SPECIAL PAPERS IN PALAEONTOLOGY

Number 11

STROMATOLITES AND THE BIOSTRATIGRAPHY OF THE AUSTRALIAN PRECAMBRIAN AND CAMBRIAN

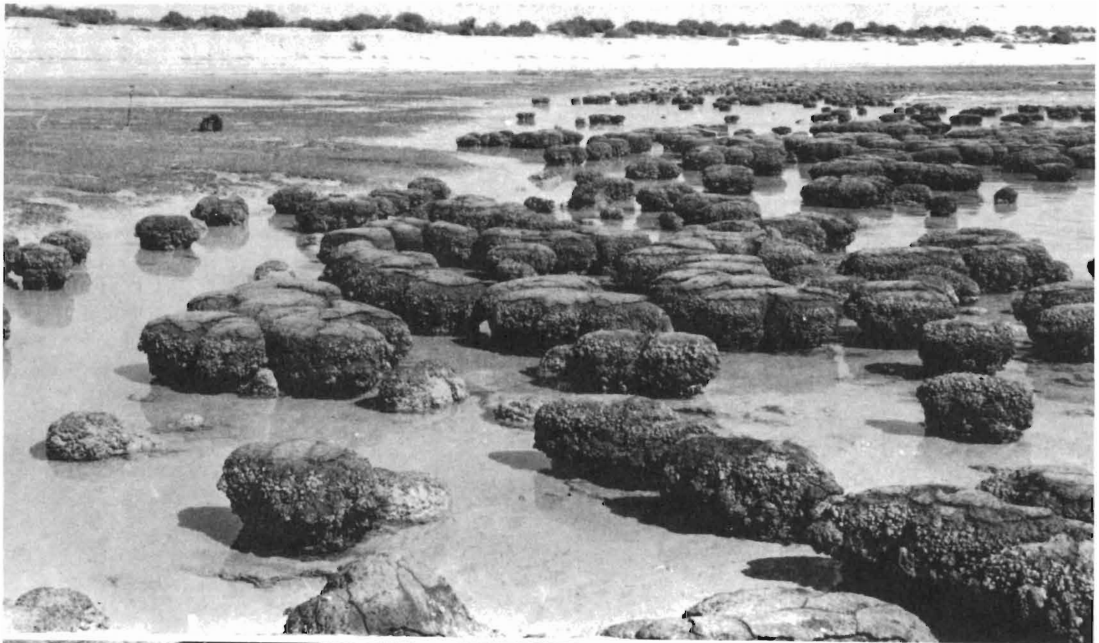
BY

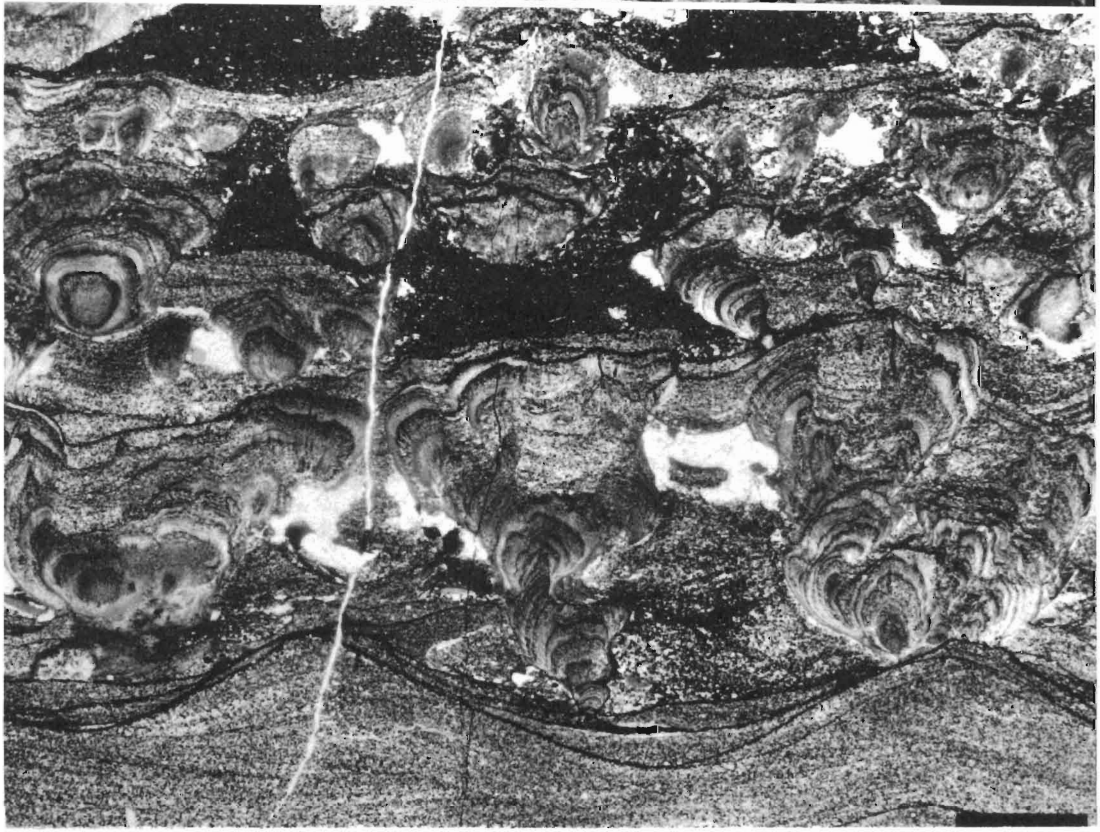
M. R. WALTER

PUBLISHED BY
THE PALAEONTOLOGICAL ASSOCIATION
LONDON

Price £10·00

Frontispiece. Top: Stromatolites in the intertidal zone of Shark Bay, Western Australia. The large stromatolites in the foreground are dead but living algal mats (dark grey) bind sediments between these and the dunes. Spade and haversack indicate scale. Bottom: *Alcheringa narrina* on ripple marks, Pillingini Tuff, Hamersley Basin. This is the oldest known Australian stromatolite (about 2190 ± 100 m.y.). Scale 5 mm.





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M. R. WALTER

With 34 plates and 55 text-figures

The Centre for Precambrian Research, University of Adelaide,
South Australia,
provided a grant towards the cost of publishing
this Special Paper

THE PALAEONTOLOGICAL ASSOCIATION
LONDON

DECEMBER 1972

WALTER, M. R. 1972. Stromatolites and the biostratigraphy of the Australian Precambrian and Cambrian. *Spec. Pap. Palaeontology*, **11,** 256 pp., 34 pls., 55 text-figs.

PRINTED IN GREAT BRITAIN

PREFACE

In October 1929, Sir Douglas Mawson, Professor of Geology and Mineralogy at the University of Adelaide and famous scientific explorer of the Antarctic continent, wrote to Professor I. I. Garwood of London University College:

'I am now on the eve of my departure South from Cape Town. The "Discovery" has been overhauled, and almost all stores are on board.

'Before leaving Australia, I picked out a few specimens of Algal Occurrences, and gave instructions for forwarding same to you. I anticipated to sending also some of our Northern Forms from the older Series, but had not time to put them together. These will go to you later.

'On my return from my last visit to London, I was able to make one rush visit to the North Flinders Range, there I got an abundance of Algal Forms, indeed, the Cambrian and Pre-Cambrian limestones thereabouts are principally composed of the remains of Algae. This will be a very interesting thing when it is written up, but I cannot attempt it until my return.'

On 29 March 1934, Mawson wrote to Dr. David White, of the U.S. Geological Survey:

'I am very interested indeed in the curious forms appearing abundantly in our oldest sedimentary rocks, which forms many geologists prefer to refer to as stromatoliths, rather than definitely assign them to algal origin. However, I myself have seen a great deal of them in the field both in South Australia and in Central Australia and am convinced that they have an organic origin. Some of my sections have yielded an indistinct structure similar to that of Girvanella. One of the outstanding features in the field is that these nodules of nearly pure carbonate material are separated by tracts of what I take to be sludge (earthy and sandy material often with some fragments of organisms) that has settled between the growing heads of the alga. In your letter you mention the same sort of thing from the United States occurrences. I found very nice material in the North Flinders Range, South Australia, back in 1924. Ever since then I have been locating similar formations in an ever-widening field. The discoveries in the MacDonnell Ranges, when Madigan accompanied me in 1927, showed that Pre-Cambrian and Cambrian strata of that region also is notable for its content of these remains.

'In 1929 I found Archaeocyathus associated with these forms in the North Flinders Range. Later on, Dr. Madigan, extending earlier observations in the MacDonnell Ranges, discovered also the association of Archaeocyathus with these forms in the topmost beds.

'I have collected information concerning similar formations in the North China, South Africa, India and Britanny early in 1927 and made a special visit to Washington to discuss the matter with Dr. Walcott and was fortunate in seeing his specimens and discussing with him the forms recorded by him from the Belt formation of North America. His death immediately afterwards was most unfortunate, so that I was not able to pursue further with him discussions on the subject.

'I have two papers practically completed indicating the stratigraphical relations of two occurrences in the North Flinders Range. The field work was done in 1928 and 1929 but the writing up has been postponed owing to the intervention of my two recent Antarctic cruises in the "Discovery".'

Mawson's views on stromatolites are summarized in an annotation for an 'Exhibit of Fossil Algae from the Flinders Range' (1929):

'During an inspection of the ancient limestones of many horizons in the Flinders Range, repeated and unequivocal evidence was forthcoming of the immensely important part played by calcareous algae in those formations. Immense thickness of limestones of Lower-Cambrian age associated with forms of Archaeocyathinae and others of the older group known as the Adelaide Series owe their origin largely to the activities of ancient forms of algae, predominant amongst which is a cryptozoon-like form. Most of these are without any typical microscopic structure and in external morphology resemble Collenia cylindrica. But there are several well defined forms. Girvanella, also oolitic and pisolitic forms are increasingly common in the upper horizons.

'The occurrence of Girvanella with its typical microscopic structure in the Cambrian division of these rocks has been known for long and Cryptozoon-like forms were recognized several years ago. But the present inspection has served to enormously extend the vertical and horizontal range of the occurrences.

'At Wooltana, thick limestone beds above tillite which have been regarded as equivalents of the Brighton limestones of the Adelaide Series are found to be fundamentally of Algal origin. These beds probably correspond with the Belt formation of Montana and the Sinian formation of China, both famous for their Algal contents.'

Mawson had assembled a large collection of stromatolites, together with specimens for comparison which he obtained from C. D. Walcott shortly before Walcott's death in 1927. He had made lengthy extracts from the relevant literature. In his later years Mawson's extensive commitments to his teaching department, to his research on the Flinders Ranges in South Australia and elsewhere, and above all to Antarctic exploration did not permit him to return to his studies on algae. In 1940, in a letter to G. Tandy at the Department of Botany of the British Museum (Natural History) he deplored the absence of specialists on 'calcareous algae' in Australia. He had published brief papers on ancient algal rocks in 1925 and (with C. T. Madigan) in 1930 and on algal limestones in the process of formation in 1929, which had greatly interested and influenced overseas workers. I recall discussing in the late 1920s and early 1930s with J. von Pia in the Vienna Natural History Museum and later with V. P. Maslov in the University of Moscow Mawson's contributions to the understanding of stromatolites, which were then being studied by these pioneer workers. When I joined Mawson's staff in 1950 he brought to my attention an important source of research material, the stromatolite collections in his department. At first I was sceptical about the possibilities of conclusive results being obtained from detailed stromatolite investigations because specific algal cellular structures were not commonly preserved in stromatolites and no clear methodology had emerged for the study and discrimination of these organo-sedimentary structures. However, Mawson's enthusiasm convinced me that work on this material should be undertaken and before his death in 1958 I promised him that it would be done.

Soon afterwards, at the International Geological Congress in Copenhagen in 1960, Logan and Ginsburg demonstrated the existence of Recent columnar stromatolites in Shark Bay on the coast of Western Australia, and of nodular stromatolites, similar to Mawson's 'algal biscuits', in the Bahamas. After the Congress I visited the Geological Institute of the U.S.S.R. Academy of Science in Moscow where I found an enthusiastic group of younger workers who were continuing Maslov's research under his guidance. They had developed methods which allowed discrimination of these complex structures and they were convinced that the use of stromatolites for stratigraphic correlation of Precambrian rocks was a practical possibility, provided these methods were strictly adhered to. The information which was generously placed at my disposal by my Russian colleagues was convincing enough to persuade research students in my laboratory to test these methods for the first time on Australian Precambrian and Cambrian material. Soon a start was made with a survey of Mawson's collections and in the following years large additions were made to them by M. R. Walter and W. V. Preiss. I am pleased to have the opportunity to introduce with this historical background information Dr. Malcolm Walter's monograph which owes in many ways much to the enthusiasm of my late teachers, colleagues, and friends: Mawson, Pia, and Maslov.

MARTIN F. GLAESSNER

Emeritus Professor
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CONTENTS

ABSTRACT. The modern Russian methods of stromatolite classification and zonation of the Precambrian are tested in Australia on stromatolites from the Amadeus, Hamersley, Bangemall, McArthur, and Georgina Basins and the Antrim Plateau Volcanics, and from the Ventersdorp 'System' of South Africa, and are found to be generally applicable. Only columnar stromatolites are used and they are classified using their column shape, orientation and branching, lamina shape and, infrequently, microstructure. Taxa intergrade, but each has a distinct mode in its range of variation and the taxa boundaries are defined between these modes.

There is a positive correlation between lamina shapes and the gross shapes of stromatolites. Studies of modern stromatolites and algae have revealed that lamina shape depends on the shape of the algal plant forming the stromatolite and that plant shape depends on the algal taxa involved as well as on the environment of growth. Hence the shape of stromatolites depends at least to some extent on the algae which build them.

Reconstructions of the appearance during growth of the Amadeus Basin stromatolites shows a resemblance to modern stromatolites in Shark Bay, Western Australia (but there are numerous differences in detailed morphology). The stromatolites in the Bitter Springs Formation of the Amadeus Basin form widespread biostromes which probably are diachronous, like those presently forming around the Persian Gulf. A petrological study indicates that although many of these stromatolites are now dolomite, they were probably originally aragonite and a morphological study indicates that they grew subtidally.

New correlations which are more precise than previously possible are made between the Amadeus Basin and Adelaide Geosyncline. The upper Bitter Springs Formation of the Amadeus Basin is intermediate in age between the Umberatana Group and the Skillogalee Dolomite of the Burra Group, Adelaide Geosyncline. Both the upper Bitter Springs Formation and the Umberatana Group contain rich stromatolite assemblages indicating correlation with the Upper Riphean (950±50–680±20 m.y.). The Skillogalee Dolomite contains a Middle Riphean (1350±50–950±50 m.y.) assemblage. Middle Riphean stromatolites also occur in the McArthur Basin and in the Bangemall Group of the Bangemall Basin. A Cambrian stromatolite from the Amadeus Basin is distinct from all Precambrian stromatolites, except some from the very latest Precambrian, but is similar to other Cambrian stromatolites in possessing a very distinctive vermiform microstructure which first appears in stromatolites just prior to the beginning of the Cambrian. A probably Early Cambrian stromatolite from the Georgina Basin is a new kind closely related to *Jacutophyton*. Two forms of *Conophyton* are identified from the latest Precambrian or Early Cambrian Antrim Plateau Volcanics. The correlations suggested are all consistent with known stratigraphic, palaeontological and radiometric data, except some new radiometric data from the Adelaide Geosyncline which have yet to be confirmed. The zoning scheme is extended to the early Proterozoic and three distinctive stromatolites are identified from the Mount Bruce Supergroup (approximately 2000 m.y. old). These are different from younger stromatolites but one also occurs in the early Proterozoic Ventersdorp 'System' of South Africa. However, a fourth stromatolite from the Mount Bruce Supergroup is indistinguishable from a Riphean form.

The taxa described are *Conophyton basalticum*, *C. garganicum australe*, *C. g. ?garganicum*, *C.* cf. *gaubitza*, *Georginia howchini*, *Acaciella australica*, *Alcheringa narrina*, *Baicalia capricornia*, *Basisphaera irregularis*, *Boxonia pertaknurra*, *Inzeria intia*, *Jurusania nisvensis*, *Kulparia alicia*, *Linella avis*, *Madiganites mawsoni*, *Minjaria pontifera*, *Patomia* f. indet., *Pilbaria perplexa*, *Tungussia erecta*, and *T. inna*.

INTRODUCTION

STROMATOLITES are layered organo-sedimentary structures built by microscopic algae and bacteria. They are growing today and not only do they occur throughout the geological column, including the Archaean, but there are very few Precambrian sedimentary carbonates without them. They show great morphological diversity and can survive moderate deformation and metamorphism. These facts indicate their potential as zone index fossils for the Precambrian. Here this potential is investigated and developed and stromatolites are used for both interregional and intercontinental correlation. But is Precambrian biostratigraphy necessary or even useful? The answer lies in the controversies surrounding the radiometric dating of many sedimentary sequences, such as the basal sediments of the Adelaide Geosyncline and the Amadeus Basin of Australia (text-fig. 1). Even where there have been intensive

TEXT-FIG. 1. Locality map showing Australian sedimentary basins discussed in the text.

dating programmes employing several isotopic decay systems uncertainties of several hundred million years often remain in the age limits finally determined for a sedimentary sequence: the north American banded iron formations are an example (see Trendall 1968). So a use for Precambrian biostratigraphy is readily found. Precambrian sediments contain other fossils as well as stromatolites, and Glaessner (1968) has discussed their use in biostratigraphy, but only stromatolites have been rigorously tested for intercontinental correlation.

'Stromatolites are notoriously variable' (Glaessner 1968). The variability of modern stromatolites is related to environmental conditions (Logan 1961; Monty 1967; Hoffman 1967), but Monty shows that the Bahaman stromatolites also vary with the algae which build them. There are other examples of modern stromatolites which differ in shape according to which algae build them and a reading of algal literature shows that this is to be expected. If algae evolved, so would the stromatolites they build. Algal floras did evolve through the Precambrian, as Schopf (1970) has described; in the opinion of a biologist (De Ley 1968), algal evolution may not have been as slow as the inadequately preserved fossils suggest.

In the U.S.S.R. during the last decade stromatolites became a standard tool for the subdivision and correlation of Late Precambrian sedimentary rocks, and new methods and classifications were developed (Semikhatov 1962; Krylov 1963, 1967; Komar *et al.* 1965; Raaben 1969*a*, *b*). This work and its early results attracted attention in Australia (Glaessner 1962, 1966; Edgell 1964) and subsequently in other countries. In the U.S.S.R. the stromatolite assemblage zones are applicable to rocks of a variety of facies developed over enormous areas (from the Baltic to the Pacific), which was sufficient to suggest their world-wide applicability, and this has now been demonstrated by Glaessner *et al.* (1969) and Cloud and Semikhatov (1969). The necessary taxonomy is troublesome because of the paucity of characteristics available and for this reason only the most complex stromatolites, the columnar ones, are given systematic treatment here.

It is appropriate that the Australian stromatolite distribution has been used to test the generality of the Russian scheme because important pioneering work on the origin and stratigraphic distribution of stromatolites was done in Australia early this century. Stromatolites were first found in Australia in the Bitter Springs Formation of the Amadeus Basin (Chewings 1914). These were described by Howchin (1914) as *Cryptozoon australicum* and *C. tessellatum*, both now renamed *Acaciella australica*. Mawson (1925, 1929) described fossil stromatolites from the Adelaide Geosyncline and modern algal deposits from southeastern South Australia, in work which was an important contribution to establishing that stromatolites are built by algae, a contentious hypothesis during the first few decades of this century. Mawson and Madigan (1930) and later Madigan (1932*a*, *b*, 1935) alone made a detailed field examination of the Amadeus Basin stromatolites and discovered two successive different assemblages of stromatolites, one Precambrian, the other Cambrian. These assemblages were enlarged by the inclusion of mottled carbonates whose origin remains to be satisfactorily explained. Madigan (1932*b*) classified the stromatolites and mottled carbonates into seven groups on the basis of external shape and lamina shape, and found that 'Particular types of growth are absolutely characteristic of certain horizons throughout this great succession of series, a strong point in favour of an organic origin, and this in localities a hundred miles apart', an observation which was a source of encouragement to later investigators who attempted to use stromatolites for correlation. An important observation made by Mawson and Madigan (and others previously) is that the distinctive *Girvanella*-built oncolites first appear in the Cambrian. These oncolites are not fundamentally different from columnar stromatolites, so there has existed for years strong evidence of the temporal restriction of stromatolite taxa.

The research published here was the first detailed study of Australian Precambrian stromatolites and was directed to investigating the validity of the various stromatolite classifications in use (and if necessary to developing a new classification) and to investigating the applicability of the Russian zoning scheme by studying a wide geographic and temporal range of stromatolites. Stromatolites were collected or obtained from as many Australian Precambrian sedimentary basins as possible. My own collecting was in the Amadeus, Hamersley, and Bangemall Basins but specimens from the Georgina and McArthur Basins and Antrim Plateau Volcanics (text-fig. 1) were also studied. The wide-ranging nature of the study allowed little possibility of detailed local investigations except in the Amadeus Basin, where excellent outcrop enabled a detailed study of stromatolite mode of occurrence and lateral variation. It was possible to spend some time on a lithofacies and environmental study of the stromatolites, and the information collected will be useful for future detailed environmental analyses; this aspect of the study of stromatolites is treated in greater detail in Preiss' (1971) complementary study of those from the Adelaide Geosyncline.

SYNOPSIS OF STROMATOLITE STUDIES

The history of stromatolite research has been the subject of frequent reviews of which Maslov's (1960) is the most detailed. A recent comprehensive review is that of Hofmann (1969*b*). The term stromatolite was introduced by Kalkowsky (1908) but these structures had been described (as concretions) as long ago as the early nineteenth century. The name *Cryptozoon* was introduced by Hall (1883) and the 'genus' soon accumulated a number of 'species' (Dawson 1896; Wieland 1914). Meanwhile, other generic names had been introduced: for example *Archeaozoon* Matthew 1890, *Gymnosolen* Steinmann 1911, and *Spongiostroma* Gürich 1906. During this early period there was much speculation about the nature of stromatolites; Howchin's (1914) discussion of the subject is representative: he saw structural resemblances between stromatolites and Protozoa (Foraminifera) but was discouraged from this view by the large size of some stromatolites. Another possibility he considered was that stromatolites may be related to the calcareous algae. He concluded: 'It seems probable that *Cryptozoön* is a primitive type that does not closely accord with any of our existing phyla, but may be an ancestral form of the Stromatoporoidea, or some other group of the calcareous Hydrozoa.' It was the work of Walcott (1914), Bradley (1929), Mawson (1929), Black (1933), and Pia (1927, 1933) which firmly established that stromatolites were built by algae and possibly bacteria. This conclusion followed detailed comparisons between modern and ancient stromatolites and algal tufas, and the discovery of microfossils by Walcott in Precambrian stromatolites and by Bradley in Eocene stromatolites; Walcott's discovery has recently been supported by Gutstadt and Schopf (1969). The view that stromatolites were the result of the life activity of algae was still criticized by some (e.g. Seward 1931) but at least in part their attention was directed against structures which are in fact abiogenic, including finely laminated soil calcretes.

The 1920s and 1930s saw increased activity, with Young, the Fentons, Maslov, and Johnson describing numerous fossil stromatolites. In Australia Mawson's (1925) interest in the subject led him, and later Madigan, to make many significant observations on fossil stromatolites as well as their modern counterparts. During the 1940s and early 1950s critical discussion of stromatolite taxonomy (Cloud 1942; Anderson 1950) contributed to a shift of emphasis, and in the West the ecology of stromatolites became the main subject for research in this field. Ginsburg made many contributions to the study of modern stromatolites and Rezak (1957) published a well documented example of the use of stromatolites for intrabasinal correlation. Outstanding recent studies of modern stromatolites are those of Logan (1961), Monty (1967), Gebelein (1969), and Davies (1970*b*).

Prior to the detailed Russian work of the last decade very few attempts had been made to use stromatolites for interregional correlation. At the time of Cloud's (1942) paper disparaging the use of stromatolites as index fossils, exploratory studies with this aim were just coming to fruition. Apparently that paper was a discouragement for many years, despite the careful, logical rebuttal by Fenton (1943). Only Maslov (1939*a*) had attempted precise interregional correlations, but Walcott, Mawson, Madigan, the Fentons, Johnson, and others had accumulated many essential and encouraging data. That Walcott (1914) recognized the potential of stromatolites for interregional correlation is shown by his statement (ibid., p. 98) that he knew of no 'true Cryptozoön older than the Cambrian fauna'. Walcott and all subsequent workers until late in the 1950s distinguished stromatolite taxa on their outward shape as seen in outcrop or a few longitudinal or transverse cuts, their size, and the gross features of their lamina shape. The Fentons (1931 et seq.), Maslov (1937*a* et seq.), and Johnson (1937 et seq.) named taxa distinguished only on these features. This results in the grouping of numerous stromatolites which probably could be distinguished by modern methods, and accounts for the frequent criticisms that stromatolite taxa are too long-ranging to be of any use in biostratigraphy. Such identifications led Maslov (1937*a*) to the conclusion that stromatolites are unimportant as index fossils although he allowed the possibility of more detailed studies proving the opposite, and indeed he later found them more useful. For some time there had been controversy about the age of sediments in the Ural which lack conventional fossils; Maslov (1939*a*) established the presence of a succession of different stromatolites through these beds and correlated it with the succession in eastern Siberia and China, where the age of the units was thought to be known. But some of his identifications were superficial in the extreme, as for instance that of *Collenia cylindrica* Grabau from the Ural. The Fentons were more cautious. Even though they described many taxa they used them only for local correlations (e.g. Fenton and Fenton 1939) and recognized the extent of environmental variation (Fenton and Fenton 1933). They were aware of the potential of stromatolites for interregional correlation but considered that more data must be accumulated before this potential could be realized (Fenton 1943), a conclusion earlier reached by Mawson and Madigan (1930). Johnson (1937 et seq.) described many new taxa from a wide range of Phanerozoic sediments, but despite the description of different taxa from rocks of different ages and statements on the restricted time ranges of some taxa he concluded that stromatolites cannot be used for more than local correlation (Johnson 1961, 1966). Cloud's (1942) disparagement of the use of stromatolites for long range correlation was based on his conviction that even *Gymnosolen*, one of the most distinctive of all stromatolite groups, ranges from the Precambrian to the Recent. As Fenton (1943) pointed out, this resulted from Cloud's very broad definition of the taxon: he called any columnar branching stromatolite *Gymnosolen*. Johnson (1966) rightly notes that similarly broad usage of *Gymnosolen*, *Collenia*, and *Cryptozoon* still pervades Western literature where, as a result, these names have little meaning.

In the U.S.S.R. during the 1950s extensive studies of Precambrian and Palaeozoic sequences lacking conventional fossils led to the intensive study of stromatolites. Maslov continued to study in detail the shape of stromatolites, while Vologdin and Korde concentrated on a search for fossil algae within stromatolites. The latter trend culminated in a voluminous and copiously illustrated book by Vologdin (1962). Towards the end of the 1950s there appeared the first of a new series of Russian publications on Precambrian stromatolites, and over the next decade new methods and classifications were developed. This upsurge in interest in the Precambrian provided a strong incentive for the study of stromatolites from a biostratigraphic view point and, besides the Russian publications discussed in later sections, has recently produced the work of Glaessner *et al.* (1969), Cloud and Semikhatov (1969), Hofmann (1969*a*), and Bertrand-Sarfati and Raaben (1970). Valdiya (1969) has shown that the potential exists for extending these methods to the Indian Precambrian, but the methodological short-cuts and unsatisfactory nomenclature he employs greatly reduce the value of his results.

Acknowledgements. The research published here formed the major part of the requirements for the degree of Doctor of Philosophy at the University of Adelaide, South Australia. It was instigated, supervised, and facilitated in many ways by Professor M. F. Glaessner, who also critically read the manuscript of this paper: to him I am deeply indebted. The interest of Mr. Haddon King and the financial assistance of his company, Conzinc Riotinto of Australia Ltd., made this project possible. Specimens and information made available by the Directors of both the Bureau of Mineral Resources, Geology and Geophysics (Australia) and the Geological Survey of Western Australia allowed a wider and more complete investigation of Precambrian sedimentary basins than would otherwise have been possible, for which I am very grateful. In a tour of Shark Bay, Western Australia, Drs. B. W. Logan and R. G. Brown provided guidance and information which have since proven extremely valuable. Mr. J. E. Banks of Magellan Petroleum Corporation kindly showed me several exposures of stromatolites in the Amadeus Basin.

I am especially grateful to my Russian colleagues for their assistance in numerous ways. Many provided literature which is not widely available outside the U.S.S.R. Drs. M. A. Semikhatov and I. N. Krylov took part with me in a lengthy correspondence which provided much important information, and they also sent numerous specimens on exchange. Dr. Mary Wade of the University of Adelaide was always willing to discuss problems and constructively criticized much of the writing which led to this paper. My colleague Dr. W. V. Preiss provoked numerous stimulating and valuable discussions and assisted on one field trip to Western Australia. Professor H. J. Hofmann of the University of Montreal offered much useful and constructive criticism.

My wife, Marilyn, and Mr. J. C. Gehling redrew my stromatolite reconstructions, and in addition my wife enlivened and assisted field work in Central Australia. I am also grateful to my parents for their assistance in arranging and expediting field work in Central Australia.

Recently Professor Preston Cloud very generously provided access to his extensive collection of Precambrian stromatolites, and conducted me on a tour of late Precambrian stromatolite localities in the Death Valley region, California. Much of the manuscript preparation was undertaken in the Department of Geology and Geophysics, Yale University; Mrs. Jean Lawless of the Peabody Museum at Yale assisted with the drafting.

The latter part of this research was financed by a Research Grant from the University of Adelaide. Financial assistance from a grant to Professor M. F. Glaessner from the American Chemical Society's Petroleum Research Fund is also acknowledged.

Contributions from the following sources towards the cost of publishing this Special Paper are gratefully acknowledged: Centre for Precambrian Research and Publications Committee (University of Adelaide), the Schuchert Fund (Peabody Museum, Yale University), and Conzinc Riotinto of Australia Ltd.

METHODS

Field methods. During this research it was decided that gross morphological features of stromatolites and the patterns of variation of these within a bed, over distances of up to many tens of metres, are of taxonomic significance and important in the interpretation of morphology. Thus detailed observations on a scale only feasible in the field are necessary. Most of the field data were recorded as photographs. Where the stromatolites were too indistinct to show on a photograph the margins of all columns in the area to be photographed were marked with a soft-tipped black-ink pen (Pl. 21, fig. 3).

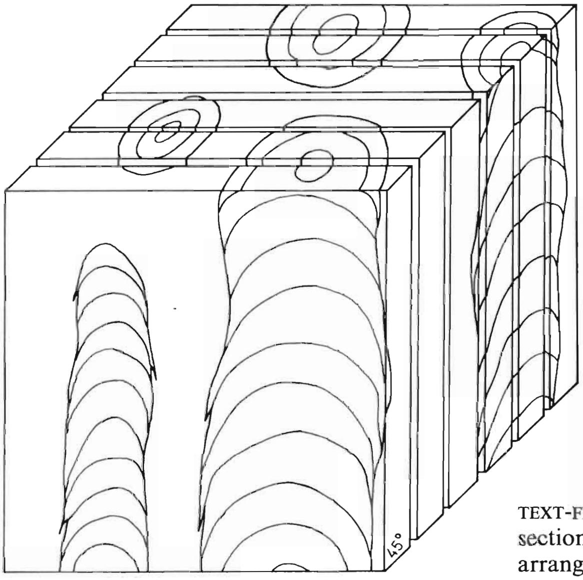
Only by studying a number of large specimens was it possible to discover the modal form, gross shape, and variability of a particular stromatolite. The original position of specimens within beds was noted and sometimes photographed. About 200 specimens were used in this study.

The following were recorded in the field:

1. shape of the stromatolitic bed;
2. mode of origination of columns;
3. structure of the top of the bed;
4. orientation of the columns;
5. frequency and type of branching;
6. shape of columns in transverse section;
7. vertical and lateral changes within beds, particularly as bioherm margins are approached.

Reconstruction. Krylov (1963) found that much data of taxonomic significance can only be obtained by detailed three-dimensional studies, and, indeed, these are essential since resemblances between sections are often fortuitous. He developed a now widely used method known to the Russians as 'graphical preparation'. This involves graphically reconstructing the shape of stromatolites from serial longitudinal sections (Raaben (1969*a*) used transverse sections). As applied here the method involves cutting slabs of such a thickness that each stromatolite column appears on at least four sections, i.e. on two slabs (text-fig. 2). Each cut provides two sections. Four sections is the minimum necessary for accurate reconstruction of small columns. In the reconstructions figured here columns frequently appeared in ten adjacent sections and occasionally in as many as thirty. The cutting of a single transverse section before the serial longitudinal sections simplified reconstruction by providing a reference line on each slab.

