ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

ALGAL STROMATOLITES OF THE EARLY PROTEROZOIC WOLKBERG GROUP, TRANSVAAL SEQUENCE

A. BUTTON

INFORMATION CIRCULAR No. 69

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

ALGAL STROMATOLITES OF THE EARLY PROTEROZOIC WOLKBERG GROUP, TRANSVAAL SEQUENCE

by

A. BUTTON
(Research Fellow, Economic Geology Research Unit)

ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 69
May, 1972

ALGAL STROMATOLITES OF THE EARLY PROTEROZOIC WOLKBERG GROUP, TRANSVAAL SEQUENCE

ABSTRACT

A hitherto-unrecorded stromatolite horizon in the Wolkberg Group of the Transvaal Sequence (1950-2300 million years) is described. The stromatolites are found in a thin sedimentary unit in a succession of basic lavas. The stromatolites and their enclosing sediments were probably formed in a volcanic lacustrine environment. It would appear that such environments were favourable for the development of the earliest stromatolite colonies, before their development on continental shelf-carbonate environments. The earliest shelf-carbonate deposits date back to some 2000 million years ago and mark an "explosion" in the area of development of algal colonies. Assuming that the earliest algae were photosynthetic, this period must have marked the first period in the earth's history where significant volumes of oxygen were biologically contributed to the atmosphere.

* * * * * * * * * * * * * * * * * * * *

ALGAL STROMATOLITES OF THE EARLY PROTEROZOIC WOLKBERG GROUP, TRANSVAAL SEQUENCE

CONTENTS

	Page
INTRODUCTION	1
LOCATION, GEOLOGICAL SETTING AND AGE OF STROMATOLITES	1
DESCRIPTION OF STROMATOLITE MORPHOLOGY	3
A. Macroscopic Features	3
B. Microscopic Features	4
ENVIRONMENT OF FORMATION OF THE WOLKBERG STROMATOLITES	4
COMPARISON WITH OTHER ARCHAEAN AND EARLY PROTEROZOIC STROMATOLITE OCCURRENCES	5
List of References	7
Key to Plate	8

* *

ALGAL STROMATOLITES OF THE EARLY PROTEROZOIC WOLKBERG GROUP, TRANSVAAL SEQUENCE

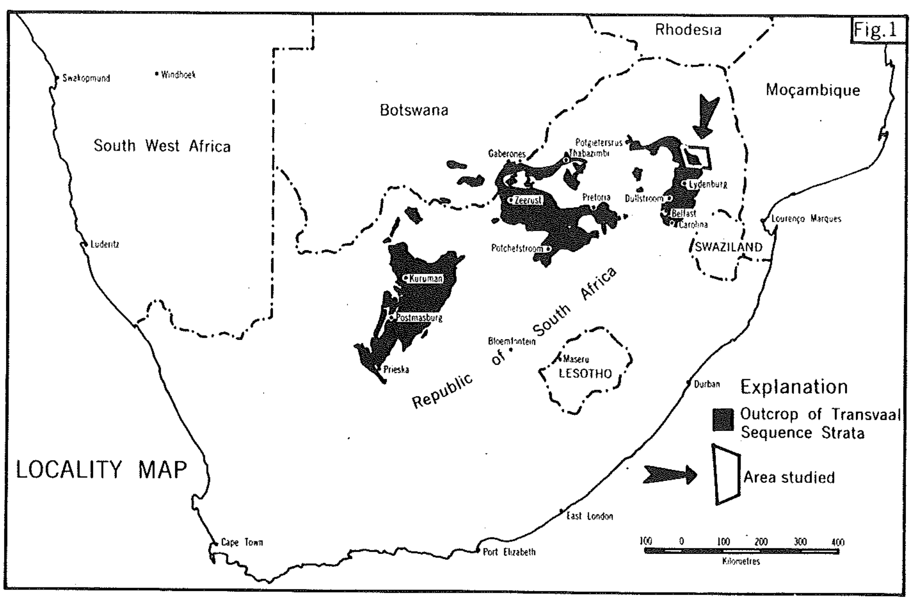
INTRODUCTION

Stromatolites have been defined as finely laminated organo-sedimentary structures, commonly calcareous in composition and columnar to hemispherical in gross morphology, resulting from accretion of detrital and precipitated minerals on successive sheet-like mats formed by communities of microorganisms, predominated by blue-green algae (Schopf and others, 1971).

