparation for the electron microprobe tests. The backscatter electron images (figs. 58, 62) show the microfossil sections and the positions of the static electron probe at which the shell composition was determined. Table 2 shows the elements tested for and indicates which were detected.

The distribution of iron, phosphorus and calcium in the microfossils is shown in figures 59–61 and 63–65. The element composition of the two microfossils is the same, except for the trace silicon and aluminium detected in the Karroo anellotubulate. These two elements were concentrated in a small area in the neck region of the microfossil and are thought to be contamination from silicate minerals adhering to the shell. The elements iron, phosphorus and calcium are evenly distributed in both specimens; this suggests that the composition is uniform for the whole fossil. It is likely that a certain amount of water is also included in the mineral structure. The amount of calcium present is far too small for the mineral to be considered as apatite. A number of minerals have been described with this composition, (e.g. vivianite), but none appears to be quite the same as the anellotubulate material.

Table 2
ELECTRON MICROPROBE RESULTS

Element tested for	*Qualitative estimate of amount present*	
	Karroo anellotubulate	*Australian anellotubulate*
Calcium	minor to trace	minor to trace
Iron	major	major
Phosphorus	major	major
Sulphur	trace	trace
Silicon	trace	not present
Aluminium	trace	not present
Manganese	not present	not present
Magnesium	not present	not present
Arsenic	not present	not present
Strontium	not present	not present

X-Ray Diffraction

X-ray diffraction tests have been carried out to determine the crystalline structure of the mineral concerned. Ball mounts of good density and fineness were prepared from three samples in which the amount of mineral matter adhering to the specimens was very low, viz:

The Baylam No. 1 sample (Ipswich basin);

the Woolamulla No. 1 sample (Perth basin); and

sample No. 51 UC.678. 91,3 m (Karroo basin). Repeated tests including one goniometer run indicated that all three of the samples were non-crystalline. This conclusion is further supported by the optical isotropism shown by thin sections of the anellotubulates under crossed nicols. The scanning electron micrographs (figs 7, 8, 21) show no signs of a microcrystalline texture.

Microchemical Tests

Both the ammonium-molybdate reagent and the ammonium-molybdate and benzidine reagent tests (Vogel, 1962, pp. 386–8) gave a positive reaction for phosphate on selected contamination-free specimens from samples at 91,3 m and 98,6 m in UC.678, and from 100 m in UC.663. These were the only samples from which sufficient clean material was available for testing.

Specific-gravity Tests

Selected clean specimens of calices from the sample from 91,3 m in UC.678 were dropped into bromoform which was progressively diluted with alcohol. The solution was carefully homogenised at each step before inserting a fresh calyx. The solution in which calices just sank was taken to be of approximately the same specific gravity as the calyx. This operation was observed with a binocular microscope. Due to evaporation and convection effects the result is only approximate, and was determined as being 2,1. More accurate tests will be performed later.

Discussion

The platy structure of the calyx wall in thin section may indicate that the shell wall was originally crystalline. If this was so, the present non-crystalline nature of the fossils suggests that the strange composition is the result of replacement. Against this interpretation is the suggestion that, although only two specimens have been analysed, there are indications that this composition is common to all of the anellotubulates examined to date, in spite of the varied mineralogy of the host sediments. Their colour in transmitted and incident light is similar, and the response of specimens from numerous samples to immersion in hydrochloric acid is the same. Furthermore, it seems remarkable that the two specimens tested by electronmicroprobe should have had the same composition, even though they come from such widely separated areas. Confident determination of the original composition of the shell will have to await the analysis of many more specimens from different areas. Wetzel (1967) mentions that his anellotubulates appear to be composed of a brown chitin-like substance. He does not make it clear whether the organic nature of the shell was confirmed by tests. It is notable, however, that the photographs that he shows, which were taken by incident light, are very white (Wetzel, 1967; Taf. 38 fig. 4; Taf. 40 fig. 1), as are the Karroo anellotubulates. When the latter are immersed in water and examined by transmitted light, they too have a brown colour and a chitinous appearance.

In the present study there was no indication of organic compounds in the shell structure. All the samples that yielded anellotubulates were also treated for palynological study. Although miospores are common, no acid-resistant remains were noted which could be linked with the annelotubulates.

DISTRIBUTION

Figure 1 shows the locations of boreholes examined. They extend from what must have been near the margin of Middle Ecca sedimentation (Arnot, Springbok boreholes) to near the basinward pinch-out of the Middle Ecca sediments (Ladybrand borehole).

In view of their abundance, in all of the boreholes sampled, it is considered likely that the fossils occur in sediments throughout the northern Karroo basin, including the Natal trough. It is unlikely that they are preserved in the more altered southern Karroo sediments. The "Anellotubulates" seem to be of worldwide distribution. Wetzel (1959) first recorded them from the Upper Lias (ϵ) of Germany, and there are unpublished reports (page 3 above) of very similar forms from the Permian and Triassic of the Perth basin, the Permian? of the Ipswich basin, and the Cretaceous of eastern Australia.

Stratigraphic distribution

The accompanying borehole logs (fig. 75) show the stratigraphic distribution of the Karroo anellotubulates. Tables 3 to 5 summarize their distribution. The figures should not be closely compared as they are intended merely to give an idea of the distribution of the microfossils in the various stratigraphic units.