Reconstructions were made in the form of block diagrams, usually with 45° angles between the frontal face and lines representing the top and visible side (text-fig. 2). Diagrams with 60° angles were used where this would make visible significant features that would be obscured on a 45° diagram. The longitudinal sections were placed parallel to the frontal face of each diagram. On 45° diagrams each successive section was displaced upwards and towards the visible side of the block by the distance from the preceding section reduced by cosine 45° (0·7). The 0·7 reduction simulates the apparent shortening due to the slope of the sides of the block away from the observer. For the same reason in 60° diagrams each section was displaced upwards by the distance from the preceding section reduced by sine 30° (0·5) and sideways by this distance multiplied by cosine 30° (0·9). Wherever possible the shape of the stromatolite on each section was traced directly on to the block diagram. It was often necessary to outline the columns in ink or pencil to make them visible through tracing paper, but etching with dilute hydrochloric acid sometimes made columns more easily visible. When the rock was so dark that ink lines were invisible through tracing paper, the column shape was first traced on to clear plastic. Only those parts not obscured by previous sections were traced on to the block diagrams. Where longitudinal sections appear on the shaded reconstructions the laminae shown were traced directly from the specimen; only selected laminae are shown. Laminae



TEXT-FIG. 2. Diagram of a stromatolite specimen sectioned ready for reconstruction, with the sections arranged as in the final reconstruction (a 45° example).

on transverse sections were sketched in without reference to the specimen, unless stated otherwise in the figure captions.

The accuracy of the reconstructions varies with the preservation of the stromatolites. To indicate the accuracy of those figured three ratings are used and are given in the figure captions:

R1—as accurate as the method allows with well preserved, distinct columns.

R2—column margins are slightly altered or indistinct; the gross shape is as accurate as for R1 but the margin structure is a little inaccurate.

R3—columns very indistinct or altered; gross structures as reconstructed moderately inaccurate (e.g. may be more or less coalescing than shown, bridges may be missed or interspace laminae mistaken for bridges); reconstructions of the column-margin structure are very unreliable.

Thin sections. The shape of laminae, column-margin structure, microstructure, and texture of each stromatolite were studied in large thin sections. The least-altered specimens were chosen for thin-sectioning, and each section was made as large as necessary to show a representative portion of the stromatolite; the thin sections are commonly about 15 cm wide, but the largest dimension of some is 25 cm. They are thicker than petrological sections, since this is required for distinctness of the features studied. Conventional petrologic study of minerals is usually possible in thin areas near the margins of sections.

Mineralogical analysis. The stromatolites are composed predominantly of carbonate minerals. These were distinguished in many of the stromatolites using staining and X-ray powder photographic techniques; only dolomite and calcite were found. With an accuracy of probably about 70–80 per cent (as found by subsequent staining and X-ray analysis) calcite was also differentiated from dolomite simply by the amount of effervescence in dilute hydrochloric acid.

Statistics. Various parameters have been measured by Komar *et al.* (1965) to support their classification of conophytons. Several of these are probably insignificant, but two have been used here: the thickness of laminae on their limbs and in their crests, and the width of the crestal zone. This method is not that of Komar *et al.* (1965), and the results are not comparable with theirs for the reasons discussed on p. 11.

Time necessary for identification. Although reconstruction is essential for the initial defining of taxa, it is not always necessary for their subsequent identification. In many cases taxa can be identified from several longitudinal sections of columns. However, for positive identification a large thin section and at least one or two reconstructions are usually necessary. Nevertheless, when the stromatolites of a region are well known and outcrop is good, an experienced person can often make reliable identifications in the field.

MORPHOLOGY AND TERMINOLOGY

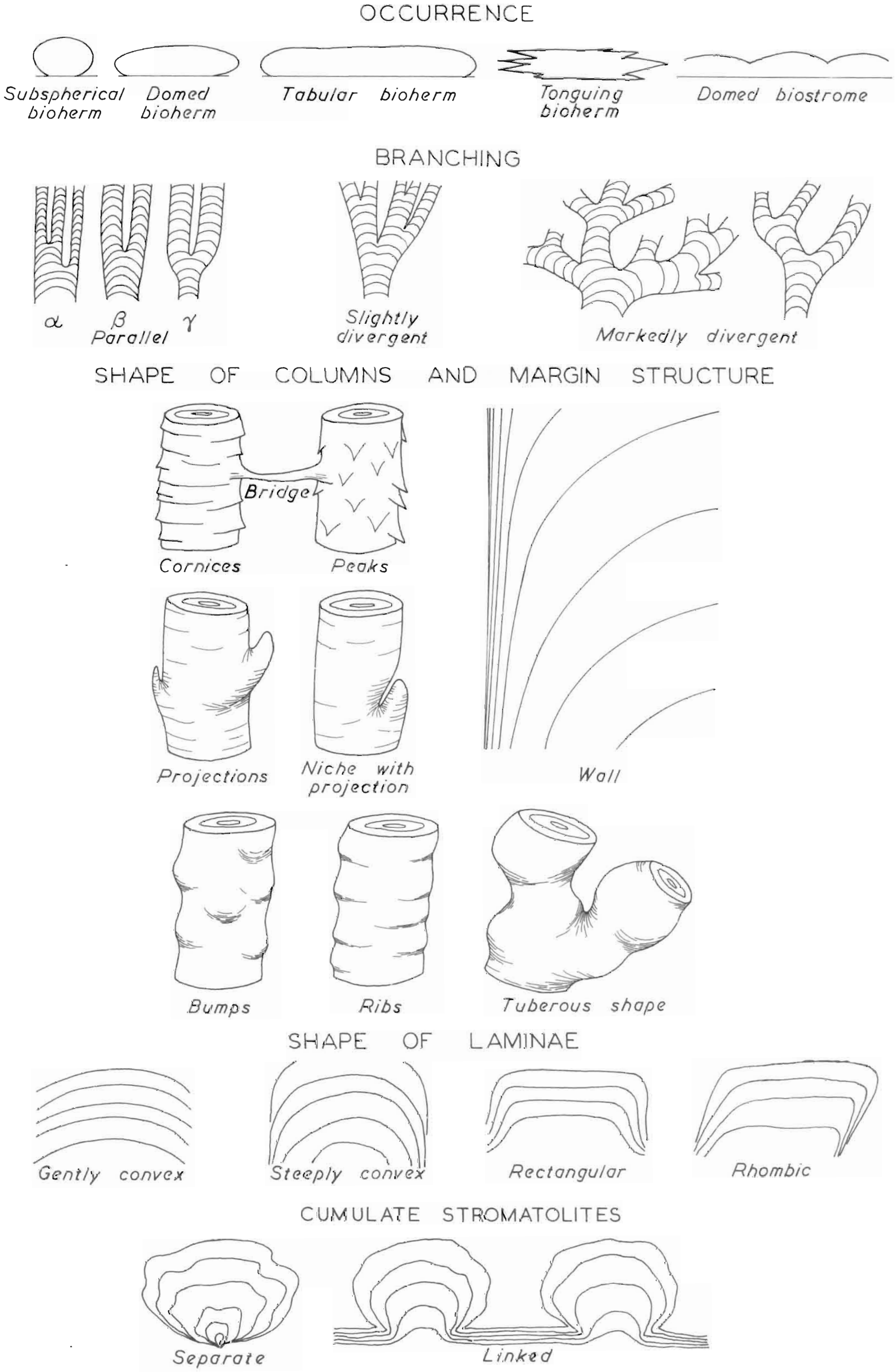
The range of morphological features available for the classification of stromatolites falls into five categories: mode of occurrence, style of branching, column shape, lamina shape (including column-margin structures), and microstructure. Text-figure 3 gives an impression of the range of variation found within four of these categories and shows many of the terms applied; a complete glossary is given at the end of this section. To minimise the introduction of new terms, suitably translated Russian terms are used wherever they are appropriate and desirable, although some replacements are necessary. The use of many of the terms was illustrated by Glaessner *et al.* (1969). Hofmann (1969*b*) introduced many new terms, most of which are unnecessary for our purposes although they may be essential to his approach. Where necessary, terms are discussed below.

There is much confusion over the use of the terms biostrome and bioherm. The definition of Nelson *et al.* (1962) are used here but some modification is necessary because, at least where they are built by stromatolites, bioherms and biostromes intergrade. After consideration of the difficulties involved in using these terms it was decided to define an arbitrary boundary between the two, such that biostromes must be at least one hundred times as long as thick. In the rare case of the full three-dimensional shape of the stromatolitic structure being known, before the structure qualifies for the term biostrome, the minimum width must be at least one hundred times the maximum thickness.

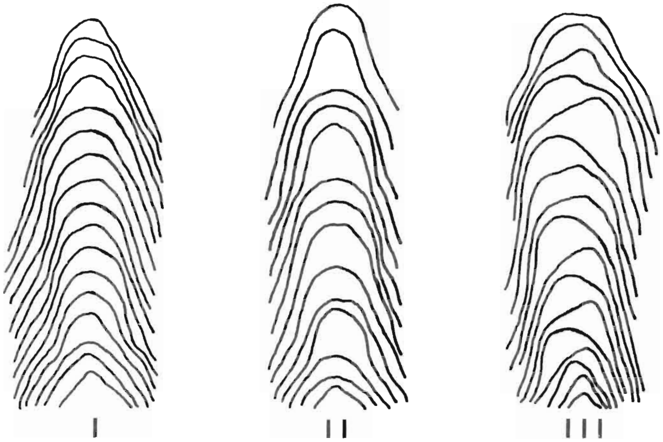
The terms used here to describe styles of branching differ from Hofmann's (1969*b*) and the two schemes are largely irreconcilable because the categories of branching found useful here are not those selected by Hofmann. The branching terms active and passive, used by some Russian authors, are abandoned as inappropriate for the reasons outlined by Krylov (1967).

The lamina shape terms 'wavy' and 'wrinkled' are subdivisions of Hofmann's (1969*b*) category 'crinkled', and are differentiated on size (see glossary). There is much confusion over the meaning of wall as applied to stromatolites: a wall is a structure at the margin of a column formed by one or more laminae from within the column bending down and coating the column margin for at least a short distance. Hofmann's (1969*b*, p. 15) statement that the presence or absence of walls is related to purely geometric factors is tautologous because that presence or absence is a geometric factor in the sense in which he uses the phrase. Contrary to his statement that walls tend to be closely associated with steeply convex laminae, the laminae of many walled stromatolites are gently convex except at their margins where they are sharply deflexed, and some columns with steeply convex laminae lack walls.

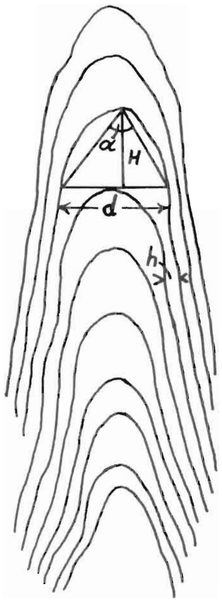
The laminae of *Conophyton* columns are predominantly conical, and Komar *et al.* (1965) recognize the existence of three kinds of crestal zones in this group (text-fig. 4). Their method of calculating a parameter dependent on the kind of crestal zone is unacceptable. They calculate the angle α in the apex of a triangle inscribed between the margins of adjacent laminae in the crestal zone (text-fig. 5). This angle depends on the dimensions of 'H' and 'd'; 'd' often depends on the slope of the laminae away from their crests and according to Komar *et al.* (1965, p. 20) their studies



TEXT-FIG. 3. Diagnostic terminology.



TEXT-FIG. 4. *Conophyton* crestal zones (from Komar *et al.* 1965).



TEXT-FIG. 5. The parameters used by Komar *et al.* (1965) in the description of *Conophyton* crestal zones: d = width of crestal zone, H/h = coefficient of thickening, α = inscribed angle.

indicate that the angle of these slopes is of no taxonomic value since they are very variable even within single columns. Thus the angle α depends partly on parameters considered by these authors to be taxonomically insignificant; I cannot agree with their statement to the contrary (ibid., p. 25). Since they also calculate the coefficient of thickening $\left(\frac{H}{h}\right)$ there is no need to calculate α. A useful mathematical parameter might be the radii of curvature of laminae in the crestal zone, which would be easily measurable with modern microscopic techniques (see Müller 1967). For descriptive purposes the coefficient of thickening and the crestal zone width have been measured in this study. Komar *et al.* (1965) take 'd' (text-fig. 5) as the crestal zone width but, as already shown, this depends on the slope of laminae and the coefficient of thickening; the measurements quoted herein are of the width of the thickened or contorted part of each lamina measured normally to the crestal zone.

The microstructure most common in Precambrian stromatolites is that which occurs in *Acaciella australica, Basisphaera irregularis, Boxonia pertaknurra,* and *Inzeria intia* (Pls. 2, 3), described below, and also in *Gymnosolen ramsayi* Krylov, *Inzeria tjomusi* Krylov, *Jurusania nisvensis* Raaben, *Kussiella kussiensis* Krylov, *Minjaria uralica* Krylov, and *Poludia polymorpha* Raaben. The laminae are moderately distinct and continuous; those which are darker are usually the most distinct and they are set in a matrix of pale carbonate, into which they frequently grade vertically. With only slight alteration they form grumous laminae (Pl. 3, figs. 1–2). Concordant stylolites may be infrequent (*A. australica*, Pl. 2, figs. 3–4) or very frequent (parts of *I. intia*, Pl. 3, figs. 3–5, and *I. tjomusi* Krylov 1963, pl. 13); the resultant microstructure is distinctive. Concordant stylolites are a constant and prolific feature of the lower, naked columns of *I. intia* but are infrequent in the upper, walled parts and seem to be infrequent in other stromatolites with walled columns. I propose that this type of microstructure, with or without stylolites, be called 'streaky'; it is often called 'platy' in the Russian literature. In well-preserved stromatolites with a streaky microstructure the laminae are moderately to very continuous. In some cases the laminae are discontinuous and have jagged margins: these may be described as irregularly streaky and may have formed by the alteration of even, continuous laminae. Hofmann's (1969*b*) term 'striated' is best used only for laminae that are considered to have originally formed as chains of lenses, as, for instance, some of the laminae of *Conophyton garganicum australe* (Pl. 6, figs. 1–3). Komar *et al.* (1965) use an equivalent Russian term in this sense.

Less common than the streaky microstructure is one in which the laminae are very continuous and have abrupt, distinct, more or less parallel boundaries. Such microstructures occur in *Baicalia baicalica* (Maslov) Krylov, *Kotuikania torulosa* Komar, *Vetella uschbasica* Krylov, *Alcheringa narrina, Baicalia capricornia*, and *Conophyton basalticum* (Pl. 5, figs. 1, 2, 5). This microstructure I propose to call 'banded'. An equivalent word is used in this context by several Russian authors. Some of these microstructures appear streaky when altered, but many streaky microstructures may be primary.

Laminae composed largely of recognizable detritus, such as those of *Tungussia inna* (Pl. 6, fig. 4), may be described as calcarenitic, oolitic, arenaceous, or lutitic. An especially distinctive microstructure occurs in many Phanerozoic stromatolites. It consists of narrow, sinuous areas of sparry carbonate surrounded by darker, usually finer-grained, carbonate. In the known examples, such as *Madiganites mawsoni* and *Ilicta composita* Sidorov, the sparry patches are less than 100 μ wide and reach a millimetre or more in length. Here this microstructure is called 'vermiform'. With slight alteration it forms a grumous microstructure. Any of the microstructural terms used may be qualified as distinct or diffuse (Hofmann 1969*b*) and regular or irregular. It is not suggested that these terms will be useful for every stromatolite, but they are widely applicable. They are not intended to replace detailed descriptions.

GLOSSARY

This glossary was compiled in co-operation with W. V. Preiss. Refer to text-fig. 3 for explanatory illustrations of the terminology.

AXIS: The centre-line of a column.

BANDED MICROSTRUCTURE: One in which the laminae are very continuous and have abrupt, distinct, more or less parallel boundaries.

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.

BIOSTROME: A stratiform organo-sedimentary structure whose minimum width is more than one hundred times its maximum thickness. Note: When the dimensions are unknown, the term 'stromatolitic bed' may be used.

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

Markedly divergent: Branching in which the axes of the new columns diverge at more than 45°.

Multiple: Branching at approximately the same level into more than two new columns.

Parallel: Branching in which the axes of the new columns are parallel. Note: Most commonly, the axes of the new columns are also parallel to the axis of the original.

α-parallel: Branching in which the width of the individual remains constant.

β-parallel: Branching in which the original column widens gradually before branching.

γ-parallel: Branching in which the original column widens abruptly before branching.

Slightly divergent: Branching in which the axes of the new columns diverge at 45° or less.

BRIDGE: Stromatolitic lamina or set of laminae linking adjacent columns.

BUMP: Low, rounded protrusion on the side of a column.

CATAGRAPHIA: Microscopic carbonate problematica. Many are probably grapestones, botryoidal lumps, and other sedimentary structures.

CLOT: A microscopic segregation of pigment.

COLUMN: Discrete stromatolitic structure with the dimension in the direction of growth usually greater than at least one of the transverse dimensions.

CORNICE: Overhanging lamina or set of laminae elongated transversely to its column axis.

CRESTAL LINE: Line joining the crests of successive laminae.

CRESTAL ZONE: The environs of the crestal line (see p. 11 for a more explicit definition of *Conophyton* crestal zones).

CUMULATE STROMATOLITE: A rounded, protruding, non-columnar stromatolite.

DENDRITIC INDIVIDUAL: An individual composed of variously inclined divergently branched columns.

DICHOTOMOUS BRANCHING: Branching into two new columns.

DOMED: With approximately constant radius of curvature.

GENTLY CONVEX: Ratio of height to width less than or equal to 0·5.

GNARLED COLUMN: With large bumps.

GRUMOUS: Mineral texture in which fine-grained patches are surrounded by coarser grains.

HYPIDIOTOPIC TEXTURE: A texture intermediate between xenotopic and idiotopic.

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

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

INTERLOBATE TEXTURE: A texture in which grain boundaries are wrinkled.

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

LAMINA: The smallest unit of layering.

LATERALLY-LINKED STROMATOLITE: With wavy laminae continuous between crests.

MACROLAMINA: A set of laminae.

MICROBIOHERM: Hand-specimen sized bioherm formed by the coalescing of individuals.

MICROPHYTOLITHS: Oncolites and catagraphia.

MICRO-UNCONFORMITY: Surface of lamination discontinuity within a stromatolite.

NAKED COLUMN: Column without walls.

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

ONCOLITE: Unattached stromatolite with encapsulating laminae.

PEAK: Overhanging lamina or set of laminae with a small dimension transverse to its column.

PIGMENT: Colouring matter, organic or inorganic.

PLATY COLUMN: A column in which one of the transverse dimensions is much larger than the other.

PROJECTION: 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.

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 with subparallel edges not perpendicular to the top.

RIB: Rounded protrusion which is elongated transversely to the column on which it occurs.

SELVAGE: Unlaminated coating on column margins.

STEEPLY CONVEX: Ratio of height to width greater than 0·5.

STRATIFORM STROMATOLITE: Non-columnar stromatolite with flat continuous lamellae (cryptalgalaminate sediment).

STREAKY MICROSTRUCTURE: One in which the laminae are moderately distinct and continuous; the darker are usually the most distinct and they are set in a pale matrix into which they frequently grade vertically (see pp. 11–12).

STRIATED MICROSTRUCTURE: One in which the laminae originally formed as chains of lenses.

STROMATOLITE: Layered organo-sedimentary structure built by microscopic algae and bacteria.

TABULAR BIOHERM: Bioherm with parallel upper and lower surfaces.

TABULAR BIOSTROME: Biostrome with parallel upper and lower surfaces.

TONGUING BIOHERM: Bioherm whose margins intertongue with the surrounding rock.

TUBEROUS COLUMN: Having prominent expansions and constrictions.

VERMIFORM MICROSTRUCTURE: One in which narrow, sinuous, pale-coloured areas (usually of sparry carbonate) are surrounded by darker, usually fine grained areas (usually carbonate).

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

WAVY LAMINA: With flexures of wavelength greater than 2 mm.

UNDULATORY STROMATOLITE: Laterally-linked stromatolite in which successive crests are not superimposed.

WRINKLED LAMINA: With flexures of wavelength less than or equal to 2 mm.

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

TAXONOMY

The classification and nomenclature used here are the empirical results of years of research, especially by Russian geologists. Any opponent of the use of Linnean nomenclature for stromatolites should read the cogent supporting arguments of Cloud and Semikhatov (1969): in summary they are simply that it most facilitates discussion. Differences of opinion and experience are inevitable at such an early stage in the use of a method, and as a result the taxonomy used here is a modification of earlier ones; in this section differences of emphasis and reasons for agreement are explained and justified. Here only columnar stromatolites and the pseudocolumnar and undulatory forms into which they grade are studied. Names are applied only to the columnar extreme of each gradational series because that is the most characteristic part. Three taxonomic categories are named: 'group', 'form', and 'variety', the last being of the lowest rank and infrequently used.

Hofmann (1969*b*) has reviewed previous taxonomies, but these must be briefly mentioned here, and the modern Russian approach needs description. Prior to the Russian work stromatolites were described from sections as seen in the field and occasionally from longitudinal, transverse, or oblique slabs or thin sections. This was the method of Howchin (1914), Walcott (1914), the Fentons (1931 et seq.), Maslov (1937 et seq.), Johnson (1937 et seq.), and others. In 1942 Cloud, like others before him, decried the use of formal binomial nomenclature for stromatolites because they may have been formed by assemblages of algae, not single species. He suggested that only actual fossil algae should be named, an approach long ago advocated by Madigan (1932*b*) and recently supported by Johnson (1966). The frequently-disparaged work of Vologdin and Korde is an attempt to put this into practice (e.g. Vologdin 1962) but, as Madigan found, algae are so rarely preserved in Precambrian stromatolites that the approach is impracticable. As Glaessner (1962) pointed out it is on the grounds of practicability that this taxonomic problem must be solved; and it was on these grounds that Rezak (1957) justified his use of a formal classification and nomenclature for Belt Supergroup stromatolites.

In 1960 Maslov published a new scheme for the classification and naming of stromatolites; this has not found general acceptance because of its cumbersome nomenclature, an example of which is *Collenia planolaminaris minutocolumnaris microstylostromica granulosa* (Maslov 1960, p. 70). Each morphological feature considered important by Maslov is given a Latin name, and the name of a stromatolite is formed by listing these features. Since such a list is not sufficient as a description, much of the point of the scheme is lost. Logan *et al.* (1964) proposed a novel solution to the nomenclature problem. They noted the variation and intergradation of stromatolites and criticized the commonly-used classification and nomenclature as being incapable of expressing these features (they did not mention the modern Russian taxonomy but only that used in the West). In its place they proposed a system of variable descriptive formulae. This has been widely adopted. It is especially useful in the field but, as Aitken (1967) and Bertrand (1968) have also found, it has many limitations; e.g. it cannot be usefully applied to the more complex stromatolites. Even for simple stromatolites the formulae can be unwieldy, e.g. $\frac{\mathrm{LLH-C \rightarrow SH-V \rightarrow LLH-S \rightarrow LLH-C}}{\mathrm{LLH-C}}$ (Logan *et al.* 1964, p. 77).

Each practising taxonomist has given a description of his or her approach: Korolyuk (1960), Semikhatov (1962), Krylov (1963, 1967), Komar (1966), Nuzhnov (1967), Raaben (1964, 1969*a*, *b*), Shapovalova (1968), Glaessner *et al.* (1969), Cloud and Semikhatov (1969), and Hofmann (1969*a*, *b*). A complete review of all their ideas would be too lengthy to include here but they have been considered in the development of my own approach which is explained below. Among the Russians still actively engaged in describing and classifying stromatolites there are three variations of approach. The two schools of thought adhered to by Semikhatov, Krylov, Raaben, Komar, Nuzhnov, Shapovalova, and others hold that the reconstruction of stromatolites by the methods applied by Krylov (1959, 1963) provides much taxonomically useful (or essential) data. The third, notably Korolyuk and Sidorov, defines taxa using data gained from slabs and thin sections, without reconstruction. Between the first two schools there is a difference of emphasis: Krylov maintains that small and consistent differences in column shape and arrangement necessitate the separation of new taxa and that microstructural differences are often due to secondary alteration and are of little taxonomic value even for defining forms ('form-species'). The others use Krylov's methods for defining groups ('form-genera') but follow Korolyuk in placing great emphasis on microstructure for the separation of forms; small morphological differences are considered taxonomically insignificant. They maintained that many microstructural features survive considerable recrystallization (Semikhatov and Komar 1965). In Raaben's (1969*a*) recent work this approach is taken to an extreme: an example is her review of the group *Inzeria*, which she greatly enlarges by the inclusion of forms with column shapes quite different from Krylov's (1963) original *Inzeria*. Numerous taxa are diagnosed by Raaben entirely on microstructure.

Korolyuk (1960) distinguished four taxonomic categories: type, subtype, group, and form. The three types recognized are continuously layered, nodular, and columnar. She stated that subtypes within the columnar type are distinguished by the presence and kind of wall. Further subdivision is into groups based on the shape of laminae, and finally into forms based on microstructure and smaller differences in lamina shape. In practice her group distinctions are made on features such as column shape and arrangement as well as lamina shape. Semikhatov (1962) stated that he followed Krylov in using for group differentiation a complex of column shape, branching, and margin structure; these he determined by reconstruction. Subdivision into forms is based on lamina shape and microstructure. He pointed out that in work previous to the 1960s and late 1950s such detailed studies were not made, and therefore it is difficult or impossible to relate taxa as now defined to those of earlier investigators.

A good example of the differing approaches is provided by the group *Minjaria* Krylov. Semikhatov (1962) includes in Krylov's *M. uralica* stromatolites with infrequent peaks and bridges which Krylov (1963) excludes because he says the original *M. uralica* has none of these. Krylov emphasizes the degree to which secondary alteration has affected the microstructure of these stromatolites, and disagrees with Semikhatov's practice of subdividing the group on such features. Raaben (1969*a*) accepts some of Semikhatov's forms as distinct but identifies them as *Gymnosolen* rather than *Minjaria*, stating that there are no significant morphological differences between these groups.

Krylov (1967, pp. 23–24) deems necessary the different naming of stromatolites from the central and marginal parts of bioherms where they are morphologically different although they have the same microstructure and lamina shape and very similar column shape, as for instance his *Linella ukka* and *Tungussia bassa*. On the other hand Semikhatov *et al.* (1967) stated that: 'The form genera of stromatoliths were identified from their morphostructure, with allowance for visible ecologic changes near the edges of bioherms, and also from the general pattern of their microtexture. The form species were instituted through their microtextural characteristics, with allowance for their morphostructure. With this as a starting point, all bioherm stromatoliths possessing an identical microtexture were put into one species' (translation by American Geological Institute).

Hofmann (1969*a*) compared Canadian Early Proterozoic and Early Riphean stromatolites with those from the Riphean of the U.S.S.R. He found some of the Russian names applicable, but had difficulty in using the Russian scheme for some of his stromatolites. This is not only because some of his stromatolites are different from described Russian forms, as he stated, but also because he did not apply the Russian methods. In particular, he did not reconstruct his stromatolites. Hofmann's (1969*b*) many objections to the Russian taxonomy are best answered by examples that show that it works, and these are presented below. But first it is necessary to comment on the taxa *Collenia* Walcott (1914) and *Cryptozoon* Hall (1883), the names of which are frequently abused. Hall's original description is not readily available, and I have not seen it, but it is quoted by Walcott (1914) and Logan *et al.* (1914). Walcott misinterpreted Hall's description, thinking that the Cambrian to Ordovician *Cryptozoon proliferum* Hall, the type 'species' of the 'genus', had upwardly concave laminae; as Goldring (1938) showed, they are convex. Goldring's illustrations and descriptions show that *Cryptozoon proliferum* is hemispherical, subspherical, or trochoid, with wavy laminae; parts of *Cryptozoon undulatum* Bassler are clavate or columnar but these shapes are exceptional for the group. Thus the conclusion of Logan *et al.* (1964) that *Cryptozoon* is 'club-shaped or columnar' is incorrect. The type form of *Collenia* is the Proterozoic *C. undosa* Walcott which apparently is an oncolite (Hofmann 1969*b*). Thus neither *Collenia* nor *Cryptozoon* are proper names for predominantly columnar stromatolites.

Validity of stromatolite taxa. The five stromatolite taxa discussed below will show that discrete taxa are recognizable, and on this basis the principles of classification will be developed. The stromatolite herein named *Acaciella australica* occurs throughout the northeastern Amadeus Basin and has been studied at eight localities up to 290 km apart. Its distinctiveness is such that at every locality except one where it is badly preserved there is no doubt about its identification despite variation in its gross shape. At Jay Creek it occurs in numerous biostromes, one of which was studied along an almost continuous outcrop length of about 2·5 km. Throughout this length it forms contiguous hemispherical and domed bioherms which are all about 1·3 m thick but which vary from 2 m to many tens of metres wide (text-fig. 29). In all of the bioherms there are broad, basal columns about 0·5–1·0 m high which simultaneously branch upwards in an α-parallel manner into numerous narrow columns. At Katapata Gap a biostrome also consists of contiguous bioherms which, however, are only about 50–60 cm high and are dominated by narrow columns; the broad columns are only a few centimetres high (text-fig. 30). At Acacia Well in some biostromes the broad columns are only a few centimetres high but the narrow columns continue up for about 1 m. Rarely there are no broad columns. The columns are parallel or radially arranged; most are straight and 2–20 mm apart. Branching of the narrow columns is randomly arranged and is predominantly α–β-parallel but includes some γ-parallel and slightly and markedly divergent. The columns are subcylindrical, up to many tens of centimetres wide in the broad column zone but predominantly 1–5 cm wide in the narrow column zone. Column margins are moderately bumpy with some longitudinal and diagonal furrows and numerous short ribs. Laminae in the broad columns are almost flat or very gently convex, rarely steeply convex; in narrow columns they are most frequently rectangular, rhombic, or gently convex. Column margins are usually smooth but only sparsely walled. In well-preserved specimens the laminae are smooth-margined and homogeneously pigmented.

No other described stromatolite from the Amadeus Basin or elsewhere has this combination of characters. In fact, it is necessary to specify only a few of these features to diagnose *A. australica*: they are the column arrangement, mode of branching, column shape, and column-margin structure.

A stromatolite in many ways similar to *A. australica* is *Boxonia pertaknurra*. This also has parallel or radially arranged broad and narrow columns, and its columns are predominantly about the same size as those of *A. australica*. The mode of occurrence appears to be similar to that of *A. australica* (but is not as well known), and the microstructure is the same, but in *B. pertaknurra* the branching from broad to narrow columns is randomly distributed and the columns have relatively smooth margins covered by a nearly continuous wall. Well-preserved specimens of the narrow columns of *A. australica* and *B. pertaknurra* are easily distinguishable, although the broad columns are in some cases identical.

Inzeria intia is another stromatolite with a broadly similar mode of occurrence to those just described. A biostrome of *I. intia* was studied over a strike length of 1 km: over this distance the proportions of the biostrome made up by the different growth stages varied markedly and in places the divergently branching, variously oriented broad columns of the lower stage were absent (just as the broad columns of *Acaciella australica* infrequently are absent). The column shape, branching, lamina shape, and microstructure do not vary along the outcrop. An interesting feature of *I. intia* is that the columns in the lower parts of the biostromes lack all but patchy walls (and here and there a selvage) but in the upper parts there is a continuous, multilaminate wall. The presence or absence of walls is used by most stromatolite taxonomists as an important taxonomic feature. In *I. intia* the acquisition of the wall is gradual over ten centimetres or so in a zone where much branching occurs; this zone is curved, conforming to the outward shape of each bioherm. It is unnecessary to classify differently the different parts of this stromatolite: stromatolites both with and without walls must be included in the group *Inzeria* (as in fact Raaben 1969*a* has done), and here in the one form *I. intia*. Other features of *I. intia* are consistently developed: walled and naked columns are the same distinctive shape; laminae become a little wavier upwards, but markedly so only in the walls. The microstructure changes slightly: concordant stylolites occur very frequently in naked columns, but are infrequent in the walled ones. In this example the column shape varies little, and is therefore made the prime characteristic of the taxon. None the less, the microstructure of the naked columns of *I. intia* is distinctive, and among Amadeus Basin stromatolites *I. intia* can be identified by this alone.

The presence or absence of a wall is usually a constant feature within a taxon (of course here I discuss taxa recognizable on other features). An example from the Amadeus Basin is *Linella avis* Krylov, easily identified by its column shape and mode of branching. This is known only from Jay Creek, but one biostrome there has been studied over a strike length of 2·5 km. Specimens from several parts of the biostrome all have columns with continuous, multilaminate walls (except at bridges, or where obliterated by alteration subsequent to burial). Similarly, all *Acaciella australica* lack such a wall, no matter what the preservation of the columns (and at least some are sufficiently well preserved to allow the certain statement that there never was any more than a sparse, patchy wall).

