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DEPARTMENT OF MINES SOUTH AUSTRALIA



GEOLOGICAL SURVEY

THE SYSTEMATICS OF SOUTH AUSTRALIAN
PRECAMBRIAN AND CAMBRIAN STROMATOLITES

Part I

by

WOLFGANG V. PREISS
PALAEONTOLOGY SECTION

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Wolfgang V. Preiss
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ABSTRACT

The methods of field study and detailed morphological analysis using three-dimensional reconstructions and thin sections, developed by one Russian school, were applied to the abundant Precambrian and Cambrian stromatolites of the Adelaide Geosyncline. Although other schools either demand formal taxonomy for algal remains only, or use informal descriptive nomenclature of morphologies which they believe are determined entirely by environment, it is concluded that valid and consistent stromatolite form-taxa can be distinguished by these studies. The recognition of stratigraphically restricted taxa suggests biostratigraphic subdivision and intercontinental correlations.

New forms Acaciella angepena, A. augusta, Baicalia burra and Boxomia melrosa, and an indeterminate form of Acaciella are described.

INTRODUCTION

Stromatolites are laminated structures formed in sediments, mostly carbonates, by the trapping and precipitation of sediment by mats of algae and bacteria. They are known throughout the sedimentary record, and are particularly abundant in otherwise unfossiliferous Precambrian sequences. This observed abundance and the diversity of forms have made stromatolites potentially

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useful as index fossils, provided that taxa can be defined which have stratigraphically restricted time-ranges. A group of Russian stromatolite specialists has been engaged in the systematic description and classification of stromatolites for the past fifteen years and their results stimulated this study of South Australian stromatolites in an attempt to apply biostratigraphic methods to the problems of the age and correlation of the Precambrian sequence in the Adelaide Geosyncline.

This paper is based on the systematics section of a thesis (Preiss, 1971a), submitted for the degree of Ph.D., University of Adelaide. Other aspects dealing with the biostratigraphy and the environmental interpretation of the stromatolite-bearing sediments will be subjects of a future publication. It is necessary here to briefly discuss the taxonomy of stromatolites and particularly to formalize several new taxa needed for subsequent discussion.

This paper, the first of three, will include an outline of previous studies, consideration of some taxonomic principles and problems, and descriptions of four new forms and one indeterminate form. The second part will comprise descriptions of a further ten forms, six of which are new. In the third part, a final three forms will be described, two of which are new, and the stratigraphic distribution of stromatolites will be discussed. Stromatolite forms will be described in alphabetical order.

Background

The history of the early study of stromatolites was comprehensively reviewed by Maslov (1960). Although most researchers prior to 1914 sought an animal origin for these

structures, for example Hall's Cryptozoon (1883) and Steinmann's Gymnosolen (1911), Walcott's (1914) discovery of filamentous microfossils in Precambrian stromatolites from the Belt Series of Montana paved the way for the understanding of stromatolite formation by algae.

Later workers clarified the role played by the algae. In particular, Black (1933) established that the algal mats of the Bahamas are polyspecific and that the mucilaginous filaments of the blue-green algae present trap detrital grains. Pia (1926) recognized the rock-building properties of modern blue-green algae. Algal filaments were also found by Bradley (1929) to occur in stromatolites of the Eocene Green River Formation of Wyoming.

During the 1930's fossil stromatolites were described by numerous authors, the most important being Young (1933a, 1933b, 1935), Fenton & Fenton (1931, 1933, 1936, 1937, 1939), Johnson (1937, 1940) and Maslov (1937a, 1937b, 1938, 1939a, 1939b). The works of others were reviewed by Maslov (1960). Most of these authors tacitly accepted the validity of a formal binomial nomenclature for stromatolites.

Cloud (1942) was the first to question the validity of such a classification, arguing that stromatolites are built by associations of algal species. Similarly, Johnson (1966) has more recently rejected the use of this nomenclature, and suggested rather that only actual algal species should be named, if they are present. Nevertheless, Rezak (1957) found it useful to retain a binomial nomenclature and used the defined taxa successfully for intrabasinal correlation.

Since the controversy regarding the classification of stromatolites arose at least three schools of thought have evolved. Firstly, a small group of Russian students (e.g. Vologdin, 1962), like Johnson, considered that only actual algal remains can be validly named. But algae are very rarely preserved in Precambrian stromatolites, and most of the micro-structures referred by Vologdin to fossil algae are very doubtfully of organic origin.

A second group rejects the concept of biological control over stromatolite morphology, and uses purely descriptive classifications to aid environmental interpretations. For example, Maslov (1960) used "generic" names such as Collenia, Conophyton, Glebulella etc. but he modified these by a series of descriptive Latin adjectives. Logan, Rezak and Ginsburg (1964) used symbols and formulae to describe various features of stromatolites, which they showed to be influenced by the local environment. Both Maslov's multinomial nomenclature and the variable descriptive formulae of Logan et al. tend to be cumbersome, and cannot in themselves describe all the useful characters of stromatolites. Some of the simpler formulae are, however, very useful in routine field descriptions. Hofmann (1969a) found difficulty in applying a binomial nomenclature to the stromatolites of the Gunflint Iron Formation, and later (Hofmann, 1969 b) discussed the significance of various characters of stromatolites, concluding that different morphologies are more likely to be environmentally than biologically controlled. Hoffman (1967, 1969) gave an outstanding example of the use of stromatolites in palaeocurrent determination.

The third school is a Russian group which describes and classifies stromatolites on the basis of morphology and microstructure, and uses them for biostratigraphy. Their first results were reported by Keller et al. (1960). Despite differences of emphasis today between different workers, all use a binomial nomenclature with the form taxa "group" (analogous to genus) and "form" (analogous to species). They have found that the time ranges of the defined taxa are restricted, and this allowed them to subdivide and correlate Late Precambrian sections throughout much of the USSR. The biostratigraphy was supported by numerous radiometric datings, both K-Ar determinations of glauconites and K-Ar, Rb-Sr and U-Th-Pb determinations on intrusives. The subdivision is as follows:-

Cambrian

-570 ± 10 m.y. -

Vendian

-680 ± 20 m.y. -

Late Riphean

-950 ± 50 m.y. -

Middle Riphean

-1350 ± 50 m.y. -

Early Riphean

-1600 ± 50 m.y.

The approach of this group was applied to Australian stromatolites, and it was found that many of the Russian taxa do occur here, in a similar order of succession (Glaessner, Preiss & Walter, 1969; Walter, 1970; Preiss, 1971a and 1971b). The resulting correlations with the dated Russian sequences were in agreement with most of the radiometric evidence available for the Australian Precambrian.

The successful use of stromatolites in biostratigraphy implies that their morphology is at least partly controlled by genetic characters of algae which evolve in time. The concept of biological control is supported by some studies of modern algal mats (Eardley, 1938; Hommeril and Rioult, 1965; Monty, 1967). Each of these authors has shown the partial dependence of mat type on the predominating algal species present. This in turn affects the microstructure and lamina shape of the stromatolite, and indirectly, the gross morphology. Thus, deciding which characters are genetically determined and which are directly shaped by local environmental factors becomes the major difficulty in classifying stromatolites.

The Russian work of recent years has shown that it is mainly the columnar stromatolites which are of value in biostratigraphy. Only Komar (1966) has given a detailed account of laterally linked stromatolites but their usefulness has not been confirmed to the extent that that of columnar forms has. In this study, attention was also concentrated on columnar forms since these have the most characters allowing them to be classified. Therefore the binomial nomenclature has been applied only to these.

The terms used here to describe stromatolite characters, are largely based on translations of Russian terms, with minor alterations and additions. Most of the new terms introduced by Hofmann (1969b) are unnecessary from the point of view of this study. The diagnostic terminology proposed by Glaessner et al. (1969, Fig. 1) has been expanded (Fig. 1), and the terms used in the descriptions are defined in the glossary, Appendix I.

Taxonomy

In general the methods of stromatolite study and classification used by the Russians Krylov (1963, 1967), Semikhatov (1962), Nuzhnov (1967) and Komar (1966) have been applied here, including binomial nomenclature. Although many of the group names have been accepted in palaeobotanical literature as genera, e.g. (Baicalia, Conophyton, Gymnosolen (Andrews, 1970), it is considered that retention of the terms group and form emphasizes the distinction between stromatolites as organo-sedimentary structures and actual fragmentary plant remains to which the terms form genus and form species may be applicable. While similar groups of characters are studied for each stromatolite, the relative taxonomic significance attached to any particular character may vary from taxon to taxon, depending on its diagnostic value. Mostly, groups are defined on the basis of gross morphology column shape, branching and margin structure. Lamina shape and microstructure are frequently useful in the distinction of forms. But sometimes these features are diagnostic at group level - Conophyton, for example, is diagnosed by its lamina shape, and is characterized by particularly distinct lamination. Baicalia tends to be characterized by banded lamination, except where altered by diagenesis. Although the presence of a wall is a diagnostic difference between some groups, Walter (1970) has described single stromatolites which are unwalled in their lower parts and walled at the top, in which case other features are diagnostic. No similar situation is known from South Australia.

It is considered unnecessary to use categories higher than the group, as Raaben (1964) has done. Her higher taxa are somewhat

arbitrary and several alternative ones could be proposed, but all are equally questionable. On the other hand, the variety as a subdivision of the form is useful in cases where finer subdivisions can be made, and is therefore retained for Conophyton garganicum.

It could be argued that a single name would be sufficient to characterize a particular stromatolite, but the value of a binomial nomenclature is that it indicates real similarities and differences between various forms. Thus groups contain one or more forms which all share a number of characters considered diagnostic for that group. Forms are distinguished within a group whenever there are sufficient gross or microstructural differences. But the essential comparison between closely related forms would be lost without a binomial nomenclature.

The chief difficulty in the taxonomy of stromatolites is the isolation of discrete character combinations, where intergradation is common. Thus, subjective choice may be required in some cases. Where the morphology remains a uniform throughout a particular occurrence a single name can easily be applied, but if there is variation within the occurrence, the definition must be broadened. Whether or not the morphology of a stromatolite from another occurrence falls within this range of variation is difficult to decide. Conversely, if a significantly different morphology occurs as a discrete portion of an occurrence, is this to be classified separately? Examples of stromatolites with a broad range of variation are Tungussia etina and Linella munyallina. Both these show a spectrum of intergrading branching types and column shapes, even within single outcrops, so that the range of variation

between specimens of different areas lies within the range of variation in one locality, and these are therefore included in the one form.

It has been found that many characters overlap, and distinctions must be made even at group level on the most commonly occurring expression, i.e. the mode, of each character. This is especially true of branching. Boxonia is characterised by alpha-parallel and some beta-parallel branching, while gamma-parallel is rare. In Gymnosolen gamma-parallel predominates, but not to the total exclusion of the other types. Similarly, there is overlap between the branching styles of Baicalia (whose forms show a tremendous variation of branching, as shown by Krylov, 1967) and that of Tungussia. But while Baicalia has predominantly slightly to moderately divergent branching, in Tungussia markedly divergent branching predominates.

Although it is often easy to recognise groups on the basis of even limited reconstructions and longitudinal sections, the identification of forms is more difficult and subjective. Forms are distinguished on minor features of column morphology, lamina shape, or microstructure. Microstructure is the most difficult character to use, partly because different types intergrade to some extent and partly because it is so easily altered by diagenesis. The distinctive lamination Conophyton is somewhat exceptional, and is amenable to statistical analysis. Although Raaben (1969a) has attempted similar studies on Inzeria and Semikhatov, Komar Serebryakov (1970) have measured the sizes of clots and pellets in Boxonia, it is uncertain whether or not the structures measured are primary.

The laminae of most South Australian columnar branching stromatolites are too diffuse and variable to allow a detailed statistical study although the well preserved representatives of the banded microstructure of Baicalia burra might be amenable.

Stromatolites can be classified only on the basis of combinations of characters, and, as Walter (1970) has also concluded, the classificatory significance of characters must vary to some extent from taxon to taxon. The classification has been found empirically to be useful in that the resulting taxa are temporarily restricted. The question arises as to the fundamental meaning of these taxa, and why they are so restricted. Several possibilities exist:

- (1) Each form is built by a particular association of algal species, and forms change as the content of the associations changes.
- (2) Each form is built by a dominant algal species, in association with other species that have little effect on stromatolite morphology.
- (3) The environment, and not the algal composition entirely controls the stromatolite morphology.

If (3) were true, we should expect a temporal restriction of forms only if the environment has systematically evolved in time. It is difficult to see how local factors such as current activity or sediment accumulation which could conceivably control stromatolite morphology, can exhibit continent-wide, if not world-wide, unidirectional change. On these grounds, this possibility must at present be rejected. If (1) were true, we could expect the

morphology to change gradually as the overall algal composition changes, one species replacing another in the association. On the other hand, if one species controls the morphology, a rapid change would be expected. At present, it is not possible to tell which of (1) and (2) is correct and possibly both apply; the first possibility may explain the intergradations sometimes observed between taxa, when classification becomes difficult.

Although Hofmann (1969b) regarded Conophyton as apart from other stromatolites, recent work has shown that conophytions possibly intergrade with columnar branching forms such as Baicalia (Shapovalova, 1968). Similarly Bertrand (1968) described intergradations of Conophyton and branched forms. While the taxonomic significance of these changing morphologies and their relationship to environmental factors has not been fully determined, it is clear that Conophyton is not fundamentally different from other stromatolites.

It is concluded that stromatolites must be defined on combinations of characters, the significance of each of which may vary in different taxa. The fact that some taxa have much broader ranges of variation than others results from the necessity of grouping intergrading morphologies present in single stromatolite occurrences.

Methods

Stromatolites were studied both in the field and in the laboratory, but field observations were often limited by outcrop conditions and lichen cover on rock surfaces. Where possible, the mode of occurrence, column shape and arrangement and branching were observed in order to gain an insight into the environmental conditions.

observed in order to gain an impression of the total variability.

The variable nature of stromatolites necessitates sampling of sufficient material to determine the modal expressions of characters present. Depending on the size of columns, large specimens weighing from 10lbs. (4.5 kg) to 150 lbs (68 Kg) were collected, and the relative position and orientation were noted. Ideally, bioherm centres and margins were both sampled.

The diagnostic gross features of columnar stromatolites can only be determined from a three-dimensional view of the structure. This is achieved by the method of "graphical reconstruction" described by Krylov (1963). A series of 10 to 15 serial longitudinal slabs 2 to 6 mm wide were cut on an oil-cooled 24" (60cm) diamond saw with a saw cut about 2 mm wide. The columns were outlined in pencil on the slabs and traced on to block diagram framework on tracing paper, each longitudinal section being parallel to the front face of the block. The reconstructions were retraced with shading to show surface morphology and finally redrafted by stippling.

Lamina shape, margin structure and microstructure were studied in large longitudinal thin sections, up to 20 cm long. Their thickness varies with the nature of the rock, but in general they must be thicker than petrological sections to preserve the distinctness of the structures. Carbonates were mostly identified by staining with Alizarin Red S, but were frequently checked by X-ray diffraction powder photographs.

Systematics

For each group from which forms are described, a diagnosis, a list of the known constituent forms and the stratigraphic and

geographic distributions are presented. Forms are diagnosed only if described here for the first time. Descriptions are given under the headings mode of occurrence, column shape and arrangement, branching, margin structure, lamina shape and microstructure. The interspace sediments and the nature of secondary alteration are also described since they provide important clues to the depositional environment and diagenetic history.

The distribution of forms refers to both their geographic distributions and to the rock-stratigraphic units in which they occur. Reference is made for each locality and stratigraphic unit to the relevant geological sheet (either 1:63,360 or 1:250,000 sheets, Geological Atlas of South Australia).

It was found convenient (Preiss 1971a and 1971b) to subdivide the Adelaidean Period (Dunn, Plumb and Roberts, 1966) into two time units: the Early Adelaidean, represented by all sediments up to the pre-tillite unconformity and the Late Adelaidean, represented by sediments from the base of the lower tillite to the base of the Cambrian. This subdivision reflects both a climatic change and a major change in stromatolite assemblages. Ages of stromatolites will be referred to as Early or Late Adelaidean, but the probably correlations with the subdivisions of the Riphean will be noted in each case.

Type specimens are kept in the Department of Geology and Mineralogy, University of Adelaide, catalogued under numbers prefixed by S.

GROUP ACACIELLA Walter, 1971

Type Form: Acaciella australica, Bitter Springs Formation, Central Australia (Walter, 1971, in press).

Diagnosis: Nearly straight, parallel or radially arranged subcylindrical, unwalled columns with alpha-, beta- and rarely gamma-parallel and slightly divergent, multiple branching. Column margins bear low bumps, and occasional small cornices and peaks.

Content: Acaciella australica, Walter, Acaciella angepena f. nov. and Acaciella augusta f. nov.