In the Precambrian of southern Africa, stromatolites have been described from a number of formations with ages ranging from around 3.0 billion years to the start of the Phanerozoic era. The writer recently discovered a stromatolite-bearing horizon in the Wolkberg Group, the lowest subdivision of the Transvaal Sequence in the Eastern Transvaal. The nature and significance of this discovery is discussed in this paper.

LOCATION, GEOLOGICAL SETTING AND AGE OF STROMATOLITES

The stromatolitic rocks to be described below were encountered in the Transvaal Drakensberg, in the area outlined in the locality map (Figure 1).

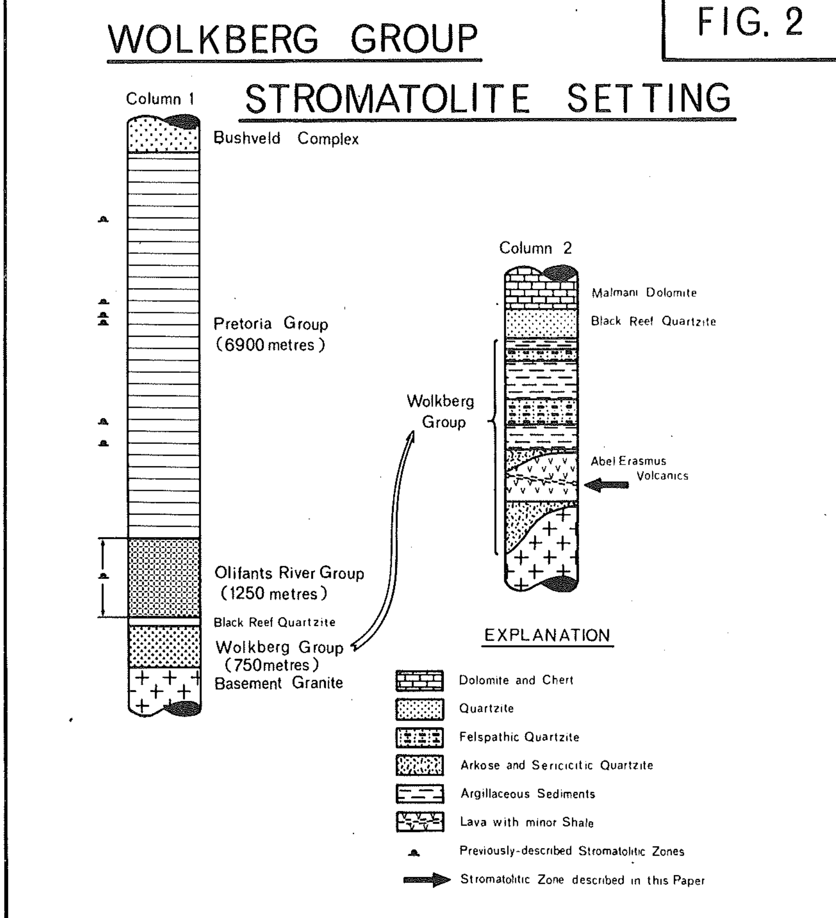


The Transvaal Sequence was deposited in an early Proterozoic cratonic basin, whose outcrop distribution is outlined in Figure 1. In the Eastern Transvaal, the Transvaal strata strike nearly north-south and dip at low angles (generally less than 10 degrees) to the west. In the area described, however, the strata have been deformed, so that locally the beds strike nearly east-west and dip to the south.

In the area under consideration, the Transvaal Sequence rests unconformably upon an Archaean granitic basement terrain. It is overlain by the basic phase of the Bushveld Igneous Complex.

The stratigraphic setting of the stromatolite horizon is indicated in Figure 2. Column 1 shows the whole Transvaal Sequence as it is developed in the area under discussion. The topmost portion of the succession (the Pretoria Group) is made up of a cyclically alternating pile of argillaceous and arenaceous strata with three interbedded volcanic horizons. The stratigraphic positions of the stromatolites previously described from the group (Button, 1971) are indicated on the left-hand side of the column.