Tungussia inna is a particularly distinctive Amadeus Basin stromatolite. Unlike those already described it has variously oriented columns and markedly divergent branching. These features clearly distinguish it from many other stromatolites. Its columns are bumpy and crooked, its laminae are wavy, and it has an almost continuous wall. These additional features are sufficient to distinguish it from other described forms of *Tungussia*. It also has an especially distinctive microstructure, which alone would suffice to distinguish it from all other Amadeus Basin stromatolites. Its distinctive feature is the inclusion of large quantities of calcarenite in relatively thick laminae.

There are some similarities in gross shape between *T. inna* and another Amadeus Basin stromatolite, *Madiganites mawsoni*, but more significantly, *M. mawsoni* closely resembles some forms of *Baicalia*. In fact, on the basis of gross shape it would be reasonable to classify *M. mawsoni* as a form of *Baicalia*. However, numerous specimens of *M. mawsoni* have been studied from a large area of the north-eastern Amadeus Basin and all have a unique microstructure which clearly differentiates them from *Baicalia* and from most other stromatolites. This is a vermiform microstructure in which sparry calcitic structures indicate the original shape and distribution of algal filaments. Because it is radically different from other microstructures, is consistently developed, and is of primary origin, this microstructure is of taxonomic importance.

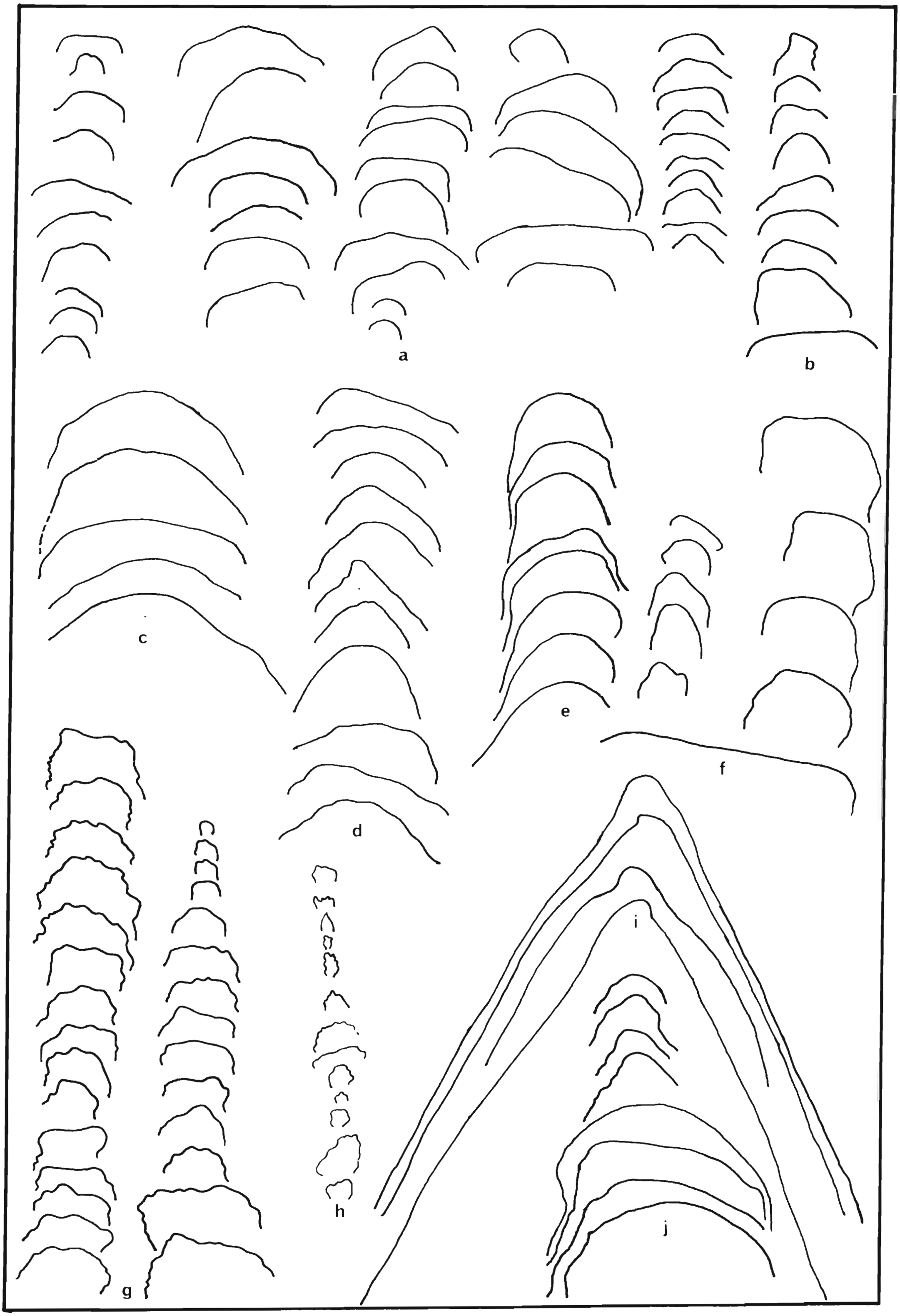
Taxonomic procedures and principles. With these examples as a basis the taxonomic procedures and principles can be discussed. The first point is the question of the relative importance of different characters. It must be emphasized at once that the taxa are defined from groups of characters; in the past the use of too few characters has led to the belief that no temporally-restricted stromatolite taxa are definable. In the examples given above the taxonomic importance of characters is variable. The possession of a wall by *Boxonia pertaknurra* is important in distinguishing it from *Acaciella australica*, but parts of *Inzeria intia* are walled and parts naked. In *I. intia* the wall is of little taxonomic significance. Microstructure is of no use in distinguishing *B. pertaknurra* and *A. acaciella* but the microstructure of *Madiganites mawsoni* is so distinctive it has been used as the prime distinguishing characteristic of the taxon. *B. pertaknurra* and *A. acaciella* have similar kinds of branching, both distinctly different from that of *Tungussia inna*. Many more examples could be given. As Hofmann (1969*b*) has stated, such a classification is internally inconsistent; this criticism can equally well be levelled at the classification of true fossils. However, this method allows the definition of discrete, temporally restricted taxa and so has both a factual basis and practical value.

Despite the variable significance of characters some are more frequently useful: these are column arrangement and branching, column shape, lamina shape (including the presence or absence of a wall), and microstructure. Other features are less useful: the presence or absence of bridges is an example. Both *A. australica* and *T. inna* grade laterally and vertically into pseudocolumnar or undulatory stromatolites, by an increase in the frequency of bridging and eventual loss even of columnar form. As Krylov (1967, pp. 11–22) has discussed, most columnar stromatolites have many-bridged and noncolumnar variants. These variants are separately named by some taxonomists: *Omachtenia* Nuzhnov apparently includes many-bridged variants of *Kussiella* Krylov. Since the increase in frequency of bridging leads to a decrease in the number of distinctive characters available for classification, these variants are not named here or in the works of many other practising taxonomists.

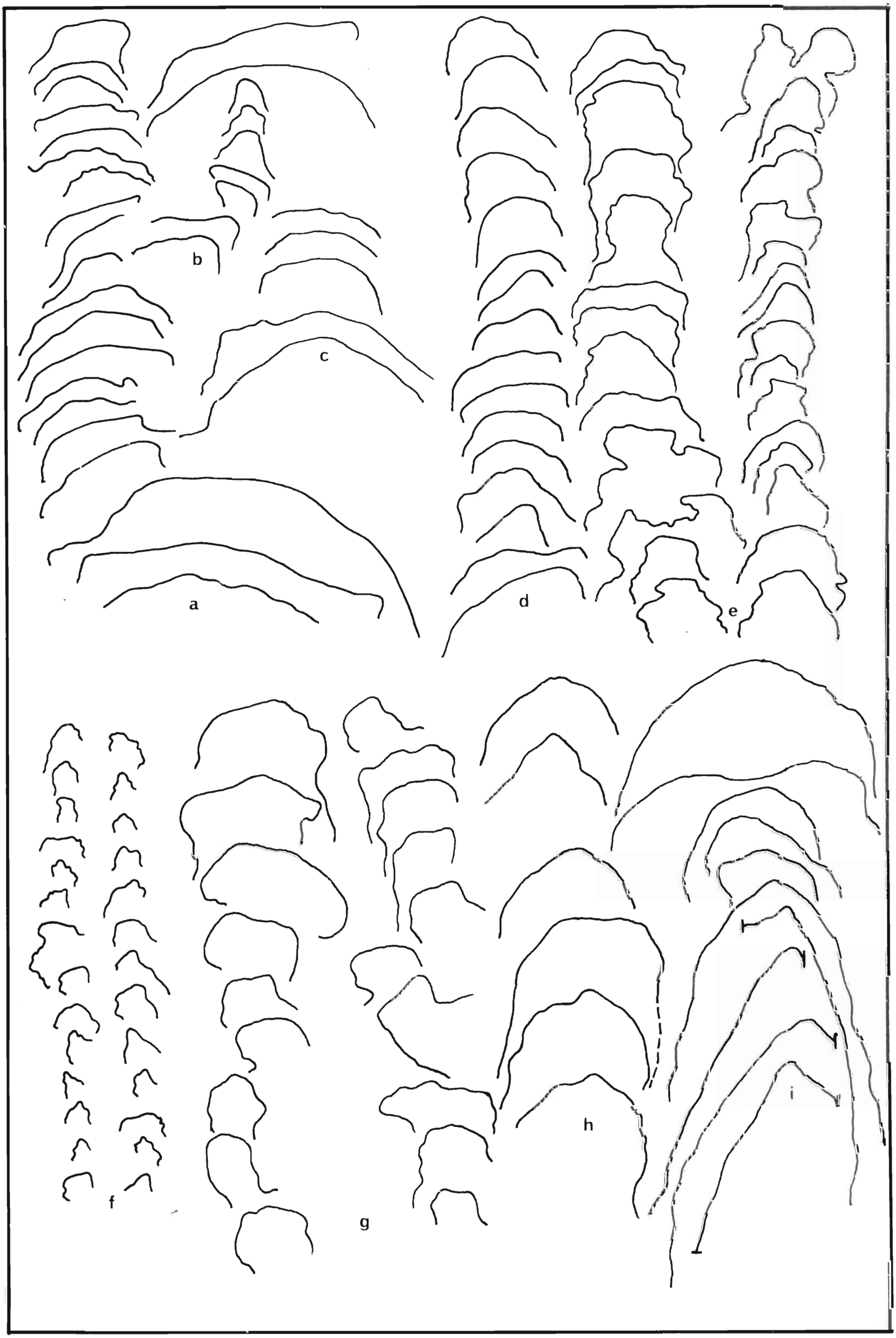
Lamina shape is a feature consistently developed within most taxa but varying greatly between them, as text-figures 6–8 show. It is a useful but not sufficient feature for the differentiation of taxa. More than the ordinary intrataxonic variation occurs between the upper and lower stages of *I. intia*: laminae of the upper stages are wavier, but this is largely due to the acquisition by these parts of a wall. Lamina shape is one of the major criteria used to identify *Conophyton* and *Jacutophyton*. Occasional conical laminae occur in other groups (as Krylov 1967 has noted) but only in *Conophyton* and *Jacutophyton* are most laminae conical. In addition, the laminae are thickened and often contorted in their crestal parts. The kind of crestal zone present is useful for distinguishing forms of *Conophyton*: in the hundreds of specimens they have studied, Komar *et al.* (1965) distinguish three kinds of crestal zones (text-fig. 7 herein). My study confirms their conclusion that these are consistently developed and taxonomically significant.

The group *Conophyton* is the prime example of the use of microstructure for the differentiation of taxa. Komar *et al.* (1965) discuss this at length in their excellent book, which is a product of the earlier research by Semikhatov (1962) and Komar (1966), in which microstructure was considered to be an important taxonomic feature. They conclude that within the group *Conophyton*, microstructural features such as the thickness and continuity of laminae and the form of their boundaries are consistently developed and taxonomically significant. These conclusions are fully supported by my work. They have shown that forms originally distinguished on qualitative features are also quantitatively distinct, and thus have provided a new approach not only for the clearer differentiation of forms but also of a lesser category, the variety. They show that the most useful parameters for distinguishing forms are the actual thicknesses of laminae and the relative thicknesses of contiguous pale and dark laminae. These parameters have been employed here for distinguishing taxa within the group *Conophyton*. Similar statistical methods have been applied to other groups. Komar (1966), Semikhatov *et al.* (1967), and Raaben (1969*a*) distinguish forms of *Boxonia* partly on the sizes of the pigment accumulations in clotty and grumous textures. Raaben (1969*a*) has measured the sizes of 'cryptocrystalline components of the structure' in forms of *Inzeria*, and has shown distinct distributions for forms as she defines them.

The microstructures of *Acaciella australica*, *Inzeria intia*, *Boxonia pertaknurra*, *Baicalia capricornia*, and *Madiganites mawsoni* have been studied in specimens collected from widely separated areas. In all cases they are consistently developed, after some allowance has been made for differing preservation. In a minority of taxa the microstructure is unusual and distinctive in one way or another: examples are the vermiform microstructure of *Madiganites mawsoni* (Pl. 1, figs. 1–2) and the thick, lenticular, detritus-rich laminae of *Tungussia inna* (Pl. 6, fig. 4).



TEXT-FIG. 6. Lamina shapes; the laminae shown are representative selections and although their orientation is the same as originally they have been spatially rearranged. A, *Acaciella australica*. B, F, *Boxonia pertaknurra* (B from columns with altered margins). C, *Minjaria pontifera* (from columns with altered margins). D, J, *Basisphaera irregularis* (J from columns with altered margins). E, *Minjaria procera*. G, *Kulparia alicia*. H, *Alcheringa narrina*. I, *Conophyton garganicum australe*. The stromatolites A–G have parallel branching; that in I does not branch, and H branches rarely. The relationship between branching and lamina shapes is discussed in the text.



TEXT-FIG. 7. Lamina shapes; the laminae shown are representative selections and although their orientation is the same as originally they have been spatially rearranged. A, B, *Inzeria intia* II. C, *I. intia* I. D, *I. intia* III base. E, *I. intia* III. F, *Patomia ossica*. G, *Linella avis*. H, *I. intia* IV (from columns with altered margins). I, *Pilbaria perplexa*. The stromatolites represented here have niche-projections or nonparallel branching. The relationship between branching and lamina shapes is discussed in the text.

TEXT-FIG. 8. Lamina shapes; the laminae shown are representative selections and although their orientation is the same as originally they have been spatially rearranged. A, *Jurusania nisvensis*. B, *Baicalia capricornia*. C, *B. lacera*. D, *Madiganites mawsoni*. E, *Anabaria divergens*. F, *Kotuikania torulosa*. G, *Tungussia inna*. H, *T. erecta* (badly preserved). The stromatolites represented here mostly have nonparallel branching. The relationship between lamina shapes and branching is discussed in the text.

Definition of forms. Hofmann (1969*b*, p. 42) stated that at least in some cases the amount of variation within presently defined groups ('genera') is as much as that between them. This is true of some taxa (especially groups), but although there frequently is a wide range of variation in particular characteristics within a form, the extremes of the range occur infrequently. For instance, it is true that branching in *Acaciella australica* is α-, β-, and γ- parallel, and slightly and markedly divergent. But only α- and β-parallel branching occur frequently, and γ-parallel and markedly divergent branching are rare. Furthermore, the frequency of branching is taxonomically significant: for example, according to Krylov (1963, 1967) and Semikhatov (1962) branching in *Minjaria* is infrequent, whereas *Gymnosolen* branches frequently; in addition, *Minjaria* columns apparently are more regularly cylindrical.

The same principles of frequency and proportion apply to all characteristics. Ribs characterize the column-margin structure of *I. intia* and bumps that of *A. australica*; but this is not to say that columns of *A. australica* are never ribbed, and those of *I. intia* entirely lack bumps. Only infrequently is the full range of possible variation of a characteristic found in a single taxon. In most cases the range present is limited, often narrowly. For instance, no Amadeus Basin stromatolites other than *Madiganites mawsoni* have a vermiform microstructure, and it is ubiquitous in *M. mawsoni*. Another example is the complete lack of a continuous, multilaminate wall on any of the many columns of *A. australica* which have been examined.

Discrete taxa are recognizable because not only are there single, distinct modes in the ranges of each character in a taxon, but in addition all of the modes overlap: it is possible to choose a specimen of a particular stromatolite in which all the significant features are modally developed, and furthermore such examples occur the most frequently. For example, specimens of *A. australica* with the typical mode of branching very frequently also have the typical column shape, lamina shape, and microstructure. The often observed intergradation of columnar, pseudocolumnar, and undulatory stromatolites has given rise to the fallacy that with suitable environmental conditions each of the total range of stromatolites could form at the one time and therefore that no discrete taxa would be definable. Many of the presently-defined forms of columnar stromatolites do intergrade, usually not as they occur in the field but in the sense that there are specimens that will fit into more than one taxon. Forms are definable because of the distinct mode in the range of variation of each stromatolite.

Definition of groups. It is possible to distinguish *forms* which are discrete taxonomic entities. More difficult is the discovery of discrete *groups*, which are assemblages whose artificiality is variable. At least some groups are very characteristic and the classification of many of their forms is at once obvious; such groups are *Baicalia*, *Boxonia*, *Conophyton*, *Gymnosolen*, *Inzeria*, and *Jacutophyton*. Even in these groups there are some forms that possibly would be better excluded, but often these were originally included because of differing concepts of the group. *Inzeria* is a good example. The type species, *I. tjomusi* Krylov 1963, was characterized by straight, transversely ribbed columns with niches and niche projections. *I. intia* Walter fits well into this original meaning of *Inzeria*. Krylov (1967) himself broadened the group by the inclusion of *I. toctogulii* which has very few niches and in which some columns are curved. Raaben (1969*a*) uses an extremely broad definition which admits forms with column shapes, margin structures, and microstructures quite different from those of *I. tjomusi* and *I. intia*. Her *I. djejimi* apparently has no niches in the strict sense; no, or only weak, transverse ribs; and tuberous rather than cylindrical columns: classification as *Baicalia* rather than *Inzeria* seems most reasonable. None the less, it may be that there is a gradational series from *I. tjomusi*, through *I. toctogulii* (and possibly *I. confragosa* and *I. nimbifera*) to '*I.*' *djejimi*, and even to forms of *Baicalia*. The similarity of *Baicalia* to *Inzeria* has been mentioned by Krylov (1963, p. 63) and is emphasized herein (p. 132). The problem is where to draw the boundary which apparently must be arbitrary. To allow a group name to have too broad a meaning robs it of usefulness, and obscures the fact that there are very strong similarities between some forms.

Conophyton and *Jacutophyton* also intergrade. At present, any *Conophyton*-like stromatolite which has narrow, oblique branches or long projections can be classified as *Jacutophyton*. Several forms of *Conophyton* have short projections, e.g. *C. garganicum garganicum* and *C. circulum* (Komar *et al.* 1965, fig. 17 and Pl. 5). In the field, projections over 10 cm long have been seen very infrequently on columns of *C. garganicum australe*. The microstructures of *J. ramsosum* Shapovalova and *J. multiforme* Shapovalova are similar to those found in the *C. cylindricum* subgroup. Bertrand (1968) has described continuous gradations from *Conophyton* through *Jacutophyton* (although she did not use that name) to columnar branching stromatolites. Shapovalova (1968) describes vertical sequences in which *Baicalia* is overlain by *Jacutophyton* and then *C. cylindricum* (and vice versa) and Krylov and Shapovalova (1970*a*) show that the contacts are gradational. The Russian work and that of Trompette (1969) shows that the narrow branches of *Jacutophyton* are an integral part of the stromatolite and not just an overgrowth on *Conophyton* columns. Here the problem of setting limits to the end members of the series may have been resolved by the separation of the intermediates as a new group (*Jacutophyton*). It is useful and realistic to have numerous narrowly defined groups.

The *Conophyton*–*Jacutophyton*–*Baicalia* series is an extreme case of intergradation, where the three groups are especially distinctive and the two end members, at least, frequently occur alone. There are examples of differently named variants with much less difference between them and which are only known to occur together. One such is *Linella ukka* Krylov and *Tungussia bassa* Krylov which apparently occur in the same bioherms and almost certainly intergrade laterally (the uncertainty is due to poor outcrop); according to Krylov (1967) *L. ukka* occurs in bioherm centres and *T. bassa* on their margins. They have in common their margin structure, lamina shape, and some features of column shape, but whereas most *L. ukka* columns are erect many of those of *T. bassa* are prostrate. The same applies to intergradational forms of *Baicalia* and *Tungussia* and *Minjaria* and *Tungussia*. Thus *Tungussia* is often a variant of other stromatolites. Krylov (1967, pp. 23–25) argues that it is expedient to name these variants differently since available specimens or exposures may not show the intergradations and therefore individual names for the parts are useful; and he says that to bring these names into synonymy when the true situation is discovered would lead to unwarranted nomenclatural instability and confusion. But there are many features in common between *T. bassa* and *L. ukka* and these are adequate for the definition of a form of *Linella* which could be recognized with a specimen of only one variant. A similar case is *Inzeria intia* where it would have been possible to define the four growth stages as different forms or groups; but there are sufficient characters in common to allow the recognition of the taxon with a specimen of only one stage. Such an approach is preferable for several reasons: it simplifies nomenclature, it may lead to a more nearly natural classification, and it may shorten the time range of some groups, especially *Tungussia*. If the naming of ecologic variants was considered useful a trinomial system could be used, e.g. *Linella ukka ukka* and *L. u. bassa* (but the third name would have a different significance from that of a *Conophyton* variety).

Krylov has recently pointed out (in Rozanov *et al.* 1969, p. 223) that the narrow definition of some groups of Precambrian columnar stromatolites is due to the large size of their bioherms and the consequential fact that all ecologic variants were not discovered in the relatively small specimens studied. In my work numerous specimens from different parts of bioherms were studied to ensure that the extent of ecologic variation was discovered.

All of this is not to say that two different stromatolites may not occur together; at the one time different algae or algal associations may have been living close together. The only possible example of this known to me is one from the Amadeus Basin. In a biostrome in the Bitter Springs Formation at Jay Creek *Linella avis* Krylov predominates. This biostrome was studied over a length of 2·5 km and over that distance several clusters of quite different columns were found among the *L. avis*; these have all the characters of *Minjaria* and were named *M. pontifera*. Whereas *L. avis* has narrow, gnarled, tuberous, crooked, frequently and complexly branching columns, those of *M. pontifera* are straight, branch rarely and simply, and are smoother. These forms occur closely juxtaposed, but unfortunately whether or not they intergrade is unknown. At present it is considered that they are so different as to necessitate different classification; this position could be maintained even if they do intergrade. Similarly, it is possible that one kind of stromatolite may grade vertically into another.

Thus two approaches are suggested: firstly to change the definitions of some taxa so that ecologic variants can be given the same name (e.g. *Linella ukka* and *Tungussia bassa*) and secondly to restrict diagnoses so that names do not come to have so broad a meaning as to be made less useful (e.g. *Inzeria*). Many of the resultant taxonomic changes will cause the upward extension of the time ranges of groups but this does not detract from their usefulness since their first, not last, appearance is used to define zones.

Conclusions. A survey of presently used classifications and of the constancy of development of characters in Australian stromatolites reveals that the taxonomic significance of characters varies from taxon to taxon. Nevertheless, several characters are particularly useful: these are columns shape, branching arrangement, and margin structure, including the presence or absence of walls. These features are used to distinguish both groups and forms of stromatolites. Column lamina shape is important for differentiating forms. In a minority of cases microstructure is also important in form distinction: forms of *Conophyton* are the prime example. Rarely microstructure is the main distinguishing characteristic of a group, as in *Madiganites*. In the distinction of forms the mode of occurrence of the stromatolite is also useful.

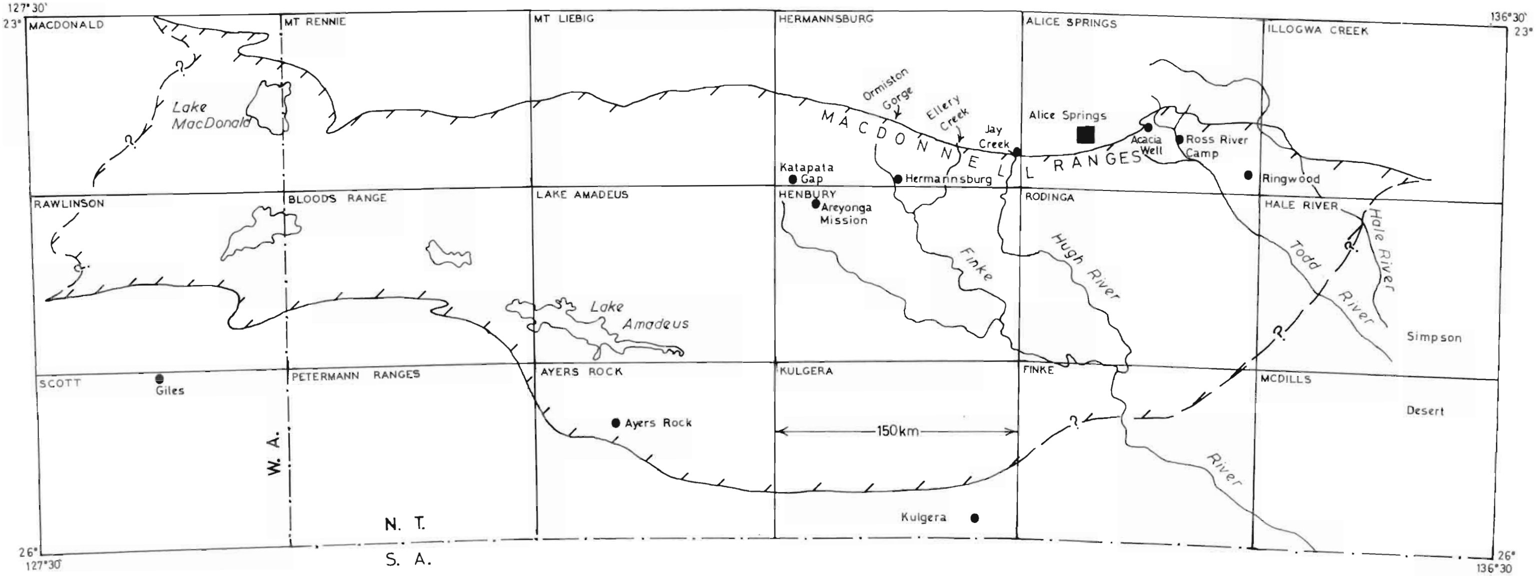
In all cases taxa are defined from combinations of characteristics. In the past the use of characteristics in isolation has led to the belief that the only definable taxa are very long ranging. The viability of the present classification is shown by the fact that frequently a knowledge of one of these characters allows prediction of the occurrence of others: for instance, among stromatolites described here, those with vermiform microstructure predominantly have bumpy columns (*Madiganites mawsoni*); stromatolites with gnarled, tuberous, crooked columns also have walls (*Linella avis*). This is besides the credence given to the classification by the demonstrable temporal restriction of its taxa.

STRATIGRAPHY

AMADEUS BASIN

The Amadeus Basin is an intracratonic trough with Precambrian and Phanerozoic sediments outcropping or immediately subsurface over about 150 000 square kilometres. It lies in Central Australia between latitudes 23° S and 26° S and longitudes 128°30′ E and 136° E. It is elongated about 720 km east–west with a maximum north–south width of 270 km (text-fig. 9). Most of this area is in the Northern Territory, but it extends into Western Australia; it is convenient to refer to this general area as Central Australia. Major sedimentary sequences in the basin are Late Precambrian (Adelaidean), Cambrian, Ordovician, possibly Silurian, Devonian, and possibly Carboniferous, with a total maximum thickness of about 9000 m. The sediments are largely sandstones, carbonates, siltstones, and shales; volcanics are rare. The Precambrian sediments reach their maximum thickness of 6000 m in southern and western parts of the basin; in the north and east, where this study was concentrated, they are up to 3000 m thick.

Away from the northern and southern margins of the basin the structure is mostly simple, with gentle, open folds. The margins are complicated by widespread faulting and recumbent folding on a variety of scales. These structures affect mainly the lowermost two formations, the Heavitree Quartzite and Bitter Springs Formation, and movement was concentrated in the incompetent siltstones, shales, carbonates, and evaporites of the lower Bitter Springs Formation. Over most of the basin metamorphism is weak or absent. In the south-west it reaches a moderate grade, and may be significant in the extreme north-east (Wells *et al.* 1967). Here we are largely concerned only with the north-eastern Amadeus Basin, the MacDonnell Ranges, where several sandstones and quartzites, particularly the Heavitree Quartzite, outcrop boldly, forming ridges with a relief of up to 300 m. The intervening carbonates, siltstones, and shales form only low ridges and rounded hills frequently with no more than 20 m of relief; just as frequently they do not outcrop at all.

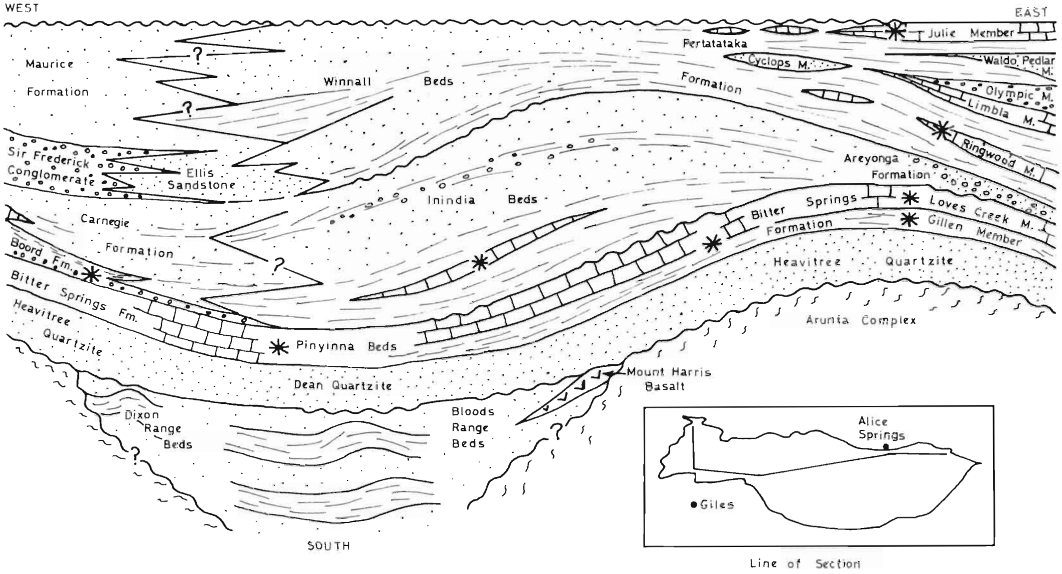


TEXT-FIG. 9. Locality map of the Amadeus Basin (shown outlined by a hachured line). The lakes are playas. The names of relevant map areas are shown.

Stratigraphy and Stromatolite Distribution

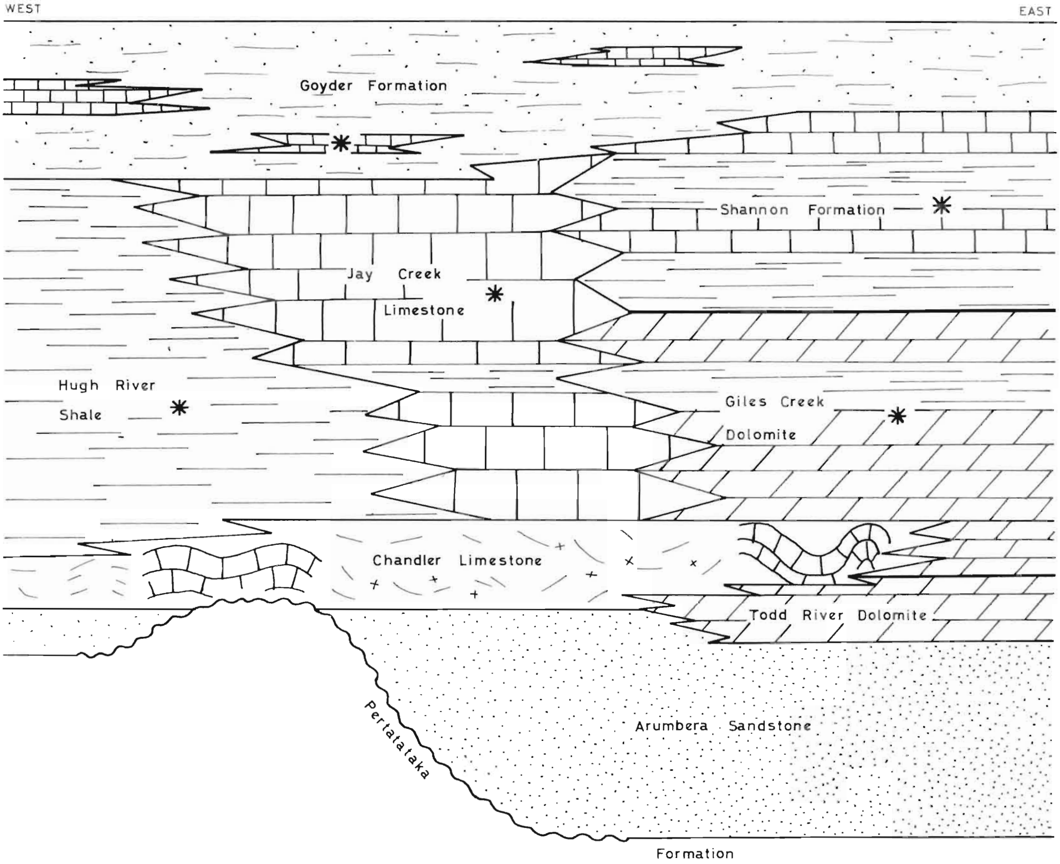
The Precambrian and Cambrian stratigraphy of the basin is summarized in text-figures 10 and 11 and has been described in detail by Wells *et al.* (1967, 1970).