Age and Distribution: Adelaidean to Early Cambrian; Loves Creek Member of the Bitter Springs Formation, Central Australia; the Lower Cambrian of South Australia; the Wundowie Limestone and Brighton Limestone equivalent, Umberatana Group, South Australia and as erratics in the lower (Sturtian) glacials, South Australia.

Acaciella angepena f. nov.

Figs. 2, 8, 9a.

Material: Forty-seven specimens from nine localities.

Holotype: S460 (Figs. 2a, 8c), Lower Cambrian ⁵/₈ mile (1km) south of Angepena H.S., Northern Flinders Ranges.

Name: After the type locality.

Diagnosis: Acaciella with vertical or radially arranged columns or pseudocolumns, which may branch upwards from either flat-laminated or small cumulate stromatolites. Columns may branch upwards into minute, irregular columns. Bridging is extremely common. Microstructure is regularly banded, with thin continuous laminae. Vermiform microstructure may be developed.

Description:

Mode of occurrence:

Cambrian stromatolites were studied in outcrop only in the Angepena area, where lenticular stromatolite beds consist of closely spaced ellipsoidal and domed bioherms 3 to 50 m wide. These overlie flaggy, laminated, dark grey limestones with irregular erosional contacts. Cumulate or pseudocolumnar stromatolite individuals commence growth upon the erosional highs, and pass up into radially arranged or parallel short columns with very numerous bridges. At bioherm margins, columns and pseudocolumns become horizontal, and laminae are deflexed parallel to the overhanging sides of the bioherm, so that here growth actually proceeded downwards (Fig. 8a & b showing longitudinal sections of a bioherm margin). Where adjacent bioherms become contiguous, they are overlain by a domed biostromal layer of columnar, pseudocolumnar and columnar-layered stromatolites, similar to those of the bioherm. At the edge of a stromatolite bed, the terminal bioherm has an abrupt vertical and the laminae bend downwards only slightly. The surrounding sediment of dark lime mud accumulated synchronously with stromatolite growth, and occasional algal laminae are intercalated with it; the bioherm probably never had more than 10cm of relief over the surrounding sediment surface. Also, there is evidence of contemporaneous compaction of the lime mud the bioherm rests upon (Fig. 8c); the lower layers of the surrounding muds are depressed, while the upper ones simply abut against and cover the bioherm.

Column Shape and Arrangement: Column shape is highly variable in single bioherms, mainly due to different degrees of coalescing and bridging. The structures vary from laterally linked pseudocolumns with some discrete small cumuli (Fig. 8d) to frequently bridged and coalescing columns (Fig. 9a), to discrete, parallel subcylindrical columns (Figs. 2d, f, g; 8f). The latter chiefly make up Mawson's (1925) collection from Italowie Gorge. In all specimens where columns are reasonably discrete, they are smooth to slightly bumpy, sometimes with pointed terminations (Fig. 2b, j), while others branch into minute columns 1 to 3 mm wide. Columns are commonly less than 1 cm in diameter, but broad, cumulate columns up to 10 cm in diameter have been observed. Transverse sections of columns are round, rounded polygonal or lobate (Fig. 2d, f, g.). Columns may be vertical or radially arranged, especially on the margins of contiguous bioherms. Dolomitization of interspaces frequently obscures the original margins of the minute columns so that their shape cannot be accurately determined.

Branching: Branching is most commonly alpha- or beta-parallel, occasionally gamma-parallel. Columns frequently branch into narrower columns which do not regain the former diameter. Some branches are in the form of thin pointed projections (Fig. 2j). At bioherm margins, branching may remain parallel (Fig. 8c) or become radial (Fig. 8b), but here the stromatolites are largely pseudocolumnar.

Margin Structure: Column margins are rarely preserved intact. Commonly they are corroded by dolomite rhombs, if the interspaces are dolomitized; otherwise very fine stylolites may

be developed. Bridging is extremely common in all specimens except those from Mawson's collection from Italowie Gorge, in which the columns are mostly discrete. These also have the smoothest margins, with only slight, occasional bumps and ribs. Columns are always unwalled, the laminae thinning only slightly near the column margin. Laminae may slightly overhang the margin, but long peaks and cornices are absent.

Lamina Shape: (Fig. 14a) illustrates common lamina shapes; most are gently convex. Of 101 lamina measured, 69% have height to diameter ratios (h/d) between 0.2 and 0.4; only 7% have ratios greater than 0.6 (Fig. 15a). Laminae are smoothly domed, without sharp changes in shape from lamina to lamina. A few of Mawson's specimens from Italowie have wavy laminae, of wave length 3 to 10mm, amplitude 1 to 3 mm (Fig. 10a).

Microstructure: Microstructure in all specimens is regularly, thinly banded, with continuous laminae of uniform thickness across a column width. In most specimens there is little contrast between dark and light laminae, except in the amount of organic pigment. Some specimens, especially from Angepena, have irregularly tubular, sinuous, anastomosing, vermiform sparry patches, 0.05 to 0.1 mm. thick, up to 0.6 mm. long, crossing the dark laminae. Dark laminae, varying in thickness from 0.03 to 0.07 mm, consist of xenotopic calcite of grain size varying from 0.003 to 0.01 mm., stained with grey organic pigment, but in some specimens, subhedral dolomite rhombs of grain size of 0.01 to 0.02 mm are interspersed. Minor subangular quartz silt may be present.

Individual laminae are very continuous, and of constant thickness across the column width, but may be markedly wavy. In specimens with vermiform microstructure, dark laminae are generally thicker, up to 0.3 mm, but remnants of finer lamination are often preserved. The boundaries of the sparry patches are often irregular and their orientation varies from perpendicular to gently inclined to the lamination, but is commonly at a high angle to it. The vermiform microstructure may be consistently developed preferentially on one side of a column. Transverse sections of the tubules are round to elongated, irregularly oriented and anastomosing. The tubules may be interpreted as algal borings in the fine, lime mud laminae, but not the whole sediment was affected, since homogeneous and bored laminae occur side by side. This fact also makes it unlikely that they are casts of actual algal filaments. The distribution of borings on one side of columns may be environmentally determined. Bathurst (1966, p. 20) illustrated a sequence of events involved and in boring by algae; if the process were stopped at stage (2), and the borings infilled with sparry calcite, a structure similar to the vermiform microstructure of A. angepena would result. Light laminae are 0.03 to 0.1 mm thick, frequently indistinct, but continuous across a column width. They are especially poorly differentiated in specimens with vermiform microstructure, where the tubules may pass across the light-dark lamina boundaries. Light laminae consist of xenotopic calcite, often with interlocking crystals 0.015 to 0.03 mm in diameter. Subhedral to euhedral 0.01 mm dolomite rhombs are scattered throughout the light laminae in some specimens.

Interspaces: Interspaces are filled either with altered micrite or fine sandy and silty micrite. Specimens from Italowie (Mawson's collection) have very narrow interspaces filled with sparse, angular quartz silt, supported by a micrite matrix (Fig. 8f), sometimes extensively dolomitized, with inequigranular hypidiotopic dolomite ranging in grain size from 0.005 to 0.1 mm. Extremely finely disseminated haematite may be present in interspaces. Stromatolites from Angepena also have sandy interspaces, but these are more frequently interrupted by bridging laminae. Subangular to subrounded quartz grains vary in diameter from 0.08 to 0.5 mm, and may be partially or wholly replaced by calcite. Ooids and small intraclasts occur very rarely.

Secondary Alteration: Dolomitization is common in all specimens, and is probably of late diagenetic origin. Within columns, rhombs have also formed in the micrite of interspaces, and in places, interspaces may be totally dolomitized. Here sparry calcite occurs as irregular patches between dolomite rhombs perhaps filling a secondary porosity. Grain size and density of dolomite rhombs decreases markedly across the column margins; perhaps interspaces were originally more porous, to cause the preferential dolomitization (in Fig. 8c note the dark calcite columns and the white, dolomitic interspaces). Stylolites may follow column margins, or may be grossly cross-cutting. Haematite dispersed through carbonate is probably secondary. In Italowie specimens, it is concentrated in interspaces which pass into fine stylolites. Minute irregular calcite veins cut the whole rock, apparently predating the major dolomitization. Large patches of coarsely sparry calcite are bounded by

markedly lobate fine stylolites, suggesting their origin as solution cavities.

Comparisons:

In gross morphology (mode of occurrence, column shape, branching and margin structure) the stromatolites from Italowie are similar to Acaciella Walter. Columns are less discrete in other areas, due to frequent bridging and coalescing, but their columnar portions are similar to those of Italowie specimens. Microstructures are uniform, except for the local vermiform structure interpreted as algal boring. Madiganites mawsoni Walter, from the Middle Cambrian Jay Creek Limestone of the Amadeus Basin, also has vermiform microstructure, but here the tubules are more consistently developed, and are complexly intertwined, the intervening micritic areas being reduced to clots. The gross form of Madiganites mawsoni is similar to some Acaciella angepena in having numerous irregular frequently bridged columns and pseudocolumns; however, it lacks the subcylindrical parallel branching discrete columns found at Italowie. Acaciella angepena resembles Vetella uschbasica Krylov in having evenly banded lamination and wide columns branching into narrow columns, but has ragged column margins and lacks the wall of V. uschbasica. Illicta composita Sidorov is similar in also possessing vermiform microstructure, but is distinguished by its very smooth, walled columns. At this stage it is difficult to be certain of the content of the form Acaciella angepena. Despite some variation of column shape (specimens from Italowie have predominantly subcylindrical, discrete columns, while those from Angepena have numerous bridges and less regular column margins), all the specimens studied are included in the one form,

since these column morphologies intergrade and the microstructures remain constant. The stromatolites are assigned to the group Acaciella on the basis of gross morphology. They are differentiated from other forms of the group by their thin, continuously banded microstructures and by the frequent development of bridges and pseudocolumns. The very narrow, minute columns into which broader columns branch are absent in other forms.

A ferruginous specimen from Old Wirrealpa is problematical. Its dark laminae are strongly haematitic, the haematite being in part distributed into minute dendrites. The small columns branch from basal cumuli, the interspaces being filled with recrystallized biomicrite (hyolithids, sponge spicules, and archaeocyathan and brachiopod fragments may be recognized). Although the gross morphology resembles that of Acaciella angepena (Fig. 2 h), the extremely regular lamination is atypical of stromatolites, and an inorganic origin for the structure cannot be excluded.

Distribution: Widespread in the dark limestones of the Lower Cambrian at Angepena, Old Wirrealpa, near Point Well, at Mern Merna, Beltana Hill, Chace Range, near Narina H.S., Moro Springs south of Balcanoona, and 3 miles west of Italowie Gorge; Flinders Ranges, South Australia. (COPLEY and PARACHILNA map sheets, 1:250,000).

Age: Early Cambrian.

Acaciella augusta f. nov.

Figs. 3a to m, 9d to f, 10.

Material: Thirteen specimens from two localities plus eight specimens of uncertain identification from a

further two localities.

Holotype: S401 (Figs. 3c, e; 10c), Brighton Limestone equivalent, Depot Creek, Southern Flinders Ranges.

Name: After the city of Port August, 20 miles (32km) south of the type occurrence.

Diagnosis: Acaciella with extremely frequent coalescing and bridging of columns at all levels, and with broad and narrow columns closely associated. Column margins bear short ribs, low bumps and short cornices. Laminae are gently to moderately steeply convex or rectangular, and of distinct, regularly streaky microstructure.

Description:

Mode of Occurrence: The stromatolites form lenticular and tonguing bichermes (Fig. 10a) varying in thickness from 3m to 50m, and extending laterally for up to nearly 2km, intercalated at varying stratigraphic levels within the Brighton Limestone equivalent. Most commonly growth commences on a substrate of ooid and intraclast grainstones, as laterally linked stromatolites, up to 3m thick; these gradually develop interspaces to form broad, bridging and coalescing columns (Fig. 9d). At various levels, these columns branch into narrower columns 1 to 3cm wide, frequently with parallel basal and slightly divergent upper branches (Fig. 10c). Occasionally, narrow columns arise directly from an undulatory or flatlaminated base (Fig. 9f). Columns repeatedly alternate with continuous undulatory or flat laminated stromatolites, which commonly

intertongue with the adjacent sediment; they apparently mark periods of reduced influx of coarse sediment. At bioherm margins, columns become slightly inclined. Rarely, there are hemispherical bioherms with columns strongly inclined at their margins.

Column Shape and Arrangement: Basal columns are up to 20cm wide, of irregular shape, with frequent coalescing and bridging. Their margins are frequently inclined, although laminae remain subhorizontal. The narrow columns are 1 to 3 cm wide, and up to 10cm long between branches (Figs. 3a to j; 10b to d). Transverse sections are round, rounded polygonal, elongated, or complexly lobate. At least some of the elongation is of tectonic origin. Columns are straight or gently curved, with slight swellings and constrictions (Fig. 3a to j); a few are short and narrow, and terminate their growth after a few centimetres (Fig. 3e). Coalescing is so frequent that almost all columns are interconnected; one specimen contains numerous irregular, short, frequently bridged and coalescing columns.

Branching: Branching is frequent at all levels, and generally multiple (Fig. 3a to j). Broad basal columns divide by alpha parallel branching into narrower columns, which frequently branch again at intervals of less than 10 cm; this branching is usually alpha- or beta-parallel, occasionally gamma-parallel, or slightly divergent (Fig. 3c,d, e & g). Near points of coalescing, branching tends to be more irregular; gamma-parallel or divergently branched columns approach each other and coalesce (fig. 3d).

Margin Structure: The lateral surfaces of all columns bear relatively low bumps, short discontinuous ribs, and a few peaks and cornices (Fig. 3 a to j). In places, bridges, varying from

delicate bridges only one or two laminae thick to massive, thick bridges (Fig. 3g), are very frequent; in other places, columns remain relatively unaffected by bridging throughout most of their length. Columns are unwalled, and between bridges and cornices their margins are relatively smooth. Depending on the degree of convexity, laminae approach the margin at various angles.

Lamina Shape: Lamina shape varies according to column diameter; narrow columns have moderately convex, or sometimes steeply convex laminae, h/d greater than 0.6 being rare. Broad columns have very gently convex to rectangular laminae (Fig. 14b). Of all laminae measured, 70% have h/d between 0.2 and 0.6 (Fig. 15b). Laminae are most frequently smooth, but sometimes broadly wavy, especially before branching. Laminae frequently become doubly-crested before branching (Fig. 10b, c & d), but the interspace so formed may be bridged over, in which case the column resumes its former growth pattern.

Microstructure: In the best preserved specimens, distinct, regular light and dark (green) laminae, and in places macrolaminae up to 4 mm thick, alternate, forming a regular streaky microstructure (Fig. 10c). Dark laminae, varying in thickness from 0.05 mm to 2 mm, are smooth to gently wavy, occasionally wrinkled, and have parallel upper and lower boundaries. Single laminae have relatively constant thickness across the column width, but frequently lens out. They consist chiefly of hypidiotopic to idiotopic dolomite, of grain size ranging from 0.005 to 0.02 mm. The crystals are equidimensional, commonly euhedral, and stained pale green, which gives the laminae their colour. Dolomite crystals are densely packed in the dark laminae, leaving only occasional irregular

undolomitized patches, consisting of xenotopic calcite, ranging in grain size from 0.003 to 0.01 mm. Light laminae vary in thickness from 0.07 to 2 mm, single laminae having constant thickness. They are sparsely dolomitized, and consist of xenotopic to hypidiotopic calcite, varying from 0.01 to 0.02 mm in grain size, with scattered euhedral dolomite rhombs, 0.005 to 0.04 mm long. Laminae are frequently grouped into broad macrolaminae, up to 4 mm thick, in which very thin, lenticular, either light or dark laminae predominate. In places, laminae are slightly wrinkled, or draped over underlying irregularities; in one case a lamina is domed over a sparry calcite nodule, which may be an open space filling (Fig. 9e). In a few places small scour structures up to 2 mm deep are cut into the tops of dark laminae. Occasional euhedral to subhedral reddish brown limonite grains of 0.01 to 0.02 mm diameter (possible pseudomorphs after pyrite) occur in both lamina types.

Interspaces: The distance between columns varies from 1 to 10 mm. Interspaces are filled with banded limestone, layers of micrite 1 to 6 mm thick alternating with thicker intervals of partially dolomitized intramicrite. Laminae in the interspace commonly abut against the column margins, having accumulated after the growth of that part of the column (Fig. 10c). The micrite laminae, consisting of xenotopic calcite of grain size varying from 0.003 to 0.01 mm, are frequently silty, and slightly graded, generally with sharp upper boundaries, and are overlain by matrix-supported intra-micrites and some oomicrites. This sediment may have been more porous, as it is extensively dolomitized; the dolomite is of similar texture to that in columns. All remnant calcite is recrystallized to a hypidiotopic sparry mosaic; no micrite matrix

remains. Alternatively, this calcite may represent infilling of voids left by dolomitization. Intraclasts, which may be preserved as undolomitized micrite, or entirely idiotopic dolomite, are from 1 to 10 mm long, and up to 1 mm thick, and may represent eroded fragments of algal mat. Strongly recrystallized dolomitized oolites are occasionally present. Intraclasts, which commonly lie at a high angle to the bedding, may have fine grained laminae draped over them. Coarse sediment influx was periodic; columns may have had up to 2 cm of relief over the interspace sediment or a bridge, then the interspaces were filled rapidly with intraclasts and finer calcareous sediment. During periods of relative quiescence, lime mud accumulated to form thin layers. In some specimens, bridging is very frequent, so that there never was more than about a centimetre of relief.

