ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

EARLY PROTEROZOIC ALGAL STROMATOLITES OF THE PRETORIA GROUP, TRANSVAAL SEQUENCE

A. BUTTON

INFORMATION CIRCULAR No. 60

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

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by

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

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ABSTRACT

Within the Pretoria Group of the Transvaal Sequence (1950-2300 million years old), five separate algal stromatolite-bearing horizons are described. These organo-sedimentary structures occur in cherts and carbonate rocks associated with the argillaceous phases of the Pretoria Group. The stromatolites conform in their geometry to the class of lateral linked hemispheroids described by Logan and others (1964). Consequently, the stromatolites and their enclosing shaly sediments probably formed on widespread intertidal mud flats. Since algae photosynthesize carbon dioxide to yield oxygen, the atmosphere during Transvaal times must have been at least partially oxygenic. The algae which existed during this period could have been directly or indirectly responsible for the formation of carbonate sediments.

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EARLY PROTEROZOIC ALGAL STROMATOLITES OF THE PRETORIA GROUP, TRANSVAAL SEQUENCE

INTRODUCTION

Algal stromatolites have been defined as "laminated structures composed of particulate sand, silt, and clay-size sediment, which have been formed by the trapping and binding of detrital sediment particles by an algal film" (Logan and others, 1964). Algal structures have long been recognised in the Precambrian strata of Southern Africa, the first being recorded by Young (1932) in the "Dolomite Series" of the Transvaal Sequence. Macgregor (1940) described stromatolite structures from the Bulawayan Group of Rhodesia, whose age, according to Bliss and Stidolph (1969), is approximately 3,000 million years. Winter (1963) has documented algal stromatolites from the Ventersdorp Sequence (2,300 million years) intersected in deep prospecting boreholes in the Orange Free State Goldfields.

Since algal colonies require rather specific environments in which to flourish, their presence in the stratigraphic record is an important aid in any attempt to decipher the sedimentational history of the succession in which their structures are preserved. Published descriptions of stromatolites in the Transvaal Sequence are confined to the lower portion of the stratigraphy, namely in the "Dolomite Series". Only one report of algal structures occurring within the overlying Pretoria Group has thus far been published. Hiemstra and Van Biljon (1959), in their description of the geology of the area around Steelpoort in the Eastern Transvaal, mention the development of stromatolites in calcareous rocks above the Magaliesberg Quartzite.

Recent mapping undertaken by the writer in the Eastern Transvaal, has established the existence of at least five separate stromatolite horizons within the Pretoria Group. These discoveries provide an insight into the possible conditions that prevailed at times during the deposition of this widespread stratigraphic unit.

LOCATION AND GEOLOGIC SETTING

The area in which the algal stromatolites were discovered is situated in the escarpment region of the Eastern Transvaal (see Figure 1). Within this area, the Transvaal strata strike north-northeast and dip at angles of 5 to 10 degrees to the west.