The Precambrian Bitter Springs Formation is abundantly stromatolitic. It lies conformably above the Heavitree Quartzite and outcrops extensively in the north-eastern Amadeus Basin, and to a lesser extent in the central and western regions (text-fig. 12). Its correlative, the Pinyinna Beds, overlies the Dean Quartzite in the south-western part of the basin. At Ellery Creek in the Hermannsburg area (text-fig. 9) the Bitter Springs Formation is 780 m thick (Wells *et al.* 1970; text-fig. 13 herein) and has a gradational contact with the Heavitree Quartzite (Banks 1964). The maximum thickness of the formation is estimated to be 900 m. Two units are distinguished, the Gillen Member overlain by the Loves Creek Member.



TEXT-FIG. 10. Precambrian stratigraphy of the Amadeus Basin (after Wells *et al.* 1967, 1970). Length of section about 800 km. Facies changes shown in the west are inferential only. * = Stromatolitic (vertical position of the symbol within the units has no significance).

The type locality of the Gillen Member is near Alice Springs and it occurs throughout the MacDonnell Ranges. Because the siltstones, shales, and carbonates of the Gillen Member are usually folded in a complex, irregular manner it is rarely possible to measure sections, but Banks (1964) measured 400 m in the type section (text-fig. 13; subsequently his 'Gillen Formation' was extended slightly). Possibly about 300 m of the Ellery Creek section belongs to the Gillen Member, but outcrop of all but the most resistant beds is very poor, as is frequently the case. Stromatolites rarely occur in the Gillen Member, but Banks (1964) discovered some at two localities: Jay Creek, and Mount Gillen near Alice Springs. In both sections they are 20–30 m above the base of the Member. Those from near Mount Gillen have been

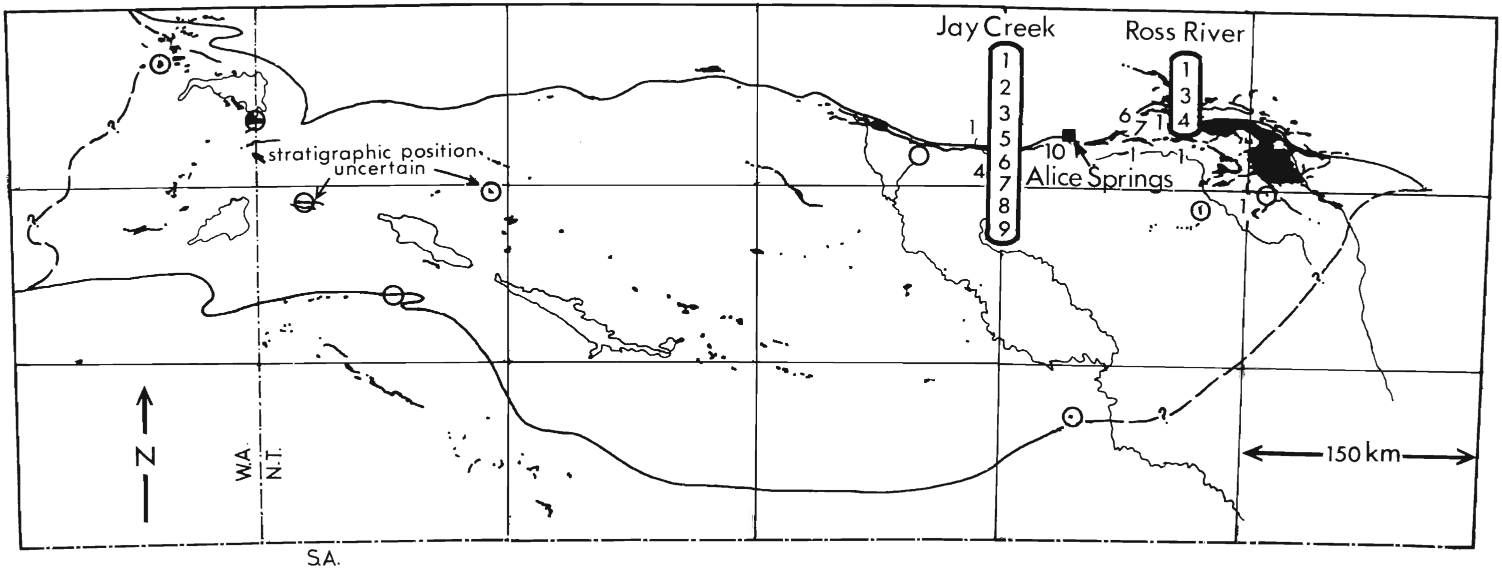


TEXT-FIG. 11. Cambrian stratigraphy of the north-eastern Amadeus Basin (from Wells *et al.* 1967). Length of section about 200 km. * = Stromatolitic (the positions of the symbols within the formations have no significance).

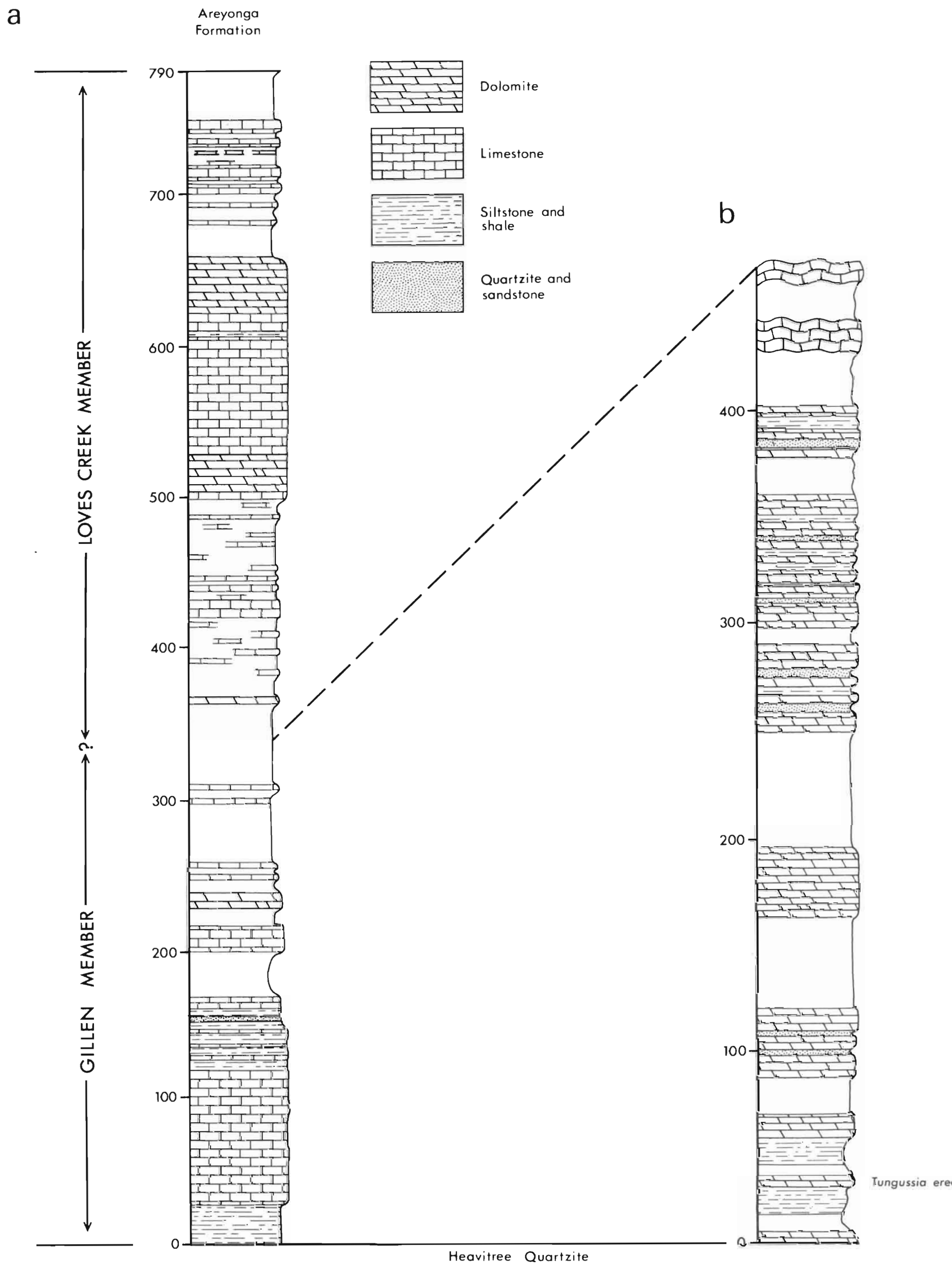
studied and are described herein as *Tungussia erecta. T. erecta* forms a biostrome 70 cm thick in the uppermost part of 3–4 m thick bed of dolomite.

The Loves Creek Member is conformably above the Gillen Member and according to Wells *et al.* (1967) between Jay Creek and Alice Springs it 'consists mostly of siltstone, with interbeds of chert, dolomite and rare limestone'. Characteristics of the unit include the frequent presence both of stromatolites and massive white-spotted red silty carbonate (or calcareous or dolomitic siltstone). Wells *et al.* (1967) report that between Alice Springs and Jay Creek the unit is about 700 feet thick and mostly siltstone; but at Jay Creek there is well over 200 m of carbonate (in very extensive beds, including one thick interbed which is red and silty) of a total thickness of the member possibly of 500 m, and a little further west at Ellery Creek over 50 per cent of the member is carbonate. The stromatolites known from Jay Creek are *Acaciella australica*, *Basisphaera irregularis*, *Boxonia pertaknurra*, *Jurusania nisvensis*, *Kotuikania? juvensis*, *Kulparia alicia*, *Linella avis*, and *Minjaria pontifera*.

Most of the boldly outcropping carbonate in the Loves Creek Member at Jay



TEXT-FIG. 12. Outcrop distribution and stromatolite occurrence, Bitter Springs Formation and Pinyinna Beds, Amadeus Basin. Outcrop distribution and basin margin from Wells *et al.* (1970). Stromatolites are reported from the central part of the basin, but as no precise localities are given they cannot be included here. ○ undifferentiated stromatolites, 1 *Acaciella australica*, 2 *Basisphaera irregularis*, 3 *Boxonia pertaknurra*, 4 *Inzeria intia*, 5 *Jurusania nisvensis*, 6 *Kotuikania? juvensis*, 7 *Kulparia alicia*, 8 *Linella avis*, 9 *Minjaria pontifera*, 10 *Tungussia erecta*.



TEXT-FIG. 13. Reference section of the Bitter Springs Formation, Ellery Creek (a) and type section of the Gillen Member near Alice Springs (b), modified from Wells *et al.* (1967). Thicknesses are in metres.

Creek occurs near the base of the member. Above the recessive weathering red silty dolomite shown on the measured section (text-fig. 14) are several ridge-forming carbonates 10 m or so thick. One contains pseudocolumnar stromatolites but no columnar forms have been found. The upper part of the member is similar east of Alice Springs, although at least locally carbonate beds are absent and sandstone occurs in a sequence dominated by red-brown siltstone (text-fig. 15). There the lower 150 m is stromatolitic dolomite which may be equated with the lower 180 m of the Jay Creek section (text-fig. 14). Correlation with the section at Ellery Creek, 45 km west of Jay Creek, is difficult and comparison of text-figures 13, 14, and 15 and the log of the sections measured at Jay Creek by Banks (1964) indicates facies changes between the areas represented.

No stromatolites were found in a brief examination of the Bitter Springs Formation near Ormiston Gorge, in the central part of the Hermannsburg Sheet area (text-fig. 9). At Katapata Gap in the extreme south-western corner of the Hermannsburg Sheet area is the westernmost known occurrence of *Acaciella australica*, which is also the only stromatolite known from there. Ten miles north-east of Undoolya Gap, in the central part of the Alice Springs Sheet area, several biostromes of *A. australica* are well exposed in limestone shown on the Alice Springs map as part of the Loves Creek Member. Individual domed bioherms are up to about 10 m wide and circular to ellipsoidal in plan. Wells *et al.* (1967, Pl. 1, fig. 2) figure a similar occurrence at the southern end of the Ross River Valley; specimens collected by Madigan from this area in 1931 are *A. australica. A. australica* was first collected by Dr. Charles Chewings and described by Howchin (1914) from half a mile west of Acacia Well, in the central part of the Alice Springs Sheet area.

Columnar stromatolites are numerous in what is mapped as the Loves Creek Member 1 mile north-north-west of Ross River Tourist Camp (Pl. 33). One biostrome of *Inzeria intia* is especially prominent and has two others just above and below it; a poorly preserved stromatolite which is probably *Boxonia pertaknurra* occurs several tens of metres stratigraphically lower at the same locality. The black chert containing excellently preserved green and blue-green algae in the Loves Creek Member near Ross River Tourist Camp (Schopf 1968) is not associated with recognizable stromatolites, although the chert laminae may be considered stromatolitic.

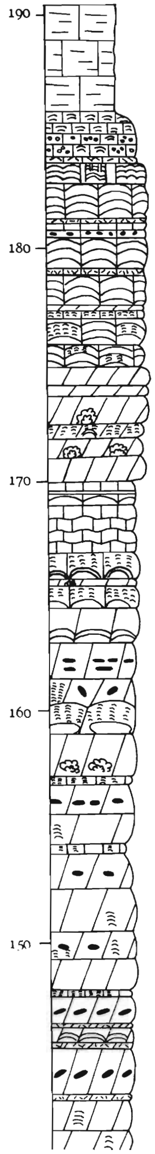
The most easterly outcrop of Bitter Springs Formation examined is that 6 miles south-south-east of Ringwood Homestead. This is a grey dolomite like those of the Gillen Member but is mapped as Loves Creek Member and contains a biostrome closely resembling those at Katapata Gap. The stromatolites are very badly altered, but laboratory examination seems to confirm field impressions that they are *A. australica.*

Cloud and Semikhatov (1969) report *Jurusania alicia* (recte *Kulparia alicia*) and *Anabaria juvensis* from the Bitter Springs Formation at a locality 38 km east of Alice Springs. The positions of the occurrences within the formation are not specified. The reasons for transferring *alicia* to the new group *Kulparia* are given on pp. 151–152. My examination of the holotype of *A. juvensis* revealed markedly divergent branching in the lower part, a banded microstructure, and a multilaminate wall which is patchy now but could have been more continuous before secondary alteration. This specimen closely resembles a stromatolite from the Jay Creek section, which has a continuous multilaminate wall (Pl. 25, figs. 3, 4; text-fig. 45G). No previously described forms of *Anabaria* have markedly divergent branching and the combination of characters listed here indicates classification as a form of *Kotuikania* would be most appropriate. More specimens are needed for complete identification.

Geologists from the Bureau of Mineral Resources have found stromatolites in the Bitter Springs Formation at many other localities over an area far too large to be examined in the present study. All those reported are indicated on text-figure 12. The only specimen available is from the northern part of the Bloods Range Sheet area (text-fig. 9); because of poor outcrop, assignment to the Bitter Springs Formation is uncertain. The specimen is too small for identification but is of a walled columnar form which may be *Boxonia* or *Minjaria*. A photograph of an occurrence near Lake MacDonald in Western Australia is figured by Wells *et al.* (1964); that photograph and others made available by A. T. Wells are insufficient to allow identification of the stromatolites (Pl. 31, figs. 3, 4). The Pinyinna Beds of the south-western margin of the Amadeus Basin are correlated with the Bitter Springs Formation. They are a poorly exposed sequence of siltstone and dolomite, and limestone containing stromatolites. In many places they are metamorphosed, the siltstones being altered to slates and schists (Forman 1966). No descriptions or photographs of the stromatolites have been published and no specimens are available.

The Areyonga Formation of the central, north-eastern, and northern basin is correlated with the Inindia Beds in the south and the Carnegie and Boord Formations of the west. These are the lower tillites of the Amadeus Basin. The Areyonga Formation rests disconformably or with angular unconformity on the Bitter Springs Formation. It is boulder claystone, conglomerate, arkose, poorly sorted sandstone and siltstone, and dolomite. Heterogeneous assemblages of faceted and striated boulders up to 2 m wide occur in siltstone. The known thickness varies from 0–500 m. Rapid facies changes occur frequently; units within the formation are lenticular. Near Katapata Gap the formation contains dolomite from which stromatolites have been reported (Ranford, *et al.* 1965). The 'stromatolites' I have seen are simple, widely-spaced, domed structures up to 30 cm wide in laminated dolomite. They may be stromatolites or slump structures. Banks (1964) recorded stromatolites from the Areyonga Formation near Laura Creek Gap (Fenn Gap, western Alice Springs Sheet). Definite stromatolites are common there in buff weathering grey dolomite; they are cumulate forms and unbranched clavate columns up to about 10 cm wide and of a similar height. However, outcrop is very poor and the dolomite is not certainly of the Areyonga Formation; no tillite is exposed. An additional complication is noted by Wells *et al.* (1967, p. 25): 'At Fenn Gap . . . the Pertataka Formation rests on the Bitter Springs Formation in one small outcrop'; i.e. the Areyonga Formation locally is absent.

The Inindia Beds of the southern Amadeus Basin are up to 2100 m of siltstone, sandstone, arkosic sandstone, claystone, shale, chert, chert breccia, fine angular conglomerate, and thin beds of dolomite and limestone. In the west, dolomites up to 15 m thick contain stromatolites. A specimen from what may be the Inindia Beds in the northern Bloods Range Sheet area (poor outcrop makes correlation uncertain) consists largely of oncolites (Pl. 31, fig. 5). The Inindia Beds disconformably



Massive red silty dolomite with white spots

Dark grey stromatolitic limestone

Light buff oolitic stromatolitic limestone

Intraformational conglomerate

Light yellow and grey stromatolitic limestone: small linked cumuli, poor Acaciella australica

Dark grey limestone

Flat-laminated, yellow-weathering, grey-green dolomite

Dark grey limestone: small A. australica^{+}

Dark grey limestone: some large A. australica

Yellow-weathering grey-green dolomite: scattered cumuli, some A. australica, many flat-laminated beds

Dark grey limestone: mostly flat-laminated, large cumuli about 10m wide, some small A. australica

Pale grey-green wavy laminated limestone

Dark grey limestone: large A. australica^{+}. Continues for at least 2.5km

Grey wavy-laminated limestone and dolomite: scattered cumuli

Dark grey limestone: Linella avis^{+} (Minjaria pontifera^{+} about 90m E of section. Continues for at least 2.5km

Yellow-weathering pinkish grey to grey-green dolomite: much flat-laminated, much poorly laminated. Separate and linked cumuli and A. australica

Jurusania nisvensis

Dark grey limestone: Linella avis

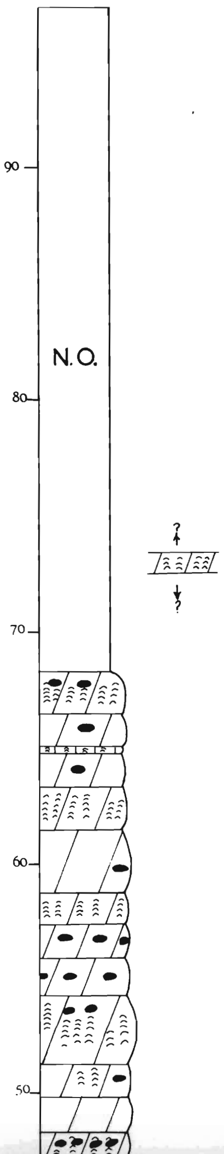
Yellow weathering grey-green dolomite: mostly flat bedded, poorly laminated, parts cherty. Scattered unbranched columns

Greenish-grey limestone: A. australica

Yellow weathering pale grey-green dolomite: some large and small unbranched columns, much flat-laminated carbonate

Dark grey limestone: A. australica

Yellow-weathering grey-green dolomite: A. australica, rare oncolites



Pale grey dolomite: Boxonia pertaknurra offset from section - in creek; position uncertain but in lower part of no outcrop interval

Yellow-weathering grey dolomite: A. australica

Dark grey limestone: A. australica

Yellow weathering grey dolomite

Beds with A. australica (and perhaps some Boxonia pertaknurra other than that

Limestone (silty)

Dolomite

Oolites

Stromatolites: undifferentiated

" cumulate

" large laterally linked hemispheroids

" pseudocolumnar

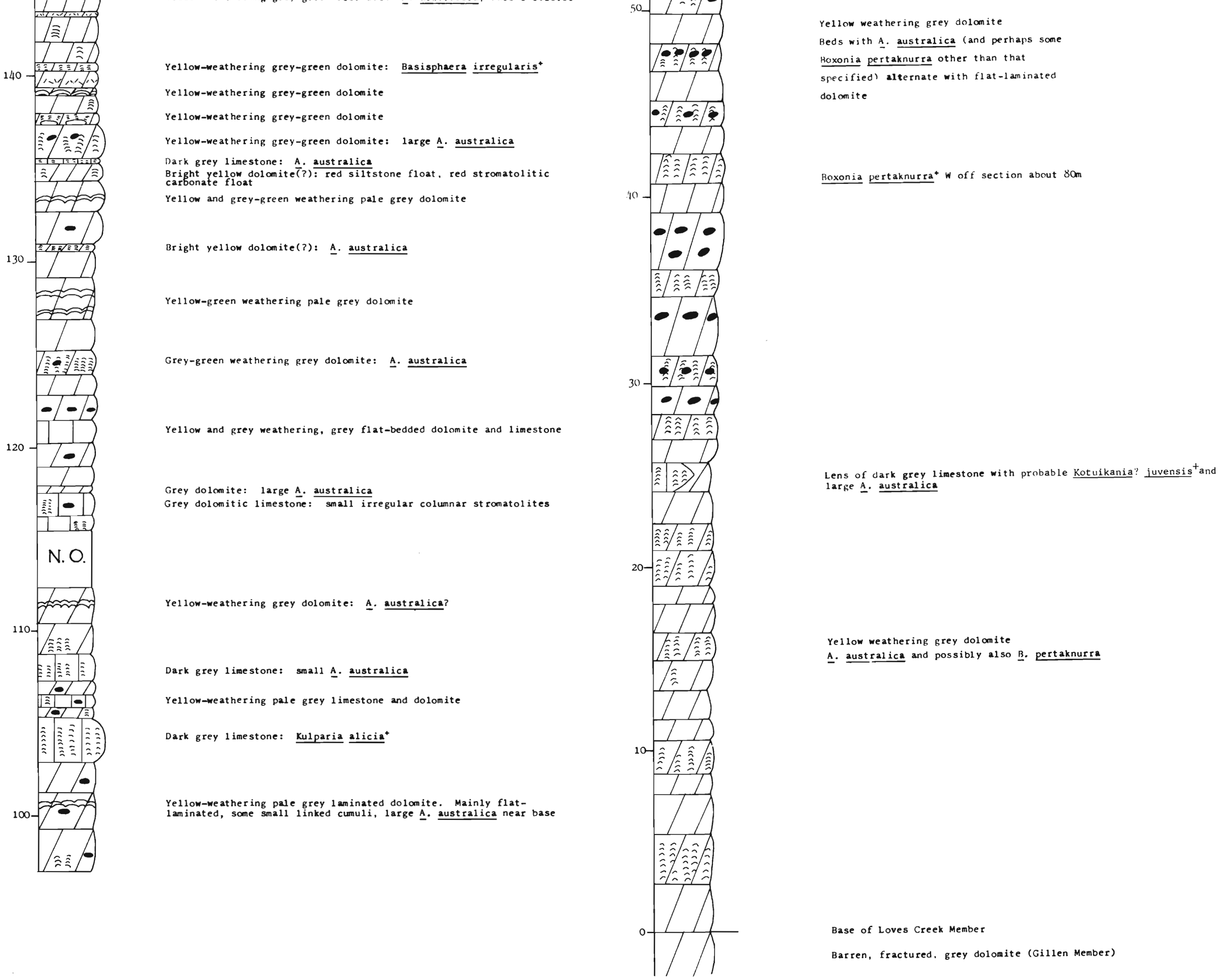
" columnar

Intraformational breccia

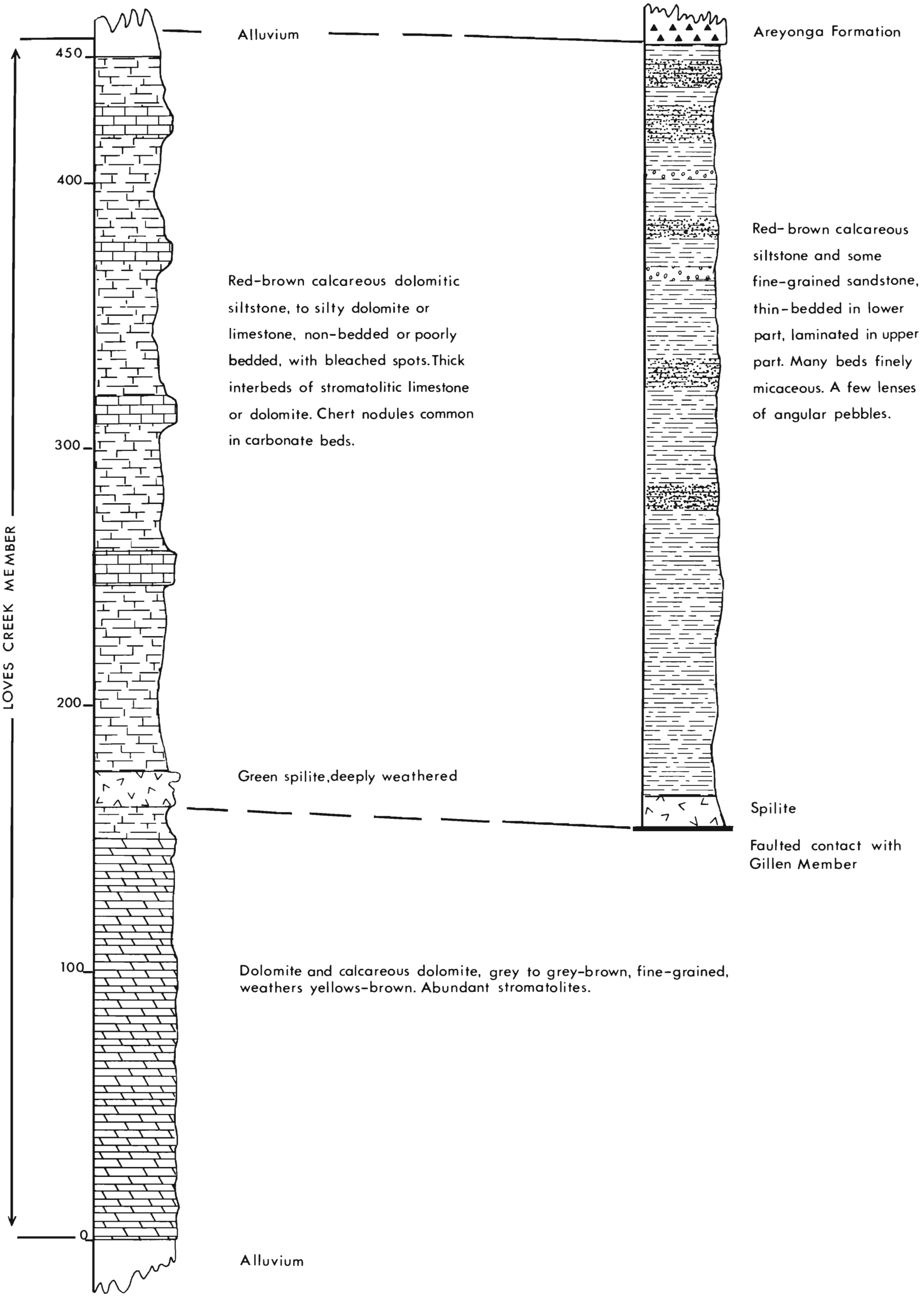
Chert - as nodules or disseminated

Stromatolite specimens studied in the laboratory

No outcrop



TEXT-FIG. 14. Lower part of the Loves Creek Member, Jay Creek, Amadeus Basin. Scale in metres.



TEXT-FIG. 15. Generalized sequence in the Loves Creek Member, north-eastern Amadeus Basin, from Wells *et al.* (1967).

or with angular unconformity overlie the Bitter Springs Formation, and an angular unconformity separates them from the overlying Winnall Beds and younger units. Disconformably above the Bitter Springs Formation in the western part of the basin is the Boord Formation, up to 850 m of pebbly sandstone, calcareous sandstone, conglomerate, siltstone, shale and stromatolitic and oolitic calcilutite and calcarenite. No stromatolites from the Inindia Beds or Boord Formation are available for study.

In the north-eastern part of the basin the Pertatataka Formation usually lies conformably between the Areyonga Formation below and the Arumbera Sandstone above. In the Pertatataka Formation grey-green and red-brown laminated siltstone and shale are the dominant rock types, but rarely outcrop. The rock is the same colour at depth in bore holes, where the red-brown hue is rare. Along much of the northern margin of the basin the formation is about 650 m thick; here it contains as well as the dominant shale and siltstone two different rock types in the Cyclops Member below and the Julie Member above. In the extreme north-east the total thickness may reach 2100 m, and there five members have been mapped; in ascending order they are the Ringwood Member, Limbla Member, Olympic Member, Waldo Pedlar Member, and Julie Member. The stromatolite *Tungussia inna* occurs in the Ringwood Member which is about one-fifth (300 m) of the way up the Pertatataka Formation. About half way up the Pertatataka Formation is the Olympic Member, the upper tillite of the Amadeus Basin Precambrian succession. It is restricted to the north-eastern part of the basin.

The Julie Member outcrops along the eastern half of the northern margin of the basin. It is much more extensive than the other members and reaches a thickness of 550 m. The uppermost part is red-brown and grey siltstone with interbeds of pink and red-brown, sandy, oolitic dolomite. Below this is dark grey dolomite which is thick-bedded and massive, oolitic, and sandy. Dark grey and blue-grey foetid limestone usually occurs near the base of the member. Lenses of sandstone are present between the limestone and dolomite. 'In a few places, poorly preserved stromatolites, with an indistinct wavy bulbous outline, are preserved in the dolomite' (Wells *et al.* 1967, p. 31); there is little to add to this. Stromatolites occur frequently in this unit in the Alice Springs Sheet area but are unknown from further west. One mile east of Acacia Well stromatolites are well exposed at the top of many buff coloured carbonate beds (Pl. 32, fig. 3). They are pseudocolumnar and cumulate types from several centimetres up to about 30 cm wide; some form irregular broad columns. Rarely the cumuli have projections a few centimetres long. Similar stromatolites occur south of the Ross River road near its junction with the road to Arltunga; here they reach widths of about 1 m.

The contact between the Pertatataka Formation and the overlying Pertaoorta Group varies from gradational to unconformable (Wells *et al.* 1967, 1970). The Pertaoorta Group is richly fossiliferous, ranging in age from latest Precambrian to Late Cambrian. The intertonguing and gradational relationships of its constituent formations in the north-eastern Amadeus Basin are shown in text-fig. 11. Stromatolites are abundant and widespread in the group where it has been studied, in the north-east. The only columnar stromatolite known from the group is *Madiganites mawsoni*, which occurs in the Jay Creek Limestone at Jay Creek and probably the same unit at Ellery Creek and in the Waterhouse Ranges, and in the Shannon Formation in the Ross River gorge (text-fig. 9).