Secondary Alteration: Little is preserved of the primary difference between the light and the dark (green) laminae, which now differ in the extent of dolomitization. The dolomite is equigranular, idiotopic, and probably secondary, although a detrital origin cannot be ruled out. If the dolomite originated by replacement of calcite, the preferential dolomitization of dark laminae may indicate that they were originally more porous. Small irregular patches of coarsely crystalline sparry calcite within both columns and interspaces post-date dolomitization, and are associated with fine calcite veins. Stylolites are very rare, being restricted to a few which are concordant with the lamination or column margins. The green staining of dolomite crystals oxidizes under subaerial weathering to form finely disseminated limonite, which may be concentrated along column margins or stylolites. Columns are

commonly slightly flattened parallel to an axial plane cleavage, which is better developed south of Depot Creek and at Mundallio Creek. The cleavage is an irregular fracture which passes around, not through stromatolite columns and is commonly expressed as stylolites in the carbonate rocks. A specimen from Mundallio Creek contains light laminae with prominent radiating structures; these consist of dolomite crystals aligned in rows almost perpendicular to the lamination (Fig. 10d), and may represent a dolomitized, earlier acicular texture. In specimens from the Wundowie Limestone (Wundowie Bore and Copley), column margins have been almost completely removed by stylolites, leading to uncertainty of identification (Fig. 3k, l & m).

Comparisons:

The predominantly parallel branching (alpha-parallel at base, then beta - or rarely gamma-parallel) and almost total absence of a wall, identify the stromatolites as Acaciella.

Acaciella augusta is distinguished from A. australica by the rarity of discrete broad basal columns, by its mode of occurrence (lenticular and tonguing bioherms instead of tabular and domed biostromes), by its extremely frequent coalescing and bridging, and by its very distinct microstructure. The mode of occurrence and microstructure also distinguish it from A. angepna: A. augusta has many wavy, sometimes lenticular laminae, and prominent macrolaminae, the dark laminae being preferentially dolomitized; A. augusta is very similar to Eucapsiphora paradisa Cloud & Semikhatov; from the Paradise Creek Formation near Mt. Isa, N.W. Queensland. E. paradisa is difficult to distinguish on the basis of the published description, but apparently has a patchy wall.

Specimens of poorly preserved stromatolites from the Wundowie Limestone near Copley and Wundowie Bore, originally tentatively identified as Linella munyallina (Preiss, 1970) are better assigned to Acaciella augusta on the basis of column shape, branching and microstructure. Where column margins are not removed by stylolites, they are unwalled.

Distribution: Brighton Limestone, Depot Creek and Mundallio Creek, Southern Flinders Ranges, and possibly the Wundowie Limestone near Copley and Wundowie Bore, Northern Flinders Ranges (PORT AUGUSTA and COPLEY map sheets, 1:250,000).

Age: Late Adelaidean, correlated with the Late Riphean of the USSR.

Acaciella form indet.

Figs. 3n, o, p & q; 9b & c.

Material: Two specimens from one locality

Description:

Mode of Occurrence: Both stromatolite specimens are erratic boulders in the lower (Sturtian) glacials; their provenance is unknown.

Column Shape and Arrangement: One specimen (S509), consists of pseudocolumns and frequently bridged columns, oriented subparallel to slightly radiating, and passing laterally into flat-laminated stromatolites (Fig. 9c). The other specimen (S539) consists of rather smooth, erect, parallel, cylindrical, discrete columns, 1 to 5 cm wide. Transverse sections are round or rounded polygonal (Fig. 3n, o, p).

Branching: Branching is commonly alpha or beta-parallel; columns either retain their width or widen gradually before branching. Axes of branching columns may be very slightly divergent (Fig. 9b). Specimen S539 shows only dichotomous branching, but S509 has some multiple, alpha-parallel.

Margin Structure: S539 has a rather smooth margin structure, with low bumps and a few very short peaks and overhanging laminae (Fig. 3n,o,p). There is no wall; laminae simply terminate, without appreciable thinning, at the column margins. Bridges are extremely frequent in S509, but otherwise column margins are similar to S539. Few columns in S509 are entirely discrete.

Lamina Shape: All laminae are gently convex (Fig. 14C), h/d never exceeding 0.5, and 84% of laminae measured have h/d between 0.2 and 0.4 (Fig. 15c). Laminae are smoothly curved, rarely rectangular, and without wrinkles or sharp flexures. Occasionally laminae are slightly wavy, and before branching always develop multiple crests (Fig. 9b & c). Laminae are not normally deflexed at the column margins.

Microstructure: Microstructure consists of very smooth or broadly wavy light and dark dolomitic striated to banded laminae. There is little contrast between laminae. Dark laminae are 0.05 to 0.5 mm thick, and commonly pinch and swell slightly across the column, and in places they are lenticular, but otherwise, they have smooth, parallel boundaries. They consist of pale grey stained hypidiotopic to idiotopic dolomite of grain size varying from 0.003 to 0.015 mm. Light laminae vary in thickness from 0.05 to 1.0 mm, generally with little change across a column, thinning

only slightly towards column margins. They consist of hypidiotopic to idiotopic transparent, unstained dolomite of grain size varying from 0.015 to 0.06mm. Very characteristic of S539 is the presence of very fine, limonite-rich solution surfaces, concordant with the laminae. Although these are probably stylolites, surfaces with little or no wrinkling, which follow the fine-scale structure of laminae exactly are especially common (Fig. 9b). In places these are only about 0.5mm. apart, and light laminae may be separated by them, without intervening dark laminae.

Interspaces: Interspace sediment is completely dolomitized, consisting of equigranular, idiotopic dolomite of grain size ranging from 0.01 to 0.05mm. There is little contrast between columns and interspaces, but small amounts of subangular quartz silt are present in the interspaces. Fragments of slightly darker stained dolomite, of similar texture to the matrix, probably represent original intraclasts. The nature of the matrix cannot be determined, but the sparsity of intraclasts suggests that these were mud supported. Intraclasts are better preserved in S509.

Secondary Alteration: Dolomitization of the stromatolites and interspaces is clearly secondary, as indicated by the general idiotopic, equigranular texture, and poor preservation of the finest structures. Stylolites are of at least two generations; the earliest stylolites are almost perfectly concordant, without lobes or wrinkles; these possibly predate the dolomite euhedra, which in places cut into them, and certainly predate a relatively coarse grained dolomite vein (grain size up to 0.1mm). The vein

is itself cut by more pronounced, slightly discordant stylolites.

Occasional cross-cutting stylolites cut interspaces and columns, some following column margins. Dolomitization almost certainly predates the erosion and deposition of the clasts into the glacial sediments.

Comparisons:

The straight, chiefly alpha- to beta-parallel branching unwalled columns allow assignment to the group Acaciella. They are clearly distinguished from Acaciella augusta by the discrete, rather smooth, more cylindrical columns; although bridging and coalescing occur in S509, this specimen is considered to represent the basal part of stromatolite bed. The distinct, subcylindrical columns with relatively smooth margins and gently convex laminae are similar to A. australica Walter, but the specimens are inadequate for identification.

Distribution: As clasts in the lower (Sturtian) glacials, on the flanks of Enorama Diapir, 4 miles North of Oraparinna H.S., Central Flinders Ranges (PARACHILNA map sheet, 1:250,000).

Age: Probably Adelaidean, but not younger than the Sturtian glacials.

GROUP BAICALIA Krylov, 1963.

Collenia baicalica Maslov (1937, p. 287).

Baicalia Krylov (1963, p.64).

Baicalia (Semikhatov, 1962, p. 198).

Baicalia (Komar, 1966, p.82).

Baicalia (Krylov, 1967, p.25).

Baicalia (Nuzhnov, 1967, p.135)

Baicalia (Cloud & Semikhatov, 1969, p.1035).

Type Form: Baicalia baicalica (Maslov) Krylov, from the
Uluntuy Suite of the Pribaikalye.

Diagnosis: Tuberos, bumpy, swelling and constricting,
parallel to markedly divergent branching columns, generally with-
out wall, with frequent overhanging laminae. Lamination is
distinctly banded.

Content: B. baicalica (Maslov) Krylov, B. kirgisica Krylov,
B. rara Semikhatov, B. unca Semikhatov, B. prima Semikhatov
B. ampla Semikhatov, B. ingilensis Nuzhnov, B. aimica
Nuzhnov,
B. minuta Komar, B. capricornia Walter and B. burra f. nov,

Age: Middle Riphean to early Late Riphean

Baicalia burra f. nov.

Figs. 4,5,6,11, 12, 13a to C.

Baicalia spp. Glaessner, Preiss and Walter (1969, p.1056).

Material: Thirty-three specimens from ten localities.

Holotype: S222 (Figs. 11a & d), Skillogelee Dolomite, 2
miles (3.2km) west of Yatina, Southern Flinders Ranges.

Name: From the Burra Group in which the stromatolites occur.

Diagnosis: Baicalia with moderately frequent, slightly to
markedly divergent branching, irregular, coalescing columns with
highly variable lamina shape and continuous, distinctly banded
microstructure.

Description: Mode of Occurrence: Two modes of occurrences
have been noted; biostromal and biohermal, the latter occurring
only at one locality (Yatina). Biostromes vary in thickness from
0.3 to 2m, the stromatolites being evenly distributed throughout

their extent, they have been followed for 100m or more, without lensing, before they disappear under soil cover. Biostromes are frequently interbedded in green shales (e.g. Myrtle Springs, Willouran Ranges), platy dolomites (e.g. Arkaroola, Worumba) or massive dolomites (e.g. Burra). The bioherms at Yatina are restricted to two thin beds; they are small lenticular stromatolitic mounds, approximately 20 to 30 cm thick, up to 1m wide (Fig. 11a), interbedded with and surrounded laterally by platy and shaly dark grey dolomites. The overlying sediment is draped over the mounds, showing that the stromatolites had at least 10 cm relief over the surrounding surface. Columns arise from substrates in several ways: (1) Flat-laminated stromatolite passes gradually up into undulatory and pseudocolumnar stromatolites, then into discrete, vertical to inclined columns, often with steeply domed laminae, e.g. Burra, West Mount Hut; (2) Columns arise directly from eroded surfaces of laminated or intraclastic dolomites (e.g. Yatina, Fig. 4a); (3) Columns arise from flat-laminated stromatolite via broad cumuli, e.g. West Mount Hut. The degree of discreteness of columns varies greatly; in some beds, columns are almost immediately bridged over by laterally linked stromatolites, but usually columns remain discrete for 20 to 30 cm. In some areas new sets of columns may arise from pseudocolumns. The upper surfaces of biostromes vary from flat (e.g. in the Willouran Ranges, Burra) to broadly undulating (e.g. Worumba).

Column Shape and Arrangement: Columns are tuberous, varying from subcylindrical to irregular, with round, oval and irregular cross sections (Figs. 4,5,6). Elongated or flattened

columns are variously oriented. The diameter of columns varies from 1 cm to 10 cm, most commonly 3 to 5 cm, with rapid swellings and constrictions. Columns are 2 to 15 cm high between branches. Some but not all columns are constricted at the point of branching (Figs. 4c, f; 5c, d). The orientation of columns varies greatly from vertical to inclined, and is sometimes sub-horizontal for short distances (Figs. 4c, 5j) Column axes vary from straight to strongly curved. In some specimens, the uppermost columns swell markedly upwards and become bridged over by laterally linked stromatolites. Adjoining columns coalesce very frequently, even in the discrete portions, but specimens from Burra show the least coalescing and bridging. In the Willouran Ranges, column growth is frequently interrupted by penecontemporaneous erosion; columns may grow over broken-off fragments of earlier columns, contributing to the irregularity of the structure.

Branching: The most common form of branching is moderately divergent (Fig. 4a, i, 6f) though some sub-parallel branching (Fig. 4e, g, m) and some very markedly divergent branching occurs (Figs. 4a, 5d & j). In some specimens several branches arise from nearly one point (Fig. 4a). Branching is moderately frequent, the length of column between branches commonly being only a few centimetres; but at any one point of branching it is usually dichotomous or less often trichotomous. In some specimens branches arise at a high angle to the main columns, and then turn sharply upwards. Some columns arise from the side of a main column (Fig. 12d). Great variation is seen even in single outcrops.

Margin Structure: The lateral surface varies from smooth to very irregular, laminae approaching the column margins at various

angles. Some specimens have very patchy walls, while the intervening unwallled areas are smooth or only slightly fringed with small peaks and cornices, for example those from Burra (Fig. 12d) Yatina (Fig. 4a), River Broughton (Fig. 5c), Arkaroola (Fig. 5 d,e). Willouran Ranges specimens contain both smooth and highly irregular edges, with large overhanging peaks composed of one or more laminae (Fig. 6b & c). Frequently large swellings are composed of numerous laminae overhanging over a constricted portion of a column (Fig. 4c). Bridges between columns are especially common near the tops and bottoms of biostromes (Fig. 6e).

Lamina Shape: The lamina shape is most commonly gently convex, but varies in single specimens from very gently convex to nearly conical; many laminae are steeply convex. Micro-unconformities are especially prominent in specimens from the Willouran Ranges, but occur to some extent in all areas. In places, branching commences upon a partly eroded column surface, (Fig. 13b). Fig. 14d illustrates the more commonly occurring lamina shapes; 92% of lamina have h/d between 0.1 and 0.6, the mode being h/d between 0.3 and 0.4 (28%) (Fig. 15d). Generally, the widest columns have the most gently convex laminae, while strongly elongated columns have laminae gently convex in the section parallel to the long axis, and steeply convex at right angles to it. Rarely do laminae turn over sharply and thin at the column margins, to form a wall. Generally, where a patchy wall is present, it is formed by the edges of steeply convex or parabolic laminae (Fig. 12c). Frequently, laminae develop two crests, anticipating-branching immediately above (Fig. 4 a, m). On a smaller scale, lamina shape varies from smooth

and regularly curved to slightly wavy, with discontinuous curvature and sharp crests. Both types occur in single specimens (Fig. 12).

Microstructure: The microstructures and textures observed in the different areas vary considerably depending on the degree of recrystallization. In the best preserved specimens, the layering comprises alternating relatively thick, continuous very distinct light and dark laminae, giving a banded appearance. Some are single homogeneous thick layers, while others are macrolaminae consisting of several very thin light-dark lamination pairs. Most commonly single laminae traverse the whole column width, except where cut by micro-unconformities. Ooids or other detrital grains may be included in the laminae. Upper and lower boundaries of laminae are usually smooth and even, sometimes wavy or broadly wrinkled, but always more or less parallel. Exceptions occur only where erosional scour has taken place during growth. Rarely, lenticular swellings occur. Light laminae vary in thickness from 0.02 to 0.5 mm, very rarely to 1.0 mm. Most light laminae thin towards the column edges, but rarely lens out. In the best preserved specimens the sparry dolomite forming them is inequigranular, xenotopic, and of grain size ranging from 0.005 to 0.06 mm. With greater recrystallization an equigranular mosaic of 0.05 to 0.2mm grain size results (e.g. Burra). The light laminae usually have sharp and smooth upper boundaries, but sometimes grade down into grumous textured laminae, consisting of irregular and interconnected micritic patches up to 0.1mm diameter, set in xenotopic equidimensional sparry dolomite with a grain size of about 0.01 to 0.03 mm, i.e. partially recrystallized dark laminae. In some specimens, e.g. Yatina, West Mount Hut,

Worumba, the light laminae contain detrital granules, including small flat intraclasts, up to 0.5mm long, and rare ooids up to 0.3 mm in diameter. Overlying laminae are draped over the larger detrital grains. Laminae in the Copley specimen may be pelletal (Fig. 12e). Dark laminae occur either singly, alternating with light laminae, or in dark macrolaminae. Thin dark laminae are commonly 0.04 to 0.3 mm thick, but macrolaminae range up to 2.5 mm in thickness, generally constant across the column, or thinning slightly towards the margins. They are either continuous, or consist of a series of aligned lenses, each up to 0.2 mm long. In well preserved specimens the dark laminae have smooth, sharp, parallel boundaries; rarely, single laminae may be wrinkled, suggesting intraformational crumpling during growth. Well preserved dark laminae consist of dense, brownish-pigmented xenotopic dolomite, of equidimensional grains 0.003 to 0.01 mm in diameter, but vertical and lateral gradations from unaltered to grumous textures are common. Where dark laminae are grouped into macrolaminae, they alternate with very thin, discontinuous light laminae, and frequently fuse to form solid, thick dark laminae.