There are numerous factors which determine the abundance, presence or absence of anellotubulates as recorded in a prepared sample. The two main post-depositional factors are thermal metamorphism by intrusive dolerites and processing effects, both of which can result in destruction of microfossils. At this stage the reasons for the very variable yields from different parts of the same lithological unit are not understood. No anellotubulates have been recovered from the red or green sediments of the Beaufort series. In con-

Table 3

STRATIGRAPHIC DISTRIBUTION OF ANELLOTUBULATES–SOUTHERN TRANSVAAL COALFIELDS

Stratigraphic Unit	*No. of samples yielding anellotubulates / No. of samples treated*					*Percentage Yield*
	Arnot 401	*Arnot 400*	*Springbok*	*UC.678*	*P.12*	
Middle Ecca Coal Measures			68/200			34

Table 4

STRATIGRAPHIC DISTRIBUTION OF ANELLOTUBULATES – WELKOM AREA

Stratigraphic Unit	*No. of samples yielding anellotubulates / No. of samples treated*			*Percentage Yield*
	SAP7	*SAP6*	*OW1/49*	
Beaufort Series (Tapinocephalus zone)	4/14	2/2	4/19	28
Upper Ecca Shales	2/23	0/2	2/23	8
Middle Ecca Coal Measures	4/25	5/15	6/23	24

Table 5

STRATIGRAPHIC DISTRIBUTION OF ANELLOTUBULATES – LADYBRAND BOREHOLE

Stratigraphic Unit	*No. of samples yielding anellotubulates / No. of samples treated*	*Percentage Yield*
Red Beds Stage	0/4	0
Molteno Stage	0/4	0
Lystrosaurus Zone	0/42	0
Daptocephalus Zone	8/54	15
Cistecephalus Zone	0/18	0
Upper Ecca Shales	22/35	73
Middle Ecca Coal Measures	2/11	18
Lower Ecca Stage	10/13	77

clusion it can be said that they are widely distributed in the carbonaceous sediments of the Ecca and Beaufort series.

AGE OF SEDIMENTS

The best evidence available for the age of the sediments containing the anellotubulates is provided by palynology. On the basis of his studies Anderson (in preparation) places the Middle and Upper Ecca sediments in the Lower Permian, with the Upper Ecca sediments extending through into the Upper Permian. The *Tapinocephalus* zone of the Beaufort series is placed in the Upper Permian, based on its reptile fauna, and the *Daptocephalus* zone is taken to be slightly younger on the evidence of its contained plants, miospores and vertebrate faunas.

DISTRIBUTION OF ANELLOTUBULATES IN THE SEDIMENTS

The Karroo anellotubulates occur in a wide variety of sediment types. They are generally only present in shales or sandstones that have a moderately high carbon content, but in the Upper Ecca and Lower Beaufort they sometimes occur on thin carbonaceous bedding planes in otherwise low-carbon shales. In the Middle Ecca they have been recovered from very highly carbonaceous shales and glauconitic-sideritic sediments overlying the coal seams. They have been reported as occurring in a limestone in the Ipswich basin in Australia (see p. 3 above).

The abundance of anellotubulates in a sediment is difficult to estimate with any degree of accuracy due to:

their commonly poor preservation and hence high degree of destruction during processing;

the low degree of sample disaggregation; and

the ease with which calices break from the body chamber.

It is appreciated that any estimate made under these conditions is likely to be highly inaccurate. However, to gain some idea of how significant they are in the sediments, the following estimates have been made. They should be considered as "order of magnitude" figures only.

Sample No. 52: UC.678. 98,6 m, Middle Ecca. Black fine-grained siltstone. *Yield Good*. 115 individuals picked. Approximately 115 individuals are estimated to have been missed or were not freed from the matrix i.e. a total of 230 per 0,15 gms of $-30 + 60$ mesh fraction, giving, very approximately, 1 000 to 1 500 individuals per gram of sediment.

Sample No. 85: U.C.678. White medium-grained sandstone. Yield poor to moderate, 35 individuals per 1,23 gms. Say 25 per cent missed, broken or not freed from matrix. Total 35 individuals per gram approximately.

MODE OF LIFE

The very wide occurrence of anellotubulates in a variety of sediments is puzzling. The variation in the conditions of the depositional environment from pyritic high-carbon shale to glauconitic-sideritic sediments and to cross-bedded carbonaceous sandstones (and limestone in Australia) is extreme, and yet the fossils are morphologically very similar in each sample assemblage. One could explain this distribution by suggesting that the anellotubulates were planktonic, but the relatively heavy nature of the shell and the lack of any obvious buoyancy structures seems to be against this. It is quite possible that the strongly reducing conditions suggested by the glauconitic, sideritic and high-carbon and pyrite-bearing sediments were confined to below the water-sediment interface and that conditions on the surface of the deposit were more uniform than the sediments suggest. On present information it is best to conclude that the anellotubulates were benthonic and achieved their wide distribution by being extremely tolerant of a wide range of environmental conditions. It is possible, of course, that they could avoid inhospitable bottom conditions by living on underwater vegetation. There is no indication of a close association of anellotubulates with wood, as suggested by Wetzel.