Age of the Amadeus Basin succession

Fossils. The Pertaoorta Group is palaeontologically well dated, clearly establishing the minimum age of the succession considered here. The lower Goyder Formation, upper Jay Creek Limestone, and upper Shannon Formation (text-fig. 11) all contain early Late Cambrian (Mindyallan) fossils. Middle Late Cambrian (late Franconian) trilobites have been found in the upper Goyder Formation. The Giles Creek Dolomite and lower Jay Creek Limestone contain an early Middle Cambrian fauna. In the lower Todd River Dolomite archaeocyathans occur with the brachiopod '*Micromitra*' *etheridgei* (Tate) which in South Australia is restricted to the Early Cambrian (Joyce Gilbert-Tomlinson, quoted by Wells *et al.* 1967). Tracks and trails occur abundantly in the upper part of the Arumbera Sandstone; several of these are diagnostic of the Early Cambrian (Glaessner 1970). Medusoids are known from the lower Arumbera Sandstone (Wade 1969) and one specimen of the pennatulid *Rangea* cf. *longa* apparently also is from this level. *Rangea longa* is a component of the famous Ediacara fauna from the Pound Quartzite of South Australia, where it is considered to be latest Precambrian (Glaessner and Wade 1966). Clearly then the stromatolite *Madiganites mawsoni* is Middle and Late Cambrian while all of the others are definitely Precambrian.

Radiometric dating of sediments. Few of the sediments have been radiometrically dated. All those reported are from shales analysed by the Rb-Sr whole-rock method. Preliminary analyses of shales in cores of the Pertatataka Formation in the Ooraminna No. 1 and Mount Charlotte No. 1 Wells gave a dating of 750 m.y. (Dunn, *et al.* 1966). Compston and Arriens (1968) interpreted the final results as fitting an isochron indicating a dating of approximately 790 m.y. The Ooraminna data were then combined with analyses of subgreywackes and quartzites of the Winnall Beds, correlatives of the Pertatataka Formation, to give an isochron of 730±45 m.y. (Compston and Taylor 1969). The bore samples analysed span almost the whole thickness of the Pertatataka Formation (P. R. Dunn, pers. comm. 1970).

Wells *et al.* (1967) report an 'apparent maximum age' of 1170 m.y. on a single specimen of shale from the Bitter Springs Formation in the Mount Charlotte No. 1 Well. Using only one specimen it is necessary to assume an initial Sr^{87}/Sr^{86} ratio. When this dating was made by V. M. Bofinger it was conventional to assume that during deposition the strontium in sediments equilibrates with that in the overlying water, assumed to be sea-water. It is now known that modern marine sediments often have higher Sr^{87}/Sr^{86} ratios than sea-water (Dasch 1969). A higher value for this ratio would result in a younger, and possibly *much* younger, dating for the Bitter Springs Formation. In their comprehensive survey of Australian Precambrian radiometric datings Compston and Arriens (1968) omit this date. Rb-Sr and K-Ar datings on glauconite from the Vaughan Springs Quartzite of the Ngalia Basin, a possible correlative of the Heavitree Quartzite, indicate a minimum age of 1280 m.y. (Cooper *et al.* 1971).

Radiometric dating of glacial sediments correlated with those of the Amadeus Basin. These also are Rb-Sr whole-rock datings. Immediately north-east of the Amadeus Basin is the Georgina Basin. The Field River Beds of this basin are considered to be glaciogene. It is not clear whether they are correlatives of one or both of the two tillites of the Amadeus Basin. Samples from the Field River Beds exhibit a 'complex isochron pattern', some indicating a 790 m.y. age but others being younger at approximately 600 m.y. (Compston and Arriens 1968, p. 575). Referring to these datings as well as those from the Pertatataka Formation listed above, Compston and Arriens (1968, p. 575) state that 'Although all of these shale ages must be regarded as minimum estimates for the age of deposition, it seems probable that the Precambrian sediments adjacent to the glacial beds in the Amadeus and Georgina Basins are not much older than 800 m.y.'

Possibly more significant than the Georgina Basin datings are those from the Kimberley region of north-western Australia where, as in the Amadeus Basin, there are two levels of Late Precambrian tillite. As in the Amadeus Basin and Adelaide Geosyncline, the younger tillite is less extensive than the older. V. M. Bofinger dated a large number of shales from this region; the results are mostly internally consistent and seem appropriate. The older tillite is dated 740±30 m.y. Shales between the tillites are dated at 685±70 m.y., and shales from above the younger tillite gave datings of 665±45 m.y. (Compston and Arriens 1968, p. 569). On the basis of correlations with the Kimberley region it is suggested that the upper and lower tillites of the Amadeus Basin are respectively about 670 m.y. and 740 m.y. old. Hence the Bitter Springs Formation is probably older than about 740 m.y.

Radiometric dating of basement rocks. In the north, Amadeus Basin sediments are underlain by metamorphic and igneous rocks of the Arunta Complex (which constitutes the Arunta Block). A gneiss from near Alice Springs is dated very imprecisely by the Rb-Sr whole-rock method at 2250 m.y. Analysis of muscovite and K-feldspar from this rock 'suggest the occurrence of an isotopic redistribution event at 1130 m.y.', which indicates that the rock may not have acted as a closed system and hence that the indicated total rock dating could be insignificant. Biotite from the gneiss is dated at about 1000 m.y. (Compston and Arriens 1968). The Arunta Complex in the Arltunga Nappe Complex east of Alice Springs is dated at 1368–1660 m.y. (Stewart 1971). The only other dated Precambrian rocks from the Arunta Block are granites occurring 150–400 km north of the nearest Amadeus Basin sediments. Two give 1695 m.y. and 1690 m.y. for concordant whole-rock and mineral Rb-Sr datings, but 1460 m.y. by K-Ar methods. Two other granites from which mica has been dated by the K-Ar method fall in a group from the central Northern Territory which average 1465±80 m.y. (Compston and Arriens 1968).

The Musgrave Block of igneous and metamorphic rocks outcrops on the south-western margin of the basin. There the basal sediments also are metamorphosed, so dates from the basement cannot simply be interpreted as indicating a maximum age for the sediments as they may register the later metamorphism. However, it is noteworthy that nine granulites analysed by the Rb-Sr whole-rock method give an isochron of 1390±130 m.y. (Compston and Arriens 1968, p. 575), which should at least be a minimum estimate of the age of part of the basement. Granites of the

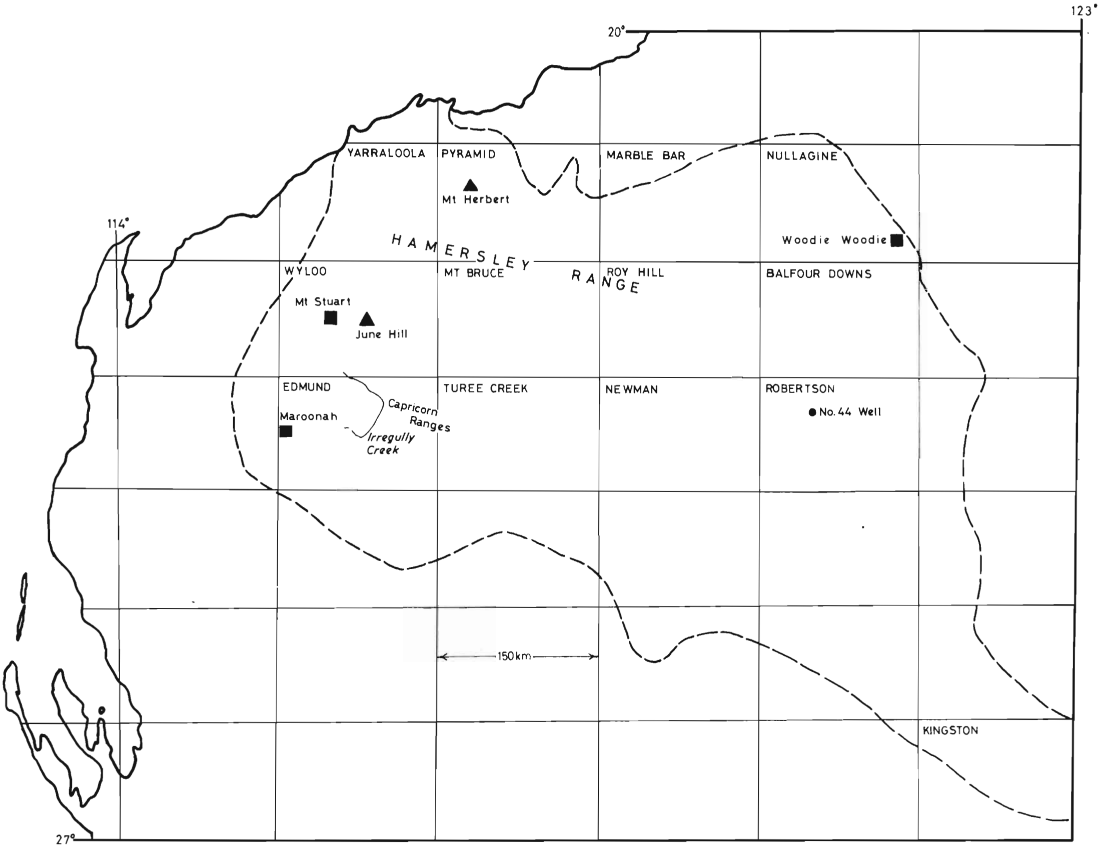
Pottoyu Complex are said to grade into and locally intrude the Dean Quartzite. The Dean Quartzite is claimed to have been a 'metamorphic barrier' which shielded the overlying Pinyinna Beds from intense metamorphism during the Petermann Ranges Orogeny (Forman 1966). The very complex folding of the Dean Quartzite and Pinyinna Beds in the Petermann Ranges Sheet area is attributed by Forman to this orogeny. Two granites from the Pottoyu Complex have been dated: by the Rb-Sr whole-rock method dates of 1190 and 1150 m.y. were obtained (error not specified). Biotite and microcline from one gave Rb-Sr datings of 600, and biotite from the other gave 570 m.y. Reasoning from structural relationships Forman (1966) concluded that most of the granites formed at a late stage of the Petermann Ranges Orogeny, and he takes the mineral datings of 600 m.y. as indicating the time of the orogeny. Forman offers no explanation for the whole-rock datings of about 1200 m.y. but Wells *et al.* (1970) interpret these as the age of the basement which later was mobilized during the Petermann Ranges Orogeny. This latter interpretation also much more reasonably explains the higher metamorphic grade of rocks below the Dean Quartzite, rather than that requiring the quartzite to act as a metamorphic barrier. Hence, despite the fact that Forman adduces evidence for the granites having formed at a late stage of the Petermann Ranges Orogeny, during which the Dean Quartzite and Pinyinna Beds were folded, it is more likely that they are older than the quartzite, since much of the sediment with which they are folded is little metamorphosed. But until the structure of the south-western margin of the basin has been unravelled the radiometric datings are of little value.

One indirect attempt has been made to set a maximum limit to the age of the sedimentary succession. Compston and Nesbitt (1967) reported a Rb-Sr whole-rock dating of 1060±140 m.y. on the Tollu Volcanics, and supported earlier correlations of these with the Mount Harris Basalt underlying the Dean Quartzite. The two volcanic sequences were considered 'cogenetic' but as they occur hundreds of kilometres apart and no detailed comparisons of their petrology and chemistry have been made, this correlation is weakly founded, despite contrary assertions by Horwitz and Daniels (1967).

It is concluded that radiometric data from the Arunta Block indicate a maximum possible age for the sedimentary sequence of at least about 1370 m.y. Unequivocal interpretation of data from the Musgrave Block in the south is not yet possible, but the prevalent datings of 1200–1400 m.y. register metamorphic and igneous events which may have preceded sedimentation in the Amadeus Basin.

HAMERSLEY AND BANGEMALL BASINS

The Mount Bruce Supergroup comprising the Hamersley Basin is unconformably overlain by the Bangemall Group of the Bangemall Basin (Daniels and Horwitz 1969). The 78 000 km^2 outcrop area of the Mount Bruce Supergroup lies across the Tropic of Capricorn in Western Australia; to the south and east it is surrounded by the Bangemall Group which outcrops over an area of 170 000 km^2 (text-figs. 1, 16). These two units were once grouped as the 'Nullagine Beds' but detailed mapping has revealed that a major period of tectonism affected the south-western outcrop



TEXT-FIG. 16. Locality map of the Hamersley and Bangemall Basins. Broken line indicates the margin of the basins. The names of relevant map areas are shown.

area of the Mount Bruce Supergroup before the deposition of the Bangemall Group. Over most of the region the sediments are unmetamorphosed.

The action during 1960 by the Australian Government of lifting its embargo on the export of iron ore led to intensive exploration and mapping of these basins. The iron formations of the Mount Bruce Supergroup now provide iron ore in prodigious amounts. Mapping was concentrated in economically interesting areas and the south-eastern region of the Bangemall Basin was neglected. This study of stromatolites from the Hamersley and Bangemall Basins is of a reconnaissance nature but adds significantly to our knowledge of stromatolite distribution, particularly in pre-Riphean rocks.

Stratigraphy and Stromatolite Distribution

Mount Bruce Supergroup. The Mount Bruce Supergroup unconformably overlies Archaean metamorphic and igneous rocks of the Pilbara Block. The succession within the supergroup is shown in Table 1, which is based on a stratigraphic table for the centrally located Mount Bruce 1:250 000 Sheet area (Hunty 1965*a*). The lowermost group, the Fortescue, varies greatly from area to area, and rock types and thicknesses in the Wyloo Group also are variable (e.g. the Duck Creek Dolomite thickens from the 300 m quoted in Table 1 to at least 900 m in the Wyloo Sheet area). Formations in the intervening Hamersley Group are remarkable for their invariability.

TABLE 1. Content of the Mount Bruce Supergroup, based on a stratigraphic table for the Mount Bruce 1:250 000 Sheet area (Hunty 1965*a*), with modifications from Daniels (1968*a*) and Kriewaldt and Ryan (1967). Thicknesses are in metres, group names are on the left; * = Rb-Sr whole-rock datings; the stratigraphic positions of the dated rocks in the Fortescue and Wyloo Groups were not specified by Compston and Arriens (1968).

UNCONFORMITY

WYLOO	Capricorn Formation	Sandstone, greywacke, dolomite shale	1200 min.	
	Ashburton Formation	Shale, greywacke	Unknown; large	
	Duck Creek Dolomite	Dolomitic limestone, chert	300	*Pilbaria perplexa* *Patomia* f. indet.
	Mount McGrath Formation	Conglomerate, sandstone, quartzite, siltstone, shale, basalt	2000	
	Beasley River Quartzite	Quartzite	90	*2020 ± 165 m.y.
	Turee Creek Formation	Greywacke, conglomerate, shale, basalt	300	
HAMERSLEY	Boolgeeda Iron Formation	Siltstone, ferruginous shale, banded iron-formation	200	
	Woongarra Volcanics	Dacite, rhyolite, pyroclastics	570	*2000 ± 100 m.y.
	Weeli Wolli Formation	Banded iron-formation, shale, dolerite	480	
	Brockman Iron Formation	Banded iron-formation, chert, shale	660	
	Mount McRae Shale	Shale, siltstone, dolomite, dolomitic shale, chert	90	
	Mount Sylvia Shale	Banded iron-formation, shale	30	
	Wittenoom Dolomite	Dolomite, dolomitic shale	150	
	Marra Mamba Iron Formation	Chert, banded iron-formation	180	
FORTESCUE	Jeerinah Formation	Shale, chert, banded iron-formation, mudstone, quartzite, dolomite, dolerite	900	
	Mount Jope Volcanics	Pillow lavas, pyroclastics (including as correlatives Pillingini Tuff and Tumbiana Pisolite)	2000	*2190 ± 100 m.y. *Alcheringa narrina* *Gruneria* f. nov.
	Hardey Sandstone	Sandstone, arkose, conglomerate, quartzite, basalt	1200	

UNCONFORMITY

Fortescue Group. MacLeod and Hunty (1966) state that 'algal fossils were first located in a limestone bed in the Tumbiana Pisolite in 1959 (Hunty 1963, 1964)'. According to Kriewaldt (1964), dolomite recorded by Traves *et al.* (1956) is a correlative of the Tumbiana Pisolite (not the Carawine Dolomite) and these authors noted the presence in that dolomite of 'numerous concentric structures from half-inch to 2 feet in diameter which may be colonies of algae or slump structures'. Kriewaldt (1964) records the presence of '*Collenia* sp.' in correlatives of the Tumbiana Pisolite in the Roeborne region. Edgell (1964) compared stromatolites from the Tumbiana Pisolite near Mount Herbert in the Pyramid Sheet area to *Collenia multiflabella* Rezak and listed them in his stromatolite assemblage five as '*Collenia* sp. aff. *C. multiflabella*'. The name Tumbiana Pisolite is not used in that area now, and consequently Kriewaldt and Ryan (1967) list this stromatolite as occurring in the Pillingini Tuff, a possible correlative of the Tumbiana Pisolite. *Alcheringa narrina*, described herein from Mount Herbert, is the same stromatolite that Edgell compared with *Collenia multiflabella.* Cloud and Semikhatov's (1969) possible *Gruneria biwabikia* from the Mount Jope Volcanics, a correlative of the Tumbiana Pisolite in the Marble Bar area, is here considered to be a new form of *Gruneria*, as yet undescribed.

Hamersley Group. In this group definite stromatolites have been recorded from only one level, the Wittenoom Dolomite and its correlative the Carawine Dolomite, in an area of thin sedimentation in the east and north-east; Edgell's (1964) iron-formation stromatolites are abiogenic. The occurrence of stromatolites is recorded by Hunty (1963, 1964, 1965*b*) who states (1964) that 'The Carawine Dolomite is known to contain *Collenia* at Woodie Woodie. . . . Some concentric structures 2 feet in diameter were seen' at several localities. The only recorded stromatolites in the Wittenoom Dolomite are in the east: 'no *Collenia* have been found in the Wittenoom Dolomite, except in the outcrop 12 miles north of No. 44 Well. This indicates that the Wittenoom Dolomite is the deeper water continuation of the Carawine Dolomite in which *Collenia* have been found . . .' (Hunty 1967). I have been able to obtain neither further information nor any specimens of these stromatolites.

Wyloo Group. Stromatolites occur in the Duck Creek Dolomite of the Wyloo Group. Halligan and Daniels (1964, p. 41) give details of a section measured through the Duck Creek Dolomite, listing the occurrence of large and small columnar '*Collenia*' and '*C. undosa*' (non-columnar Duck Creek stromatolites are shown in Pl. 32, figs. 4–5). Edgell (1964) described and figured from the Duck Creek Dolomite '*Collenia undosa*', '*Collenia australasica*' (sic) and '*Newlandia lamellosa*'. Contrary to Edgell's opinion the *C. australasica* is not the same as Howchin's *Cryptozoon australicum* (recte *Acaciella australica*); Edgell's one small specimen is too small to be identified (pp. 177–179). It is likely that the '*Newlandia lamellosa*' (which apparently was not collected by Edgell) was not concave upward as Edgell states but in fact the reverse, in which orientation it resembles cumulate stromatolites common in the Duck Creek Dolomite (Pl. 32, fig. 4). Edgell was probably misinformed; otherwise he would have identified this stromatolite as *Collenia undosa* (compare his Pl. 5, fig. 1 with his Pl. 4, fig. 4). The large columnar stromatolites common in the Duck Creek Dolomite are described herein as *Pilbaria perplexa*;

they are known from the Duck Creek valley and from near Wyloo Homestead. The most southerly exposures of the Duck Creek Dolomite are in the Turee Creek 1:250 000 Sheet area: 'Algal structures at this locality consist of internally banded, cylindrical forms approximately half an inch in diameter and several inches long' (Daniels 1968*b*). These are identified here as *Patomia* f. indet.

Bangemall Group. In the south the Bangemall Group overlies the folded and metamorphosed Capricorn and Ashburton Formations of the Wyloo Group. It is mostly only gently folded and is well exposed in rugged hills south of the Hamersley Ranges. The most detailed stratigraphic columns published (Table 2) are those for the Edmund 1:250 000 Sheet area (Daniels 1966*a*, 1968*a*) whence came most of the stromatolites studied. Stromatolites were first recorded from the Bangemall Group by Halligan and Daniels (1964) who found '*Collenia undosa* type' and '*Conophyton* type' in the lower 'Top Camp Dolomite' (now called the Irregully Formation) and by Edgell (1964, p. 253) who noted that 'the genus *Conophyton* has also been distinguished in the Upper Proterozoic Bangemall Beds. . . .' In addition, Edgell reported *Collenia undosa* from near Windidda Station in the Kingston Sheet area well to the south-east of the main outcrop area of the Bangemall Group: the rocks there are probably correlatives of the Bangemall Group. According to Hunty (1965*b*) *Collenia undosa* occurs in the Nullagine Sheet area in the Waltha Woora Beds, a correlative of the Kurabuka Formation of the upper Bangemall Group (Hunty 1967).

TABLE 2. Content of the Bangemall Group in the Edmund 1:250 000 Sheet area (after Daniels 1968*a*). Thicknesses are in metres. * = Rb-Sr whole-rock dating on shale.

Kurabuka Formation	Sandstone, silty shale, shale	?	
Fords Creek Shale	Greenish shale, with some greywacke and chert	1700	
Coodardoo Formation	Greywacke with minor siltstone and shale	150-360	
Curran Formation	Shale with siltstone and chert	75	*1080±80 m.y.
Ullawarra Formation	Shale, siltstone, rare sandstone, and dolomite	?1500-1800	(thickness includes dolerite sills)
Devil Creek Formation	Dolomite, dolomitic shale, and dolomite breccia	60-360	*Baicalia capricornia*
Discovery Chert	Thin-bedded black or grey chert	60-360	
Kiangi Creek Formation	Sandstone with minor shale and chert	?600	
Irregully Formation	Dolomite, dolomitic shale, sandstone, chert, conglomerate, and breccia	?900	*Baicalia capricornia* *Conophyton garganicum australe*

UNCONFORMITY

Folded and metamorphosed Ashburton and Capricorn Formations, Wyloo Group, Mount Bruce Supergroup

Daniels (1966*b*) presents isopach, facies, and stromatolite distribution maps for the formations of the Bangemall Group; stromatolites occur in the Irregully and Devil Creek Formations. He figures *Baicalia capricornia* and states that in the Devil

Creek Formation 20 miles north-north-west of Coodardoo Gap in the Edmund 1:250 000 Sheet area the columns of this stromatolite 'all lie parallel to the bedding plane and show a preferred orientation of 124°'. The columns there are fragmentary and many are randomly arranged (Pl. 18, fig. 1) being neither at 124° nor parallel to bedding planes (which are very difficult to discover). The fragmentation and disorientation of the columns was probably caused by slumping of a large mass of partly-lithified stromatolitic sediment. Glaessner (1968, Pl. 1A) figures *Baicalia capricornia* at the type locality, in the western part of the Edmund Sheet area. Other stromatolite occurrences are mentioned by Daniels (1965*b*, 1966*a*, 1968*a*, 1968*b*). The Irregully Formation also contains *Conophyton garganicum australe* which is known from Irregully Creek on the Edmund 1:250 000 Sheet area and Fords Creek on the Turee Creek 1:250 000 Sheet area. Large oncolites and cumulate stromatolites occurring in the Bangemall Group are shown in Pl. 32, figs. 1–2.

Age of the Hamersley and Bangemall Basins successions

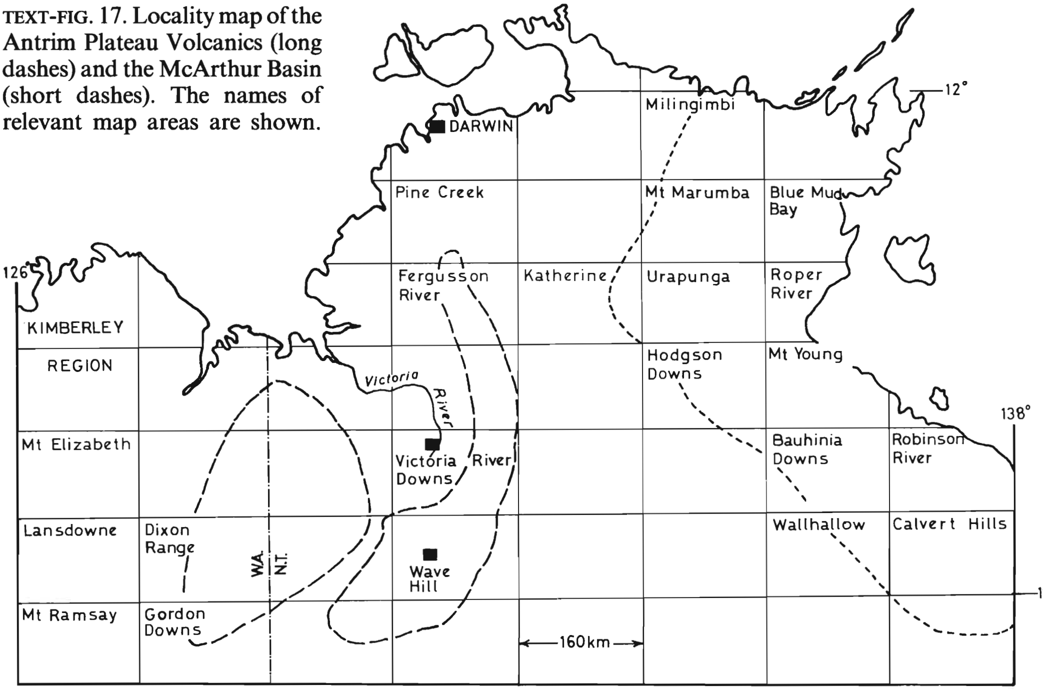
Up until 1963 the Mount Bruce Supergroup and the Bangemall Group were combined as the 'Nullagine Beds' because they were thought to be equally little metamorphosed and deformed. The tectonized Wyloo Group, referred to as the 'Ashburton Beds', was believed to be a correlative of the Archean 'Mosquito Creek Beds' (Maitland 1919). In 1963 the first detailed analysis of the stratigraphy of the 'Hamersley Iron Province' was published (MacLeod *et al.* 1963). The Fortescue, Hamersley, and Wyloo Groups were defined and some of the 'Ashburton Beds' were shown to belong to the Wyloo Group. Halligan and Daniels (1964) named and defined the Bangemall Group and the Mount Bruce Supergroup. Then in 1965 Leggo *et al.* published the results of a programme of Rb-Sr whole-rock dating: 1. a basement granite, only poorly dated, with a 'reasonable older limit' of 3040 m.y.; 2. 2100 m.y. for the Woongarra Volcanics of the Hamersley Group; 3. between 1720 and 1850 m.y. for a tuffaceous siltstone within the Wyloo Group; 4. a minimum age of 1720 m.y. for the Boolaloo Granite which intrudes the Wyloo Group. They also reported a model lead dating by Riley of 1700 ± 150 m.y. on galena in a vein cutting the Duck Creek Dolomite of the Wyloo Group. These datings enabled later workers to classify the Mount Bruce Supergroup as Early Proterozoic (Dunn *et al.* 1966) or define it as the type 'Nullaginian System' (Brown *et al.* 1968). More Rb-Sr whole-rock datings are reported by Compston and Arriens (1968). Acid igneous rocks interbedded in the Fortescue Group are dated at 2190 ± 100 m.y.; they may be intrusive. The Woongarra Volcanics of the Hamersley Group are reliably dated at 2000 ± 100 m.y., revising the dating quoted above. 'An age of 2020 ± 165 m.y. for layered igneous rocks interbedded in the Wyloo Group gives a younger limit for the age of the group, but more samples are needed. The 2020 m.y. mean value of this younger limit conflicts with the 1850 m.y. reported for the age of a tuffaceous siltstone in the Wyloo Group by Leggo *et al.* (1965), but we now believe that tuffaceous rocks often give unreliable Rb-Sr ages' (Compston and Arriens 1968). Granite intruding the Wyloo Group near, but not contiguous with, outcrops of the Bangemall Group (Minnie Creek granite) is dated at about 1690 m.y. Gneisses which apparently are those shown on the Edmund 1:250 000 Sheet as probably metamorphosed Ashburton Formation (Wyloo Group) gave a poorly fitted isochron of 1730±240 m.y. This, combined with the fact that some of the granites (granodiorites) have been deformed (Daniels 1965*a*), strengthens the contention that the clustering of determinations about 1700 m.y. dates the waning phase of tectonism of the Mount Bruce Supergroup. Since the overlying Bangemall Group is unaffected, 1700 m.y. is a maximum age for these sediments. Compston and Arriens (1968) also report an Rb-Sr whole-rock dating on shales from the Curran Formation of the Bangemall Group: these gave an isochron of 1080±80 m.y. Acid lavas in the Group gave a poor isochron of about the same age.

In summary, the Fortescue Group is probably about 2190±100 m.y. old, the Hamersley Group 2000±100 m.y., and the Wyloo Group 2020±165 m.y. The Bangemall Group is younger than 1700 m.y. and probably about 1080±80 m.y. old.

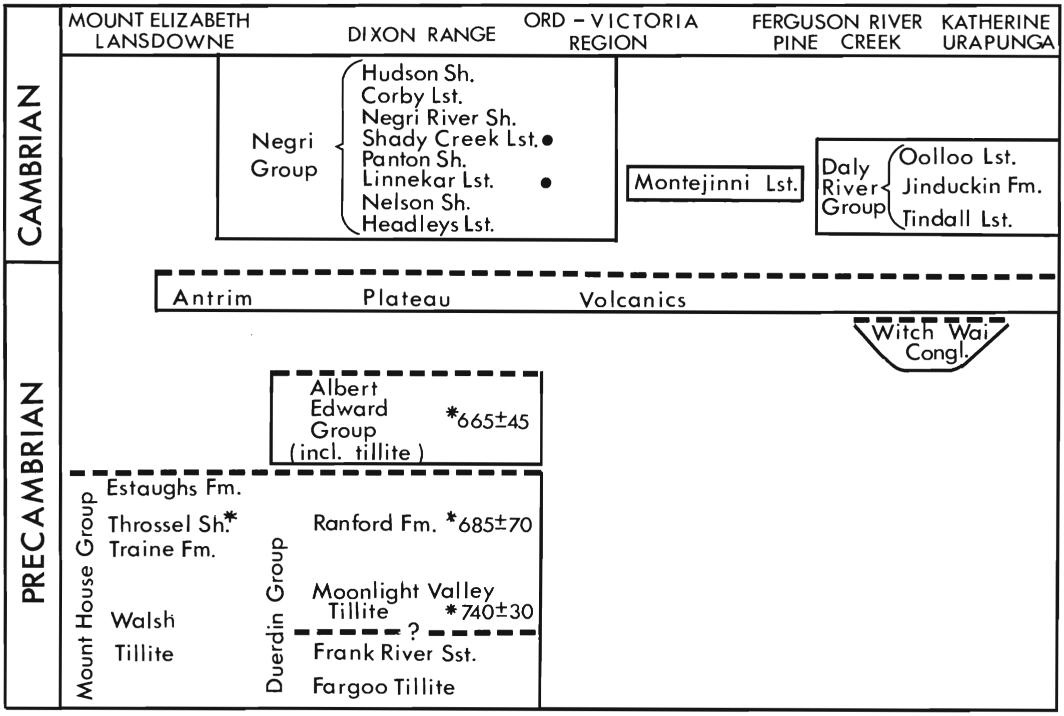
An attempt by Edgell (1964) at Precambrian biostratigraphy using stromatolites from the Hamersley and Bangemall Basins and other regions failed. The correlations postulated have now been refuted by the rigorous use of stromatolites and by isotopic dating. The reconciliation attempted by Crook (in Brown *et al.* 1968, p. 41) between Edgell's work and later isotopic datings presents no new data on stromatolites. The statement by Crook (ibid., p. 36) that the Precambrian age of the Bangemall Group is established by the presence within the group of *Collenia* is untenable.

ANTRIM PLATEAU VOLCANICS

The Antrim Plateau Volcanics and their correlatives outcrop over an area of about 44 000 km^2 in Western Australia and the Northern Territory (text-fig. 17). They are



TEXT-FIG. 17. Locality map of the Antrim Plateau Volcanics (long dashes) and the McArthur Basin (short dashes). The names of relevant map areas are shown.



TEXT-FIG. 18. Stratigraphy of the Cambrian and late Precambrian deposits of the east Kimberley and north-western Northern Territory regions. Congl. = conglomerate, Fm. = formation, Lst. = limestone, Sh. = shale, Sst. = sandstone, * = Rb-Sr dating, ● = Early Middle Cambrian fossils, ▬ ▬ ▬ = unconformity.

very little deformed. The stromatolites *Conophyton basalticum* and *C.* cf. *gaubitza* Krylov which occur in sediments interbedded with the volcanics were previously thought to be in sediments predating them (Traves 1955; Edgell 1964). They may be Early Cambrian or Vendian.