Interspaces: A few specimens have interspaces filled predominantly with bedded dolomite mud (e.g. Burra), but generally the sediment is unbedded intrasparite or oosparite, less commonly intramicrite. Frequently, intraclasts are derived from the erosion of stromatolitic columns: in places, a large fragment torn from a column has acted as a base for new growth. Intraclasts are flat to gently curved tabular dolomite pebbles up to 3 cm long, 1 to 2 mm thick, and only slightly rounded. Many are fragile and could have survived very little transport. They contain the typical internal

laminations of the associated stromatolites, and are probably derived directly from them. Occasional flat pebbles stand vertically, but generally they lie flat or imbricated. Ooids vary in shape from round to oval, have a diameter of 0.2 to 1.0 mm, and consist of one dark - rimmed sparry layer coating a micritic core, or less commonly, several sparry layers. Most commonly, allochems are closely packed and cemented by a clear, sparry dolomite cement. Some specimens contain significant amounts of dolomitic mud, variously recrystallized, forming a matrix between allochems; in these cases the sediment is poorly laminated.

Secondary Alteration: Secondary alteration has extensively modified the textures and often the microstructures of stromatolites from many areas. The following four stages of alteration may be recognized:

(1) Penecontemporaneous. The fact that dolomite consistently constitutes the whole rock to the exclusion of calcite, while still preserving fine structures, suggests very early dolomitization, during the growth of the stromatolites. It is also possible that penecontemporaneously dolomitized lime muds were reworked and trapped in the algal mats. During growth, erosion by strong currents scoured the living surfaces of columns, creating micro-unconformities. In some specimens, e.g. West Mount Hut, laminae may be separated by lenticular vughs, later filled with sparry dolomite (Fig. 12c). These voids were probably formed by arching up of laminae, perhaps due to lateral expansion in growth of the algal mats building the stromatolites.

(2) Early Diagenetic. Black chert very commonly replaces portions of stromatolites and interspace sediments. Sometimes dark laminae are preferentially silicified, perhaps during growth, but more commonly, silicification post-dates the growth of the columns (e.g. one side of a column may be replaced). In places, silicified laminae are broken by minute dolomite filled cracks.

(3) Late Diagenetic. Dark laminae and macrolaminae may be recrystallized to grumous textures, consisting of patches of dark, dense micritic dolomite (remnants of the original carbonate) varying greatly in size from 0.005 to 0.1 mm, set in a matrix of xenotopic sparry dolomite, of equidimensional grains ranging in size from 0.01 to 0.03 mm. Light laminae are commonly slightly recrystallized and sparry, consisting of hypidiotopic to idiotopic, equidimensional dolomite grains of similar size to those of the sparry matrix of the grumous textures. Coarsely recrystallized laminae also occur, in places cutting across the fine structure of primary laminae and corroding their boundaries. They consist of idiotopic transparent dolomite of grain size up to 0.1 mm.

(4) Tectonic. The only specimens affected by tectonic deformation are from the Burra region. Here columns are slightly flattened and laminae are crenulated along a slight tectonic foliation. These are also the most highly metamorphosed, displaying the greatest degree of recrystallization. Tensional joints filled with coarsely crystalline dolomite are common in most areas.

Comparisons:

The stromatolites are assigned to the group Baicalia on the basis of their tuberous, swelling and constricting, bumpy, variously oriented columns, general absence of wall, numerous

overhanging peaks and short cornices, and generally divergent branching. Some specimens have horizontal columns for short distances resembling Tungussia, but are distinguished by the absence of the multiple horizontal branching characteristic of Tungussia, and by their generally more ragged column margins. Baicalia burra is distinguished from B. prima Semikhatov, B. aimica Nuzhnov and B. capricornia Walter, by their frequently divergent branching and general complexity of columns, and from B. minuta Komar by the larger size and more complex structure. Some specimens resemble B. baicalia (Maslov) Krylov, but most have more inclined and irregular columns. B. lacera, B. rara, B. ampla and B. unca Semikhatov are not adequately illustrated for reliable comparison, and the illustrated microstructures are badly altered; single specimens of B. burra may show microstructures similar to B. unca, B. lacera, and especially the pelletal laminae of B. rara. Some specimens have long overhanging peaks and thus resemble B. ingilensis Nuzhnov, but are distinguished by more frequent and divergent branching. B. burra most closely resembles B. rara Semikhatov and B. maica Nuzhnov; it is distinguished from B. rara in that neither pelletal laminae nor knee-shaped bends in columns are consistently developed, and from B. maica by its more irregular and coalescing columns, and its more continuous laminae.

Distribution: Widespread in the Skillogalee Dolomite, Burra Group: Dutton's Trough H.S., 10 miles (16 km) south of Burra; Scrubby Range, 17 miles (27 km) south of Burra; 2 miles (3 km) west of Yatina; River Broughton, 5 miles (8 km) west of Spalding; 7 miles (11 km) south-west of Worumba; 7 miles (11 km) south of Arkaroola; 2 miles

(3km) west of Copley; 2 miles (3km) east of Myrtle Springs H.S. near Leigh Creek; West Mount Hut, 17 miles (27km) west of Witchelina H.S. and Chintapanna Well, about 10 miles west of Witchelina H.S. Possible B. burra occurs also in the Skillogalee Dolomite, Depot Creek, but these have not been studied in detail. Specimens from the River Wakefield Group, Carrieton (Fig.13c) are inadequate for identification, but are possibly to be included (BURRA, ORROROO, PARACHILNA, COPLEY, ANDAMOOKA and CURDIMURKA map sheets, 1:250,000).

Age: Early Adelaidean, correlated with the youngest Middle Riphean of the USSR.

GROUP BOXONIA Korolyuk, 1960.

Boxonia Korolyuk (1960, p.139).

Boxonia (Komar, 1966, p.79)

Boxonia (Cloud & Semikhatov, 1969, p.1036)

Boxonia (Glaessner, Preiss & Walter, 1969, p.1056)

Type Form: Boxonia gracilis Korolyuk, from the Bokson Suite, Eastern Sayan.

Diagnosis: Straight, subcylindrical columns with moderately frequent alpha--to beta-parallel branching and smooth, walled margin structure.

Content: B. gracilis Korolyuk, B. lissa Komar B. krasivica Golovanov, B. allahjunica Komar & Semikhatov, B. ingilica Komar & Semikhatov, B. bianca Raaben and B. pertaknurra Walter. Raaben (1969a) places B. grumulosa Komar into partial synonymy with B. gracilis Korolyuk. B. diverata Sidorov has only a patchy wall and may

therefore be excluded.

The South Australian form is Boxonia melrosa.

Age: Late Riphean and Vendian.

Boxonia melrosa f. nov.

Figs. 7a to h, 13d, e and f.

Material: Four specimens from one locality

Holotype: S 503 (Figs. 7b, c & d; 13e) 1 mile (1.6km) west of Melrose township, Southern Flinders Ranges.

Name: After the type locality.

Diagnosis: Boxonia with long, narrow, closely spaced columns, alpha - and beta - parallel branching, without very broad basal columns, with occasional rounded projections, and with indistinctly banded moderately convex laminae lacking pelletal microstructure.

Description:

Mode of Occurrence: The stromatolites are relatively poorly exposed in a faulted area, so that relationships are not clear. At least two bioherms occur, preserved as grey or pale buff dolomite. The beds are overturned, dipping south at about 40°. The narrow, parallel columns arise directly from laterally linked stromatolites, partly pseudocolumnar, the base of which is not exposed. The overlying columnar portion is approximately 6 metres thick and consists of vertical columns near the centre of the bioherm, and inclined columns at the margins, where they pass laterally into pseudocolumnar stromatolites. Columns are overlain by wavy laminated

stromatolites, which cover the whole bioherm. Bioherms are of cumulate shape, broadly domed, up to 60 metres long, and are surrounded by flat-bedded dolomite.

Column Shape and Arrangement: Columns are straight, erect, subcylindrical, smooth to gently bumpy, with circular or slightly lobate, rounded polygonal cross-sections, of diameter 1 to 5 cm. (Fig. 7a to h). The diameter of a single column generally remains constant throughout its length. Columns may reach a length of up to 20 cm between branches, but some columns are only a few centimetres high, occasionally in the form of rounded projections.

Branching: Branching varies from alpha to beta-parallel: gamma-parallel branching is rare (Fig. 7h). Commonly a 3 to 5 cm column divides into two or three narrower, parallel, very closely spaced columns, 1 to 2 cm in diameter (Fig. 7c,d,f). Occasionally, two narrow columns may coalesce (Fig. 7c). Not all branches develop into long columns; some terminate their growth only a few centimetres above branching (Fig. 7d).

Margin Structure: The lateral surface is even, smooth or with low, broad bumps, up to several centimetres wide, with a relief of 1 to 5 mm. Peaks and cornices are entirely absent, but very rarely bridges up to 1 cm thick occur between adjacent columns. A multi-laminate wall is almost ubiquitous. At the margins of columns laminae are poorly preserved, but in places up to 10 laminae may be seen to comprise the wall. Single laminae generally extend for a distance of 1 to 2 cm down the column margin (Figs. 13d, e & f).

Laminae Shape: Laminae are most commonly moderately convex, hemispherical, in places approaching rectangular (Fig. 14e).

Frequently they are slightly asymmetrical, especially in inclined columns. Before branching, laminae usually develop two crests. The degree of convexity, h/d , is moderately constant, even in columns of differing widths. 91% of laminae measure have h/d between 0.3 and 0.7, the mode (39%) being between 0.5 and 0.6 (Fig. 15e). The shape of crests varies from tightly arcuate to gently rounded (Fig. 14e). Most laminae are broadly wavy (wavelength up to 8 mm, amplitude 1 to 2 mm) but not wrinkled.

Microstructure: Microstructure is poorly preserved in both pale and dark specimens; laminae are broadly continuous, with smooth, parallel upper and lower boundaries, but may be broken into a series of clots and lenses by recrystallization, and even where their continuity is preserved, they are extensively embayed by recrystallized carbonate. Microstructure is indistinctly banded with alternating darker and lighter laminae. Light laminae vary in thickness from 0.08 to 0.4 mm, but usually thin towards column margins. Continuity is usually retained across a column, although the finest laminae frequently lose their identity by recrystallization. The laminae consist of transparent, slightly inequigranular (of grain size 0.01 to 0.04mm) equidimensional dolomite of polygonal, hypidotopic texture. Within this occur irregular 0.05 to 0.1 mm segregations of darker, greyish pigment, with no relation to grain boundaries. These are apparently remnants of pigment left by partial recrystallization, as they may grade into more or less continuous laminae. Distinct round to oval pellets (as in Russian Boxonia) are absent. Dark laminae are less continuous, and often diffuse. Their thickness varies from 0.08 to 0.3 mm; towards the margins they frequently thin or lens out completely, and do not take part in the formation of the wall. (The layering

in the wall is extremely indistinct). In places, they lens out also within the central part of a column. Dark laminae are composed of equidimensional xenotopic, equigranular dolomite (of grain size ranging from 0.003 to 0.01mm), and in places, are disrupted into a series of irregular clots and lenses separated by sparry dolomite.

Interspaces: Interspaces between columns are extremely narrow (usually less than 5 mm), and are filled with partially recrystallized dolomite mud, now largely of finely grumous texture, containing in places, round or ovoid clastic pellets, ranging in diameter from 0.2 to 0.7 mm. Much of the sediment is vaguely laminated, the laminae abutting against the walls of columns, which they post-date.

Secondary Alteration: Stromatolite columns and interspaces consist of dolomite, considered to result from the replacement of original calcium carbonate. Most fine structure has been lost; dark laminae are outlined mainly by segregations of dark pigmented dolomite, but recrystallization has partly embayed and partly obliterated the fine dark laminae. The irregular distribution of pigment is due to recrystallization. In places, coarser, sparry laminae of grain size up to 0.08mm occur, and may contain dismembered remnants of dark laminae. Stylolites are moderately frequent, and usually discordant to the lamination. In places they follow column margins for short distances, removing the wall. Occasional thin dolomite veins follow the path of stylolites. Some stylolites are parallel to overall bedding, and displace column axes slightly (Fig. 7e)

Comparisons: The stromatolites are assigned to the group Boxonia on the basis of their long, smooth walled columns with

moderately frequent alpha - and beta - parallel branching. Katavia Krylov and Acaciella Walter have similar gross structure; Katavia is distinguished by its very prominent bumps, while Acaciella generally lacks a wall. Minjaria Krylov also has parallel straight columns but is distinguished by its less frequent branching. Most other described forms of Boxonia have well defined pelletal microstructures; forms are largely distinguished on the basis of the size of the pellets. A specimen of B. gracilis sent by M.A. Semikhatov and I.N. Krylov, has pellets consisting of rounded carbonate grains with dark, fine-grained rims. These are absent in B. melrosa, which also has less wrinkled laminae. B. melrosa is distinguished from B. ingilica Komar & Semikhatov by its ubiquitous wall and straight columns: B. allahjunica Komar & Semikhatov apparently has some complex branching. B. lissa, Komar, B. gracilis Korolyuk, B. grumulosa Komar, B. bianca Raaben and B. krasivica Golovanov may all be synonymous. B. melrosa is distinguished from B. pertaknurra Walter, which also lacks a pelletal microstructure, by its more steeply convex laminae, its occasional short, projection-like columns and by the absence of well defined broad basal columns. B. melrosa most resembles B. lissa, from which it is distinguished by the absence of pelletal microstructure, and by the presence of some short, projection-like columns.

Distribution: Brighton Limestone equivalent, one mile west of Melrose (ORROROO map sheet 1:250,000).

Age: Late Adelaidean, correlated with the Late Riphean of the USSR.

REFERENCES

- Aitken, J.D., 1967. Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southwestern Alberta. J. Sedim. Petrol. 37, 1163-1178.
- Andrews, S.H.N., 1970. Index of Generic Names of fossil plants, 1820 - 1965. Bull. U.S. geol. Surv. 1300. 354p.
- Bathurst, R.G.C., 1966. Boring algae, micrite envelopes and lithification of molluscan biosparites. Geological Journal 5, 15 - 32.
- Bertrand, J., 1968. Les édifices stromatolitiques précambriens de la "Série à stromatolites" du Nord-Ouest de l'Ahagger (Sahara). Bull. Soc. geol. Fr. 7(10) 168 - 178.
- Binks, P.J., 1968. ORROROO map sheet Geological Atlas of South Australia, 1:250,000 series, geol. Surv. S. Aust.
- Black, M. 1933. The algal sediments of Andros Island, Bahamas. Phil. Trans. R. Soc., ser.B, 222, 165-192.
- Bradley, W.H., 1929. Algae reefs and oolites of the Green River Formation. Prof. Pap. U.S. geol. Surv. 154, 203 - 223.
- Cloud, P.E., 1942. Notes on stromatolites. Am. J. Sci. 240, 363 - 379.
- Cloud, P.E. & Semikhatov, M.A., 1969. Proterozoic stromatolite zonation. Am. J. Sci. 267, 1017 - 1061.
- Coats, R.P., Horwitz, R.C., Crawford, A.R., Campana, B. & Thatcher, D., 1969. Mount Painter Province, Geological Atlas of South Australia, Special Series, 1:125,000, geol. Surv. S. Aust.

- Coats, R.P., 1971. Copley map sheet. Geological Atlas of South Australia 1:250,000 series, geol. Surv. S. Aust. (in prep.)
- Dalgarno, C.R. & J.E. Johnson, 1966. PARACHILNA map sheet, Geological Atlas of South Australia, 1:250,000 series, geol. Surv. S. Aust.
- Dalgarno, C.R., Johnson, J.E., Forbes, B.G. & Thomson, B.P., 1968. PORT AUGUSTA map sheet. Geological Atlas of South Australia, 1:250,000 series, geol. Surv. S. Aust.
- Dunn, P.R., Plumb, K.A. & Roberts, H.G., 1966. A proposal for time-stratigraphic subdivision of the Australian Precambrian. J. geol. Soc. Aust. 13, 593 - 608.
- Eardley, A.J., 1938. Sediments of the Great Salt Lake, Utah. Bull. Am. Ass. Petrol. Geol. 22, 1305 - 1411.
- Edgell, H.S., 1964. Precambrian fossils from the Hamersley Range, Western Australia, and their use in stratigraphic correlation. J. geol. Soc. Aust. 10, 235 - 262.
- Fenton, C.L., & Fenton, M.A., 1931. Algae and algal beds in the Belt Series of Glacier National Park. J. Geol. 39, 670 - 686.
- Fenton, C.L. & Fenton, M.A., 1933. Algal reefs or bioherms in the Belt Series of Montana. Bull. geol. Soc. Am. 44, 1135 - 1142.
- Fenton, C.L. & Fenton, M.A., 1936. Walcott's "Pre-Cambrian Algonkian algal flora" and associated animals. Bull. geol. Soc. Am. 47, 609 - 620.
- Fenton, C.L. & Fenton, M.A. 1937. Early algae as environment indications and index fossils. Int. Geol. Congress, 17th, Moscow, Abstracts, p.215.