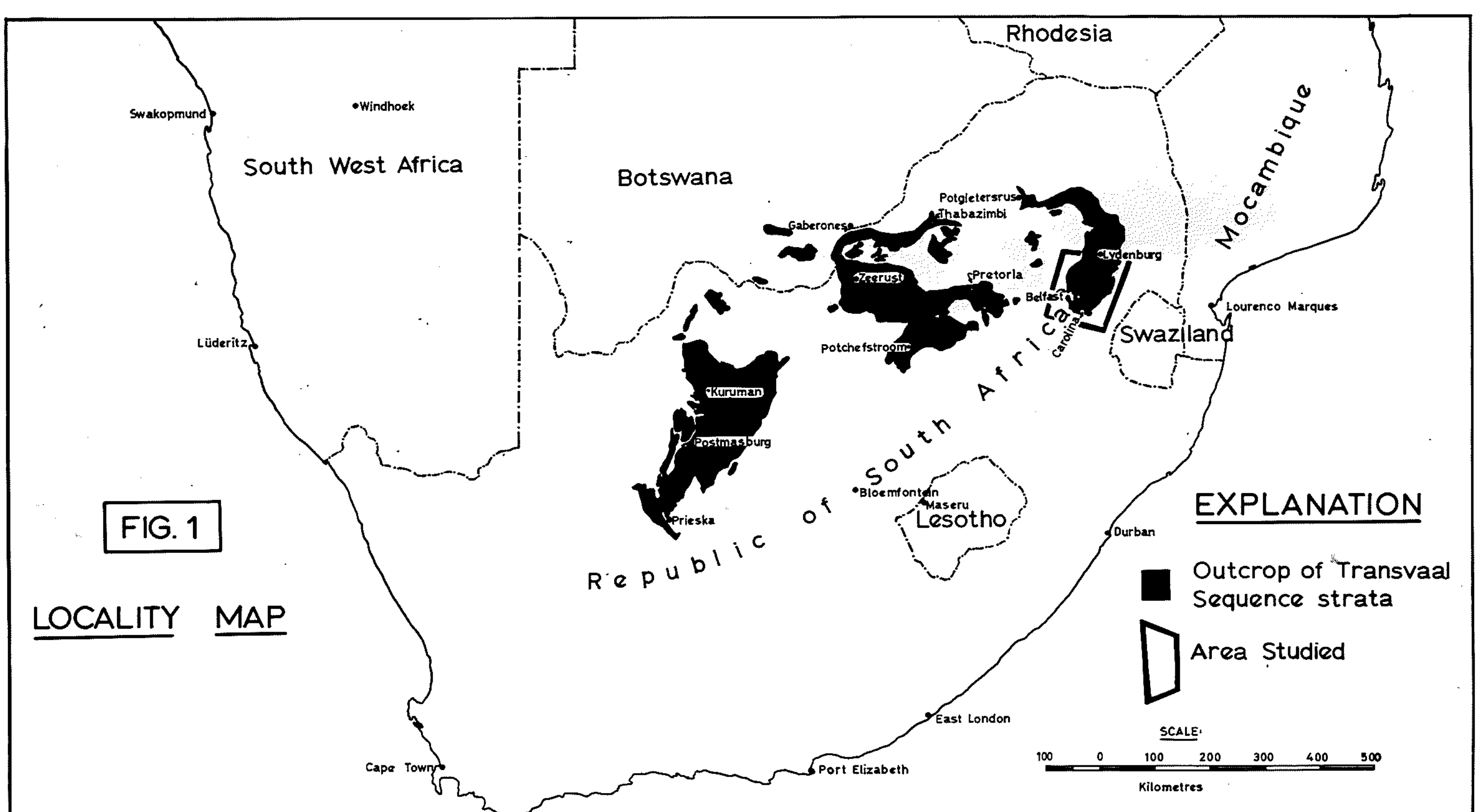


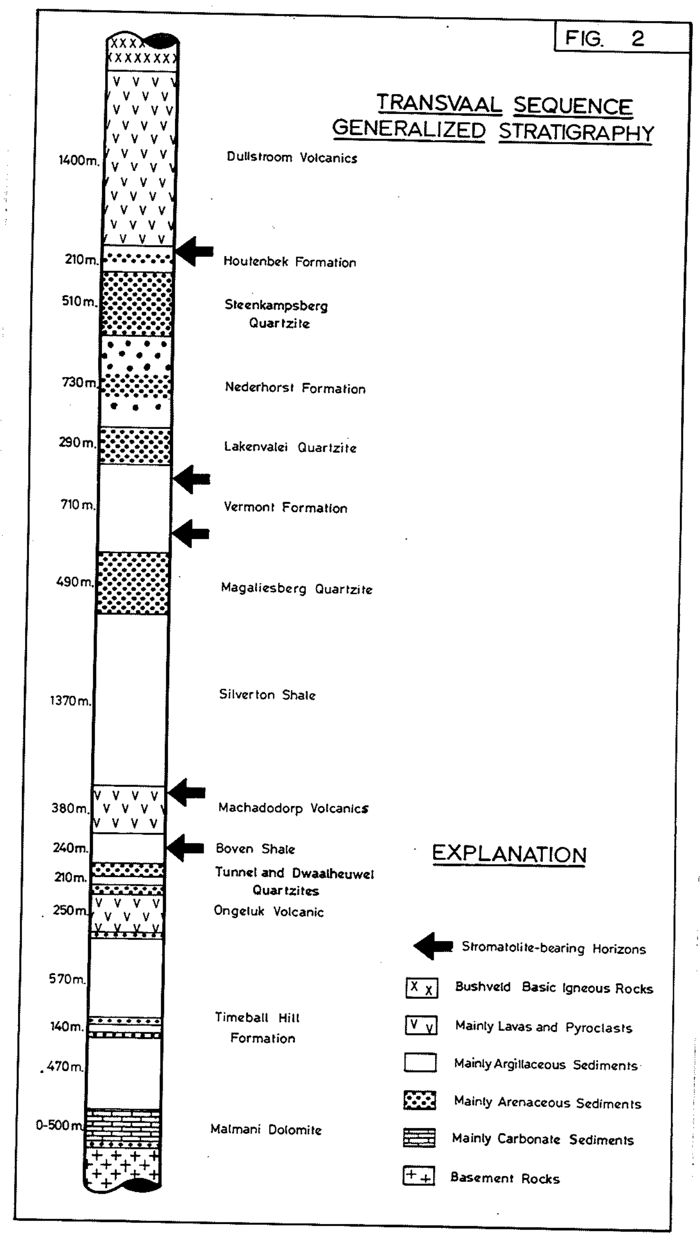
FIG. 1

LOCALITY MAP

The Transvaal Basin is one of a number of Proterozoic sedimentary basins which are situated on the Kaapvaal crustal fragment. As a group, these basins are characterized by their relatively undeformed state and freedom from high-grade regional metamorphism. They are situated on continental-type basement terrain and are therefore of an intracratonic type.

The Transvaal Sequence rests upon the early Precambrian (Archaean) granite-greenstone basement terrain, the age of which varies from 3400 to 2200 million years (Allsopp and others, 1962; 1969) and is overlain semi-conformably by the basic portion of the Bushveld Igneous Complex. The age of this intrusive suite has been firmly established as being of the order of 1950 million years (Nicolaysen, 1962). The lower age limit of the Transvaal strata can be set by their relationship to the Ventersdorp Sequence, which they overlie. Van Niekerk and Burger (1964) presented evidence suggesting that the Ventersdorp lavas were extruded some 2,300 million years ago. On this basis, the Transvaal strata have an age ranging between the limits of 1950 and 2300 million years.

FIG. 2



A generalized stratigraphic column of the Transvaal Sequence for the area under discussion, is shown in Figure 2. The succession commences with the Malmani Dolomite which rests on a thin suite of clastic sediments. Within this carbonate-chert succession, algal stromatolites have been well-documented (Young, 1932, 1933, 1934, 1940; Young and Mendelssohn, 1948; Toens, 1966). Banded iron-stones are associated with the Dolomite, but are not present in the area studied. A prominent unconformity, present on a basin-wide scale, separates the Dolomite from the overlying Pretoria Group.