Stratigraphy and Stromatolite Occurrence

Pertinent features of the stratigraphy are given on text-figure 18 and discussed in the section on the age of the Volcanics. The Antrim Plateau Volcanics consist of a number of flows (possibly twelve in one area: Harms 1959) of volcanic rocks which 'range from olivine-basalts to quartz-basalts, and have distinct affinities with the tholeiitic- or plateau-basalts . . .' (Edwards and Clarke 1940). They are fine to coarse grained and vesicular or amygdaloidal at the tops of flows; some agglomerates and tuffs are present. The maximum thickness measured is about 1000 m. No definite pillow structures are known (Dow *et al.* 1964; Randal and Brown 1967).

There are many interbeds of sediments within the volcanics, including conglomerates, sandstones, siltstones, shales, limestones, and cherts (Harms 1959; Dunn 1963*a*, *b*; Dow *et al.* 1964; Randal and Brown 1967). In the Gordon Downs Sheet area about 30 m of conglomerate, sandstone, siltstone, and limestone are included in the basal Antrim Plateau Volcanics; these originally were named the

Lacey Creek Formation and yielded Edgell's (1964) *Conophyton* cf. *inclinatum* Rezak (recte *C.* cf. *gaubitza* Krylov) (J. H. Lord, pers. comm. 1969; M. H. Johnstone, pers. comm. 1969). Edgell was informed that the columns of *C.* cf. *gaubitza* occur parallel to bedding or with apices downwards: this is probably due to slumping, or may have resulted from mistaking bridges for column laminae. Traves (1954, 1955) first described stromatolites from the volcanics, identifying them as *Collenia frequens* Walcott, but it was his opinion that they are in silicified inliers of older rocks: 'Abundant fossils have been collected from two isolated inliers of silicified sediments in the Volcanics, which are presumed to belong to the Victoria River Group' (Traves 1955, p. 23). At one locality an 'outcrop has been surrounded by basalt so that it has been entirely silicified, and quartz veins, rock crystal, and basalt are found throughout the outcrop' (Traves 1955, p. 24). These outcrops are well illustrated in Traves' two publications. Although there are stromatolites in the Victoria River Group (Traves 1956) the relevant areas have now been mapped in more detail revealing that the siliceous stromatolites are interbedded in the upper part of the Antrim Plateau Volcanics, and that the stromatolites Traves (1954) described are from a metachert bed which outcrops over an area of many square miles. These stromatolites have been restudied and herein are named *Conophyton basalticum*.

Age of the Volcanics

Locally the uppermost volcanics are soft agglomerates or vesicular flow tops, which suggested to Matheson and Teichert (1948) and Harms (1959) a lack of significant erosion prior to the deposition of the overlying Negri Group. Traves (1955) and Dow (1965) considered that in the areas they were describing the Antrim Plateau Volcanics are conformably overlain by the Negri Group or Montejinni Limestone, but Dow and Gemuts (1967, 1969) and Randal and Brown (1967) record the presence of a slight angular unconformity between both of these units and the volcanics. Furthermore, there is a 7 m thick weathering profile on the volcanics below the Negri Group (Dow *et al.* 1964).

The oldest fossils in the Negri Group are about 230 m above its base, in the Linnekar Limestone. They are *Redlichia forresti*, *Biconulites hardmani*, and *Girvanella*. The overlying Shady Creek Limestone contains *Xystridura*, *Redlichia*, *Wimanella*, *Billingsella* cf. *humboldti*, *Biconulites hardmani*, and 'girvanellids' (Traves 1955). Öpik (1967) assigns this fauna to his Ordian Stage which he considers to be early Middle Cambrian, although it may be equivalent to what elsewhere is called late Early Cambrian. Because of the nature of the contact between volcanics and the Negri Group the volcanics have been considered little older than the Group and thus Early Cambrian (Traves 1955; Matheson and Teichert 1948). The recent discovery of a slight unconformity and a weathering profile indicates the possibility of a greater age. In the eastern areas of outcrop of the Antrim Plateau Volcanics they are unconformably overlain by the Daly River Group. The Tindall Limestone, at the base of the Group, contains *Redlichia*, *Xystridura*, ptychopariids, *Biconulites hardmani*, *Hyolithes*, *Helcionella*, *Lingulella*, *Acroteta*, *Obolus*, *Paterina*, *Chancelloria*, and *Girvanella*, which are early Middle Cambrian according to Öpik (Öpik 1956; Walpole *et al.* 1968).

The Antrim Plateau Volcanics rest with disconformity or angular unconformity on all older sediments except some thin sandstones which are included with the Volcanics (Dunn 1963*a*) or distinguished as a separate formation (Dunn 1963*b*). In the east the Witch Wai Conglomerate is a restricted valley-fill on top of the Tolmer Group overlain disconformably by the Volcanics (Malone 1962). Traves (1955, p. 32) describes the contact in the area he studied: 'The erosional unconformity between Upper Proterozoic sediments and the Volcanics is well illustrated along the Victoria River. . . . In this area the Volcanics are found in old valleys, some of them 200 feet deep, in sediments of the Victoria River Group. . . .' Harms (1959) describes similar contacts with the Mount House Group and Victoria River Group, noting that rocks under the Volcanics are often baked and silicified. An angular unconformity separates the Volcanics and the Albert Edward Group (Dow 1965). No radiometric datings are available for the Victoria River or Tolmer Groups. Cloud and Semikhatov (1969) have identified the typically Late Riphean (950±50–680±20 m.y.) stromatolite *Inzeria tjomusi* Krylov from the Hinde Dolomite of the Tolmer Group. The Victoria River Group unconformably underlies the Tolmer Group.

The youngest dated rocks beneath the Volcanics are the Albert Edward Group (Dow 1965) and its correlative the Louisa Downs Group, both of which contain a tillite. In an unpublished thesis quoted by Dow and Gemuts (1969) Bofinger gives datings for shales from these groups obtained by the Rb-Sr whole-rock method. The Elvire Formation of the Albert Edward Group gave 653±48 m.y. and the Timperley and McAlly Shales of the Albert Edward and Louisa Downs Groups 666±56 m.y.; these are all quoted by Bofinger as the 'minimum age of deposition'. These datings form part of a group which is mostly internally consistent, including 740±30 m.y. for the lower tillite (Moonlight Valley Tillite) and 685±70 m.y. for the Throssel Shale of the Mount House Group and the Ranford Formation of the Duerdin Group (overlying the lower tillite). The two tillites of the Amadeus Basin are late Late Riphean to Vendian. The lower tillite (Sturt Tillite) of the Adelaide Geosyncline is Late Riphean while the upper tillite is Late Riphean to Vendian (Glaessner *et al.* 1969). An age of 680±20 m.y. for the Late Riphean–Vendian boundary (Keller 1969) is consistent with the correlation of the tillites from these three areas.

The available evidence limits the age of the Antrim Plateau Volcanics to between early Vendian and early Middle Cambrian. This is an interval of about 100 m.y. of which no more than 30 m.y. is Cambrian, and therefore there is little reason to suggest that these *Conophyton* occurrences are inconsistent with Russian observations that no *Conophyton* are younger than the Vendian.

McARTHUR BASIN

The McArthur Basin occupies about 120 000 km^2 in the north-eastern Northern Territory (text-fig. 17). It contains about 10 000 m of Precambrian sediments including the type Carpentarian of Dunn *et al.* (1966). Many of the sediments contain stromatolites and a number of specimens from the McArthur Group collected by officers of the Bureau of Mineral Resources, Geology and Geophysics, have been available for study.

Stratigraphy and Stromatolite Occurrence

Lying unconformably above basement metamorphics are several spatially separated acid volcanic units. The dominantly arenaceous Tawallah Group and its correlatives overlie the volcanics, usually unconformably. The McArthur Group and its correlatives, with a large proportion of dolomite, is variously conformable or unconformable above the Tawallah Group. Unconformably above these units is the arenaceous and lutitic Roper Group. The total thickness of the three groups of sediments reaches about 10 000 m. Recent mapping of the McArthur Group in the Bauhinia Downs Sheet area has disproved the existence of a previously reported carbonate reef complex and a completely revised stratigraphic scheme has now been proposed (Plumb and Brown, in press). The composition and stratigraphy of the McArthur Group and the occurrences therein of stromatolites will be discussed in detail by Roberts *et al.* (in prep.) and Dunn *et al.* (in prep.). All of the data on stromatolite occurrence listed here are from explanatory notes to the 1:250 000 scale geological maps.

In the Mount Marumba Sheet area the Cottee Formation of the Katherine River Group contains 'hemispherical algal mounds with radii up to 30 feet. The mounds consist of concentric layers of laminated dolomite up to a few inches thick; the laminae are "wavy" ' (Roberts and Plumb 1965). The same formation in the Milingimbi Sheet area also contains stromatolites. Stromatolites (usually referred to as 'algae') are reported from the Tawallah Group, particularly the Wollogorang Formation, in the Robinson River, Wallhallow, and Mount Young Sheet areas.

Stromatolites occur in many formations in the McArthur Group. They have been recorded in the following sheet areas: Blue Mud Bay, Wallhallow, Bauhinia Downs, Mount Young, Calvert Hills, Robinson River, and Urapunga. The stromatolites I studied are *Conophyton garganicum* (*garganicum*?) from the Karns Dolomite, Emmerugga Dolomite, Barneys Creek Formation, Reward Dolomite, and possibly the Tooganinnie Formation and Amelia Dolomite. Cloud and Semikhatov (1969) also record *C. garganicum* from the McArthur Group. The McArthur Group is correlated with the Mount Rigg Group, of which the Dook Creek Formation contains stromatolites. These are reported from the Urapunga and Mount Marumba Sheet areas. On Mount Marumba rocks of the Dook Creek Formation 'are frequently exposed as discrete biohermal mounds or as groups of bioherms, particularly near the base of the sequence (west of Mount Jean) and near the top, in the Bulman District' (Roberts and Plumb 1965). According to Cloud and Semikhatov (1969) the Dook Creek Formation contains *Conophyton* f. indet. and *Inzeria tjomusi* Krylov. As these authors observe, a diagnostic feature of *I. tjomusi*, niches enclosing projections, is absent from the Dook Creek material which also is poorly preserved; my study of their specimens revealed that poor preservation prevents observation of the characteristic microstructure of *I. tjomusi*. More specimens are needed for identification of these stromatolites. Cloud and Semikhatov (1969) cast doubt on the correlation of the Mount Rigg and McArthur Groups because this reported occurrence of *I. tjomusi* contradicts the available radiometric data. The identification is too provisional to cause abandonment of the correlation.

The only possible stromatolites reported from the Roper Group are pebbles of 'algal chert' in the basal Limmen Sandstone on Mount Marumba, and 'cone-in-cone limestone', which may mean conophytons, in the Urapunga Sheet area.

Age of the McArthur Basin succession

Four major publications discussing the geochronology of the McArthur Basin are those of McDougall *et al.* (1965), Richards (1963), Dunn *et al.* (1966), and Compston and Arriens (1968). Compston and Arriens summarize the presently accepted data.

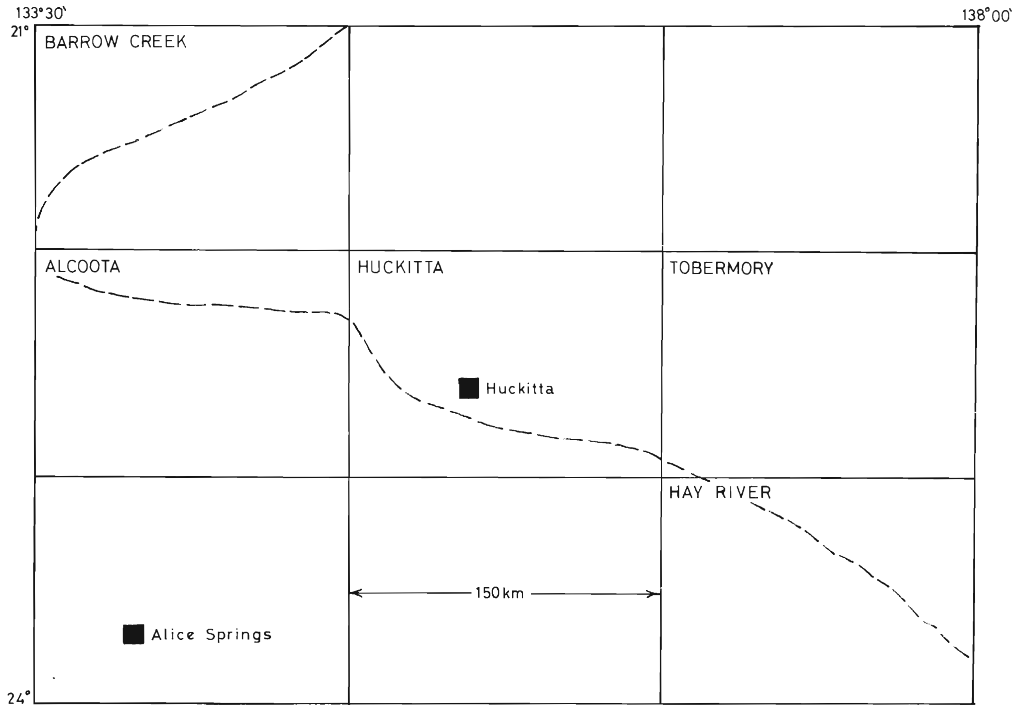
The maximum age of the McArthur Group is well established as less than 1750 m.y. There is a model lead age of 1560 m.y. from within the group. The overlying Roper Group is probably at least 1390 m.y. old, and if several interpretations and correlations are correct is somewhere near 1510 ± 120 m.y. old. The minimum age of the succession is poorly established. A more comprehensive and detailed study of the McArthur Group stromatolites could help establish more precisely the minimum age of the group, and would be an important contribution considering the tentative and contradictory nature of the radiometric data and the use of this sequence as the type Carpentarian.

GEORGINA BASIN

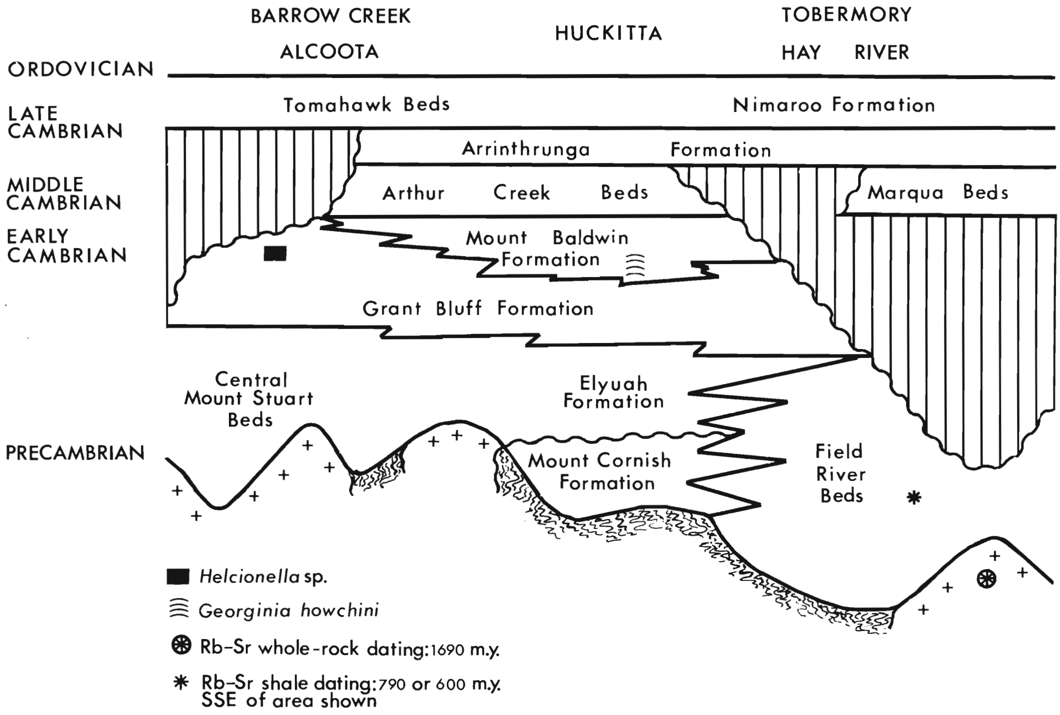
The Georgina Basin consists of several hundred to several thousand metres of little-deformed Adelaidean (late Proterozoic) to Devonian sediments covering an area of about 320 000 km^2 (text-fig. 1) in the Northern Territory and Queensland (using the definition of the basin given by Brown *et al.* 1968, p. 50). The geology of the basin is described in detail by Smith (1967). The material available to me is several small but interesting and significant specimens collected in the south-western Georgina Basin (text-fig. 19) by officers of the Bureau of Mineral Resources, Geology and Geophysics. Those studied are from the Mount Baldwin Formation of Early Cambrian or, less likely, Vendian age and are especially significant because they are defined as a new group and form closely related to *Conophyton* (which became extinct during the Vendian).

Stratigraphy and Stromatolite Occurrence

The stratigraphic sequence in the south-western Georgina Basin is summarized on text-fig. 20. The Mount Cornish Formation and Field River Beds are glaciogene consisting of siltstone with boulders, cobbles and pebbles, laminated siltstone and sandstone with subordinate amounts of carbonates, arkose, and greywacke; many of the erratics are striated and some are faceted. The vertical positions of the formations relative to each other are unknown; Smith's (1967) interpretation that they are of different ages and are correlatives of the two tillites of the Amadeus Basin is very weakly based. Overlying the Mount Cornish Formation with probable disconformity is the Mopunga Group, three dominantly clastic formations with vertically gradational boundaries (Elyuah, Grant Bluff, and Mount Baldwin Formations); possible lateral intergradation is indicated by the observation (Smith 1964, p. 29) that where the Grant Bluff Formation thickens the Mount Baldwin Formation



TEXT-FIG. 19. Locality map of the south-western Georgina Basin. Broken line indicates basin margin. The names of relevant map areas are shown.



TEXT-FIG. 20. An interpretation of the Precambrian to Ordovician stratigraphy of the south-western Georgina Basin indicating the possibility of a Precambrian age for *Georginia howchini*. Map names are given at the top of the diagram.

thins. The Elyuah Formation is dominantly arkose and green and grey shale. The Grant Bluff Formation is quartz sandstone, greywacke, grey to brown siltstone and shale, and thin dolomite. The Mount Baldwin Formation, from which the studied stromatolite came, is dominantly red sediments (sandstone, greywacke, siltstone, shale, and dolomite) with some green shale and yellow dolomite. The Middle Cambrian Arthur Creek Beds overlie the Mount Baldwin Formation with apparent conformity.

Stromatolites probably from the Mount Baldwin Formation are mentioned by Noakes (1956) and Casey and Tomlinson (1956). The only definite published report is on figure 16 of Smith (1964) where they are shown about 75 m below the occurrence of archaeocyathans in one section, about two-thirds of the way down the formation. The section locality is shown on Smith's figure 9: the stromatolite occurrence seems to coincide with macrofossil locality 36 on the Huckitta 1:250 000 Sheet. The stromatolites studied are *Georginia howchini.*

Overlying metamorphic basement in the Barrow Creek Sheet area is the Central Mount Stuart Beds, a sequence of red and brown sandstones, red arkose and siltstone, and greywacke. These are probably correlatives of the Elyuah Formation, and possibly also the Mount Cornish Formation. Conformably above the Central Mount Stuart Beds is the Grant Bluff Formation. Outcrop is sparse and no contact with the Upper Cambrian Tomahawk Beds is seen; locally these lie unconformably on the Central Mount Stuart Beds or the basement (Smith and Milligan 1964). Smith (1964, p. 36) notes that in the Alcoota Sheet area 'there is much soil cover between the Grant Bluff Formation and fossiliferous Upper Cambrian sediments, and the Mount Baldwin Formation, or an equivalent of it, could be present but concealed'. Alternatively, the upper Grant Bluff Formation in the Barrow and Alcoota Sheet areas could be a correlative of the Mount Baldwin Formation as Smith (1963*b*) considered possible for the Hay River and Tobermory Sheet areas (text-fig. 20); these formations have gradational boundaries in the Huckitta Sheet area.

Age of the Mount Baldwin Formation

Early Cambrian archaeocyathans and brachiopods occur in the upper third of the Mount Baldwin Formation (Smith 1963*a*). The exact stratigraphic position from which *Georginia howchini* came is unknown but I assume it to be the same as the stromatolites mentioned on figure 16 of Smith (1964), about two-thirds of the way down the formation. Therefore, knowledge of the age of the lower part of the Mount Baldwin Formation in the Huckitta Sheet area is crucial.

The Early Cambrian mollusc *Helcionella* is found near the top of the Grant Bluff Formation in the Barrow Creek Sheet area (Smith and Milligan 1964). The stratigraphic relationships described above indicate that the Grant Bluff and Mount Baldwin Formations may in part be lateral equivalents (text-fig. 20); hence *Georginia howchini* may be older than the *Helcionella.* Wade (1969) has described two scyphozoan-like medusae, *Hallidaya brueri* and *Skinnera brooksi*, from what is probably the Central Mount Stuart Beds in the Alcoota Sheet area. *S. brooksi* is not known from elsewhere but *H. brueri* also occurs in the Arumbera Sandstone about one-quarter of its thickness up from the base, 23 km south-west of Alice

Springs. As at least the upper Arumbera Sandstone at that locality is earliest Cambrian the *H. brueri* cannot be older than latest Precambrian. The time range of *H. brueri* is unknown but its occurrence in the Central Mount Stuart Beds suggests for them a very late Precambrian age. The Georgina Basin *H. brueri* may be older than *Georginia howchini* but the likelihood of facies changes between the Alcoota and Huckitta areas makes this uncertain. The analyses for radiometric dating of what was considered to be the Field River Beds gave complex results: several samples appear to register a 790 m.y. age but others are younger at about 600 m.y. (Compston and Arriens 1968, p. 575). In summary, it is extremely unlikely that *G. howchini* is older than Late Vendian and probable that it is Early Cambrian.

Other Stromatolite Occurrences in the Georgina Basin

Latest Precambrian to Ordovician stromatolites occur frequently in the Georgina Basin but there, as elsewhere, are poorly known. Available information is minimal and often tantalizing: such a case is Öpik's (1960, p. 101) mention of 'calcareous algae with filaments preserved' in the Middle Cambrian to Early Ordovician Nimaroo Formation (see also Pritchard 1960; Reynolds 1965; Nichols 1966). Only the Mount Baldwin Formation stromatolites have been studied, although examination of a specimen from the Grant Bluff Formation revealed a columnar possibly parallel branching stromatolite too poorly preserved to be reconstructed.

Stromatolites have long been known from the Middle Cambrian Arrinthrunga Formation of the southern Georgina Basin. They were first recorded by Madigan (1932*b*, p. 96) in a unit which appears from published maps most likely to be the Arrinthrunga Formation: 'Good "*Cryptozoön*" were plentiful. One "head" was a fan-shaped mass five feet across and two feet six inches high, entirely built up of the Chewings type of "*Cryptozoön*", cylindrical laminated tubes, with laminae convex upwards, and all radiating from the base.' These occurred with possibly Cambrian fossils. Madigan (1937) again noted the presence of Cambrian stromatolites in this area. Casey and Tomlinson (1956) rejected Madigan's assessment of a Cambrian age for these 'because of the presence of *Collenia* and the absence of undoubted Cambrian fossils. One of the species of *Collenia* is similar to, and possibly identical with, *Cryptozoon* (*Collenia*) *tessellatum* Howchin. *Collenia tessellata* is one of the commonest algae in central Australia; it occurs in association with other species of *Collenia* of late Proterozoic aspect, and is not known to occur with Cambrian fossils. A very similar form is found in the Flinders Ranges of South Australia, and Mawson and Madigan (1930, p. 416) consider this South Australian form "to be probably late pre-Cambrian or Lower Cambrian" in age.' That such superficial comparison of stromatolites does not allow correct deductions on age is shown by the fact that the Arrinthrunga Formation is now reliably dated by conventional fossils as Late Cambrian. Smith (1963*a*, 1964, 1965) has recorded stromatolite occurrences in the formation in the Huckitta and Tobermory Sheet areas; his plate 4 in the 1964 publication shows an exposure parallel to bedding of large cumulate stromatolites.

LITHOFACIES RELATIONSHIPS AND PALAEOECOLOGY

In this section the lithofacies relationships of some Australian stromatolites are outlined. A detailed sedimentological and ecological study of stromatolites is beyond the scope of this work, but the information collected here will be useful for future facies analyses. Its special relevance here lies in the fact that it illustrates several important sedimentological relationships which are relevant to stromatolite taxonomy, and, in the case of the Bitter Springs Formation, it allows comparisons with areas of present sedimentation and stromatolite growth. The rock types in which stromatolites occur and with which they are spatially associated were recorded in detail for the Bitter Springs Formation of the Amadeus Basin; information on this subject is also available for other stratigraphic units in that basin. Some data are available from the other areas from which stromatolites are described here.

An unusual occurrence of stromatolites is that of *Conophyton basalticum* and *C.* cf. *gaubitza* in the Antrim Plateau Volcanics of northern Australia (pp. 46–49). The volcanics consist of a number of flows of olivine-basalt to quartz-basalt with vesicular or amygdaloidal tops; some agglomerates and tuffs are present but no pillow structures are recorded. The stromatolites occur in metachert interbedded with the volcanics and in one case accompanied by other sediments. Much of the quartz comprising the stromatolites is now coarse grained although the grain size ranges down to 5 μ. Many laminae consist partly of carbonate. *Alcheringa narrina*, described herein, also occurs in a volcanic sequence, the Fortescue Group of the Hamersley Basin. It occurs in cherty dolomites which are not contiguous with lava flows but which contain occasional volcanic shards, large mica flakes, and a large amount of clay which presumably is the alteration product of volcanics.

The Bangemall Group of the Bangemall Basin contains *Baicalia capricornia* and *Conophyton garganicum australe*. I have seen the *Conophyton* only in thick-bedded dolomites of the Irregully Formation where both of the biostromes observed have as their upper surfaces penecontemporaneous erosion surfaces (text-fig. 26). In one case the biostrome is overlain by several centimetres of green shale and then dolomite with cumulate stromatolites, in the other by barren dolomite. Disconformities cut the tops of *Conophyton cylindricum* biostromes described from the U.S.S.R. by Shapovalova (1968). Daniels (1966*b*) noted the association of stromatolites, desiccation cracks, and intraformational conglomerates in parts of the Irregully Formation. Where I have seen them, the desiccation cracks occur in thin quartzites and red siltstones interbedded with carbonates containing *B. capricornia*, cumulate stromatolites, or large oncolites (Pl. 32, figs. 1–2). The quartzite interbeds have truncated ripple marks frequently with '*Manchuriophycus*' crack infillings in their troughs. At one locality in the Devil Creek Formation fragmented columns of *B. capricornia* occur in a slump breccia (Pl. 18, fig. 1).

The Cambrian Pertaoorta Group of the Amadeus Basin contains both abundant and uniform columnar stromatolites and abundant and diverse shelly fossils, but where I have observed the stromatolite beds no shelly fossils occur within them. The complex intertonguing and gradational relationships of the formations of the Pertaoorta Group are shown in text-fig. 11. All of the columnar stromatolites studied from these units are *Madiganites mawsoni*. Thin beds of stromatolitic limestone occur within the siltstone and shale of the Hugh River Shale. The Giles Creek Dolomite is up to 400 m green and purple siltstone and shale with interbeds of fossiliferous limestone overlain by dolomite. Where the dolomite is thin-bedded it has 'a few stromatolite colonies. The colonies are of a different type and are less abundant than those of the Shannon Formation' (Wells *et al.* 1967, p. 39). Actually, these too may consist of *M. mawsoni* since this occurs in a variety of forms which in the field are not easily equated. Other fossils present in the Giles Creek Dolomite include *Girvanella*, hyolithids, gastropods, brachiopods, and trilobites. The Shannon Formation is up to 700 m of interbedded green and brown shale, siltstone, grey, grey-brown, and pink limestone, and grey, fawn, and yellow thin-bedded and laminated dolomite. The proportion of limestone to dolomite is variable. Oolites, intraformational breccia, and cross-bedding are present. There are numerous stromatolitic biostromes, most often composed of limestone. Biostromes exposed in the Ross River valley are domed, being formed of contiguous domed bioherms about 1 m wide and 60 cm thick, within which are the columns of *M. mawsoni*. The Jay Creek Limestone is limestone, dolomite, siltstone, and rarely sandstone, with a maximum thickness of about 420 m. The limestone is yellow-brown to grey, thin to thick-bedded, and includes many beds which are oolitic and stromatolitic. The siltstone and shale is grey-green and red-brown. Halite pseudomorphs are found near the base of the formation. Some beds of limestone 'contain many algal bioherms up to 6 feet across and 3 feet high' (Wells *et al.* 1967, p. 42). At Jay Creek there are numerous hemispherical stromatolites from several to 50 cm wide, and *M. mawsoni* forms several biostromes 15–30 cm thick. *M. mawsoni* was collected by C. T. Madigan from the Waterhouse Ranges on the Henbury Sheet area; Madigan (1932*a*) describes the Jay Creek Limestone from several areas giving special attention to its stromatolites. Other fossils present in the formation include *Girvanella*, hyolithids, and trilobites. The Goyder Formation of sandstone, siltstone, dolomite, and limestone also contains stromatolites but these have not been studied; in addition trilobites, gastropods, and hyolithids are common.

Sand-sized oolites and intraclasts are abundant in the Pertaoorta Group and frequently fill the spaces between stromatolite columns, but they are rare or absent within the columns. This is in marked contrast with the stromatolites in the Ringwood Member of Pertatataka Formation in the Amadeus Basin. The Ringwood Member also contains abundant calcarenite in the form of oolites and intraclasts, but in this case *Tungussia inna*, the only columnar stromatolite known from the unit, has columns composed largely of calcarenite. Wells *et al.* (1967, p. 27) describe the member above the green siltstone and shale at its base: the 'association of tough cherty [stromatolitic] dolomite overlain by grey-green and dark grey cross-laminated fragmental dolomite and limestone is characteristic. The carbonate rocks are dark grey, yellow, grey-brown, blue-grey, and mottled where they contain pellets. They are oolitic, thin to medium-bedded, cross-laminated, and in places consist entirely of pellets of silty carbonate. Some of the dolomite and limestone beds are sandy. A thin sequence of fine yellow oolitic dolomite forms a good marker bed near the base of the member. In most places it is succeeded by fine dolomite, weathering light yellow-brown, which contains irregular stromatolite colonies. . . . The overlying carbonate rocks are mostly thin-bedded, dark blue-grey, and fragmental. Cross-bedding, lenses and laminae of fine limestone, irregular nodules of oolitic chert, and pellets of silt and silty dolomite are common in places.' The 'stromatolite colonies' are *T. inna*, which forms thin biostromes and occasional isolated small hemispherical bioherms.

The most abundantly stromatolitic unit in the Amadeus Basin is the Bitter Springs Formation. The stromatolites are largely restricted to the upper unit, the Loves Creek Member, the rock types of which are described below in some detail, but some also occur in the Gillen Member. The lithology of the Gillen Member is illustrated in text-figure 13. Pseudomorphs after halite are locally present in the siltstone of the member and the Ringwood Dome, 5 miles south-west of Ringwood homestead, is composed of gypsum belonging to this unit. Halite 'in the Bitter Springs Formation in Ooraminna No. 1 and Mount Charlotte No. 1 Wells is also referred to the Gillen Member' (Wells *et al.* 1967, p. 15). Gypsum outcrops at a number of localities (Forman 1966, p. 26). The only stromatolite known from the Gillen Member is *T. erecta*, which occurs near Mount Gillen in the upper part of a bed of dolomite several metres thick interbedded in red and green siltstones and shales (no halite casts or gypsum are known from these clastics).

Characteristics of the Loves Creek Member of the Bitter Springs Formation include the frequent presence both of massive red silty carbonate (or calcareous or dolomitic siltstone) with white spots and of stromatolites. Stromatolites occur within the member throughout the Amadeus Basin (text-fig. 12). At least half of the 500 m or so thickness of the unit is carbonate. I have measured a section through part of the Loves Creek Member at Jay Creek (text-fig. 14). About 15 per cent of the carbonate there is limestone, about 85 per cent dolomite (as determined by appearance, reaction to acid in the field, and many checks using X-ray and staining techniques in the laboratory). Nearly all of the dolomite is pale grey to grey-green on freshly broken surfaces, but weathers to a yellow-grey colour. It is thick-bedded and laminated; about 50 per cent of the beds contain columnar stromatolites, most of which are *Acaciella australica* but also *Boxonia pertaknurra*, *Basisphaera irregularis*, and *Jurusania nisvensis* (*B. pertaknurra* may be more plentiful than indicated on text-figure 14 since it is not always distinguishable in the field from *A. australica*). Cumulate stromatolites up to several metres wide with smooth or wavy laminae occur with moderate frequency in dolomite in the upper part of the measured section, and pseudocolumnar types the units of which have widths of up to 1 m or more are plentiful there. Perhaps about 30–40 per cent of the dolomite lacks obvious stromatolites but has laminae which are wavy and wrinkled and probably stromatolitic. Thin beds of intraformational breccia are infrequent in the dolomite. Chert is plentiful, both as nodules and as evenly silicified carbonate; it is almost completely restricted to the dolomite (text-fig. 14). The red silty dolomite at Jay Creek is unbedded, unlaminated, contains no stromatolites, and outcrops hardly at all. One sample dissolved in HCl contained about 20 per cent by volume of quartz grains in the size range 1–30 μ (clay to silt size). Much smaller amounts of detrital quartz are present in the boldly outcropping dolomites and limestones forming most of the measured section. The insoluble residue after HCl dissolution of the dolomites and limestones also includes some microcline, iron oxides, and clays (sheet silicates).