FIG. 2



The Pretoria Group rests with an intraformational unconformity on the Olifants River Group. In the area described, the lowest formation of this group (the Malmani Dolomite) is developed, and consists of carbonate sediments with chert and volumetrically insignificant amounts of shale and quartzite. Stromatolites are very common in the Malmani Dolomite and have been described by Young (1932, 1933, 1934, 1940), Young and Mendelssohn (1948), Toens (1966) and by Eriksson (1971).

The carbonates of the Malmani Dolomite grade downward to the Black Reef Quartzite which, in turn, grades into the uppermost formation of the Wolkberg Group. In Column 2

(Figure 2), the stratigraphy of the Wolkberg Group is outlined. The Wolkberg Group is typified by the alternation of arenaceous and shaly rocks. The arenites are generally sericitic or felspathic. The lower arenaceous formations usually have a channel-type geometry and may include conglomeratic beds. The shaly rocks are often somewhat carbonaceous and may be dolomitic or calcareous. The succession as a whole appears to have been deposited under conditions of intermittent dessication, as indicated by mud-cracks and clay-flake rocks.

Within the lower portion of the Wolkberg Group are developed some 130 to 220 metres of volcanic rocks, the Abel Erasmus Volcanics. This formation consists essentially of carbonated basaltic lava, in places showing pillow structures. Pyroclastic phases are present, but are volumetrically unimportant.

At a stratigraphic level which ranges from 70 to 130 metres above the base of the volcanics, a 10 to 20 metre thickness of shale, rarely with an associated quartzite bed, is developed. These shales are usually carbonaceous and dolomitic in composition and in places show ripple-marks and mud-cracks. Within the shales are developed beds of stromatolitic carbonate rocks, which are partially replaced by chert in places. This shale horizon, with its contained stromatolites, has been traced along approximately 30 kilometres of strike, but may extend over an even greater distance.

The age of the Transvaal Sequence is indirectly established with relation to the rocks lying adjacent to it. In the central Transvaal, the lowermost Transvaal strata (in this case the Black Reef Quartzite) rest unconformably upon lavas of the Ventersdorp Sequence. The age of these lavas has been established as being of the order of 2,300 million years (van Niekerk and Burger, 1964).

The Transvaal Sequence is overlain and intruded by the basic mass of the Bushveld Igneous Complex. This suite of igneous rocks has been dated at approximately 1950 million years (Nicolaysen, 1962). Deposition of the main body of Transvaal strata thus took place in the period ranging from 1950 to 2300 million years ago.

The age of the Wolkberg Group cannot be directly or indirectly established at present, since both the Ventersdorp (2300 million years) and the Wolkberg underlie the Black Reef Quartzite. Logical geological reasoning suggests that the Wolkberg has a somewhat younger age than the Ventersdorp, since it grades upwards to the Black Reef Quartzite and may be regarded as the first phase of Transvaal deposition. Conversely, the Black Reef covers the Ventersdorp succession with a profound interregional unconformity, suggesting an earlier age for the Ventersdorp. The possibility that the Wolkberg and Ventersdorp could, in part, be contemporaneous cannot be positively discounted.

DESCRIPTION OF STROMATOLITE MORPHOLOGY

A. MACROSCOPIC FEATURES

The macroscopic features of stromatolites were studied in the field and by the sectioning and etching of polished faces of rock. The stromatolites are found in two gross forms. In the first case, they are developed in essentially planar sheet-like bodies of unknown lateral dimension (Plate I B). In the second mode of occurrence, minor stromatolite structures are "parasitic" on larger domical forms with diameters ranging from 20 to 50 centimetres and heights from 5 to 15 centimetres. These larger domes are spaced at variable distances from one-another. They are generally laterally linked by laminae which can be traced from one dome to the next. Plate I A shows the surface expression of small-scale structures on one of the larger domes.

The smaller-scale structures usually have a columnar geometry with diameters of the columns ranging from 1 to 4 centimetres and the heights from 2 to 10 centimetres.