The Pretoria Group consists of cyclically alternating arenaceous and argillaceous horizons interlayered with three separate and distinct volcanic episodes. Basic sills are intruded into the sedimentary and volcanic assemblages and tend to become thicker and more frequent stratigraphically upwards. The basic sills are also responsible for the thermal alteration of the sediments adjacent to them.

In the area described, the total thickness of the Pretoria Group, exclusive of basic sills, has been estimated to be approximately 7,900 metres. The stromatolite-bearing horizons are found in the upper four-fifths of this pile and are described below under the headings of the formations in which they are found.

CLASSIFICATION OF ALGAL STROMATOLITES

In this paper, the geometric classification of algal stromatolites developed by Logan, Rezak, and Ginsburg (1964) is used. Logan and his co-workers classify stromatolites according to the manner of arrangement of the hemispheroid, which is the basic geometric unit present in all stromatolites. Although this method of classification is capable of accommodating the highly complex forms found in some stromatolites, only three fundamental subdivisions are of primary importance in deciding their environment of formation.

The first of these groups is that in which the algal lamination is continuous across adjacent domes. Stromatolites displaying these structures belong to the group of lateral linked hemispheroids (abbreviated LLH). They are formed on protected intertidal mud flats where the severity of wave action is reduced and does not disrupt the algal mat which spans the space between adjacent domes.