- Fenton, C.L. & Fenton, M.A., 1939. Pre-Cambrian and Palaeozoic algae. Bull. geol. Soc. Am. 50, 89 - 125.
- Gebelin, C.D., 1969. Distribution, morphology and accretion rate of recent subtidal algal stromatolites, Bermuda. J. sedim. Petrol. 39, 49 - 69.
- Glaessner, M.F., Preiss, W.V., & Walter, M.R., 1969. Precambrian Columnar Stromatolites in Australia: Morphological and stratigraphic Analysis. Science, 164, 1056 - 1058.
- Hall, J.D., 1883. Cryptozoon (proliferum) n.g. (and s.p.). Rep. N.Y. State Mus. 36, pl.6 & caption.
- Hoffman, P.F., 1967. Algal stromatolites: use in stratigraphic correlation and paleocurrent determination. Science, 157, 1043 - 1045.
- Hoffman, P.F., 1969. Proterozoic paleocurrents and depositional history of the East Arm fold belt, Great Slave Lake, Northwest Territories. Can. J. Earth Sci. 6, 441 - 462.
- Hofmann, H.J., 1969a. Stromatolites from the Proterozoic Animikie and Sibley Groups, Ontario. Geol. Surv. Pap. Can. 68 - 69, 77 p.
- Hofmann, H.J. 1969b. Attributes of stromatolites. Geol. Surv. Pap. Can. 69 - 39. 58p.
- Hommeril, P. & M. Rioult, 1965. Étude de la fixation des sédiments meubles par deux algues marines: Rhodothamniella floridula (Dillwyn) J. Feldm. et Microcoleus chthonoplastes Thur. Marine Geol. 3, 131 - 155.
- Howchin, W., 1914. The occurrence of the genus Cryptozoon in the (?) Cambrian of Australia. Trans. R. Soc. S. Aust. 38, 1 - 10.

- Johnson, J.H., 1937. Algae and algal limestone from the Oligocene of South Park, Colorado. Bull. geol. Soc. Am. 48, 1227 - 1236.
- Johnson, J.H., 1940. Lime-secreting algae and algal limestones from the Pennsylvanian of Central Colorado. Bull. geol. Soc. Am. 51, 571 - 596.
- Johnson, J.H., 1966. A review of the Cambrian algae. Colo. Sch. Mines. Q. 61, 162p.
- Kalkowsky, E., 1908. Oolith und Stromatolith im norddeutschen Bundsandstein. Z. dt. geol. Ges. 60(1), 68 - 125.
- Keller, B.M., Kazakov, G.A., Krylov, I.N., Nuzhnov, S.V. & M.A. Semikhatov, 1960. Novyye dannyye po stratigrafii rifeyskoy gruppy (Verkhniy Proterozoy). (New data on the stratigraphy of the Riphean Group (Upper Proterozoic)). Izv. Akad. Nauk. USSR Ser. Geol. 1960 No.12, 26 - 41 (Trans. Izv. Acad. Sci. USSR geol. Ser. 1960 No.12, 21 - 34).
- Komar, Vl.A., 1966. Stromatolity verkhnedokembriyskikh otlozheniy severa Sibirskoy platformy i ikh stratigraficheskoe znachenie (Stromatolites of the upper Precambrian deposits of the North Siberian platform and their stratigraphic significance). Trudy geol. Inst., Leningr. 154, 122p.
- Komar, Vl. A., Raaben, M.E. & Semikhatov, M.A., 1965. Konofitony Rifeya USSR i ikh stratigraficheskoe znachenie (Conophytions of the Riphean of the USSR and their stratigraphic significance). Trudy geol. Ints. Leningr. 131, 72p.

- Korolyuk, I.K., 1960. Stromatolity nizhnego kembriya i proterozoya Irkutskogo amfiteatra (Stromatolites from the Lower Cambrian and Proterozoic of the Irkut Amphitheatre). Trudy. Inst. Geol. Razrab. Goryuch. Iskop. Adad. Nauk SSSR, (1), 161p.
- Krylov, I.N., 1963. Stolbchatye vetvyashchiesya stromatolity rifeyskikh otlozheniy Yuzhnogo Urala i ikh znachenie dlya stratigrafii verkhnego dokembriya. (Columnar branching stromatolites of the Riphean deposits of the Southern Urals and their significance for the stratigraphy of the Upper Precambrian). Trudy. geol. Inst., Leningr. 69, 133p.
- Krylov, I.N., 1967. Rifeyskie i nizhnekembriyskie stromatolity Tyan'-Shanya i Karatau (Riphean and Lower Cambrian stromatolites of Tien-Shan and Karatau). Trudy geol. Inst., Leningr. 171, 76p.
- Krylov, I.N., Nuzhnov, S.V. & Shapolalova, I.G., 1968. 0 Stromatolitovykh kompleksakh srednego rifeya (On the stromatolitic complexes of the Middle Riphean). Dokl. Akad. Nauk SSSR, Ser. Geol. 181, 426 - 429.
- Logan, B.W., 1961. Cryptozoön and associate stromatolites from Recent, Shark Bay, Western Australia. J. Geol. 69, 517 - 533.
- Logan, B.W., Rezak, R., & Ginsburg, R.N., 1964. Classification and environmental signifance of algal stromatolites. J. Geol. 72, 68 - 83.
- Maslov, V.P., 1937a. Nizhne-paleozoyskie porodobrazuyushchie vodorosli vostochnoy Sibiri (Lower Palaeozoic rock-building Algae of Eastern Siberia). Problemy Paleont. 2-3, 249 - 314. (Engl. summary, 314 - 325).

- Maslov, V.P., 1937b. O rasprostraneniі karbonatnykh vodorosley v vostochnoy Sibiri (On the distribution of the calcareous algae in Eastern Siberia). Problemy Paleont. 2-3, 327 - 342.
- Maslov, V.P., 1938. O prirode stromatolita Conophyton (On the nature of the stromatolite Conophyton). Problemy Paleont. 4, 325 - 332.
- Maslov, V.P., 1939a. Popytka vozzrastnogo opredeleniya nemykh tolshch urala, pomoshch'yu stromatolitov (An attempt of the age determination of unfossiliferous beds of the Urals with the aid of stromatolites). Problemy Paleont. 5, 277 - 281. (Eng. transl. 281 - 284).
- Maslov, V.P., 1939b. Rod Collenia (The genus Collenia). Problemy Paleont. 5, 297 - 310.
- Maslov, V.P., 1960. Stromatolity (ikh genezis, metod izucheniya svyaz' s fatsiyami i geologicheskoye znachenie na primere ordovika sibiroskoy platformy). (Stromatolites; their genesis, methods of study, connection with facies and geologic significance in the example of the Ordovician of the Siberian Platform). Trudy Geol. Inst., Leningr. 41, 188p.
- Mawson, D., 1925. Evidence and indications of algal contributions in the Cambrian and Precambrian Limestone of South Australia. Trans. R. Soc. S. Aust. 49, 186 - 190.
- Mirams, R.C., 1964. BURRA map sheet. Geological Atlas of South Australia, 1:250,000 Series, geol. Surv. S. Aust.
- Monty, C.L.V., 1967. Distribution and structure of Recent stromatolitic algal mats, eastern Andros Island, Bahamas. Annls. Soc. geol. Belg. 90 (3), 55 - 99.

- Nelson, H.F., Brown, C.W. & Brineman, J.H., 1962. Skeletal limestone classification in Ham, W.E. (Ed.) Classification of Carbonate Rocks, a symposium, Am. Ass. Petrol. Geol. Mem. 1, 224 - 252.
- Nuzhnov, S.V., 1967. Rifeyskie otlozheniya yugo-vostoka Sibirskoy platformy (Riphean deposits of the southeast Siberian platform). Inst. Geol. Yakutsk. Filial Sibirsk. Otdel. Akad. Nauk SSSR; Moscow, 160 p.
- Pia, J., 1926. Pflanzen als Gesteinbildner. Berlin, 355p.
- Preiss, W.V., 1971a. The biostratigraphy and palaeoecology of South Australian Precambrian Stromatolites Unpublished Ph.D. thesis, University of Adelaide.
- Preiss, W.V., 1971b. Stromatolite biostratigraphy in the Late Precambrian. Quart. geol. notes, geol. Surv. S. Aust. 38, 3 - 11.
- Raaben, M.E., 1964. Stromatolity verkhnego rifeya Polyudova Kryazha i ikh vertikal'noye raspredelenie. (Stromatolites of the Upper Riphean of the Polyudov Mountains and their vertical distribution). Byull. mosk. Obshch. Ispyt. Prir., otd. geol., 39 (vyp.3), 86 - 109.
- Raaben, M.E., 1969a. Stromatolity verkhnego rifeya (Gimnosolenidy) (Upper Riphean stromatolites (Gymnosolenida). Trudy geol. Inst., Leningr. 203, 100p.
- Raaben, M.E., 1969b. Columnar stromatolites and Late Precambrian stratigraphy. Am. J. Sci. 267, 1-18.
- Rezak, R., 1957. Stromatolites of the Belt Series in Glacier National Park and vicinity, Montana. Prof. Pap. U.S. geol. Surv. 294D, 127 - 154.

- Semikhatov, M.A., 1962. Rifey i nizhniy kembriy Yeniseykogo Kryazha (The Riphean and Lower Cambrian of the Yenisei Mountains). Trudy geol. Inst. Leningr. 68, 242 p.
- Semikhatov, M.A., Vl. A. Komar & S.N. Serebryakov, 1970. Yudomskiy Kompleks Stratotipicheskoy Mestnosti (The Yudomian Complex of the Strato-typical Area). Akad. Nauk SSSR, Trudy 210, 207p.
- Shapovalova, I.G., 1968. O novoy gruppe stromatolitov Jacutophyton iz verkhnego proterozoya vostochnogo sklona Aldanskoy anteklizy (On a new group of stromatolites Jacutophyton from the Upper Proterozoic of the eastern slopes of the Aldan anteclyze). Dokl. 17 nauch. Sess. Yakut. fil. Sibir. otd. Akad. Nauk SSSR, "Tektonika, stratigrafiya i litologiya osadochnykh formatsiy Yakutii, 97 - 103.
- Steinmann, G., 1911. "Uber Gymnosolen ramsayi, eine Coelenterate von der Halbinsel Kanin. Bull. Soc. geogr. Finlande 31, 18 - 23.
- Thomson, B.P., Coats, R.P., Mirams, R.C., Forbes, B.G., Dalgarno, C.R., & Johnson, J.E., 1964. Precambrian rock groups in the Adelaide Geosyncline. A new subdivision. Quart. geol. Notes, geol. Surv. S. Aust. 9, 1 - 19.
- Vologdin, A.G., 1962. Drevneyshie Vodorosli SSSR (The most ancient algae of the SSSR, 656p.
- Walcott, C.D., 1914. Cambrian Geology and Paleontology II: Pre-Cambrian Algonkian algal flora. Smithson. misc. Collns, 64, 78 - 156.

- Walter, M.R., 1970. Stromatolites and the biostratigraphy of the Australian Precambrian. Unpubl. Ph.D. Thesis, University of Adelaide.
- Walter, M.R., 1971. Stromatolites and the biostratigraphy of the Australian Precambrian and Cambrian (in press.)
- Young, R.B., 1933a. The occurrence of stromatolithic or algal limestones in the Campbell Rand Series, Griqualand West. Trans. geol. Soc. S. Afr. 35, 29 - 36.
- Young, R.B., 1933b. Conditions of deposition of the Dolomite Series. Trans. geol. Soc. S. Afr. 36, 121 - 135.
- Young, R.B., 1935. A comparison of certain stromatolithic rocks in the Dolomite Series of South Africa, with modern algal sediments in the Bahamas. Trans. geol. Soc. S. Afr. 37, 153 - 162.

APPENDIX

GLOSSARY

Axis: The centre-line of a column.

Bioherm: A circumscribed organo-sedimentary structure whose minimum width is less than or equal to one hundred times its maximum thickness, embedded in rocks of different lithology.

Note: the definitions of the terms Bioherm and Biostrome are based on those given by Nelson, Brown and Brineman (1962) but since, at least in stromatolites, the two integrate, an arbitrary limit must be set.

Tabular bioherms have parallel upper and lower surfaces, while domed bioherms have gently convex upper surfaces. Subspherical bioherms had the highest growth relief relative to their width.

Tonguing bioherms are bioherms which had little or no growth relief, and therefore intertongue at their margins with the surrounding sediment.

Biostrome: A stratiform organo-sedimentary structure whose minimum width is more than one hundred times its thickness.

Note: in practice it is rarely possible to see the three dimensional shape of the structure in outcrop. The distinction between bioherms and biostromes must therefore be based on the dimensions visible in outcrop. If the outcrop is inadequate, the informal term "bed" is used.

Tabular biostromes have parallel lower and upper surfaces. Domed biostromes either may consist of juxtaposed domed bioherms, or may be continuous with juxtaposed domes on their upper surfaces.

Branching: The division of a column into new, discrete columns. The columns become discrete when they are first separated by an interspace.

In parallel branching, the axes of the new columns are parallel (most commonly they are also parallel to the axis of the original column).

Alpha-parallel branching is parallel branching in which the width of the individual remains constant.

In beta-parallel branching the original column widens gradually before branching, while in gamma-parallel branching, it widens abruptly before branching.

In slightly divergent branching, the axes of the new columns diverge at less than 45° , while in markedly divergent branching they diverge at more than 45° .

Dichotomous branching is branching into more than two columns at approximately one level.

Bridge: A stromatolitic lamina or set of laminae linking adjacent columns.

Bump: A low, rounded protrusion on the side of a column.

Coalescing columns: Adjacent columns which join and continue growth as one column.

Column: A discrete stromatolite structure, with the dimension in the direction of growth greater than at least one of the transverse dimensions. Column shape and arrangement often vary according to the position in the bioherm.

Columnar - layered stromatolite: A stromatolite in which short columnar and laterally linked (usually pseudocolumnar) portions alternate.

Cornice: Peripheral overhanging portion of a lamina or set of laminae, elongated transversely to the column axis.

Crest: The summit of an upward-convex laminae.

Crestal line: The line jointing the crests of successive laminae.

Crestal zone: The environs of the crestal line. In Conophyton, the crestal zone is specifically the zone of thickening and contortion of the laminae; the width of the crestal zone is the width of the thickened and/or contorted portions of laminae.

Cumulate stromatolite: A rounded protruding non-columnar stromatolite.

Domed: With approximately constant radius of curvature.

Flat-laminated stromatolite: Non-columnar stromatolite with flat, continuous laminae.

Gently convex lamina: A lamina whose ratio of height to diameter is less than or equal to 0.5. Measurements of this ratio are best treated statistically by plotting on a histogram.

Gnarled column: A column with large bumps.

Grumous: A mineral texture in which fine-grained patches are surrounded by coarser grains.

Hypidiotopic: A mineral texture intermediate between xenotopic and idiotopic.

Idiotopic: A texture in which the mineral grains are bounded by crystal faces.

Individual: A single discrete stromatolite within which either the laminae are continuous or which comprises a group of columns arising from a single basal column.

Interspace: The space between columns, usually filled with sediment.

Lamina: The smallest unit of layering in a stromatolite.

Lanceolate: An elongate transverse section of a column, tapering at both ends.

Laterally linked stromatolite: Stromatolite with wavy laminae which are continuous between crests.

Macrolamina: A set of laminae.

Microstructure: The fine-scale structure of the stromatolite lamination, in particular the distinctness, continuity, thickness and composition of the laminae.

Banded microstructure is characterised by very continuous laminae with sharp, distinct, more or less parallel boundaries. In streaky microstructure less distinct and continuous laminae frequently grade into one another. The darker laminae are usually more distinct.

Striated microstructure consists of primary chains of lenses, oriented parallel to the lamination (this excludes cases where originally continuous laminae are disrupted by recrystallisation).

Vermiform microstructure consists of narrow, sinuous, pale coloured areas (usually of sparry carbonate) surrounded by darker, usually finer grained areas.

Micro-unconformity: Surface of lamination discordance due to penecontemporaneous erosion within a stromatolite.

Niche: A deep indentation in the side of a column.

Parabolic lamina: A lamina whose axial longitudinal section approximates a parabola.

Peak: Overhanging portion of a lamina or set of laminae with a small dimension transverse to the column.

Pellet: Ovoid to sub-ovoid micritic carbonate grain of silt or sand size, lacking internal structure.