Certain laminae in the columns are continuous from one column to the next, such columns are said to exhibit a "lateral-linked" geometry (Logan and others, 1964). Other laminae do not span from one column to the next and are of the "stacked hemispheroidal" type. There is a vertical alternation within the columns from a stacked hemispheroidal to a lateral-linked habit, with the former group predominating (Plate I C, I D and I F). In the stacked hemispheroidal group, individual laminae vary in shape, being convex, steeply convex or rectangular. The radii of columns is usually fairly constant, although some columns may show a gradual broadening upwards. A tendency towards branching of columns seen in Plate I D and I F. The individual branches do not diverge so that the branching may be said to be of the "parallel type" (Glaessner and others, 1969).

The space between the columns is usually filled with unbedded detritus. These inter-columnar fillings range in breadth from 1 to 10 millimetres and are usually less than 5 centimetres high.

At the top of the specimen pictured in Plate I C, a few centimetre-size spherical oncolites can be seen. The central portions of the oncolites show concentric lamination. The oncolites can be seen to have acted as foundations for further stromatolite growth, since, on their upper surfaces, younger columns may be seen to have grown.

B. MICROSCOPIC FEATURES

Under the microscope, the stromatolite columns are seen to be made up of a delicately laminated mosaic of fine-grained crystalline dolomite. In places the dolomite is replaced by laminae or lenses of very fine-grained microcrystalline silica. Both the dolomite and the chert contain a dusting of opaque black carbonaceous specks, in places organized into thread-like bodies which could possibly represent the remnants of original algal filaments. Small pyrite euhedra are encountered in the chert. Some of the carbonate laminae carry scattered grains of quartz and some feldpar. Splinters of isotropic material are present in some of the carbonate laminae and probably represent shards of volcanic glass.

Where intrastratal movements have caused a slight deformation of the stromatolites, the cores of the stromatolite columns are often filled with secondary minerals, principally quartz and calcite with some mica also being present. These secondary fillings have a parabolic geometry and are confined to the crests of hemispheroidal laminae. The quartz and calcite exhibit a columnar crystalline habit parallel to the axis of the stromatolite column.

The inter-columnar detritus is composed of a mosaic of microcrystalline dolomite and silica with scattered grains of calcite. Floating in this carbonate mass are angular sand-sized grains of quartz, felspar (albite, microcline and orthoclase) and some possible volcanic shards. Flakes of chlorite and muscovite are also present in this assemblage.

The stromatolitic sediments appear to have been essentially unmetamorphosed, devitrification of volcanic glass not having been effected.

ENVIRONMENT OF FORMATION OF THE WOLKBERG STROMATOLITES

The Wolkberg stromatolites were formed in a body of water which was subjected to periodic dessication. This expanse of water had a limited areal extent and rested on a volcanic terrain which, at that time, had seen recent volcanic activity. It may probably best be envisaged as a shallow lake. The waters of the lake may have had a somewhat elevated temperature and were possibly charged with the products of volcanic emanations.

During a period of quiescence, algal colonies flourished in this relatively small body of water. A minor (possibly fluvial) inflow of water provided the shaly sediments (on which the stromatolites formed) as well as the quartz and felspar grains found associated with the structures.

COMPARISON WITH OTHER ARCHAEAN AND EARLY PROTEROZOIC STROMATOLITE OCCURRENCES

In southern Africa, stromatolites have been reported from rocks which span an interval of geologic time of some 2.5 billion years, from around 3.0 billion years to approximately 0.5 billion years ago. The oldest of these are found in limestone interbedded in the Bulawayan lavas of Rhodesia (Macgregor, 1940). Schopf and others (1971), in their re-examination of these structures, present evidence suggesting an age of 2.6 to 3.0 billion years for these stromatolites.

Winter (1963) described stromatolites from calcareous sediments in the 2.3 billion year old Ventersdorp Sequence. The stromatolites are encountered in shaly sediments in a thick volcanic pile. Winter postulated a lacustrine environment for the formation of these stromatolites. The Wolkberg stromatolites (described in this paper) were formed in an environment which was apparently very similar to the setting in which the stromatolites of the Ventersdorp Sequence were formed.