The second group consists of vertically stacked hemispheroids in which the algal laminae are not continuous across the gap separating adjacent domes. This type of structure (abbreviated SH) is formed on exposed intertidal mud flats where the wave action is severe enough to disrupt the algal mat between adjacent algal heads.

The third group includes all structures in which hemispheroids are arranged in various ways to produce spherical structures (abbreviated SS). These structures are produced in conditions of agitated shallow water, generally below the low-water mark.

DESCRIPTION OF THE STROMATOLITE OCCURRENCES

A. THE BOVEN SHALE

The Boven Shale which is approximately 240 metres thick, consists of argillaceous sediments with minor carbonate and chert interlayers. The formation has a gradational lower contact with the Tunnel Quartzite. The gradational suite includes thin layers of argillaceous quartzite and quartz-wacke interbedded in shale. The lower portion of the formation consists of olive or grey-green shales and mudstones. The middle portion is made up of black carbonaceous shales, while the uppermost portion consists of greenish shales. Within the carbonaceous zone, thin beds of chert and carbonate rock have been reported (Visser and Verwoerd, 1960), but no algal stromatolites were recorded.

The stromatolites found by the writer are present in thin beds of chert in the middle carbonaceous portion of the Boven Shale. The sediments in this interval are usually somewhat altered by intrusive basic sills. Carbonaceous shales have, in some places, been converted to graphite-bearing material while elsewhere, in the cherty rocks, metamorphism has caused partial re-crystallization of chert and veining by thin quartz-pyrite stringers.

The algal structures of this unit are hemispherical in shape and often have a tendency to be ellipsoidal. The domes vary in their long axis dimensions from 10 to 30 centimetres, with an average value being approximately 20 centimetres. They may be arranged close to one another (Plate 1 A), or they may be separated as in the example shown in Plate 1 B. Good cross-sections are not generally encountered, and it is thus often difficult to establish whether bedding planes in the structures are continuous from one dome to the next. However, the impression is gained from domes such as those displayed in Plate 1 A, that the bedding planes are continuous. They might therefore be classified as lateral linked hemispheroids.

The chert, where relatively free from the metamorphic imprint of basic sills, generally has a delicately banded structure with individual laminae measureable in millimetres. Plate 1 C shows a polished slab of this chert, the light-coloured layers being composed of clear, partially re-crystallized chert, while the dark layers consist of a very fine silica mosaic with a dusting of opaque, black carbonaceous specks.

B. THE MACHADODORP VOLCANICS

Well-developed algal structures in the Machadodorp Volcanics were found by the writer at only one locality, in the area to the north of Carolina. The essentially volcanic succession in which the stromatolites occur consists of pyroclastic rocks ranging from tuffs to boulder agglomerates. The upper portions, however, include pillowed lavas with lesser amounts of tuff, carbonaceous shale, and chert. This assemblage grades into the Silverton Shale by the diminution of the volcanic suite stratigraphically upwards.

Outcrops of the sediments near the top of the Machadodorp Volcanics are poor and most of the chert is found as slabs littering the surface. It is pale greenish-grey in colour and is conspicuously banded or laminated. Plate 1 D shows a slab of this chert broken at right-angles to the bedding plane and displaying domed structures with diameters ranging from 10 to 15 centimetres. Bedding planes are continuous from one dome to the next, and the domes are closely spaced. The algal stromatolites are thus assigned to the group of close-spaced, lateral linked hemispheroids (LLH-C).

C. THE VERMONT FORMATION

The stromatolite zones found in the Vermont Formation have been traced from near Belfast in the south to the Lydenburg area in the north. Within the argillaceous sediments separating the Lakenvalei and Magaliesberg Quartzites, two distinct zones of stromatolitic calcareous rocks have been encountered (Figure 2). The lower horizon, referred to as the Berg-en-Dal horizon by Van Biljon (1949), is situated between 100 and 150 metres above the Magaliesberg Quartzite. Chemical analyses, quoted by Van Biljon, indicate that the Berg-en-Dal carbonates are magnesian-rich, with CaO contents ranging from 18 to 29 per cent and MgO contents ranging from 18 to 28 per cent. The upper calcareous horizon occurs between 80 and 100 metres below the Lakenvalei Quartzite.