Pigment: Organic or inorganic colouring matter.

Platy column: A strongly transversely elongated column.

Projection: A small columnar or conical outgrowth from the side of a column.

Pseudocolumnar stromatolite: Laterally linked stromatolite in which successive crests are superimposed, forming column-like structures (pseudocolumns).

Rectangular lamina: Lamina which in a longitudinal section of a column is flat-topped with edges deflexed at about 90° .

Rhombic lamina: Lamina which in a longitudinal section of a column is flat-topped but has sub-parallel edges not perpendicular to the top.

Rib: A low, rounded protrusion which is elongated transversely to the column on which it occurs.

Selvage: An unlaminated coating on column margins. Possible explanations for this include (a) micritization by algal boring (b) inorganic precipitation of lime (c) a thin algal film on column margins during growth. In some forms a selvage-like structure is probably the result of differential recrystallisation of a wall.

Steeply Convex lamina: A lamina whose ratio of height to diameter is greater than 0.5.

Tuberous column: A column with prominent expansions and constrictions.

Wall: Structure at the margin of a column formed by one or more laminae from within the column bending down and coating the margin for at least a short distance.

Wavy lamina: A lamina with flexures of wavelength greater than 2 mm.

Wrinkled lamina: A lamina with flexures of wavelength less than 2 mm.

Undulatory stromatolite: Laterally linked stromatolite in which successive crests are not superimposed.

Xenotopic texture: A texture in which the mineral grains are anhedral or irregularly shaped, i.e. not bounded by crystal faces.

Fig. 1

Diagnostic terminology found useful in the description of stromatolites. The diagrams illustrate features discussed in Appendix I.

Fig.1.

DIAGNOSTIC TERMINOLOGY

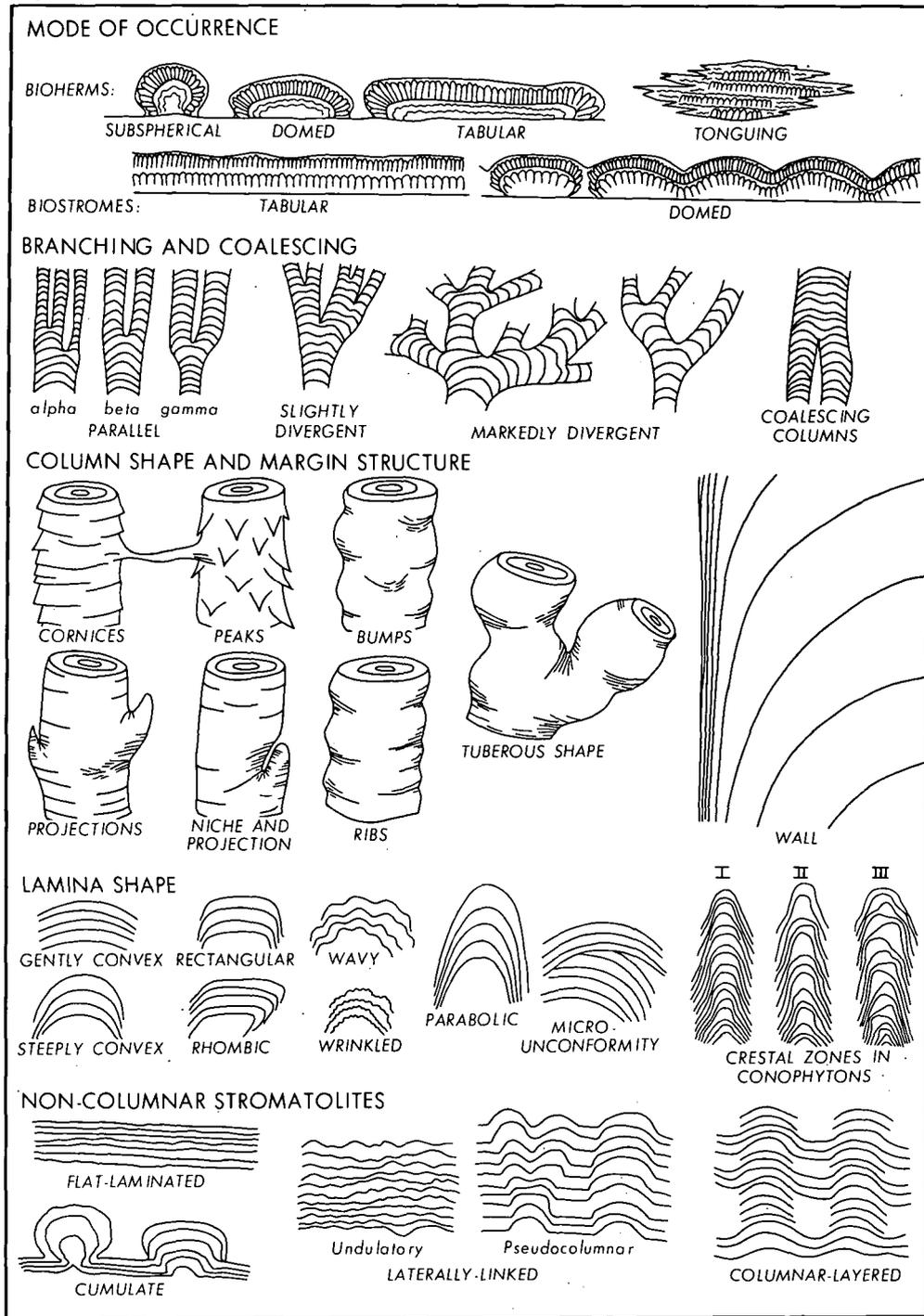


Fig. 2

All reconstructions are natural size.

- (a) to (i) : Acaciella angepena, from Lower Cambrian limestones; Flinders Ranges.
- (a) : Holotype, S460; $\frac{5}{8}$ mile south of Angepena H.S.
- (b) : S458; $\frac{5}{8}$ mile south of Angepena H.S.
- (c), (e) & (i) : S459; $\frac{5}{8}$ mile south of Angepena H.S.
- (d) & (g) : S8; 3 miles west of Italowie Gorge (collected by Sir Douglas Mawson)
- (f) : S44; 3 miles west of Italowie Gorge (collected by Sir Douglas Mawson)
- (h) : S564; near Old Wirrealpa (collected by Mr. P.G. Haslett).
- (j) : Possible Acaciella angepena, 3 miles west of Italowie Gorge.

Fig.2

2 cm.

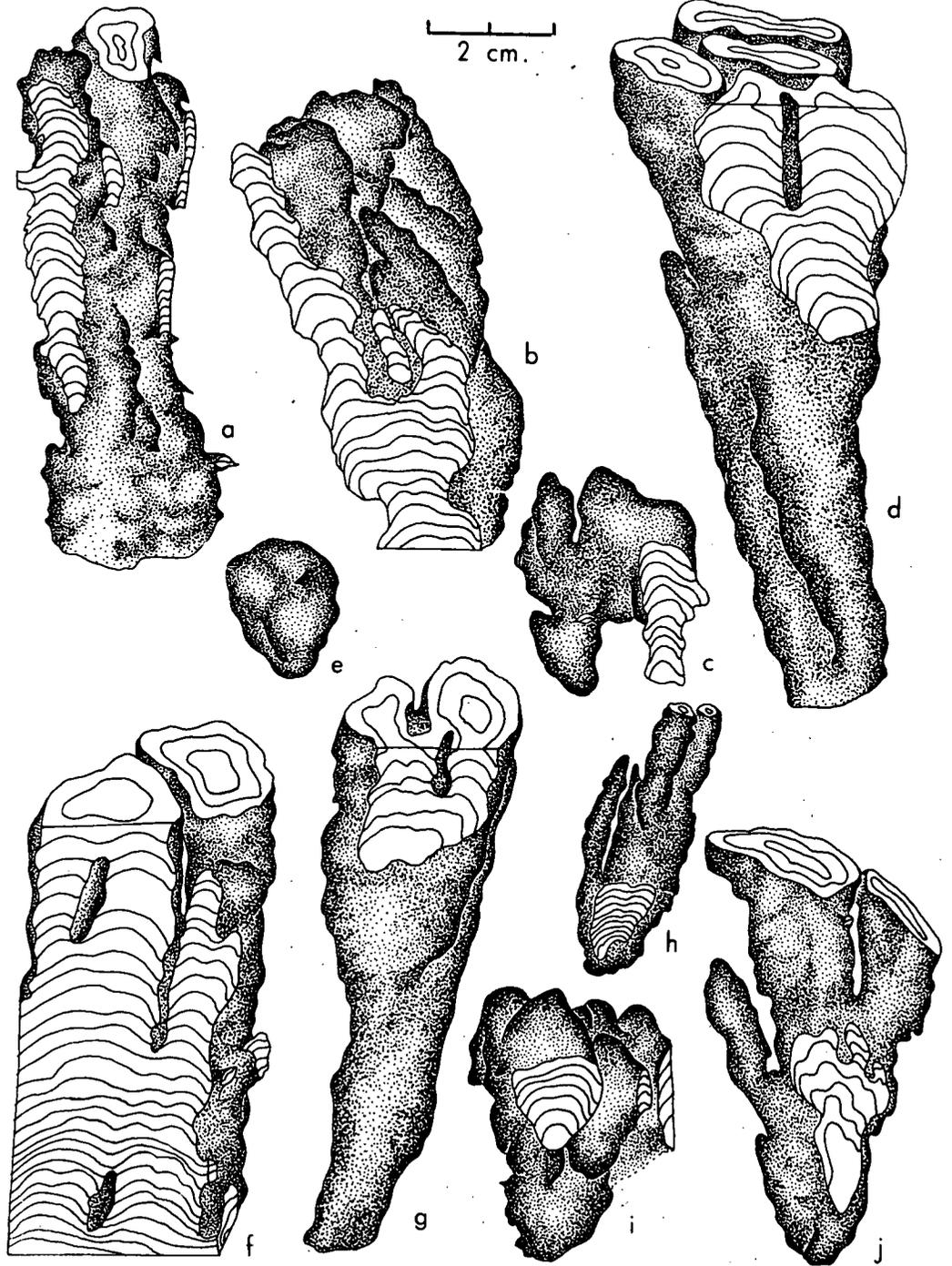


Fig. 3.

All reconstructions x 1/3

- (a) to (j) : Acaciella augusta: Brighton Limestone equivalent,
Umberatana Group; Southern Flinders Ranges.
- (a)(b)(d)
& (i) : S404; Depot Creek
- (c), (e) : Holotype, S401; Depot Creek.
- (f) : S538; Mundallio Creek
- (g), (h) : S396; Depot Creek
- (j) : S537; Depot Creek
- (k)to(m) : S471; Possible Acaciella augusta, Wundowie
Limestone, Wundowie Bore, Northern Flinders
Ranges.
- (n)(o)&(p) : S539. Acaciella f. indet. from an erratic
in the Sturtian glacials, N.E. of the Enorama
Diapir.
- (n) : S509; Acaciella f. indet., from the same locality.
Traced from a thin section

Fig. 3

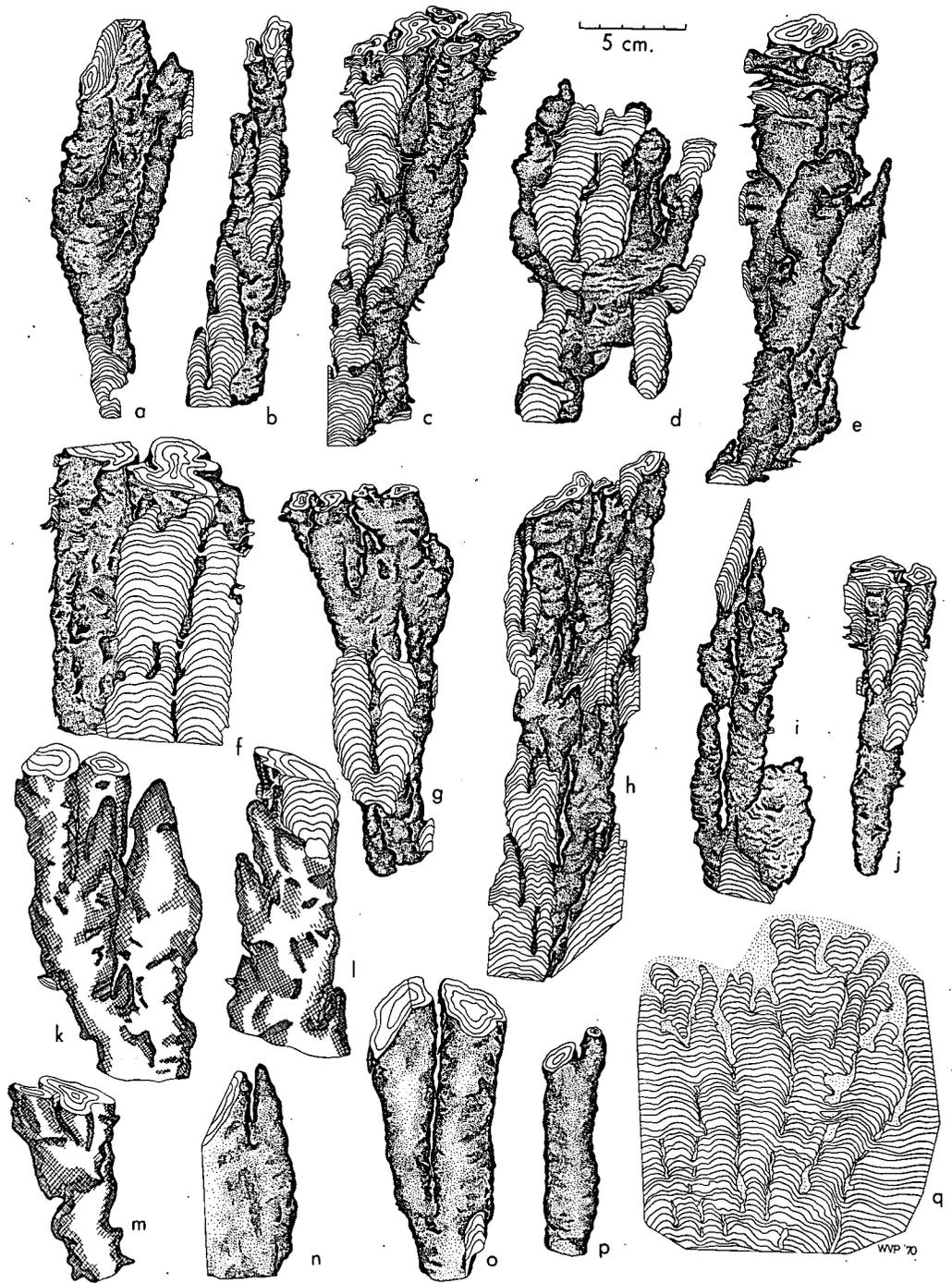


Fig.4.

Reconstructions (a),(b),(d),(e),(f),(g),(h),(i),(j),(k),(l), (m), x1/3

(c) x 1/6

- (a) to (m) : Baicalia burra: Skillogalee Dolomite, Burra Group; Southern Flinders Ranges.
- (a) & (c) : Holotype S222; 2 miles west of Yatina
- (b) : S218; 2 miles west of Yatina
- (d) : S151; 8 miles southwest of Worumba H.S.
- (e) & (f) : S150; 8 miles southwest of Worumba H.S.
- (g)(i)(j) : S221; Dutton's Trough H.S. 9 miles south of Burra.
- (h) & (l) : S314; Dutton's Trough H.S. 9 miles south of Burra.
- (j) : S533; Dutton's Trough H.S. 9 miles south of Burra.
- (k) : S534; Dutton's Trough H.S. 9 miles south of Burra.
- (m) : S383; float specimen, River Broughton, west of Spalding.