AFFINITIES

It has not been possible to assign these microfossils with assurance to any recorded fossil group, except the problematic anellotubulates described by Wetzel. He suggested that they may belong to the coelenterata. The radial symmetry exhibited by some of the Karroo specimens, as well as their general morphology and the common occurrence of "budding", seems to fit this interpretation. Any more informed suggestion as to their affinities will be most welcome.

ASSOCIATED FOSSILS AND PALAEOENVIRONMENT

The fossils known to occur in sediments which have yielded anellotubulates are recorded here in an attempt to bring together the available evidence relating to the environment of deposition. For the sake of completeness, all of the fossils known from the Ecca Series that bear on the nature of the environment are listed here. Fossil locations are shown in figure 1.

Macrofossils

The Middle Ecca sediments contain a number of coal seams, several of which are economically exploited. Anellotubulates are commonly found in carbonaceous sediments containing fragments of leaves and stems.

In borehole P.12 at the Sigma Colliery (fig. 1, 75) anellotubulates occur in a carbonaceous shale together with isolated fish-scales. Two metres below the fossils and resting on a thin coal seam is a 20 cm glauconite band. The fish-scales have been identified, from photographs, by Dr. B. G. Gardiner of Queen Elizabeth College, London (written comm., 1972) as belonging to an *Acrolepid*-like fish. It is interesting to note that Le Roux (1960) described a conchostrachan, *Cyzicus* sp., which is a fresh-water dweller, from the upper part of the coal measures in the adjacent Vereeniging coal field. In 1910 Woodward described tentatively identified *Acrolepis* sp. fish-scales which had been found by Hatch (1910a) in phosphatic nodules at the top of the Upper Ecca shales near Intombe Camp, Ladysmith. Hatch (1910b, p. 227) also mentioned "fragments of bone which have been determined as Labyrinthodont". Haughton (1920, p. 11) noted that the same nodules have also yielded "a single fragmentary jaw, almost certainly reptilian". This combination of fossils suggests a shallow-water swampy environment that was perhaps locally saline but not marine (i.e. no connection with the ocean).

Bivalves said to have inhabited fresh to brackish water have been reported from the Natal Middle Ecca coal measures. Du Toit (1936, p. 344) tentatively identified *Carbonicola (Anthracosia)* sp., from a torbanite seam in the Wakkerstroom area. H. N. Visser of the Geological Survey found another specimen at the same locality in 1940. Rilett (1951) described *Unio alettaensis* from near Dundee. The Nautiloid cephalopod *Discetoceras bowdeni*, described by Rilett (1963) from the Aletta iron ore mine near Dundee, is presently the subject of a controversy over its taxonomic position at class level. In brief, it was found in Middle Ecca sediments in a carbonaceous shale 1,2 m above the carbonaceous siderite band that yielded the *Unio alettaensis* mentioned above, and 24 m below the main economic coal seams (no. 1 and 2 seams). Although cephalopods are regarded as being exclusively marine animals, the taxonomic uncertainty of Rilett's specimens and the lack of any other associated definitely marine organisms suggest that they should not be taken to indicate marine conditions. The other macrofossils recorded above suggest fresh- to brackish-water conditions. It should be noted that the sediments under consideration are relatively well exposed in outcrop and in underground development of the coal fields. If a significant marine incursion had taken place during Ecca times it is reasonable to expect that marine invertebrate faunas would have been found.

Microfossils

Hart (1969) described Acanthomorphitae acritarchs from several boreholes in the Vereeniging, Vierfontein and Welkom areas. J. Anderson (per. comm., June 1972) has recovered similar acritarchs from the Sigma Colliery fish-scale bearing shales mentioned previously. Hart (1969) is of the opinion that the acritarchs indicate a marine environment, especially when considered in conjunction with the presence of glauconite, which occurs above some of the Middle Ecca coal seams. This interpretation depends largely on what is included in "marine". It should be noted that no marine invertebrates (with the exception of the problematic cephalopod described by Rilett, 1963) have been described from Ecca sediments in the Karroo basin. In this study, siliceous sponge spicules were the only microfossils found which could be taken to indicate marine conditions (p. 10). It therefore seems to be preferable, until more evidence is available, to think of the depositional environment of the acritarchs and the glauconite as being saline, but brackish rather than normal marine, and as having had no connection with the ocean and its invertebrate faunas.

The "possible conodonta" reported by Hart (1964, p. 290) from the Sigma Colliery were later said by Hart (1966, p. 293), in an unpublished report, to have been re-identified as "part of the skeleton of fishes". These remains are most probably from the fish-scale shale mentioned above. I have attempted to trace the reference made by Hart (1969, p. 53) to conodonts in the southern Karroo. He states that "Conodont occurrence has been mentioned by Van Eeden, Director of South African Geological Survey, as occurring in the south-western outcrops of the Karroo and in the Sambokkraal borehole (private communication, 1964), but this has not been documented". These "conodonts" are mentioned again by Hart (1970, text-fig. 29). I have been unable to confirm the existence of these microfossils.

A. Keyser (verb. comm., 1971) and Bischoff (verb. comm., June 1971), who was formerly of Gewerkschaft Elwerath, mentioned that microfossils compounded of apatite were recovered from thin limestone bands in the Lower Ecca shales of Natal (location unknown). The microfossils were rare and badly distorted and were not definitely identified as being conodonts. The confidential Elwerath report detailing their occurrence is unobtainable. Until the presence of conodonts in the Karroo basin has been confirmed, they should not be used to substantiate marine conditions of deposition.