Most of the outcropping limestones at Jay Creek are dark grey both when freshly broken and when weathered, but some are pale grey. All contain columnar branching or pseudocolumnar stromatolites. Thin beds of oolites and intraformational breccia are present in the limestone near the top of the section. *Linella avis* Krylov and *Kulparia alicia* (Cloud and Semikhatov) have been found only in limestone and the only other columnar branching stromatolite in limestone at Jay Creek is *A. australica*. Limestone beds with *K. alicia* and pseudocolumnar stromatolites are uniformly calcareous, but in the *L. avis* and *A. australica* biostromes the stromatolite columns are limestone though the interspaces are pale grey dolomite; the limestone is finer grained and contains more organic matter than the dolomite which results in the colour contrast visible in photographs (e.g. Pl. 26). Large, irregular patches of the columns rarely are also dolomite.

A taxonomically and ecologically significant point that should be made here is that in the Loves Creek Member there is a diverse assemblage of stromatolites in identical or very similar rocks. A striking example is the occurrence of *L. avis* and *A. australica* at Jay Creek: they both form extensive biostromes in which the stromatolites are dark grey limestone though the interspaces are pale grey dolomite. In thin section the rocks are identical. Yet these two stromatolites are especially distinctive and different. This indicates that more than the environment of deposition (at least as reflected in the rock type) is important in determining the shape of stromatolites. This is the same conclusion reached below in a discussion of modern algae and stromatolites (pp. 92–96).

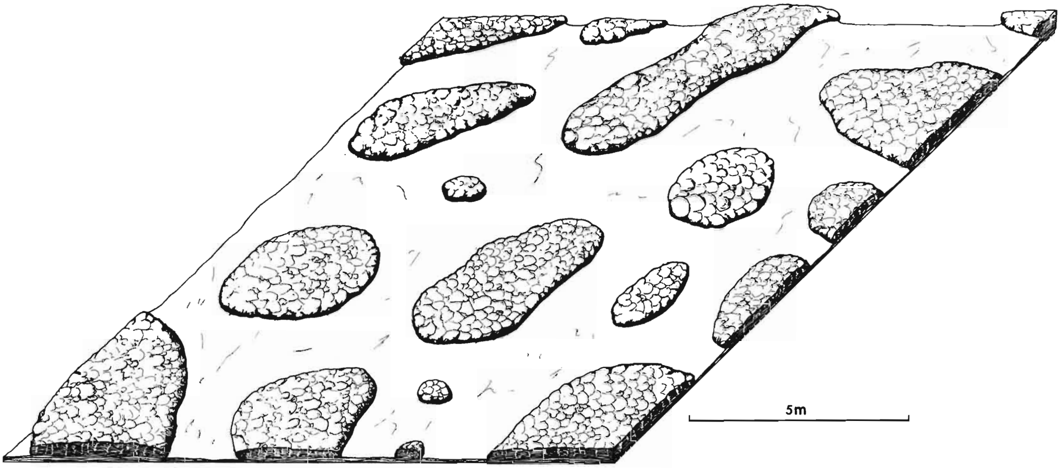
Preservation of the stromatolites. Patchily silicified stromatolites are very common, but the stromatolites from the Antrim Plateau Volcanics are unusual in consisting largely of quartz. It is conventional to interpret siliceous stromatolites as originally calcareous, and since there is much relict carbonate in the Antrim stromatolites, that interpretation applies here. However, this conventional interpretation seems sometimes to be applied with too little consideration of the possibility that some stromatolites may originally have been siliceous, and so a brief digression is justified.

Weed (1889) described the formation by algae of siliceous pillars, clavate and mushroom-shaped structures in pools of cool, silica-rich water associated with volcanic hot springs at Yellowstone, U.S.A. Weed's description of these structures showed that they are probably stromatolites, and the presence there of stromatolites was confirmed by the thin-sections figured by Barghoorn and Tyler (1965). Later studies (Allen 1934; White *et al.* 1956) have largely discounted Weed's idea that the algae were important as silica precipitators, but his pioneering study did show that algae can flourish in silica-rich waters, and can build stromatolites in them. It is possible that the main process involved is silica trapping, analogous to the detrital carbonate trapping demonstrated by Monty (1967) and others to be important in the formation of some modern calcareous stromatolites. The excellent preservation of micro-organisms within the cherty stromatolites of the Gunflint Formation has led Barghoorn and Tyler (1965) and Cloud (1965) to the conclusion that the silica is a primary sediment. Thus stromatolites can be primarily siliceous, although the stromatolites of the Antrim Plateau Volcanics apparently were originally calcareous. It is probable that the volcanics were extruded subaerially and the stromatolites grew in lakes in hollows in the basalt flows. This is because no definite pillow structures have been reported from the volcanics, they are inter-bedded with possible fluviatile and aeolian sediments (Dow *et al.* 1964; Randal and Brown 1967) and because locally they fill erosional valleys on older rocks.

A striking feature of several of the stromatolite biostromes in the Loves Creek Member of the Bitter Springs Formation at Jay Creek is that the stromatolite columns are black while the interspace fillings are very pale grey (Pl. 26). In all cases X-ray, staining, and acid tests have shown the black columns to consist largely of calcite. The same tests show that the pale grey interspace fillings frequently are largely dolomite, but in some there is much calcite, and infrequently calcite predominates. The black pigment is organic. The interspace fillings are often crudely layered, the layers most frequently being 1–5 mm thick. There are three types of layers in predominantly dolomitic interspaces: 1. almost homogeneous hypidiotopic to idiotopic dolomite of 20–150 μ grain size; 2. almost homogeneous xenotopic calcite of 5–25 μ grain size; 3. mixed layers which frequently contain calcite intraclasts partly replaced by dolomite. Pale grey calcitic interspaces have a distinctly different texture, in which a background of xenotopic calcite of 5–20 μ grain size is overprinted by very irregularly xenotopic calcite with a grain size of up to 150 μ. This appears to be a recrystallization texture, whereas the dolomitic interspace fillings formed by replacement of calcite. Where interspace fillings have been dolomitized there are gradational contacts between the filling and the contiguous columns, and between the groundmass of the filling and included calcitic intraclasts; there are all variations from well-preserved calcitic intraclasts to almost invisible dolomitized intraclasts. The same type of dolomite occurs in columns, especially along concordant stylolites: the more concordant stylolites in a calcitic column, the more dolomite is present. The Jay Creek calcitic *Acaciella australica*, with moderately frequent concordant stylolites, are about 10 per cent dolomite; the Ross River *Inzeria intia*, with very frequent concordant stylolites, are about 30–40 per cent dolomite. The dolomite appears to have formed later than some calcite veins that cut both interspace fillings and columns, including the concordant stylolites. Therefore this dolomitization occurred after lithification. It was selective, being concentrated in the most porous and permeable parts of the rocks; i.e. in the coarser interspace infillings and along stylolites and some laminae. Stromatolites with walls rarely have concordant stylolites and rarely show evidence of post-lithification dolomitization; this is true of the upper parts of *I. intia*, the lower parts of which lack walls and have been dolomitized.

Some stromatolites from the Loves Creek Member consist entirely of dolomite, and yet fine structures in them are even better preserved than in the calcitic stromatolites. They have not been subjected to the destructive dolomitization just described. In contrast to the destructive dolomite, that comprising these stromatolites is xenotopic to hypidiotopic with a grain size of 5–30 μ (where little recrystallized). The best example is *A. australica* from Katapata Gap; in others the dolomite is a little coarser grained and more frequently hypidiotopic. Because of the excellent preservation of fine laminae and the very fine grain size, it could be suggested that these stromatolites grew by the trapping of clay to silt-size dolomite particles. This is not likely because the interspaces of the Katapata *A. australica* include numerous dolomite grapestones, botryoidal lumps, oolites, and other coated grains, all of which are abundant in modern carbonate-depositing environments, where they consist of aragonite (e.g. Illing 1954; Kendall and Skipwith 1969). Friedman and Sanders (1967) consider that such evidence clearly indicates dolomitization of originally aragonitic sediment. The dolomite of the interspace sediments is texturally indistinguishable from that in columns, and therefore probably only one generation of dolomite is present. Because this dolomitization had quite different results from the post-lithification dolomitization, it is considered to have occurred prior to lithification, probably soon after sedimentation. Such early dolomitization has been described from Recent sediments in a number of areas, particularly the Persian Gulf (Illing *et al.* 1965; Kinsman 1969; Kendall and Skipwith 1969) and the Bahamas (Shinn *et al.* 1965). The conditions necessary for this type of dolomitization are found in upper intertidal and supratidal areas. By analogy, it is suggested that the environment of deposition of the Loves Creek Member may have been like that marginal to the present Persian Gulf, although more humid (because of the paucity or absence of gypsum). Whether a stromatolite was dolomitized or preserved as its original calcium carbonate may have depended on events after stromatolite growth, in particular whether the sediments were prograding so that supratidal sediments came to immediately overlie intertidal and subtidal sediments, which were then dolomitized (as adjacent to the Khor al Bazam; Kendall and Skipwith 1969), or whether subsidence was keeping pace with or exceeding sedimentation, so that no such process of early dolomitization could occur.

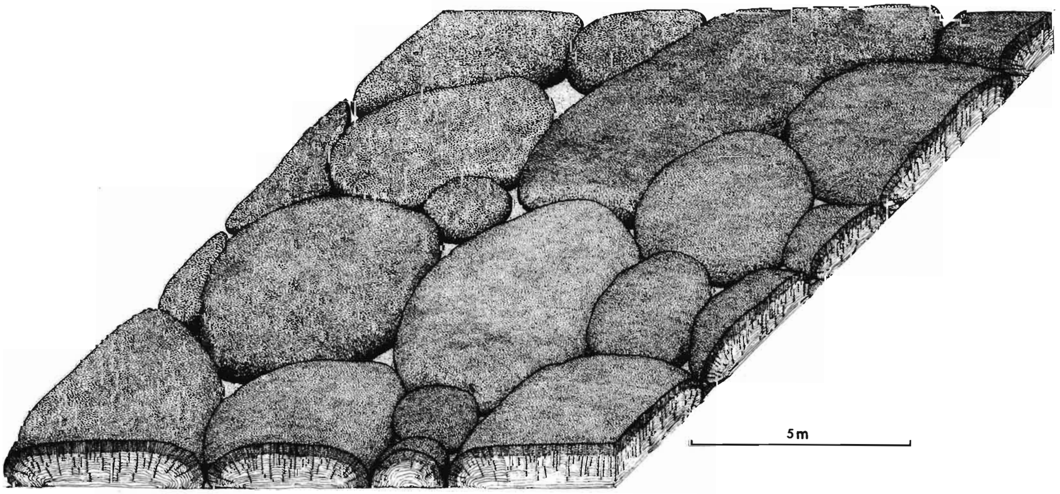
Mode of occurrence of the stromatolites and their appearance during growth. Only the Loves Creek Member stromatolites are well enough known to be discussed here. The two limestone beds of *Linella avis* and *Acaciella australica* near the top of the measured section at Jay Creek (text-fig. 14) were followed for about 2·5 km, the total length of the outcrop present. The thickness of the biostromes remains more or less unchanged as do the stromatolites within them, except that discrete patches of *Minjaria pontifera* occur in the *L. avis* biostrome. A limestone biostrome of *Inzeria intia* at Ross River (Pl. 21, fig. 1) in the eastern Alice Springs Sheet area was traced for more than 1 km without its ends being found. The thickness of this biostrome changes gradually by as much as 50 per cent, and the relative thicknesses of its component parts are variable. Extensive biostromes are the typical mode of occurrence of the vast majority of the Bitter Springs Formation stromatolites, but within the biostromes of *A. australica*, *L. avis*, *I. intia*, *Kulparia alicia*, and possibly also *Boxonia pertaknurra* are small, contiguous bioherms up to about 30 m wide. Isolated bioherms of *A. australica* are rare. *Basisphaera irregularis*, *Jurusania nisvensis*, and *Kotuikania*? *juvensis* form small bioherms scattered in beds; this mode of occurrence is unknown for any other of the Bitter Springs Formation stromatolites. The use of the term 'reef' (implying 'bioherm') on published sections of the Bitter Springs Formation (Wells *et al.* 1967) is known to be inappropriate for the Gillen Member, where it has been applied to a biostrome, and is unlikely to be correct where it has been used in describing the Loves Creek Member, where it probably also means biostrome.



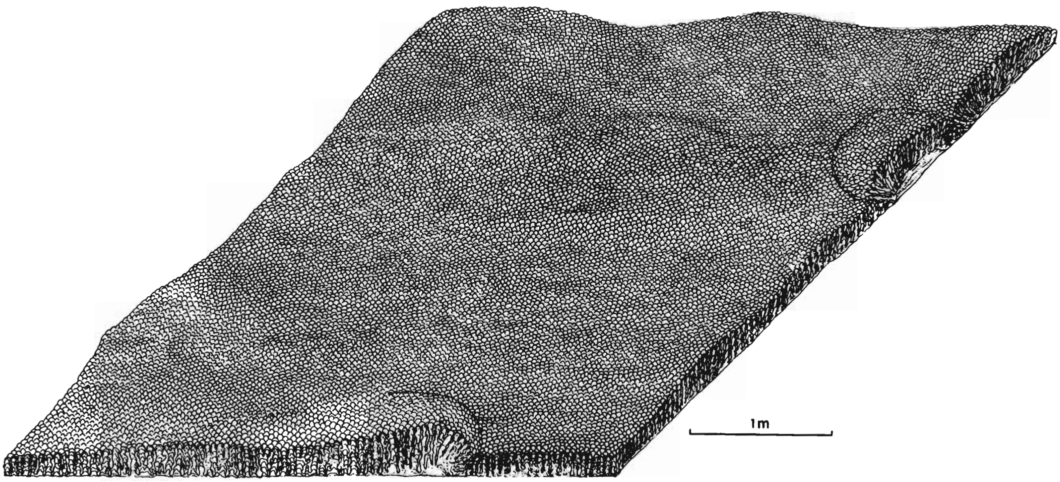
TEXT-FIG. 21. Reconstruction of the appearance at an early stage of growth of a biostrome of *Acaciella australica*, based especially on observations of biostromes in the Bitter Springs Formation near Jay Creek and Undoolya Gap, Amadeus Basin.

This dominant mode of occurrence as biostromes contrasts with that prevalent in the Brighton Limestone equivalents of the Adelaide Geosyncline, where even members of the form genera *Acaciella* and *Inzeria* occur in large isolated bioherms (Preiss 1971).

Text-figures 21–24 show reconstructions of depositional surfaces of three stromatolites from the Loves Creek Member near Jay Creek. These are representative of all the described stromatolites from this member. The most frequently occurring stromatolite in the Amadeus Basin is *A. australica* (Pls. 13–14; text-figs. 22, 29–30),

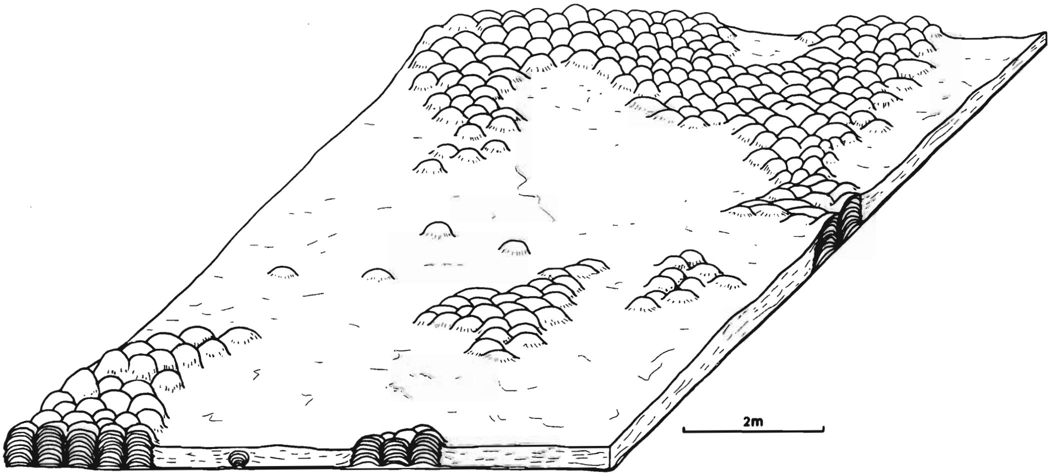


TEXT-FIG. 22. Reconstruction of the appearance at a late stage of growth of the same *Acaciella australica* biostrome shown in text-fig. 21.



TEXT-FIG. 23. Reconstruction of the appearance during growth of a biostrome of *Linella avis*, based on the observation of a biostrome in the Bitter Springs Formation near Jay Creek, Amadeus Basin.

the bioherms of which (where seen near Williams Bore, east MacDonnell Ranges) are approximately circular or elliptical in plan. There are all gradations from small bioherms formed by a single individual (one 'bush') to tabular biostromes with numerous individuals. The biostromes are from less than 0·1 m up to 1·3 m thick. Bioherms range from 0·3 m to several tens of metres wide. The radial arrangement of columns, frequently with columns inclined at only 20–30° above the horizontal on bioherm margins, and the continuation of some laminae from the top of bioherms over the margins and down to the bioherm base, show that the full height of many of the bioherms was exposed during growth. Infrequently, interbiohermal



TEXT-FIG. 24. Reconstruction of the appearance during growth of the basal columns of *Basisphaera irregularis*, based on the observation of bioherms in the Bitter Springs Formation near Jay Creek, Amadeus Basin.

sedimentation almost kept pace with bioherm growth. Text-figures 21 and 22 show two growth stages of a biostrome of *A. australica* near Jay Creek, one instant during the growth of the lower, broad column part, and an instant just before the bioherms became contiguous and were roofed over by continuously laminated carbonate sediment. In the reconstructed early growth stage (text-fig. 21) the stromatolites resemble some forming in ephemeral lakes associated with the Coorong Lagoon in South Australia, except that these have no columns within them. There the shape of each 'bioherm' results from the erosion of large desiccation polygons and their subsequent modification by algal growth. However, other processes leading to the patchy growth of algae can be envisaged, and it is probable that these Jay Creek *A. australica* grew subaqueously or intertidally. Similar stromatolite bioherms in Shark Bay apparently form by the growth of erosional remnants of originally continuous algal mats (Logan 1961). In many cases column growth continues beyond the stage shown in text-figure 22, and the bioherms coalesce. The same is true of *I. intia*, which during growth would have closely resembled *A. australica*. The maximum growth relief of individual columns of *A. australica* was probably about 1 cm; this is shown by lamina shape, bridge shape, and length of vertically standing intraclasts in the interspaces. The columns of the lower growth stages of *I. Intia* possibly had a similar growth relief but the upper walled columns projected at least 2 cm above their substrate (as proven by the presence of the wall).

L. avis Krylov forms tabular or domed biostromes 0·3–1·0 m thick in the Loves Creek Member near Jay Creek. Often the narrow *L. avis* columns grow directly from a flat substrate (Plate 26, figs. 2–3); here bioherms are not definable. Elsewhere, columns radiate from irregularities in the substrate (Pl. 26, fig. 4). Columns are crowded out between centres of radiation (Pl. 26, fig. 1); the lines of crowding are taken as bioherm margins. The shapes of laminae and the almost ubiquitous wall indicate at least 1 cm growth relief for columns, and in some cases at least 2·5 cm. The reconstructed appearance of *L. avis* is shown in text-figure 23. During growth *B. pertaknurra* may have appeared very similar. At least some of the *B. pertaknurra* columns near Jay Creek started as algal mats draped over erosional highs in the substrate.

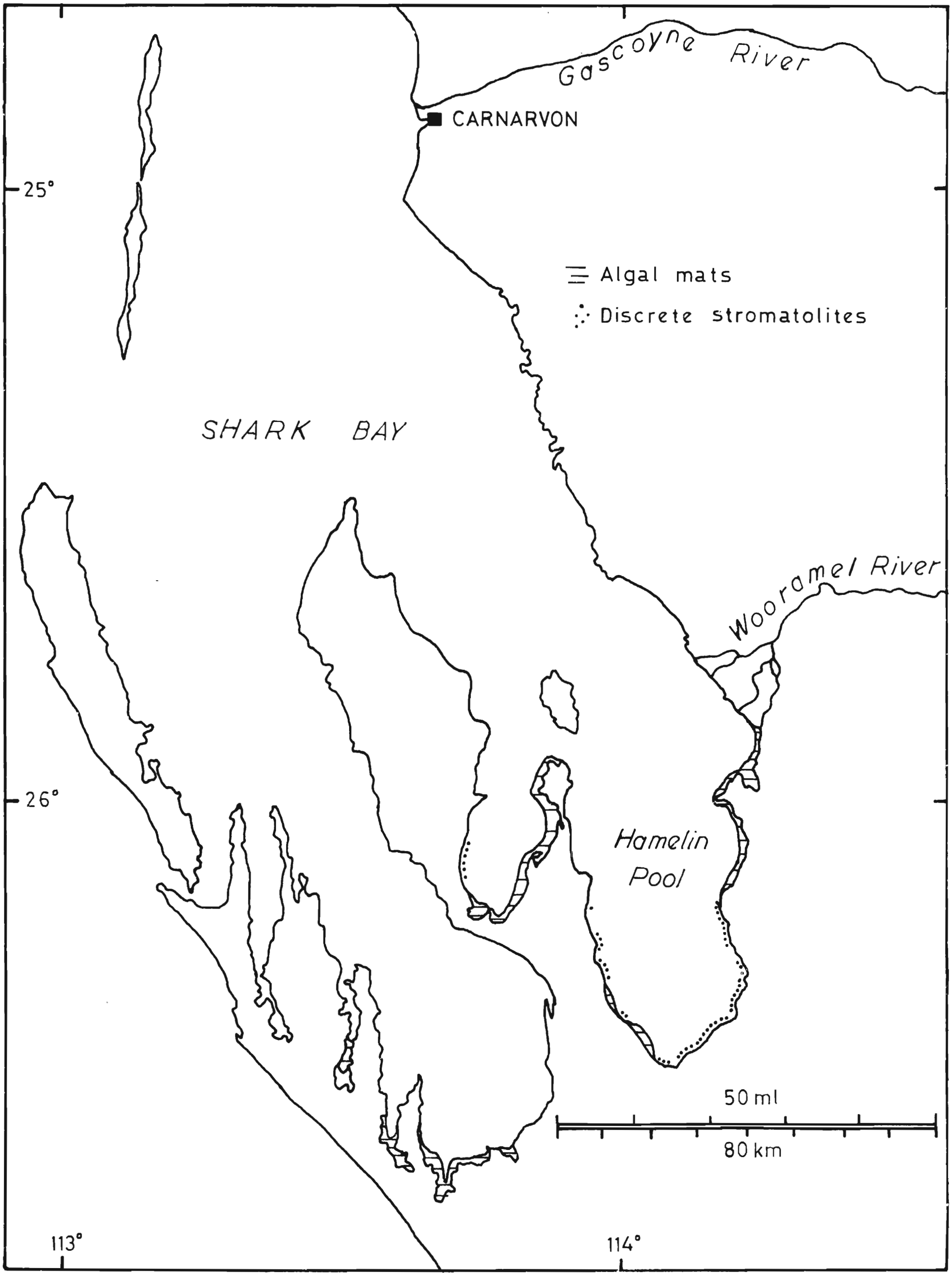
Text-figure 24 shows a stage during the growth of the broad basal columns of *B. irregularis*, reconstructed from its occurrence near Jay Creek. The columns occur in clusters, with one or two scattered in between. The lamina shape and bridges indicate a variable growth relief for the columns, from 1 or 2 cm up to about 20 cm.

With the data available for *K. alicia* it appears that it would have resembled a late stage of growth of *A. australica* or *I. intia*, with coalesced bioherms: i.e. the depositional surface would have been domed. Lamina shapes indicate about 1 cm of growth relief for the *K. alicia* columns. *J. nisvensis* occurs in scattered domed bioherms, each one of which would have looked much like an *A. australica* domed bioherm.

Environment of growth of the Amadeus Basin stromatolites. In the absence of lithofacies studies on the Bitter Springs Formation little can be written on this subject, but there are several points worth mentioning. The scene around the shore of Shark Bay, Western Australia (text-fig. 25), is strikingly similar to those reconstructed in text-figures 21–24. There are numerous domed and subspherical stromatolite bioherms (Pl. 7), very similar in shape to those of *A. australica* and *J. nisvensis*, but they do not have columns within them (Dr. B. W. Logan, pers. comm. 1968). Large columnar stromatolites occur very frequently: they are mostly 10–30 cm wide and reach a height of 70 cm. Branching is rare. Frequently they occur in clusters, with one or two scattered in between (Pl. 7, fig. 1; Pl. 9). In this mode of occurrence and in size and gross shape they resemble the broad basal columns of *B. irregularis* from the Bitter Springs Formation (text-fig. 24). They differ from *B. irregularis* in that at least some of the Shark Bay columns are only crudely laminated (Pl. 9, fig. 6) and none branch upwards into numerous narrow columns. Algal mats in the Gladstone area of Shark Bay (just south of the Wooramel River delta) have mamillose surfaces (Pl. 8); each mamilla is homologous with a column in the Precambrian bioherms, but in the Recent forms laminae are apparently continuous; in an exploratory section (Pl. 8, fig. 2) there were no pseudocolumns, but laminae were wavy as in much of the Bitter Springs Formation. The crude lamination of many of the Shark Bay stromatolites is due to the thickness and irregular surfaces of the algal mats forming them (Pl. 8, fig. 3) as well as to the coarseness of much of the sediment; where the sediment is fine and the mats are smooth, laminae are thinner and more distinct (Pl. 9, fig. 3; Davies 1970*b*). Oolites and detritus derived from the hard parts of molluscs, foraminifera, and calcareous algae are abundant in Shark Bay, but such coarse sediments were less common in the north-eastern Amadeus Basin in Loves Creek Member times.

Stromatolites are most extensively developed in and around Hamelin Pool, the head of the eastern part of the bay. Blue-green algae form the only abundant vegetation in the marginal zones of Hamelin Pool and on the surrounding flats. Stromatolites are restricted to water less than 2–3 m deep; algal mats and discrete stromatolites occur in a narrow zone from immediately subtidal, through intertidal, to immediately supratidal: the maximum width of this zone is about 1 km. Different types of algal mats inhabit different parts of the zone. The Wooramel River which enters Shark Bay just north of Hamelin Pool has built a 10 km wide delta of red gypseous silt about a metre thick. The red silt overlies carbonate which locally also is red. Algal mats are growing on the delta front and to the north and south (Logan and Cebulski 1970; Davies 1970*a*; Logan, pers. comm. 1968). Despite high groundwater salinities on the supratidal flats of Shark Bay, no Recent dolomite is known.

The greatest similarities between Shark Bay and the Amadeus Basin of Loves Creek Member times are the gross shapes of many of the stromatolites and the association of carbonates and red silts. Important differences are the preponderance of coarse sediment in Shark Bay and the paucity there of dolomite. Dolomite is abundant in sediments of the upper intertidal zone and the sabkhas (supratidal flats) on the southern side of the Persian Gulf, and stromatolites are presently forming there in the intertidal and supratidal zones (Emery 1956; Evans *et al.* 1964, 1969; Illing *et al.* 1965; Kinsman 1969; Kendall and Skipwith 1968, 1969*a*, *b*). No columnar or large cumulate stromatolites have been reported. Aragonite muds and aggregates (including grapestones and botryoidal lumps) are widespread in the coastal lagoons. The sediments there are rapidly prograding into the coastal lagoons,



TEXT-FIG. 25. Distribution of algal mats and discrete stromatolites in Shark Bay, Western Australia (after Logan 1961). Algal mats are more extensive than shown.

with the result that it can be shown that the very widespread carbonate beds are diachronous (which is probably also true of those in the Loves Creek Member). Again there are similarities with the sediments of the Loves Creek Member, but an important difference is that gypsum and anhydrite are abundant components of the sabkha sediments but are rare or absent in the Loves Creek Member; no carbonate structures which indicate the former presence of these evaporites have been observed. On Andros Island in the Bahamas intertidal and supratidal dolomite occurs without other evaporites (Shinn *et al.* 1965). The subtidal, intertidal, and supratidal stromatolites from there are especially well known, but include no columnar or large cumulate forms (Black 1933; Monty 1967).

No sedimentary structures diagnostic of subaerial deposition are known from the stromatolitic carbonates or their contiguous beds in the Bitter Springs Formation. The red colour of some interbeds is not a reliable indicator of subaerial deposition, as is indicated by the red colour of Devonian inter-reef sediments in north-western Australia (Playford and Lowry 1966). Because sea-water has the necessary abundant supply of dissolved carbonate it is reasonable to interpret the environment of deposition of the carbonates as marine (in a broad sense, including coastal lagoons). This is supported by the comparisons with modern environments of carbonate deposition. During growth most of the stromatolites formed bioherms or mounds with a relief of several tens of centimetres, or even up to 1·3 m. For growth they must have been covered at least intermittently by water and therefore were intertidal or subtidal. No tidal channel deposits have been recognized and there are very few micro-unconformities in the stromatolite laminae, indicating little erosion, and therefore a continually submerged (subtidal) environment is favoured.

In summary, the Loves Creek Member stromatolites most probably grew in shallow lagoons or a shallow near shore marine environment. Playford and Cockbain (1969) have demonstrated that Devonian stromatolites they studied grew in up to 45 m of water and this figure may be taken as a probable maximum depth for the Precambrian stromatolites. Comprehensive facies studies will be necessary to confirm the interpretations suggested.

For the other Amadeus Basin stromatolites there is very little data but it is noteworthy that the Cambrian Pertaoorta Group stromatolites occur in a glauconitic rock sequence rich in trilobites, archaeocyathans, brachiopods, hyolithids, and other presumably marine shelly fossils. In the occurrences familiar to me these fossils do not occur in the stromatolite beds. The stromatolites may have grown in hypersaline environments. Halite casts are reported (Wells *et al.* 1967) from several stromatolitic formations of the Pertaoorta Group.

TEMPORAL DISTRIBUTION AND CORRELATION OF STROMATOLITE OCCURRENCES

Recently in Australia two attempts have been made to use stromatolites for interregional correlation. Robertson (1960) copiously figured but only briefly described Early Riphean stromatolites from Queensland. He neither made reconstructions nor studied thin sections. The stromatolites were compared with those from other regions, but the comparisons are superficial and many possibilities were overlooked; so his conclusion that 'it seems unlikely that it will prove possible to use stromatolites for correlation between separate regions' is ill-founded. Edgell (1964) came to the opposite conclusion and established the presence of an apparent succession of stromatolite assemblages, which he used for correlation within the Australian Precambrian. Unfortunately he did not reconstruct his stromatolites and so was led into some erroneous identifications. He incorrectly identified '*Cryptozoon*' *australicum* Howchin from the Early Proterozoic Duck Creek Dolomite of the Hamersley Basin. Further error resulted from his acceptance of Traves' (1954) identification of *Collenia frequens* from the Victoria River Group of the Northern Territory. Traves' specimens belong to a new form, *Conophyton basalticum*; and furthermore, recent mapping shows that they occur in the Antrim Plateau Volcanics, not the Victoria River Group. One of Edgell's Early Proterozoic assemblages (*Collenia brockmani* and *C.* cf. *kona*) consists of abiogenic, diagenetic structures, not stromatolites. After studying Edgell's specimen of '*Newlandia lamellosa*' I consider that he was misinformed by the collectors and this in fact was convex upwards, not the reverse, and should have been identified by him as *Collenia undosa* (compare his Pl. 5, fig. 1 with his Pl. 4, figs. 1 and 5). Edgell's apparent belief that *Conophyton* is restricted to the latest Precambrian is now known to be incorrect (Komar *et al.* 1965). Lastly, he made the mistake of earlier workers by relying for identification on too few features. Of his five assemblages only the oldest and youngest are valid: these are *Alcheringa narrina* (his *Collenia* sp. aff. *multiflabella*) and *Girvanella*.