Fig. 4

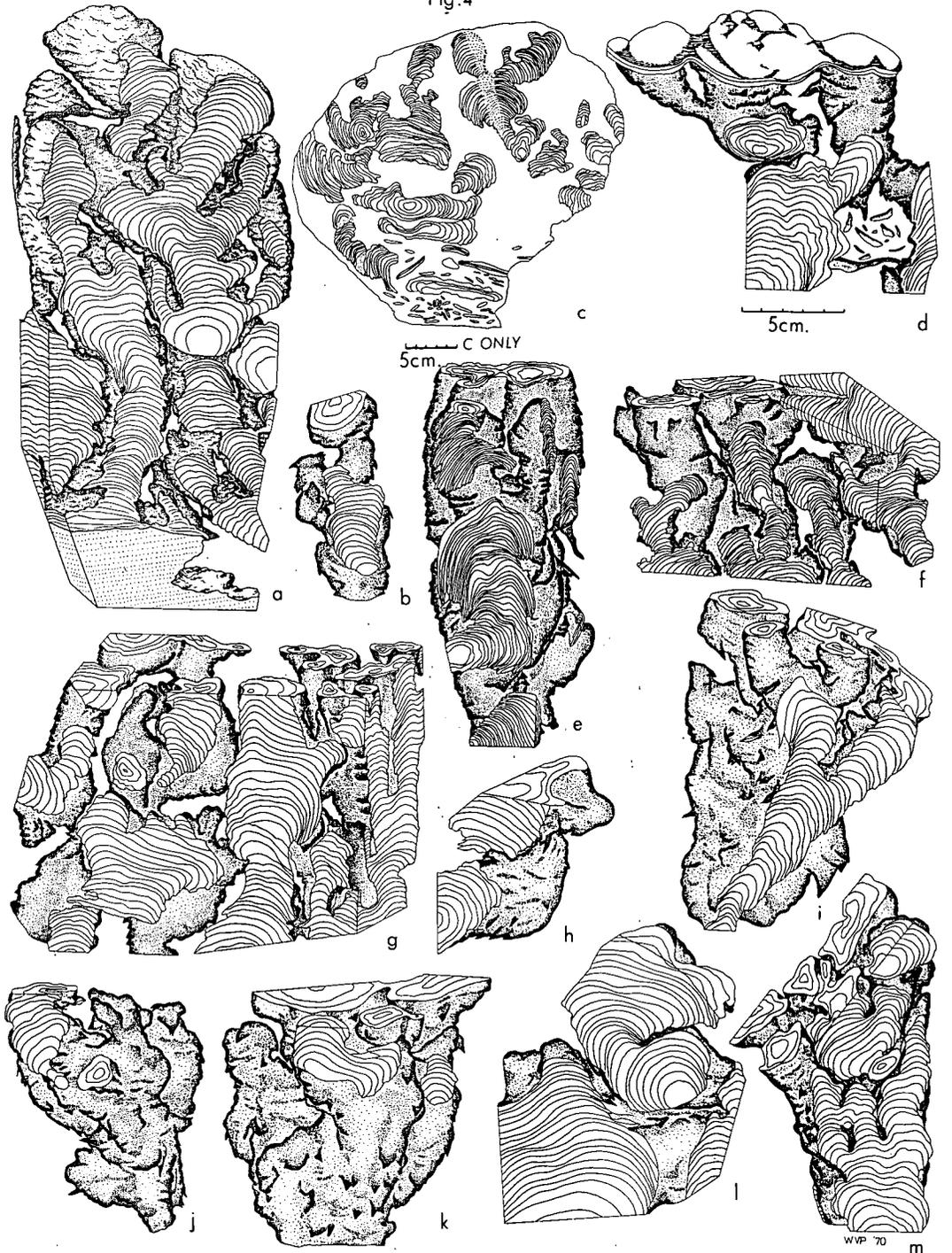


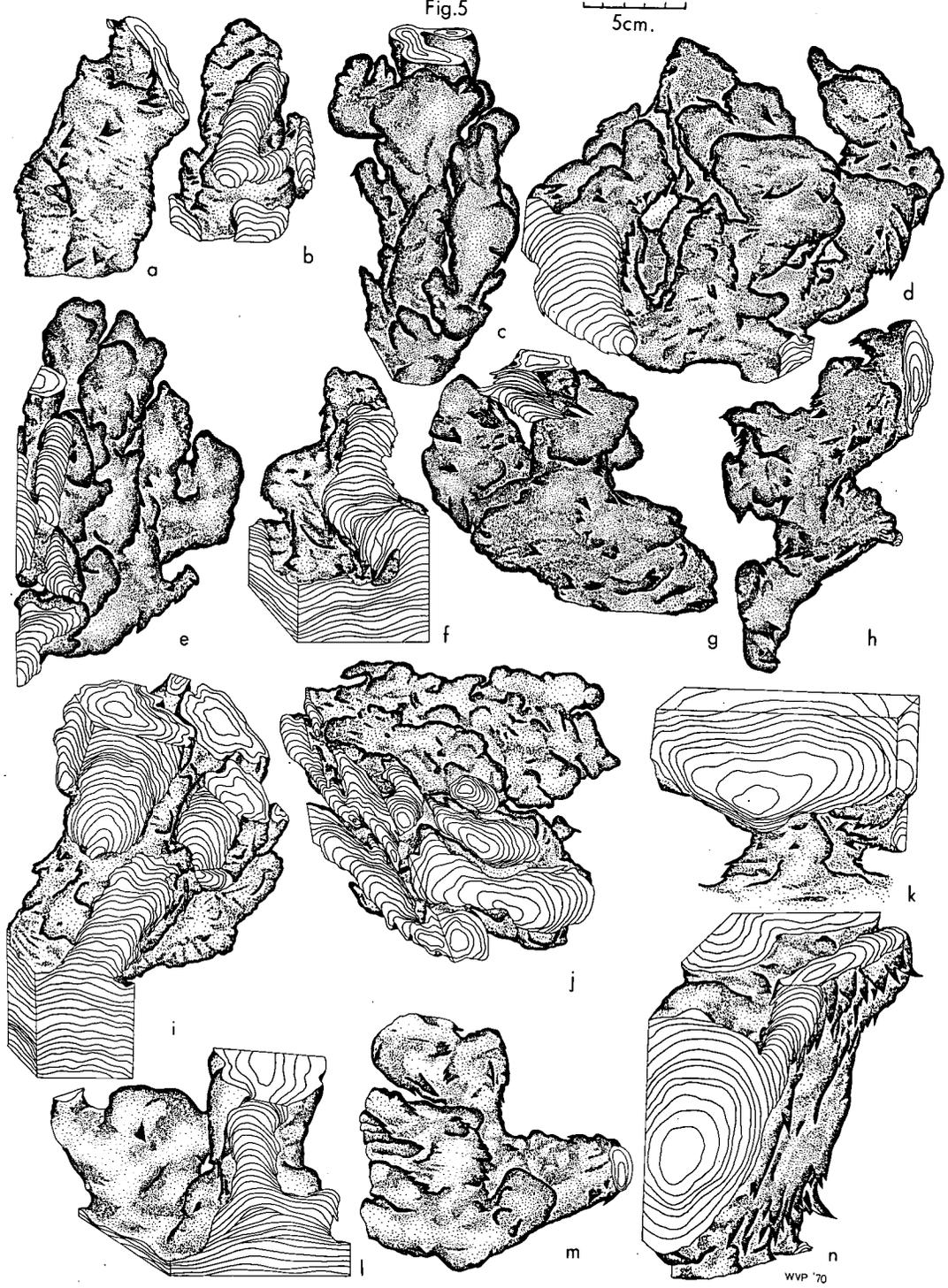
Fig.5.

All reconstructions x 1/3

- (a) to (n) : Baicalia burra: Skillogalee Dolomite, Burra Group
- (a) : S533; Dutton's Trough H.S. 9 miles south of Burra
- (b) : S534; Dutton's Trough H.S. 9 miles south of Burra
- (c) : S383; River Broughton, west of Spalding
- (d) : S456; 4 miles south of Arkaroola
- (e) : S457; 4 miles south of Arkaroola
- (f) : S491; 1½ miles east of Myrtle Springs (upper member)
- (g) : S489; 1½ miles east of Myrtle Springs (upper member)
- (h) : S490; 1½ miles east of Myrtle Springs (upper member)
- (i) : S488; 1 mile east of Myrtle Springs (lower member)
- (j) : S487; 1 mile east of Myrtle Springs (lower member)
- (k) : S319; the Avondale Mine, Lyndhurst (collected by Mr. P.J. Binks.)
- (l) : S302; West Mount Hut, Willouran Ranges
- (m) : S99; West Mount Hut, Willouran Ranges (collected by Mr. C.R. Dalgarno)
- (n) : S97; Chintapanna Well, Willouran Ranges (collected by Mr. C.R. Dalgarno.)

Fig.5

5cm.



WVP '70

Fig. 6.

All reconstructions x 1/3

- (a) to (f) : Baicalia burra: Skillogalee Dolomite, Burra Group; NW Flinders Ranges.
- (a), (b) & (f) : S96; Chintapanna Well, Willouran Ranges (collected by Mr. C.R. Dalgarno)
- (c) : S98; West Mount Hut, Willouran Ranges (collected by Mr. C.R. Dalgarno)
- (d) : S496; 3 miles west of Copley
- (e) : S301; West Mount Hut, Willouran Ranges

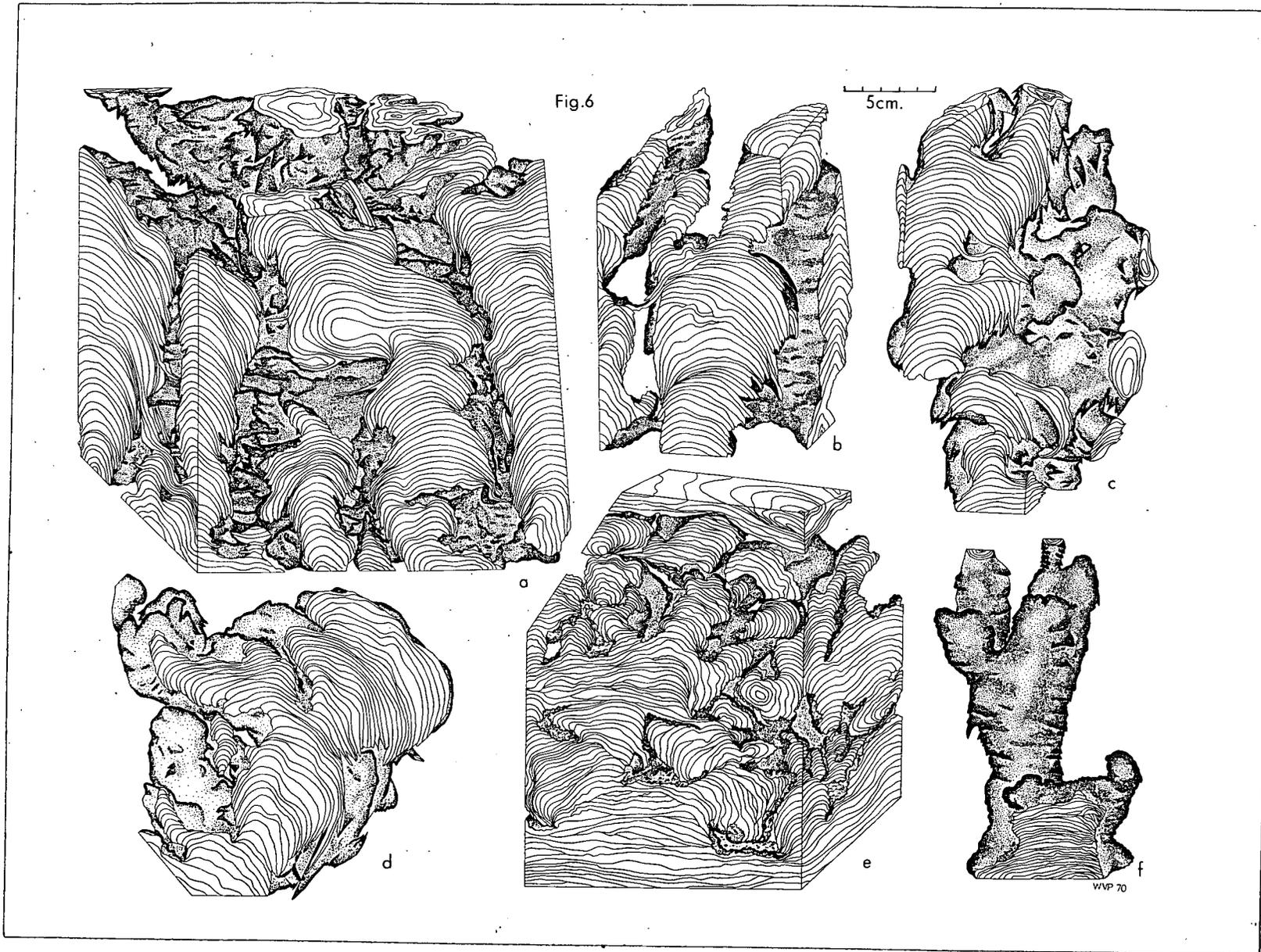


Fig. 7

All reconstructions x 1/3

(a) to (h) : Boxonia melrosa: Brighton Limestone equivalent,
Umberatana Group; $\frac{1}{2}$ mile west of Melrose.

(a), (e), (g) : S502
& (h)

(b), (c) & : Holotype, S503
(d)

(f) : S504

Fig.7

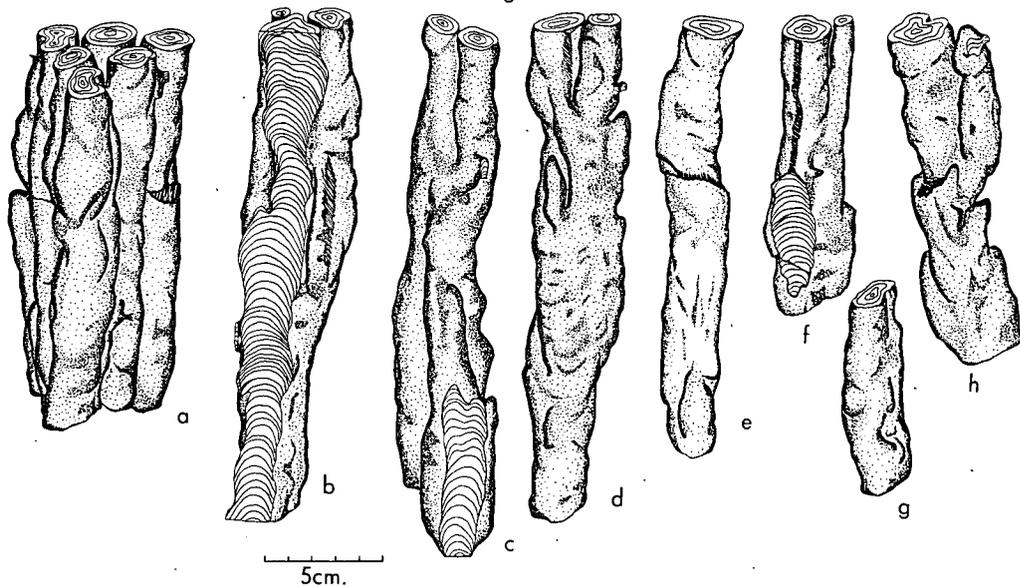


Fig. 8

Acaciella angepena: Lower Cambrian. Sections perpendicular to bedding, showing mode of occurrence and microstructures.

- (a) Marginal section of a bioherm. Note that laminae are completely recurved under the bioherm edge. Specimen is in situ. The ball point pen is 16 cm long. Angepena.
- (b) Etched sections of recurved margins of the bioherm in (a) (S300). Note that here growth partly proceeded downwards. Specimen collected from the outcrop shown in (a). Specimen is 15 cm wide. The section is cut perpendicular to bedding.
- (c) Lateral termination of a bioherm, which sank into the soft substrate during growth. White areas are dolomitized. Width of specimen is 21 cm (S460). Angepena.
- (d) Pseudocolumns with rare interspaces. Note the domed laminae grown upon partly buried intraclasts, and the extremely continuous lamination; Angepena (S462).
- (e) Evenly laminated ferruginous structure, possibly of inorganic origin. Thin section. Lower Cambrian, near Wirrealpa. The dark laminae are outlined by finely disseminated haematite. (S564; specimen collected by Mr. P. Haslett.)
- (f) Evenly laminated, discrete columnar form from Italowie Gorge (S44, Mawson's specimen).