In the present study, three other forms of mineral-shelled microfossils have been found in association with anellotubulates:

Problematica A (figs. 66, 67)

These consist of irregular masses of white mineral material containing spherical pits dispersed through the matrix. They occur together with anellotubulates in the following samples (fig. 75):

LA 1/68 borehole Near base of Upper shales	4 901 ft (1 493,5 m) 4 925 ft (1 501 m) 4 950 ft (1 508,7 m) 4 975 ft (1 516,4 m)
In the Lower Ecca shales	5 419 ft (1 651,7 m) 5 032 ft (1 533,6 m) 5 055 ft (1 540,8 m) 5 082 ft (1 549 m)

OW1/49 borehole
Upper part of the Upper
Ecca shales 761 ft (232 m)

SAP7 borehole
Bottom of ? *Daptocephalus*
zone 223 ft (70 m) (Beaufort)

The spherical pits are sometimes filled with pyrite. In thin section (fig. 67) the material appears to be micro-crystalline. Individual crystals have a rhomboid cross-section. Under crossed nicols the material appears to have been extensively altered, and the apparent crystallinity is probably a relict structure. It responds to mineral acids in much the same way as the anellotubulates, but differs in not giving a positive reaction in the phosphate microchemical tests. It is definitely not calcareous nor does it appear to be genetically related to the anellotubulates. It is possible that the problematica A was formed by mineral processes during diagenesis.

Problematica B (figs. 68–70)

These consist of very small spheres of silica which are insoluble in hydrochloric acid. When examined in thin section, using interference contrast, they appear to be composed of a cellular mass of thin-walled polygonal chambers. Under the scanning electron microscope these polygonal chambers can be seen on the exterior of a specimen. They have been recovered from only one sample, a carbonaceous shale at 10,05 m in the Arnot 401 borehole. As their origin is unknown, they are of no help in indicating the nature of their depositional environment.

Sponge Spicules (figs. 71–74)

Siliceous sponge spicules have been recovered from only one sample in OW1/49 at 896 feet (273,1 m) in the upper part of Upper Ecca shales. Only monaxon spicules (styles) are present. A distinct but partly obliterated axial canal is present. Identification of the parent sponge has not been attempted due to the unreliability of determination from loose spicules, especially of this simple type (Laubenfels, 1955, p. E28). It appears that such spicules can be produced by both fresh-water and marine sponges (Laubenfels, 1955, p. E33). The Geological Survey of South Africa (report to SOEKOR, July 1970) reported sponge spicules "monaxon sclera of the strongyloid type" from 577 feet (175,8 m) in the Upper Ecca shales in borehole SAP6 (Fig. 75). They were attributed to the monactinellid Desmospongia, which typically occur in shallow marine intertidal zones. Judging by the remarks made by Laubenfels (1955, op. cit.) it seems to be unwise to conclude without supporting evidence that they derive from marine sponges.

A problematic fragment of a fossil was found by the Geological Survey of South Africa at 4 600 feet (1 402 m) in the SP1/69 borehole, in the Lower Beaufort (*Tapinocephalus* zone lithological equivalent?). R. Wass of Sydney University reported on the fossil as follows: "The size of the fragment . . . prevents any definite determination. It could be a small fragment from a bryozoan and it could also be a small fragment from a brachiopod . . . I have also examined the cuttings from this borehole but have located no other fossil material suitable for identification" (report to SOEKOR, December 1970).

Wass (pers. comm., June 1971) emphasised that the identification was extremely tentative, and the fragment could even be a fragment of bone. Accepting this degree of uncertainty, there is no environmental information to be gained from this record.

Theron (1967, p. 15, 22) mentioned probable radiolarian spicules in the Matjiesfontein chert member at the base of the Lower Ecca shales near Laingsburg in the Cape. This report is discussed in McLachlan and Anderson (in prep.). It is considered to be unconfirmed.

Behr (1965) described, in some detail, detrital deposits of heavy minerals in Ecca sandstones in the Bothaville, Delmas and Carolina areas of the Northern Karroo (fig. 1). Their stratigraphic position is not clearly established. Behr interpreted the deposits as having been formed by wave action on the shores of a regressive sea. He put the estimated fetch of the waves necessary to form these accumulations at 160 km, suggesting an extremely large body of water that must have been very deep, especially in the southern part of the basin. This interpretation is not supported by Haughton (1969, p. 412), who mentions that recent drilling has suggested that these deposits are formed of consolidated post-Karroo dune material.

In conclusion, the available evidence suggests that the water in which the Karroo anellotubulates lived was normally fresh. Certain lines of evidence (the glauconite bands, spinose acritarchs and sponge spicules) suggest that the water was at times saline, but the lack of recognisable marine faunas indicates that a connection with the oceans was unlikely. The Australian Permian and Triassic annellotubulates appear to have lived in a similar environment. Even those from the Caryngina formation are not associated with the marine faunas which occur higher in the sequence.