Stromatolites in the Berg-en-Dal horizon vary in diameter from one locality to the next. They are usually hemispherical and lateral linked. They may be either closely or distantly spaced. The stromatolites show very fine lamination due to compositional variations in the carbonate assemblages of which they are composed. In some cases the carbonates are black or dark grey in colour, suggesting the presence of some uncombined carbon. Plate I E shows a series of such domes, as well as the lateral continuity of some bedding planes. In Plate I F the bedding surface of a series of gently curving stromatolitic domes is displayed.

At one locality "algal biscuits" were found associated with the stromatolites. The "biscuits" are elongate, varying from 10 to 30 centimetres in length and being approximately 5 centimetres thick. Their long axes are oriented nearly parallel to bedding as is illustrated in Plate 2 A. Bedding planes are seen to curve completely around an original core of ripple-marked carbonate rock. Mawson (1929) has described similar structures from the coastal regions of South Australia. Here the "algal biscuits" litter the surface of inter-dune flats which are subjected to alternate periods of wetting and drying. They owe their origin to the presence of certain blue-green algae.

Within the Berg-en-Dal horizon, structures found associated with the carbonate rocks include mud-cracks, ripple-marks, and, in one case, oölites.

The upper zone of calcareous sediments in the Vermont Formation is usually difficult to locate, since the stratigraphic interval immediately below the Lakenvalei Quartzite is prone to intrusion by basic sills, some of them being over 200 metres thick. Frequently, the calcareous sediments are altered to fosterite-diopside-antigorite rocks. No chemical analyses of this carbonate suite are available, but the mineralogical composition of the altered carbonate sediments suggests that they are appreciably magnesian in composition.

Stromatolites in the upper calcareous zone were found in the northern part of the area, in the Lydenburg district. Plate 2 B, shows a block of carbonate rock from this region, which has been partially serpentinized. On the bedding plane, concentrically banded spherical structures, averaging 10 centimetres in diameter, are displayed. These structures are the bedding plane projections of lateral linked hemispheroids. The domes may be either closely or distantly spaced.

D. HOUTENBEK FORMATION

This formation embraces all the sedimentary rocks which lie above the Steenkampsberg Quartzite and below the Dullstroom Volcanics (see Figure 2). The sediments developed here include quartzite, altered shales, cherts, limestones, and calc-silicate rocks. The stromatolites occur in a limestone-chert-calc-silicate assemblage occupying a position immediately below the Dullstroom Volcanics to the west and northwest of the town of Belfast.

In this area, the Steenkampsberg Quartzite is overlain by shaly rocks displaying shallow-water features. These grade upward into quartzite, the latter in turn, grading into carbonate-bearing quartzite and a suite of carbonate rocks with beds of chert, calc-silicate rock, and quartzite lenses. This entire assemblage is overlain by chert and altered shale, the latter being covered by the Dullstroom lavas.

The carbonate rocks are mainly limestones, but carry appreciable quantities of silica, either as chert, or combined in calc-silicate minerals, such as wollastonite. In two analyses of carbonates from this horizon, Van Biljon (1949) lists values of approximately 45 and 49 per cent CaO and low quantities of MgO (less than 2 per cent).

The stromatolites found in this formation are lateral linked. Both close and widely separated domes are present, varying from less than 10 centimetres to approximately 40 centimetres in diameter. Plate 2 C shows two such domes, laterally linked by very delicate laminae. In Plate 2 D a weathered-etched joint face displays numerous small and closely spaced domes developed along bedding planes. Plate 2 E is a bedding-plane view of the same structures.

Sedimentary structures found associated with the stromatolites include ripple-markings and cross-bedding. An example, provided in Plate 2 F, shows a cross-bedded unit in some limestone from this formation.

THE SIGNIFICANCE OF THE ALGAL STROMATOLITES IN THE PRETORIA GROUP

The presence, in the 2000 million year old Transvaal Sequence, of organo-sedimentary structures similar to those found on present day intertidal mud flats indicates that essentially similar conditions may have prevailed during the deposition of these early Proterozoic sediments. Since algae are capable of producing oxygen from carbon dioxide in the process of photosynthesis, it seems highly likely that oxygen must have been present in some quantities in the atmosphere during these early times. A similar conclusion was reached by Hart (1963) in his discussions on the algal stromatolites of the 2,300 million year old Ventersdorp Sequence.