These three occurrences are similar in respect of their limited areal extent and in their close association with volcanic assemblages. It may be mentioned that stromatolites with a similar geologic setting have been reported from a volcanic phase of 2190 million year old Fortescue Group of the Western Australian shield (Daniels, 1966; Compston and Arriens, 1968).

The basal portion of the Transvaal Sequence appears to record a fundamental change in earth history, for here, the earliest widespread southern African shelf-carbonate deposits are found. The Transvaal dolomites are preserved over an area of roughly 100,000 square kilometres, and reach thicknesses of up to some 2,000 metres. The vast majority of this carbonate succession shows evidence of algal activity. Stromatolites from this unit have been documented by Young (1932, 1933, 1934, 1940), Young and Mendelssohn (1948), Toens (1966) and Eriksson (1971).

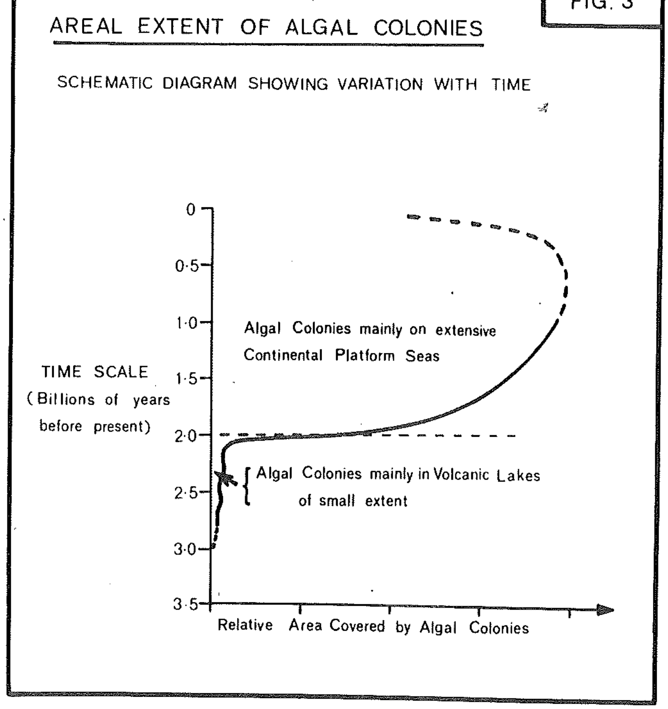
Other widespread shelf-carbonates in southern Africa are similarly stromatolitic. They include the middle Precambrian Lomagundi dolomites of Rhodesia (Jacobsen, 1962), and the late Precambrian/earliest Cambrian Otavi carbonates of South West Africa (Schwellnus and le Roex, 1944; Kruger, 1969).

In other continents the period of the first extensive shelf-carbonate precipitation at a time of about 2000 million years has parallels; for example the Animikian carbonates of the Superior Province in North America and the carbonates of the Hamersley and Wyloo Groups of the Western Australian shield (Trendall, 1968).

On the basis of the evidence presented above, a schematic and highly tentative diagram showing the variation in the area covered by algal colonies throughout geologic time has been constructed (Figure 3). It is suggested that, prior to about 2 billion years ago, the total area of the earth's surface covered by algal colonies at any one time was very small and was confined essentially to volcanic lakes. The life-span of the colonies was also relatively short, being limited to periods of volcanic quiescence.

The fact that the colonies thrived principally in volcanic environments is thought to be significant. It is speculated that the waters of the volcanic lakes were favourable to the development of algae, either because of their slightly elevated temperatures or because of the presence of dissolved gases or cations.

FIG. 3



Schopf and others (1971) produce evidence suggesting that the earliest (2.6-3.0 billion year old) stromatolites were photosynthetic and were thus capable of consuming carbon-dioxide from a proto-atmosphere and releasing oxygen to it. This being the case, it can be deduced that, in the period prior to about 2.0 billion years ago, oxygen was produced for short periods of time over small areas which were widely separated. As pointed out by Cloud (1965), such oxygen would rapidly be scavenged by oxygen-hungry cations in the vicinity, with little or none remaining in a free state in the atmosphere.