ACKNOWLEDGEMENTS

I would like to acknowledge the assistance of Union Corporation and Anglo American Corporation in allowing borehole material to be sampled. Anglo American Diamond research laboratories also very kindly allowed use of their scanning electron microscope. Scanning electron micrographs were also provided by the Witwatersrand University electron microscope unit. I should especially thank Johannesburg Consolidated Investment Mineral laboratories for providing the excellent electron microprobe results and for allowing use of their X-ray diffraction apparatus. Southern Oil Exploration Corporation (SOEKOR) has kindly given permission to publish this paper and has assisted in the drafting of the figures.

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Note 1:

M. F. Glaessner (1971, verb. comm.) and P. J. Jones (1972, written comm.) have remarked on a superficial resemblance of the anellotubulates to the foraminifera *Aschemonella longicaudata* Anderson, 1964, from the Lower Permian of England. Differences in wall structure and composition seem to exclude this possibility but, if possible, the foraminifera will be examined.

Note 2:

C. Teichert (1973, written comm.) has drawn my attention to the worm-like pseudo-fossils described by McCunn (1972). There is a superficial resemblance to the anellotubulates but there are also several major differences: the high saline requirement for formation of the pseudo-fossils is not evident in the anellotubulate environments, and the pseudo-fossils lack the distinctive anellotubulate calyx. Further information on the wall structure of these pseudo-fossils would be interesting.

EXPLANATION OF PLATE

All figures are x 200 unless otherwise stated. All specimens except those indicated, derive from borehole UC.678. 91,3 m. The cracks in many of the specimens are due to dehydration under vacuum.

Figures 4 to 31 are scanning electron micrographs.

Fig. 4	Lateral view of individual anellotubulate.
Fig. 5.	Antapical view of body of specimen in Fig. 4. There is no evidence of any former point of attachment to suggest that the individual was part of a colony.
Fig. 6.	Apical view calyx of specimen in Fig. 4.
Fig. 7.	Detailed texture of calyx rim of specimen in Fig. 4. x 1 800.
Fig. 8.	Detailed texture of body of specimen in Fig. 4. x 1 800. The texture of the rim and the interior of the calyx is generally considerably finer than that of the body.
Fig. 9.	Lateral view of individual anellotubulate. Note the two small calices budding from the body.
Figs. 10–12.	Lateral views of individual anellotubulates. Fig. 12, note two small calices budding from the body.
Fig. 13.	Oblique lateral view of individual anellotubulate.
Fig. 14.	Oblique lateral view of individual anellotubulate. The smooth texture of part of the body wall suggests that the rougher textured parts may have resulted through corrosion.
Figs. 15–19.	Lateral view of individual anellotubulates. Note the differences in detailed shape of the body, the calyx and the neck region. The small protruberance at the antapex of Fig. 17 is a feature that recurs in a number of specimens. It appears to be an extension of the body and not a small daughter calyx.
Fig. 20.	Lateral view of detached calyx. Note the small aperture at the proximal end of the calyx, which formerly linked with a body chamber.
Fig. 21.	Detailed texture of specimen in Fig. 20. There is no indication of a crystalline fabric. x 3 600.
Figs. 22–23.	Lateral views of anellotubulates illustrating rejuvenescence. Note the small calyx emerging from within the large calyx.
Fig. 24.	Oblique lateral view of anellotubulate. Note relatively large calyx to body area and concentric growth? rings on calyx. Compare with Fig. 36.
Fig. 25.	Apical view of calyx showing a very small constricted aperture at the base.
Fig. 26.	Lateral view of anellotubulate with tubular calyx.
Fig. 27.	Lateral view of detached tubular calyx. Note annular growth rings. Borehole LA1/68. 5 315 ft (1 625 m).
Fig. 28.	Lateral view of detached tubular calyx. Borehole UC.663. 327 ft (100 m).
Fig. 29.	Lateral view of detached calyx. Note the two small lateral openings at the distal end of the calyx. Borehole UC.663. 327 ft (100 m).
Figs. 30–31.	Lateral view of anellotubulate with tubular calyx. The distal opening of the calyx appears to have been sealed off with shell material.


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EXPLANATION OF PLATE

Figs. 32 and 34 x 100. All others x 200. Figs. 32–39, 40 from borehole UC.663. 327 ft. (100 m). Figs. 38, 41–43 from borehole UC.678 (91,3 m). All figures except Fig. 34 are scanning elecron micrographs.

Fig. 32. Fragment of colonial form. Note the four large calices with numerous small depression-like calices in between. x 100.

Fig. 33. Complete colonial? form. Note the simple small depression-like calices near the centre of the body.

Fig. 34. Complete colonial form (see Figs. 56–57). Note numerous small calices. They also occur on the under side of the specimen. Incident light photograph. x 100.

Fig. 35. Individual anellotubulate with several buds.

Fig. 36. Lateral view of anellotubulate with tubular calyx. Note small calyx to body area. Compare with Fig. 24.

Fig. 37. Anellotubulate showing cup-shaped calyx and tubular calyx on same individual. The distal portion of the tubular calyx was accidentally broken off.