According to Logan and others (1964), growth of algal colonies is confined mainly to the intertidal zone. Only rarely are such colonies found in the supra-tidal zone. The sub-tidal environment is, according to these authors, characterized more by the presence of spherically structured stromatolites. In their classification, Logan and his co-authors make the fundamental distinction between those stromatolites in which bedding planes are continuous across adjacent domes and those in which they are not. The stromatolites from the Pretoria Group appear to fall mainly into the former class wherever exposure is good enough to make the distinction. Such structures are, according to Logan and others (1964) indicative of protected intertidal mud flats, where the severity of wave action is such that the algal mats spanning the distance between adjacent domes are not disrupted. A mud flat environment of deposition is thus envisaged for the stromatolitic horizons of the Pretoria Group.

When viewed in their stratigraphic setting, it is seen that the stromatolites are usually associated with argillaceous sediments. Shallow-water structures such as mud-cracks, clay-galls, ripple-marks, and ripple cross-laminations are often present in these rocks. Some of these structures are indicative of very shallow water depositional conditions and periodic dessication of soft sediments. Many of the silt-shale units in the upper portion of the Transvaal Sequence may thus possibly be the products of sedimentation on widespread mud-flats where, according to Dunbar and Rogers (1957), such structures are common.

During periods in which uplift in the source area yielded fine clastic sediment to the depositional basin, no algal colonies formed since the deposition of mud and silt probably smothered the colonies by cutting off the sunlight essential to their growth. During periods of tectonic inactivity, however, when source areas were not providing muddy sediment, clear water conditions probably prevailed, during which times the algal colonies flourished.

Visser (1957) considered that the Transvaal sediments were deposited under shallow-water lacustrine conditions. Willemse (1959) favoured the concept of deposition in "an epicontinental sea connecting with a deeper portion towards the west .....". The writer's observations are entirely in accord with Willemse's conclusion. Intertidal mud-flats are typical of areas where an ocean laps on to and over a low-lying continental margin.

The source of the clastic carbonate grains trapped by the algal filaments to form stromatolites is problematical, since the original nature of the grains has been destroyed by the metamorphic overprint which is present throughout the area investigated. It could, however, be speculated that the algae themselves actively produced calcium carbonate or were instrumental in causing the deposition of lime. According to Feray and others (1962), some modern-day algae secrete needles of aragonite internally. When these algae die, the needles of carbonate are set free and may be enmeshed in the filaments of later algal colonies. A second explanation may revolve around the fact that algae remove carbon dioxide from solution during the process of photosynthesis. In so doing they may encourage the dissociation of soluble calcium bicarbonate to form the insoluble calcium carbonate. One or other, or both of these two processes could possibly explain the association between the carbonate rocks of the Transvaal Sequence and their included algal stromatolites.

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KEY TO PLATES

Plate 1

A. A group of closely spaced algal domes in chert of the Boven Shale.

B. Two hemispherical stromatolites in chert of the Boven Shale.

C. A polished slab of chert from the Boven Shale. Millimetre-scale black and white lamination is evident.

D. A cross-section of a block of chert from the Machadodorp Volcanics, showing two closely spaced, lateral linked hemispheroids. The delicate bedding units vary from millimetre to centimetre scale.

E. A cross-section of a series of stromatolitic domes from the Berg-en-Dal horizon, Vermont Formation.

F. A bedding plane view of a series of gently curving algal domes in the Berg-en-Dal horizon, Vermont Formation.

Plate 2

A. An elongate "algal biscuit" from the Berg-en-Dal horizon, Vermont Formation. The concentric nature of bedding planes is clearly seen on the left hand side of the "biscuit".

B. A bedding surface of a partly serpentinized carbonate rock from the upper calcareous zone of the Vermont Formation. The bedding surface shows a number of concentric structures; these are bedding plane views of a group of lateral linked hemispheroids.

C. Two lateral linked hemispheroids in finely laminated limestone of the Houtenbek Formation.

D. A cross-sectional view of closely spaced lateral linked hemispheroids in a laminated chert and limestone rock of the Houtenbek Formation.