It is envisaged that algae evolved slowly in small volcanic lakes until a critical period in earth-history was reached, some 2.0 billion years ago. At this stage, the evolution of (one or a combination of) the earth's crust, the proto-atmosphere, the ancient sea-water chemistry, or the algae themselves was such that the scene was set for widespread precipitation of carbonates on shallow seas covering stable continental platforms. The simultaneous appearance of extensive algal colonies may not be fortuitous. It is possible that the algae themselves developed the ability to fix calcium carbonate at this critical period and that the widespread appearance of carbonate sediments is a reflection of this newly acquired attribute of the algae. Shelf-carbonate deposition was widespread at least up to the beginning of the Phanerozoic era and persists until the present day where certain species of algae are known to be instrumental in the precipitation of calcium carbonate (Feray and others, 1962).

The "explosion" in the area of development of algal colonies (Figure 3), must have important implications on the thinking of the development of the earth's atmosphere. Following Cloud (1965), it is thought that prior to about 2 billion years ago, oxygen was probably produced over limited areas and rapidly scavenged by cations. At this critical time, oxygen started being produced over larger areas and for longer periods of time, possibly saturating oxygen-scavengers and starting local build-ups of this element in the waters of platform seas. A gradual expansion in the areas subjected to oxygenation probably occurred and oxydative weathering was seen for the first time. The subsequent erosion of oxydatively-weathered rocks could then give rise to the continental red-beds which first started appearing around 1.7 billion years ago and became more abundant in younger times.

In Figure 3, a reduction in the areal extent of algal colonies during the Phanerozoic is suggested. Garret (1970) has shown that the diversification of metazoan life-forms during this era was responsible for the decline in the importance of algae, since some metazoans fed on algal filaments while others destroyed algal structures during their burrowing activities. Garret's conclusions were strengthened by the observation of Awramik (1971), that the number of stromatolite forms preserved in sediments reached a maximum in the Upper Riphean ($\sim$ 800 million years), and then declined sharply in lateset Precambrian and Phanerozoic times.

* *

LIST OF REFERENCES

Awramik, S.M., 1971, Precambrian Columnar Stromatolite Diversity : Reflection of Metazoan Appearance : Science, Vol. 174, p. 825-826.

Button, A., 1971, Early Proterozoic Algal Stromatolites of the Pretoria Group, Transvaal Sequence : Trans. geol. Soc. S. Afr., Vol. 74, p. 201-210.

Cloud, P.E., 1965, Significance of Gunflint (Precambrian) Microflora : Science, Vol. 148, p. 27-35.

Compston, W. and Arriens, P.A., 1968, The Precambrian Geochronology of Australia : Canadian Journal of Earth Sciences, Vol. 5, p. 561-583.

Daniels, J.L., 1966, The Proterozoic Geology of the North-West Division of Western Australia : Proc. Aust. Inst. Min. and Metall., No. 219, p. 17-26.

Eriksson, K.A., 1971, A Basin Analysis of the Transvaal Sequence in the Potchefstroom Synclinorium, Transvaal and Orange Free State : Unpub. M.Sc. Thesis, Univ. of the Witwatersrand, 79 pp.

Feray, D.E., Heuer, E. and Hewatt, W.G., 1962, Biologic, Genetic and Utilitarian Aspects of Limestone Classification, p. 20-32, In : Ham, W.E. (Editor) - Classification of Carbonate Rocks : Memoir 1, Amer. Assn. of Petroleum Geologists, Tulsa, Oklahoma, U.S.A., 279 pp.

Garret, P., 1970, Phanerozoic Stromatolites : Noncompetitive Ecological Restriction by Grazing and Burrowing Animals : Science, Vol. 169, p. 171-173.

Glaessner, M.R., Preiss, W.V. and Walter, M.R., 1969, Precambrian Columnar Stromatolites in Australia : Morphological and Stratigraphic Analysis : Science, Vol. 164, p. 1056-1058.

Jacobsen, J.B.E., 1962, The Geology of the Lomagundi District : Unpub. M.Sc. Thesis, Univ. of the Witwatersrand, 127 pp.