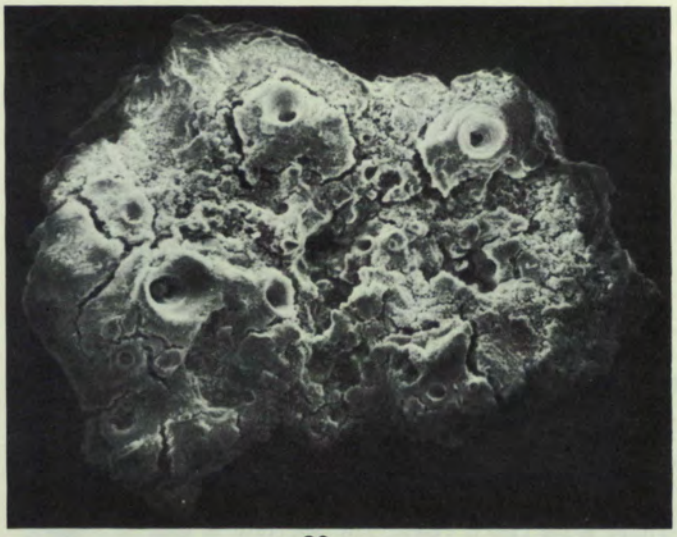
Fig. 38. Anellotubulate with large calices at either end of body chamber.

Fig. 39. Anellotubulate with cup-shaped calyx supported at end of elongate stalk.

Fig. 40. Anellotubulate with irregular flattened body.

Figs. 41–42. Anellotubulates with two calices of equal size. Fig. 42, the aperture of the left hand calyx is sealed with shell material.

Fig. 43. Anellotubulate with several smaller budded calices.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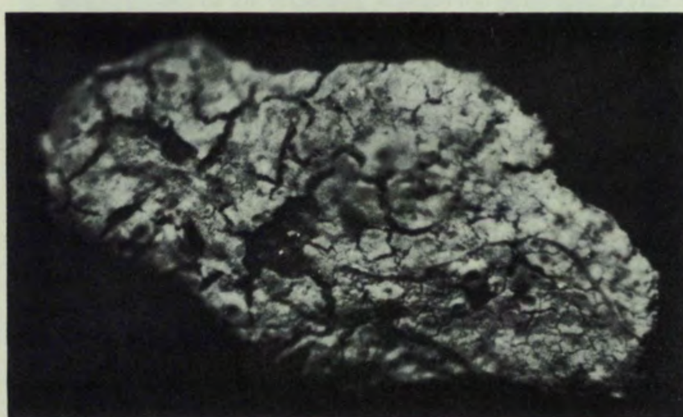
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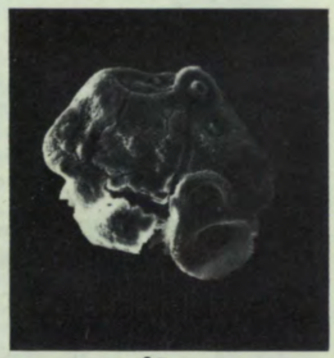
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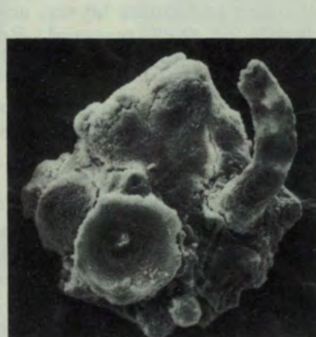
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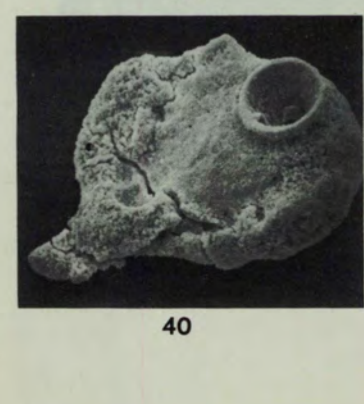
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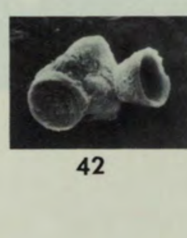
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EXPLANATION OF PLATE

All figures x 200 except where otherwise stated.

Figs. 44–47. *Examples of anellotubulate symmetry.* Incident light photographs.

Fig. 44. Apical view of calyx with regular triangular outline. Borehole UC.663. 327 ft. (100 m).

Fig. 45. Apical view anellotubulate. There is no raised calyx. The aperture is six lobed (partly obscured by shell material). Borehole UC.678. 91,3 m.

Fig. 46. Apical view of short tubular calyx. The large aperture is distinctly six lobed and (bilaterally?) symmetrical. Borehole Springbok, 306 ft. (93 m).

Fig. 47. Apical view of short tubular calyx. Aperture and calyx outline circular. Borehole UC.663. 327 ft (100 m).

Figs. 48–57. *Thin sections photographed by transmitted light.*

Fig. 48. Longitudinal section of individual anellotubulate. The dark black material is carbon and pyrites filling the body chamber. Note the irregular wall thickness. It is composed of several layers of fine granular material. Specimen sectioned was similar to that shown in Fig. 11. Borehole UC.678. 91,3 m. Thin section No. 15.

Fig. 49. Longitudinal section of anellotubulate with two calices, similar to that in Fig. 38. (Calyx on lower left hand side of specimen partly destroyed during section grinding). No indication of partitioning of body chanber. Borehole UC.678. 91,3 m. Thin section No. 18.

Fig. 50. Detail of specimen in Fig. 49 x 400, showing calyx structure built up of successive thin platy layers.