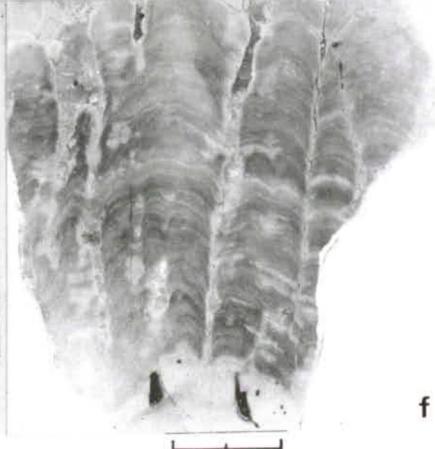
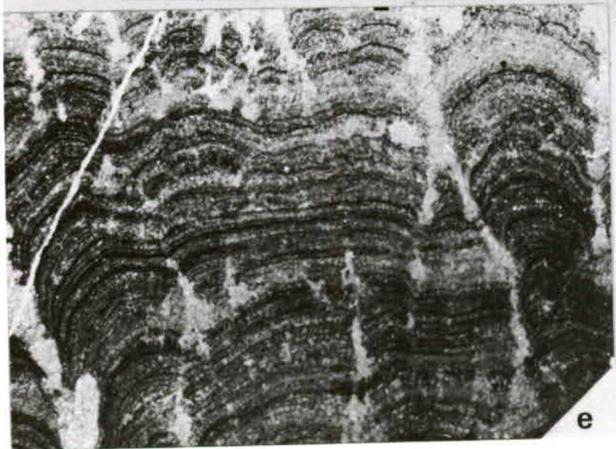
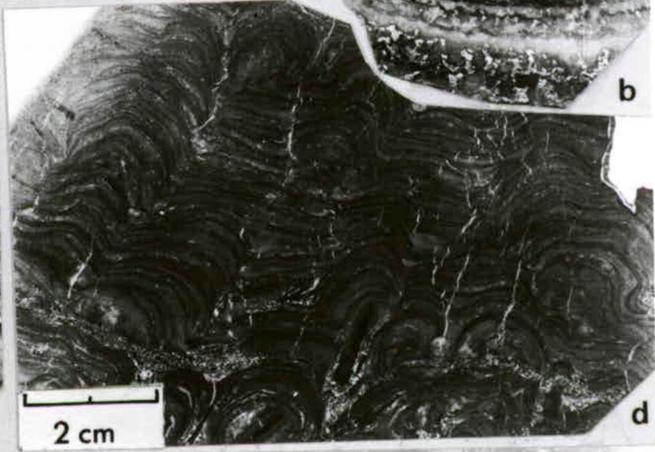


Fig. 9

- (a) Irregular columns from the margin of a small bioherm; Acaciella angepena, Angepena (S458). Note the vermiform microstructure, interpreted as due to algal boring, disrupting the normally very even, continuous lamination.
- (b) & (c) Acaciella f. indet. Both specimens are erratics from the lower glacials, north of the Enorama Diapir. Thin sections. Note the very numerous concordant stylolites in (b). (S539 and S509 respectively. S539 was collected by Dr. B. Daily).
- (d) to (f) Acaciella augusta: Brighton Limestone, Depot Creek. Vertical sections showing mode of occurrence and microstructure.
- (d) Details of transition from broad, frequently bridged basal columns to upper, narrow, discrete columns. Broad columns in lower right-hand corner have inclined margins and sub-horizontal laminae.
- (e) Lenticular open spaces between laminae, possibly representing original gas vesicles (S163).
- (d) Portion of a bioherm showing the intercalation of columnar and laterally linked stromatolites.

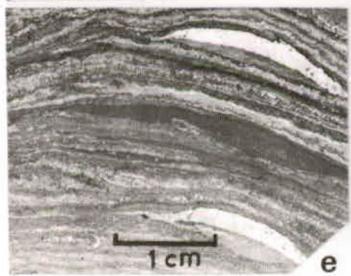
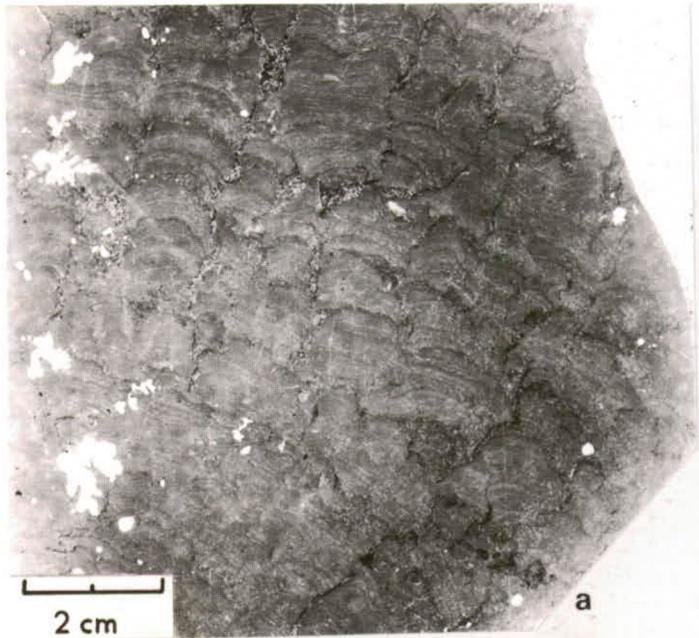


Fig. 10

Acaciella augusta: Brighton Limestone, Depot Creek.
Mode of occurrence and microstructure
(thin sections).

- (a) Margin of a bioherm (pale coloured at right of photograph) intertonguing laterally with massive-bedded oosparite (at left).
- (b) & (c) (S404 and S401 respectively). The gross shape and branching of columns. The interspaces are filled with interlayered micrite and intramicrite, in 0.5 to 1.0 cm bands. (c) is natural size. In (b), laminae become doubly-crested before branching, but in the centre of the photograph (c) is an example of a short interspace between crests bridged by the overlying laminae; the column resumes its former growth pattern.
- (d) Recrystallized specimen from Mundallio Creek (S538), illustrating radiating recrystallized acicular textures in the lower part of the photograph.



2 cm

b



c



2 cm

d

Fig.11

Baicalia burra: Skillogalee Dolomite. Sections perpendicular to bedding, showing the mode of occurrence and micro-structure.

- (a) Small lenticular bioherms interbedded in thinly bedded dolomites; Yatina.
- (b) Portion of a biostrome interbedded in massive, fine grained dolomites; Dutton's Trough H.S. Longitudinal section of partially silicified columns; the section is parallel to the tectonic cleavage, in the plane of flattening of the columns.
- (c) Irregular columns with numerous micro-unconformities and highly variable lamina shape; West Mount Hut
- (d) Moderately divergent branching columns, with some pelletal laminae. Thin sections; Yatina (S222, holotype).
- (e) Slightly divergent branching in regular, subcylindrical columns. Thin section; Dutton's Trough H.S. (S533). The specimen is taken from the biostrome shown in Fig. 11b.

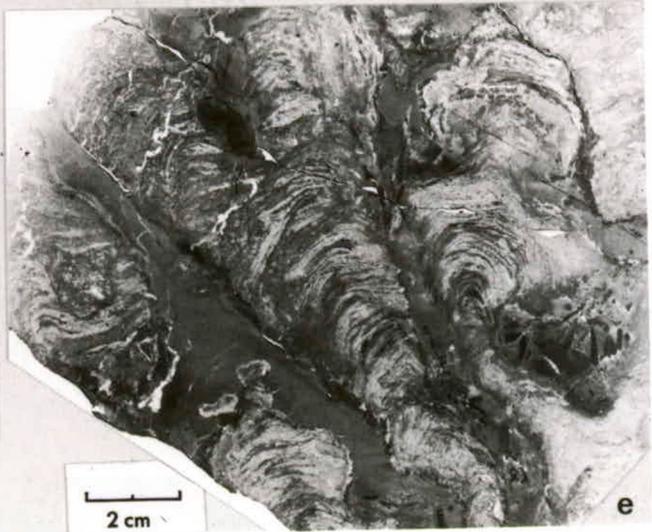
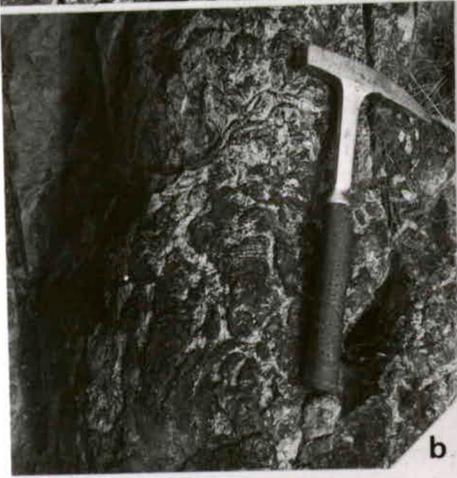


Fig. 12

Baicalia burra: Skiblogalee Dolomite, etc.

- (a) Tuberos and inclined columns with evenly banded microstructure and high-angle micro-unconformities. Thin section; Myrtle Springs (S487).
- (b) Baicalia burra with minor pelletal laminae. Thin section; Worumba (S150).
- (c) Subcylindrical columns with steeply domed, evenly banded laminae. Thin section; West Mount Hut (S302).
- (d) Branching of narrow columns from the sides of a main, wide column; Dutton's Trough H.S. (S534). The specimen is taken from the biostrome shown in Fig. 11b.
- (e) Baicalia burra with predominantly pelletal laminae. Thin section; Copley (S496).
- (f) Complex branching of columns from Arkaroola. Thin section (S457).

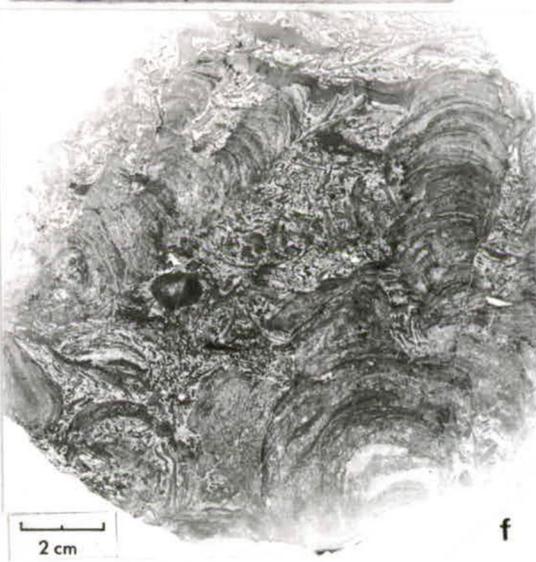
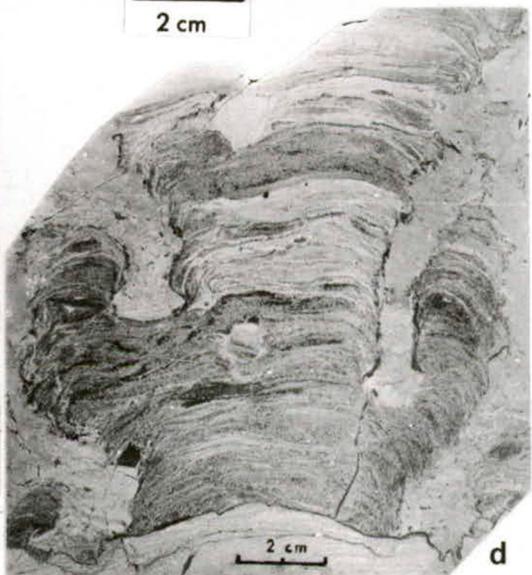
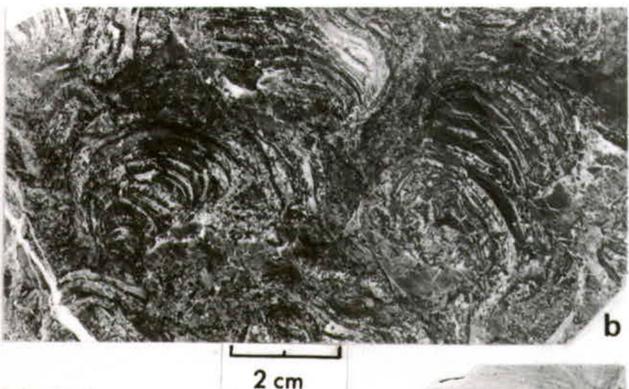
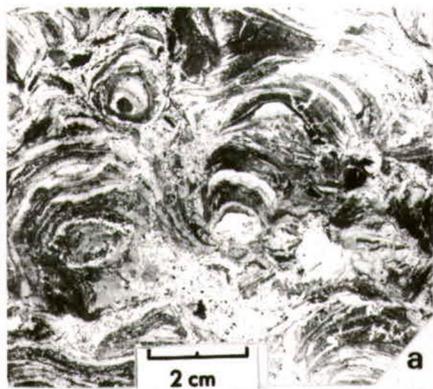


Fig. 13.

- (a) Baicalia burra with finely silicified laminae. Thin section; Wörumba. Natural size (S151). Note the vertical tectonic veins.
- (b) Baicalia burra. Cut slab illustrating parallel branching columns with high-angle micro-unconformities and banded lamination; Chintapanna Well (S96, specimen collected by Mr. C. R. Dalgarno). Note the overgrown stromatolite fragment in the lower left quadrant, and the branch arising from an eroded column in the upper right.
- (c) Indeterminate stromatolite, possibly Baicalia burra. Thin section; River Wakefield Group, Carrieton (S322).
- (d) to (f) Boxonia melrosa: Brighton Limestone, Melrose.
- (d) Hand specimen illustrating longitudinal sections of columns.
- (e) Thin section of Boxonia melrosa: Brighton Limestone, Melrose (holotype, S503). The lamination is indistinctly banded, and becomes diffuse in the wall zone.
- (f) Thin section illustrating lamination and wall structure. Natural size (S177). Note: the upper left and lower left corners of the thin section are composed of highly weathered rock.



a



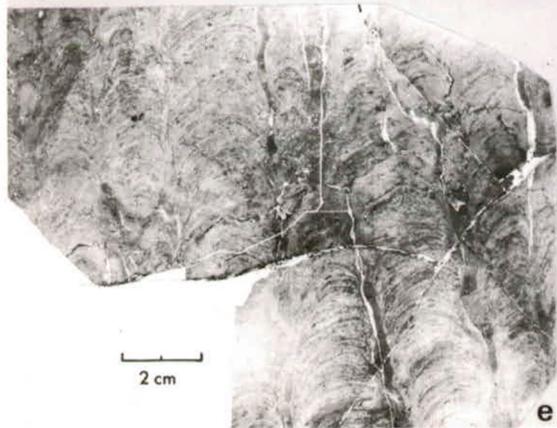
b



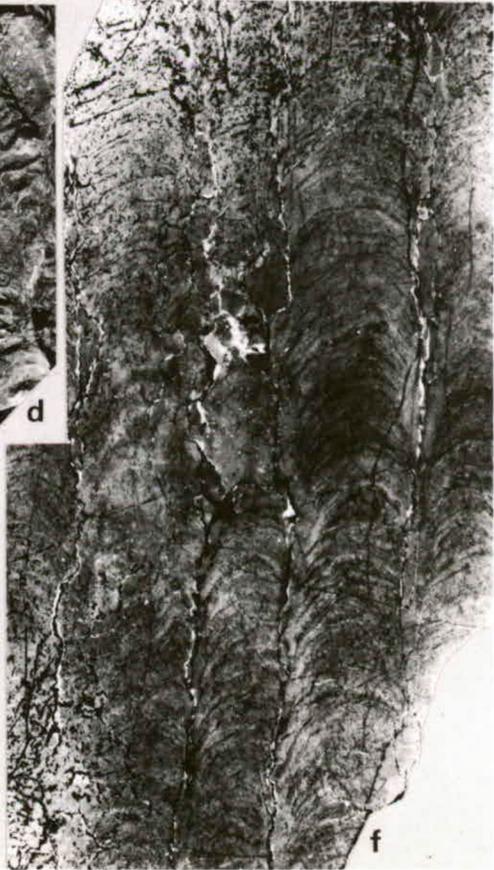
c



d



e



f

Fig. 14

Representative examples of lamina shape.

- (a) Acaciella angepéna.
- (b) Acaciella áugusta.
- (c) Acaciella f. indet.
- (d) Baicalia burra
- (e) Boxonia melrosa

Fig.14

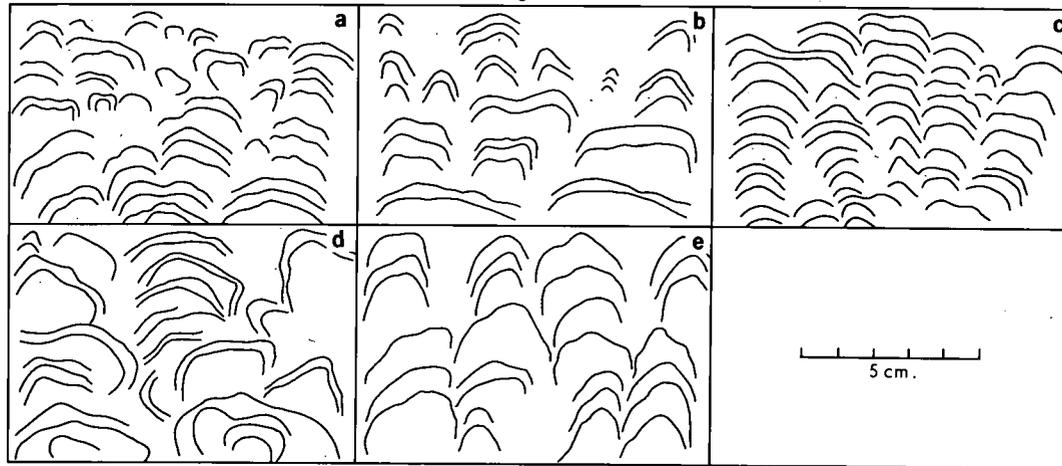


Fig. 15

Histograms of lamina convexities. The convexity of a lamina is the ratio of the height of that lamina to its diameter (h/d). Histograms are plotted for each stromatolite form at intervals of 0.1. n is the number of measurements made for each form.

- (a) Acaciella angepena.
- (b) Acaciella augusta.
- (c) Acaciella f. indet.
- (d) Baicalia burra
- (e) Boxonia melrosa

Fig. 15