Kruger, L., 1969, Stromatolites and Oncolites in the Otavi Series, South West Africa : Jour. Sed. Petrol., Vol. 39, p. 1046-1056.

Logan, B.W., Rezak, R. and Ginsburg, R.N., 1964, Classification and Environmental Significance of Algal Stromatolites : Jour. Geol., Vol. 72, p. 68-83.

Macgregor, A.M., 1940, A Pre-Cambrian Algal Limestone in Southern Rhodesia : Trans. geol. Soc. S. Afr., Vol. 43, p. 9-15.

Nicolaysen, L.O., 1962, Stratigraphic Interpretation of Age Measurements in Southern Africa : Petrologic Studies, A.F. Buddington Volume, Geol. Soc. Amer., p. 569-598.

Schopf, J.W., Oehler, D.Z., Horodyski, R.J. and Kvenvolden, K.A., 1971, Biogenicity and Significance of the Oldest Known Stromatolites : Jour. Paleontol., Vol. 45, p. 477-485.

Schwellnus, C.M. and le Roex, H.D., 1944, Columnar, Conical and Other Growths in the Dolomite of the Otavi System, S.W.A. : Trans. geol. Soc. S. Afr., Vol. 47, p. 93-104.

Toens, P.D., 1966, Precambrian Dolomite and Limestone of the Northern Cape Province : Mem. 57, Geol. Surv. S. Afr., Pretoria, 109 pp.

Trendall, A.F., 1968, Three Great Basins of Precambrian Banded Iron Formation Deposition : Bull. geol. Soc. Amer., Vol. 79, p. 1527-1544.

van Niekerk, C.B. and Burger, A.J., 1964, The Age of the Ventersdorp System : Annals Geol. Surv. S. Afr., 3, p. 75-86.

Winter, H. de la R., 1963, Algal Structures in the Sediments of the Ventersdorp System : Trans. geol. Soc. S. Afr., Vol. 66, p. 115-121.

Young, R.B., 1932, The Occurrence of Stromatolitic or Algal Limestones in the Campbell Rand Series, Griqualand West : Trans. geol. Soc. S. Afr., Vol. 35, p. 29-36.

Young, R.B., 1933, Conditions of Deposition of the Dolomite Series : Trans. geol. Soc. S. Afr., Vol. 36, p. 121-135.

Young, R.B., 1934, A Comparison of Certain Stromatolitic Rocks in the Dolomite Series of South Africa, with Modern Algal Sediments in the Bahamas : Trans. geol. Soc. S. Afr., Vol. 37, p. 153-162.

Young, R.B., 1940, Further Notes on Algal Structures in the Dolomite Series : Trans. geol. Soc. S. Afr., Vol. 43, p. 17-22.

Young, R.B. and Mendelssohn, E., 1948, Domed Algal Growths in the Dolomite Series of South Africa, with Associated Fossil Remains : Trans. geol. Soc. S. Afr., Vol. 51, p. 53-62.

* *

KEY TO PLATE I

A. A 30-centimetre stromatolite dome in a dolomite-chert rock. The surface expression of second-order columns and domelets are clearly seen.

B. The surface expression of second-order columns and domelets on a planar surface in a dolomite-chert rock.

C. A vertical face of a dolomite-chert rock, smoothed and etched with dilute HCl. Second-order stromatolites show lateral-linked and stacked-hemispheroidal habits. At the top-centre of the specimen, oncolites are seen to have acted as the foundations for further stromatolite growth.

D. A smoothed face of a dolomite-calcite rock, etched with dilute HCl and with dominant features outlined in white ink. A columnar geometry is seen to have been propagated upwards through successive stages involving both lateral-linked and stacked-hemispheroidal habits.

E. A polished face of a chert rock showing the dominance of a lateral-linked habit in second-order stromatolites. The domelets, in places being situated one above the other, may give a gross columnar geometry to the stromatolites.

F. A section through the same specimen as Plate I D, but at right angles to it. Surface is smoothed, acid-etched and accentuated with white ink. A tendency to parallel branching of columns can be seen. Laminae are convex and steeply convex.

* *

PLATE 1