Fig. 51. Transverse section of calyx. Only two of the denser platy layers show up as concentric rings. Borehole UC.678. 91,3 m. Thin section No. 33.

Fig. 52. Longitudinal section of anellotubulate illustrating "rejuvenescence". A second calyx has formed from within the original one. Borehole UC.678. 91,3 m. Thin section No. 16.

Fig. 53. Longitudinal section of tubular calyx. The wall appears to be composed of three-layers–thin smooth inner and outer layers, and a thick internal layer composed of diagonal layers of shell material. Borehole Baylam No. 1, 3 056 ft. 2 ins. (930 m) (Ipswich basin, Australia). Thin section No. 24.

Fig. 54. Thin section of specimen similar to that shown in Fig. 35. Individual anellotubulate with several calices. No indication of internal subdivisions. The dark layer on the inside of the body chamber is limonite. Borehole UC.663. 327 ft. (100 m). Thin section No. 25.

Fig. 55. Detail of calyx of specimen shown in Fig. 52. x 400.

Fig. 56. Thin section of colonial form shown in Fig. 34. In contrast with the other smaller specimens, the body chamber is filled with clay and fragments of carbon. The very dark patch in the middle is pyrites. The layer of shell material is discontinuous due to contraction cracks. x 50. Borehole UC.663. 327 ft. (100 m). Thin section No. 32.

Fig. 57. Detail of specimen shown in Fig. 56. Note sectioned small calyx of left hand side.

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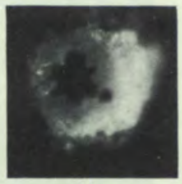

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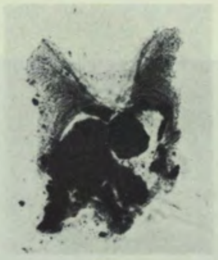

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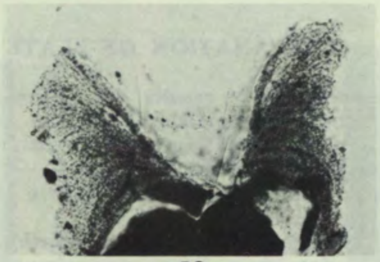

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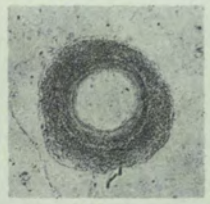

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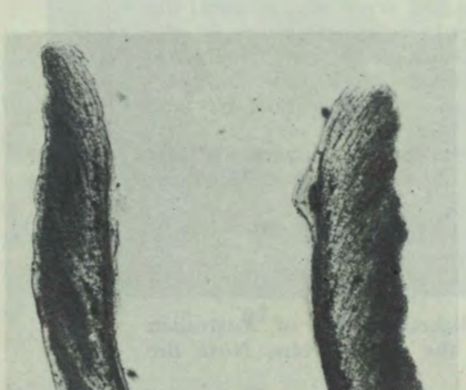

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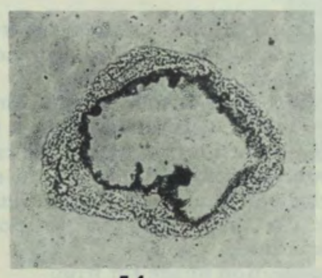

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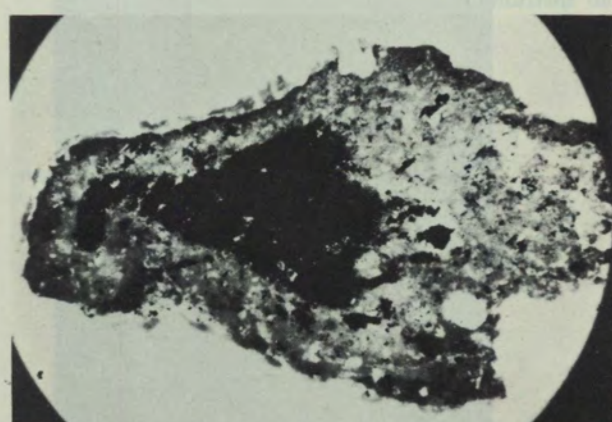

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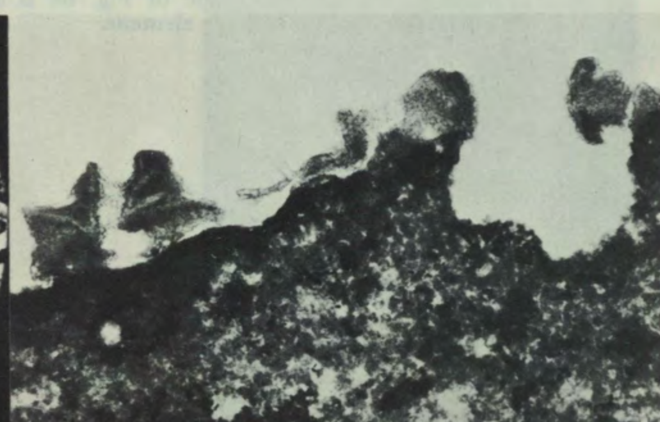

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EXPLANATION OF PLATE

Illustration of electron microprobe results. All figures are x 200. Figs. 58–61, are of a Karroo anellotubulate–from Borehole UC.678. 91,3 m. The specimen was very similar to that shown in Fig. 11. Figs. 62–65 are of an Australian anellotubulate from the Woolamulla No. 1 well, 8 060 ft. (2 456 m), Perth Basin.