E. A bedding plane surface in chert of the Houtenbek Formation, showing closely spaced stromatolitic domes.

F. A cross-bedded unit in limestone of the Houtenbek Formation.

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Plate 1

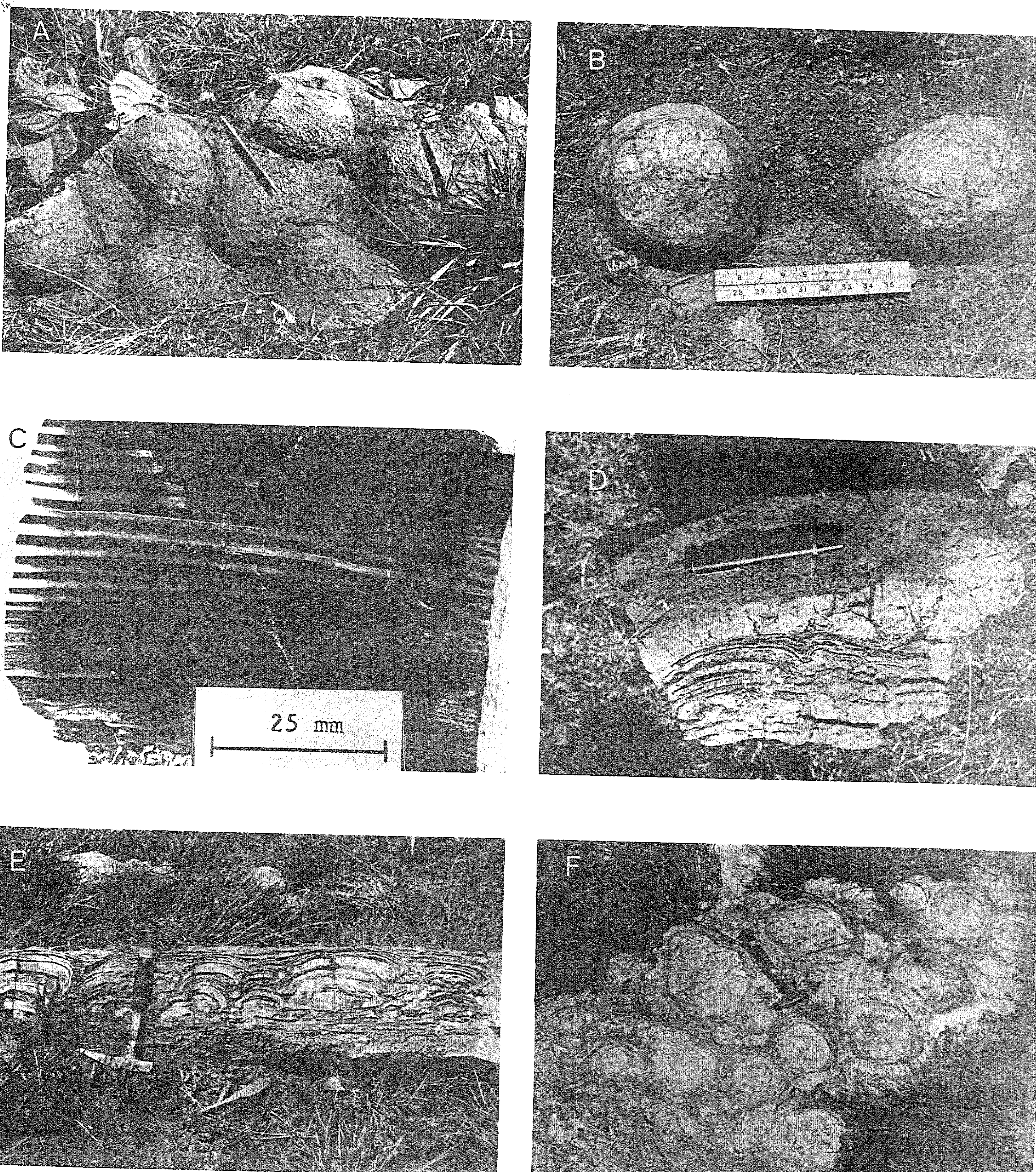

Plate 2