The backscatter electron image plots the relative densities within the polished specimen.

An X-ray distribution image indicates the distribution of an element in a polished section. The density of light dots gives a very approximate indication of the quantity of element present. Comparison of the images for different elements provides a very rough guide to their relative abundances. More accurate estimates were made from the graphically recorded electron probe results (not presented here).

Fig. 58. Backscatter electron image of longitudinal polished section of Karroo Specimen. The body chamber contains amorphous carbon. "p" indicates pyrites. Initial element determinations were made with the static electron probe at point "a".

Fig. 59. Fe K alpha X-ray distribution image for iron. Note the concentration of iron in the pyrites. Major amounts of iron are evenly distributed through the anellotubulate shell.

Fig. 60. P K alpha X-ray distribution image for phosphorus. Major amounts of phosphorus are evenly distributed through the shell.

Fig. 61. Ca K alpha X-ray distribution image for calcium. Minor to trace amounts of calcium are evenly distributed through the shell.

Fig. 62. Backscatter electron image of longitudinal polished section of Australian anellotubulate. "a" indicates the position of the static probe. Note the layered wall structure.

Fig. 63. Fe K alpha distribution image for iron.

Fig. 64. P K alpha distribution image for phosphorus.

Fig. 65. Ca K alpha distribution image for calcium.

Iron and phosphorus are evenly distributed as major elements. (The fall off in dot density on the left hand side of Fig. 64 is an instrument affect.) Calcium is evenly distributed as a minor to trace element.

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EXPLANATION OF PLATE

Fig. 66. Problematica A. Borehole LA1/68. 4 975 ft (1 705 m). Note irregular pits. Incident light photograph. x 200.

Fig. 67. Problematica A. Borehole LA1/68. 5 032 ft (1 440 m). Thin section. Transmitted light. Some of the circular sectioned pits are partly filled with pyrites (black). The matrix has been altered. The white rhombs are the relicts of the former crystalline matrix. Problematica A may be of inorganic origin. Thin section No. 21. x 400.

Fig. 68. Problematica B. Borehole Arnot 401, 10,05 m. Spherical siliceous microfossil. Scanning electron micrograph. x 800.

Fig. 69. Detailed surface texture of Fig. 68. Scanning electron micrograph. x 1 600.

Fig. 70. Problematica B. Thin section No. 26. Transmitted light, interference contrast. x 800. Note that the cellular structure persists right through the microfossil.

Figs. 71–74 Siliceous sponge spicules. Borehole OW1/49. 896 ft. (274 m). Upper Ecca shales. Note the partly obliterated axial canal in Fig. 72. Transmitted light (immersed in glycerine). x 100.

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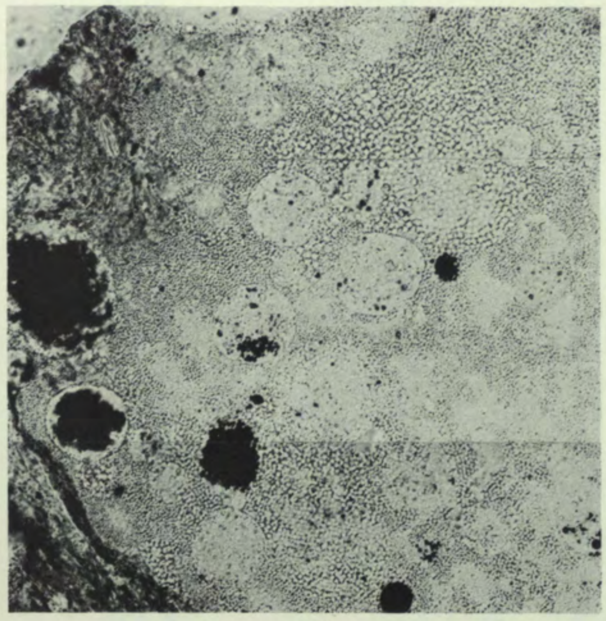

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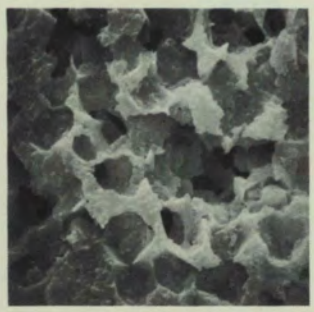

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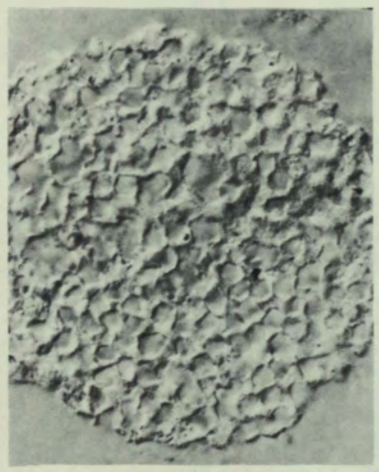

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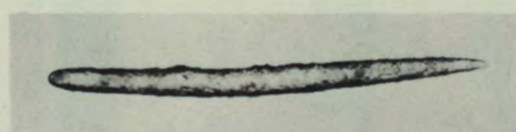

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