THE STROMATOLITE SEQUENCE IN AUSTRALIA

The sequence described here and summarized in Table 3 has been established by superposition, radiometric dating, and palaeontological dating using conventional fossils, largely without reference to stromatolites, although the stromatolite assemblages were used to determine the relative positions of the Amadeus Basin and Adelaide Geosyncline rock units.

Within the sequence comprising the Hamersley and Bangemall Basins of Western Australia three assemblage zones are distinguished. The oldest contains the form *Alcheringa narrina*, the oldest known Australian stromatolite, and occurs in the Fortescue Group. Cloud and Semikhatov (1969) tentatively identify *Gruneria biwabikia* from the Fortescue Group but their illustration shows a stromatolite with much narrower columns than the typical *G. biwabikia* so here it is referred to as *Gruneria* f. nov. The best estimate of the age of the Fortescue Group is 2190±100 m.y. (for details of this and all other age determinations quoted here the reader is referred above to the sections on the stratigraphy of the various basins). The Wyloo Group, dated at 2020±165 m.y., contains the next younger assemblage, *Pilbaria perplexa* and *Patomia* f. indet. The Bangemall Group lies unconformably above the Wyloo Group. It is less than 1700 m.y. and probably about 1080±80 m.y. old and contains the stromatolites *Baicalia capricornia* and *Conophyton garganicum australe*.

Cloud and Semikhatov (1969) describe a stromatolite which they refer to the group *Kussiella* from the Elgee Siltstone of the Kimberley Basin of Western Australia.

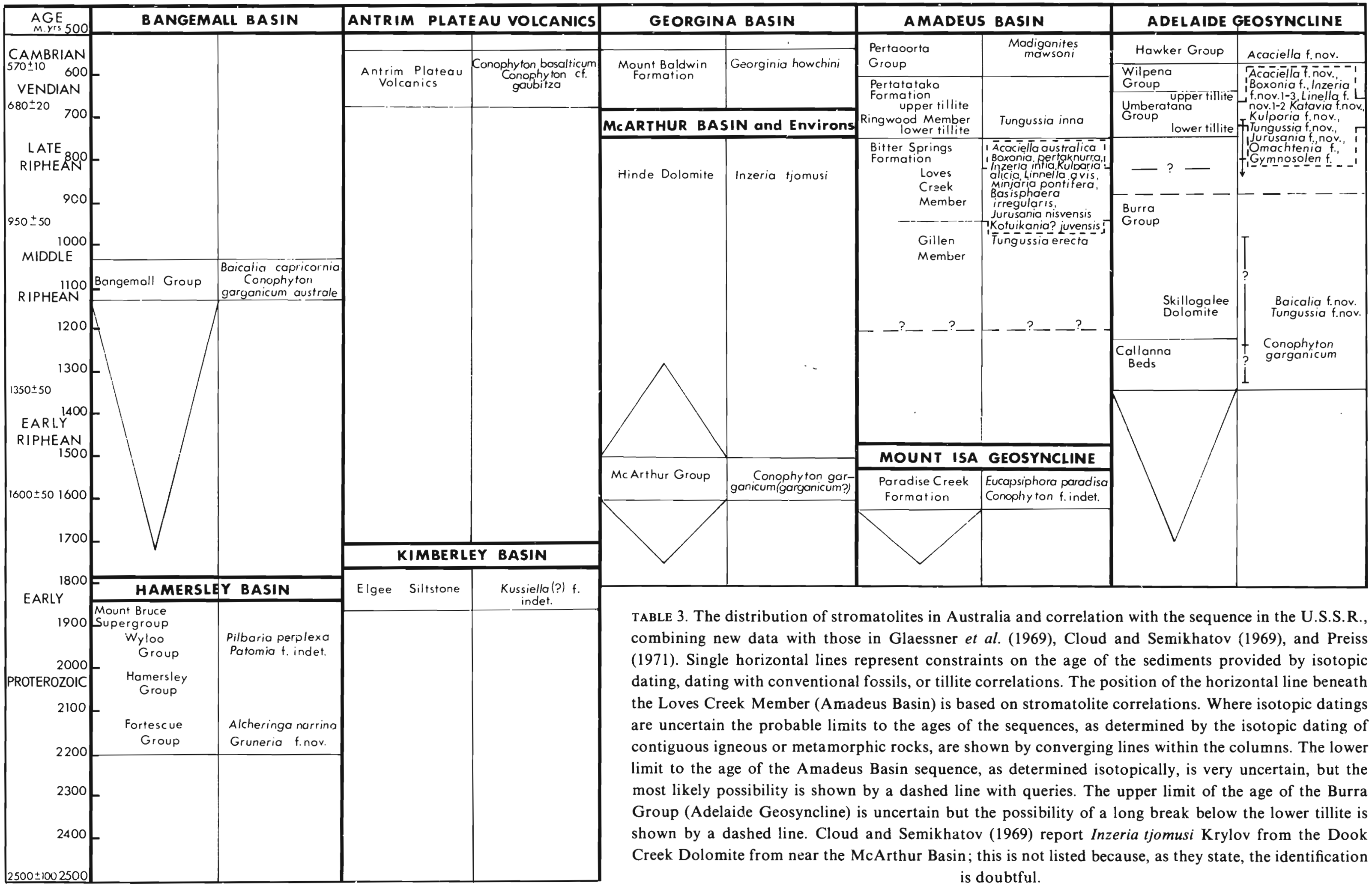


TABLE 3. The distribution of stromatolites in Australia and correlation with the sequence in the U.S.S.R., combining new data with those in Glaessner *et al.* (1969), Cloud and Semikhatov (1969), and Preiss (1971). Single horizontal lines represent constraints on the age of the sediments provided by isotopic dating, dating with conventional fossils, or tillite correlations. The position of the horizontal line beneath the Loves Creek Member (Amadeus Basin) is based on stromatolite correlations. Where isotopic datings are uncertain the probable limits to the ages of the sequences, as determined by the isotopic dating of contiguous igneous or metamorphic rocks, are shown by converging lines within the columns. The lower limit to the age of the Amadeus Basin sequence, as determined isotopically, is very uncertain, but the most likely possibility is shown by a dashed line with queries. The upper limit of the age of the Burra Group (Adelaide Geosyncline) is uncertain but the possibility of a long break below the lower tillite is shown by a dashed line. Cloud and Semikhatov (1969) report *Inzeria tjomusi* Krylov from the Dook Creek Dolomite from near the McArthur Basin; this is not listed because, as they state, the identification is doubtful.

Because of poor preservation assignment to *Kussiella* must be considered tentative. The Elgee Siltstone is more than 1800±25 m.y. old (Compston and Arriens 1968). From the Paradise Creek Formation of the Mount Isa Geosyncline (Queensland) they describe the new stromatolite *Eucapsiphora paradisa.* Compston and Arriens show that the Paradise Creek Formation is probably between 1550 m.y. and 1700 m.y. old. In the McArthur Basin the McArthur Group is less than 1750 m.y. old and possibly less than 1600 m.y.; it is older than 1280 m.y. and possibly older than 1510±120 m.y. It contains the stromatolite *C. garganicum.* Insufficient well-preserved specimens are available to allow certain identification to the varietal level, but the material available is indistinguishable from *C. garganicum garganicum.* Cloud and Semikhatov (1969) also report *C. garganicum* from the McArthur Group. Columnar, branching stromatolites from the same unit have not yet been studied. Cloud and Semikhatov (1969) report *Inzeria tjomusi* Krylov from the Hinde Dolomite and the Dook Creek Formation adjacent to the McArthur Basin in the Northern Territory. The Dook Creek Formation is radiometrically dated as more than 1230 m.y., which Compston and Arriens (1968) consider may be too young. As Cloud and Semikhatov point out, the Dook Creek *I. tjomusi* is poorly preserved and lacks some of the diagnostic features of the group, so identification is 'somewhat conditional'. The Hinde Dolomite has not been radiometrically dated but Dunn *et al.* (1966) consider it to be about 600–700 m.y. old.

The most diverse assemblage is in the Bitter Springs Formation of the Amadeus Basin. This formation is directly overlain by the lower of two late Precambrian tillites and is therefore probably older than 740±30 m.y. It is much more difficult to set an older age limit for the formation but it is probably younger than 1200–1400 m.y.: datings within this range occur frequently in the Musgrave Block basement on the southern margin of the Amadeus Basin (but in this region the basinal sediments as well as the basement are metamorphosed and there is doubt as to which of the metamorphisms the datings register). There are two stromatolitic levels within this formation. The lower is near the base of the Gillen Member (the lower part of the formation) and contains only *Tungussia erecta.* The other is about half way up the formation, in the Loves Creek Member (and especially near its base). Here occurs in great abundance *Acaciella australica* (Howchin) with lesser amounts of *Basisphaera irregularis*, *Boxonia pertaknurra*, *Inzeria intia*, *Jurusania nisvensis* Raaben, *Kulparia alicia* (Cloud and Semikhatov), and *Linella avis* Krylov. Cloud and Semikhatov (1969) describe *Anabaria juvensis* from an unspecified level within the Bitter Springs Formation; this form is best classified as *Kotuikania*? *juvensis.*

Columnar stromatolites are known from two other levels in the sequence of the Amadeus Basin. In the Ringwood Member of the Pertatataka Formation, between the two late Precambrian tillites (and nearer the lower), occurs *Tungussia inna.* Shale datings of 730±45 m.y. and about 790 m.y. have been obtained using samples from throughout the Pertatataka Formation; assuming correlation of the two tillites with those in the Kimberley region datings from there may be used. There the lower tillite is dated at 740±30 m.y. and shales from just above the upper tillite at 665±45 m.y. Higher in the Amadeus Basin sequence, in parts of the Pertaoorta Group palaeontologically well dated as Middle of Late Cambrian, occurs *Madiganites mawsoni.*

Georginia howchini is found in the lower Mount Baldwin Formation of the Georgina Basin. It is probably Early Cambrian but may be late Vendian. The Antrim Plateau Volcanics contain *Conophyton basalticum* and *C.* cf. *gaubitza* Krylov; they are Early Cambrian or Vendian, the latter being most likely.

CORRELATION WITHIN AUSTRALIA

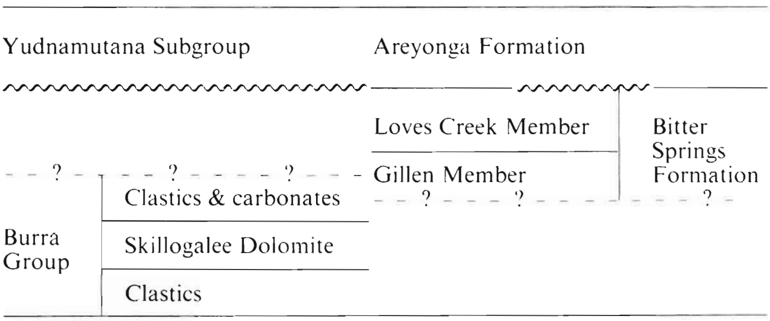
Many correlations have been made between sequences in the Amadeus Basin and Adelaide Geosyncline. Wells *et al.* (1970) consider the Bitter Springs Formation to be lithologically similar to the Skillogalee Dolomite of the Burra Group (Table 4) and point out that quartzites underlie both these units. This is the same correlation earlier proposed by David and Browne (1950) and used by Mawson (1957) when restating his opinion that the Areyonga Formation is tillitic and is a correlative of the Sturt Tillite of the Adelaide Geosyncline. Dunn *et al.* (1966) interpreted radiometric dates as possibly indicating that the Bitter Springs Formation is older than the Burra Group.

TABLE 4. Tentative correlation of the Adelaide Geosyncline and Amadeus Basin sequences, made by Wells *et al.* (1970) in their text and figures. Though the correlation of the upper units is acceptable the conventional correlations of the lower units are now modified as shown in Table 5. Only selected units are shown.

		Central Flinders Ranges	NE Amadeus Basin	
Cambrian		Hawker Group		
			Arumbera Sandstone	
Marinoan	Wilpena Group	Pound Quartzite	Julie Member	
		Wonoka Formation	Cyclops Member	Pertatataka Formation
		Bunyeroo Formation		
		ABC Range Quartzite	Waldo Pedlar Member	
		Nuccaleena Formation		
	Umberatana Group	Elatina Formation (glaciogene)	Olympic Member (glaciogene)	
			Limbla Member	
Sturtian		Etina Formation		
		Brighton Limestone equivalents	Ringwood Member	
		Yudnamutana Subgroup (glaciogene)	Areyonga Formation (glaciogene)	
Torrensian		Burra Group: Skillogalee Dolomite	Bitter Springs Formation	
Willouran		Callanna Beds	Heavitree Quartzite	

The correlations made by Glaessner *et al.* (1969) are now more strongly based. Using stromatolites, and taking into account the tillite correlations, these authors showed the Loves Creek Member of the Bitter Springs Formation to be intermediate in age between the Umberatana Group and the Skillogalee Dolomite of the Burra Group. With the identifications reported here, and the further investigation of Adelaide Geosyncline stromatolites by Preiss (1971), *Tungussia*, as well as *Baicalia*, is known from the Burra Group, and there are now known to be six stromatolite groups (but no forms) in common between the Umberatana Group and the Loves Creek Member: these are *Acaciella*, *Boxonia*, *Inzeria*, *Jurusania*, *Kulparia*, and *Linella*. This great similarity of assemblages exists despite much difference in the mode of occurrence of the stromatolites in the two units: many of the Umberatana Group stromatolites form isolated bioherms surrounded by oolitic and coarsely intraclastic carbonate, but almost all of those in the Loves Creek Member occur as very extensive biostromes in which oolites and large intraclasts are only sparsely distributed. Thus the stromatolites are similar despite original environmental differences. The Umberatana Group and Loves Creek Member are not directly correlated because correlation of the intervening tillite is considered more precise (Table 5); the non-synchroneity of glaciations suggested by Crawford and Daily (1971) is unlikely to be significant over the distances and with the precision considered here. The similarity of these assemblages contrasts with their difference from the *Baicalia–Tungussia* assemblage of the Skillogalee Dolomite of the Burra Group. This assemblage occurs in a variety of rock types (Glaessner *et al.* 1969) whereas in the Loves Creek Member a variety of stromatolites all occur in identical or very similar rocks. This supports the conclusion that more than environmental differences are necessary to explain the different stromatolite assemblages.

TABLE 5. New correlation of the lower units of the Adelaide Geosyncline and Amadeus Basin, based on a comparison of stromatolite assemblages (modified after Glaessner *et al.* 1969).



It should be noted that the Skillogalee Dolomite is near the base of the Burra Group, and the stromatolitic part of the Loves Creek Member is half way up the Bitter Springs Formation; so the upper Burra Group could be as young as the lower Bitter Springs Formation (i.e. the Gillen Member). The group *Tungussia* is long-ranging, occurring in the Burra Group, Ringwood Member, and Gillen Member, and so cannot aid precise correlation of the Gillen Member. None the less it is known from no rocks older than the Burra Group and thus the Gillen Member of the Bitter

Springs Formation may be as old as the Skillogalee Dolomite but probably no older. The occurrence of *Baicalia* f. nov. in the Burra Group and of *Conophyton garganicum* in the Burra Group or Callanna Beds places these units in the same assemblage zone as the Bangemall Group of the Bangemall Basin, which contains *Baicalia capricornia* and *C. garganicum australe*. Such a correlation is supported by radiometric data indicating an age of about 1080±80 m.y. for the Bangemall Group and probably less than 1350±45 m.y. for the Burra Group (Compston and Arriens 1968), but it is made less tenable by a single Rb-Sr dating of 867±32 m.y. on the metamorphic basement underlying the Burra Group (Cooper and Compston 1971). This last dating is on rocks that were remetamorphosed during the Ordovician and at present receives little support from other geological data. Among correlations suggested by Cloud and Semikhatov (1969) is that of the Hinde Dolomite containing *Inzeria tjomusi* with the Bitter Springs Formation containing *I. intia*.

The inclusion of data from the Adelaide Geosyncline has supported conclusions about the distinctiveness and temporal significance of the assemblages described from the Bangemall Group (Bangemall Basin) and the Loves Creek Member of the Bitter Springs Formation (Amadeus Basin). Using stromatolites, correlations between the Adelaide Geosyncline and Amadeus Basin have been made more precise than previously possible. In the next section it is shown that these correlations are supported by comparisons with the succession of stromatolite assemblages in the U.S.S.R.

STROMATOLITE SEQUENCES IN THE U.S.S.R

Russian work of the last decade has revealed a sequence of stromatolite assemblages in the late Precambrian of the U.S.S.R. with which the Australian sequence can be compared. In the U.S.S.R. sediments formed between 1600±50 m.y. ago and the base of the Cambrian (570±10 m.y.) form a time-rock unit called the Riphean. This unit records 1000 m.y., i.e. it is almost twice as long as the Phanerozoic. Four major subdivisions of the Riphean are now widely recognized in the U.S.S.R.: the Lower, Middle, and Upper Riphean, and the Vendian or Terminal Riphean. The subdivision into all but the Vendian was first made using distinctive stromatolite assemblages (Keller *et al.* 1960). Keller's co-authors discovered the same sequence of assemblages in three widely spaced regions: the southern Ural, central Siberia, and far-eastern Siberia. Since then the same sequence of assemblages has been found in many other regions of the U.S.S.R. including northern Siberia (Komar 1966), Kirgizia, and southern Kazakhstan (Krylov 1967), and assemblages from the Ural and Siberia have been described in detail (Semikhatov 1962; Krylov 1963; Raaben 1964, 1969*a*, *b*; Komar *et al.* 1965). Thus the succession is now known over a wide area in the U.S.S.R. in sections almost 5000 km apart. The Upper Riphean assemblage also occurs in Spitzbergen, about 3000 km from the Ural stratotypes of the subdivisions (Raaben and Zabrodin 1969).

The uppermost subdivision, the Vendian, was first defined on the north-western Russian Platform (Byelorussia) as the Valday and Volyn 'Series', conformably underlying palaeontologically dated Early Cambrian. An unconformity was the lower boundary. The Vendian was a lithological and diastrophic unit, rather than palaeontological. Meanwhile, in Siberia a distinctive stromatolite and microphytolith assemblage was recognized in the Yudoma 'Series', conformably below the Lower Cambrian and unconformably above the Upper Riphean (Semikhatov *et al.* 1970). The Yudoma 'Series' was then tentatively classified as Vendian (Keller 1966; Keller and Semikhatov 1967). This correlation is now widely accepted. The Yudoma microphytolith assemblage has been found immediately below the original Vendian and occurring with it are stromatolite fragments identified as *Boxonia grumulosa* Komar which elsewhere occurs only in the Yudoma 'Series' (Zhuravleva and Chumakhov 1968). The Vendian is now usually employed as a term for a stage characterized by an assemblage of stromatolites and microphytoliths.

Many tens of K-Ar datings on glauconite have been made on samples from the stratigraphic sections containing stromatolites (e.g. Keller and Semikhatov 1967; Nuzhnov and Yarmolyuk 1968; Kazakov and Knorre 1970). The vast majority of these confirm the correlations based on stromatolites. However, the almost ubiquitous practice of quoting the datings without limits of error makes their interpretation difficult. Analysis by the Russians of the numerous datings from all possible regions of the U.S.S.R. indicate the following age limits for the four main Riphean subdivisions: 1600±50 m.y.—Lower Riphean—1350±50 m.y.—Middle Riphean—950±50 m.y.—Upper Riphean—680±20 m.y.—Vendian—570±10 m.y. This pattern is strengthened by Rb-Sr, K-Ar, and U-Th-Pb datings on igneous rocks.

Unconformably under the Early Riphean stratotype in the southern Ural are granites and metamorphics yielding K-Ar datings of 1600 m.y.; Rb-Sr dating of the granites gives 1720–1870 m.y. Early Riphean sediments in southern Siberia overlie granites 1570±80 m.y. old (Rb-Sr). Salop's (1968) opinion that the Lower Riphean is older than 1660 m.y. depends on tenuous lithological correlations contradicted by these data. In the southern Ural, intrusives into the Lower Riphean are unconformably overlain by the Middle Riphean; by Rb-Sr and K-Ar datings these are 1350–1400 m.y. old. In south-eastern Siberia there also is a break between the Lower and Middle Riphean, and granites intrusive into the older sequence are 1414–1440 m.y. old; various pre-Middle Riphean basic intrusives are dated (K-Ar) at 1300–1350 m.y. (Keller and Semikhatov 1967) and 1250–1280 m.y. (Kazakov and Knorre 1970). During the Middle Riphean there was a period of tectonism including the intrusion of basic rocks at about 1100 m.y. (Keller 1966; Keller and Semikhatov 1967). Some authors define the Middle Riphean as ending then (Salop 1968), but the palaeontological boundary does not fall there.

In south-eastern Siberia tectonism involving igneous activity affected Late Riphean deposits. The Vendian Yudoma 'Series' unconformably overlies intrusives and Late Riphean sediments. Dating of the intrusives by Rb-Sr, K-Ar, and U-Th-Pb methods gives results ranging from 600–690 m.y. (Yelyanov and Moralev 1961; Keller and Semikhatov 1967). Syntheses of all available data have produced as estimates of the age of the Late Riphean–Vendian boundary 680±25 m.y. (Keller and Semikhatov 1967) and 680±20 m.y. (Keller 1969).

Before considering the stromatolite assemblages some other data useful in intercontinental correlation may be mentioned. Late Precambrian tillites are known from all continents and in many areas, at least, occur at two levels. In the Vendian of the U.S.S.R. tillites and tilloids are widespread (Keller 1963; Bessonova and Chumakhov 1968; Keller *et al.* 1960; Chumakov 1971). Salop (1968) is of the opinion that tillites occur not only in the Vendian but also in Late Riphean sequences in the U.S.S.R., although this is as yet poorly established. Dunn *et al.* (1971) suggest that these glaciations be used to define a new chronostratigraphic unit.

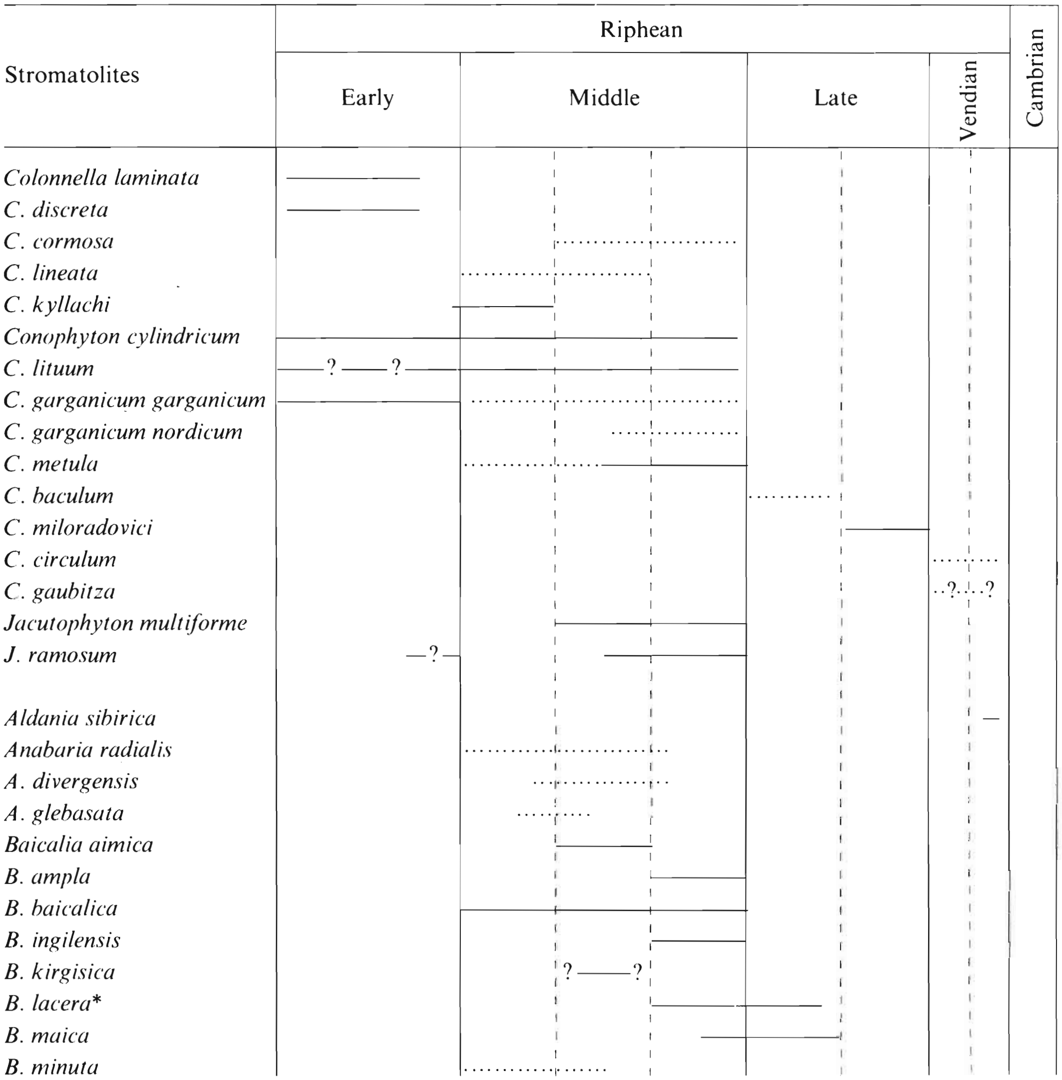
All available information on the time ranges of stromatolites in the U.S.S.R. was used in the compilation of Table 6. The table incorporates numerous modifications of the ranges given by the original authors; these were gleaned from the most recent literature available. It is impracticable to discuss the evidence for the limits to these ranges except where they are controversial or are important in correlations with the Australian stromatolite succession. All described taxa from the modern literature are listed, except some of Korolyuk's (1960) which I could not place in the scheme because I have been unable to ascertain their age. *Nomina nuda* and stromatolites whose descriptions are unavailable are excluded. Columnar, unbranched stromatolites (*Colonnella*, *Conophyton*) are placed first, followed by *Jacutophyton* and then columnar branching forms arranged in alphabetical order. Listed last are non-columnar forms; the ranges of these are mostly only known from Komar's (1966) work in northern Siberia. As Raaben (1969*b*) has recently summarized the literature on stromatolite distribution in the Riphean of the U.S.S.R., only a general outline is necessary here.

Early Riphean. There are no groups exclusive to the Early Riphean. Forms of *Kussiella* Krylov are abundant and widespread, but the group is known in small numbers also from the Middle and Late Riphean. *Conophyton* Maslov occurs abundantly and extensively in Early Riphean deposits, but none of its forms or varieties are restricted to this interval. The extension of the range of *C. lituum* Maslov (emend. Komar, Raaben, and Semikhatov) to the Early Riphean is based on one specimen, the stratigraphic level of which is uncertain (Komar *et al.* 1965). Two forms of *Colonnella* Komar and several non-columnar stromatolites are restricted to the Early Riphean of northern Siberia (Komar 1966). Such stromatolites have been little studied in other regions.

Middle Riphean. The Middle Riphean is palaeontologically clearly differentiated and contains a more diverse assemblage than the Early Riphean. The most distinctive and widespread new elements are the similar groups *Baicalia* Krylov and *Tungussia* Semikhatov. The lower boundary of the Middle Riphean is placed at the first appearance of *Baicalia.* Some groups and forms continue through from the Early Riphean: these include *Kussiella* f., *Omachtenia omachtensis*, and *Omachtenia* f. which are found in the lower subdivision of the Middle Riphean in south-eastern Siberia (Nuzhnov 1967; Krylov *et al.* 1968).

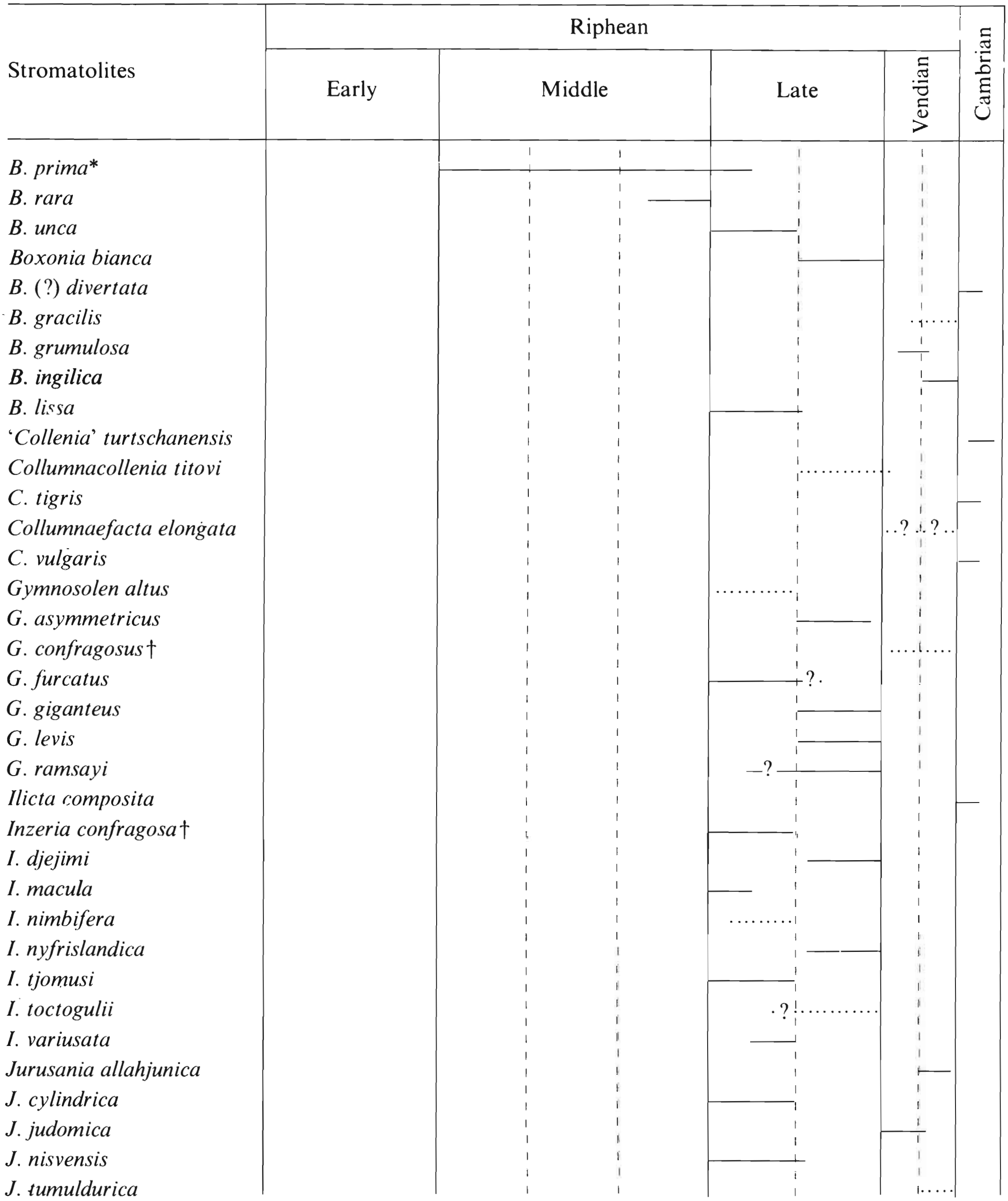
Recently a three-fold subdivision of the Middle Riphean has been attempted (Krylov *et al.* 1968). The subdivision is made mainly on the presence and abundance of forms of *Baicalia* and *Jacutophyton* Shapovalova. The oldest unit is not yet widely known, and in the dissenting opinion of Nuzhnov should be grouped with the middle unit. The middle unit has *Baicalia aimica* Nuzhnov and the striking form *Jacutophyton multiforme* Shapovalova; it occurs in the southern Ural and in several

TABLE 6. Time ranges of stromatolites in the U.S.S.R. *Colonnella*, *Conophyton*, and *Jacutophyton* are placed first, followed by columnar branching forms, and then non-columnar stromatolites. The ranges have been assembled from all available literature and incorporate modifications made since the names were first published. The widths of the columns representing the Early, Middle, and Late Riphean, Vendian, and Cambrian are proportional to the time spans of these units; this is not so for the other, minor subdivisions. The subdivisions within the Middle and Late Riphean and the Vendian are apparently not yet widely accepted, and there are anomalous occurrences which cast doubt on their validity; where I have been unable to determine exactly ranges relative to these subdivisions the line representing the range is dotted (. .). If in addition doubts about the range are expressed in the Russian literature, this is indicated with a question mark (?). The positions of the ends of ranges should not be taken as precise. Taxa of doubtful validity are enclosed by quotation marks (‘ ’).



* Komar and Semikhatov (1969) do not show *B. lacera* extending into the Late Riphean.

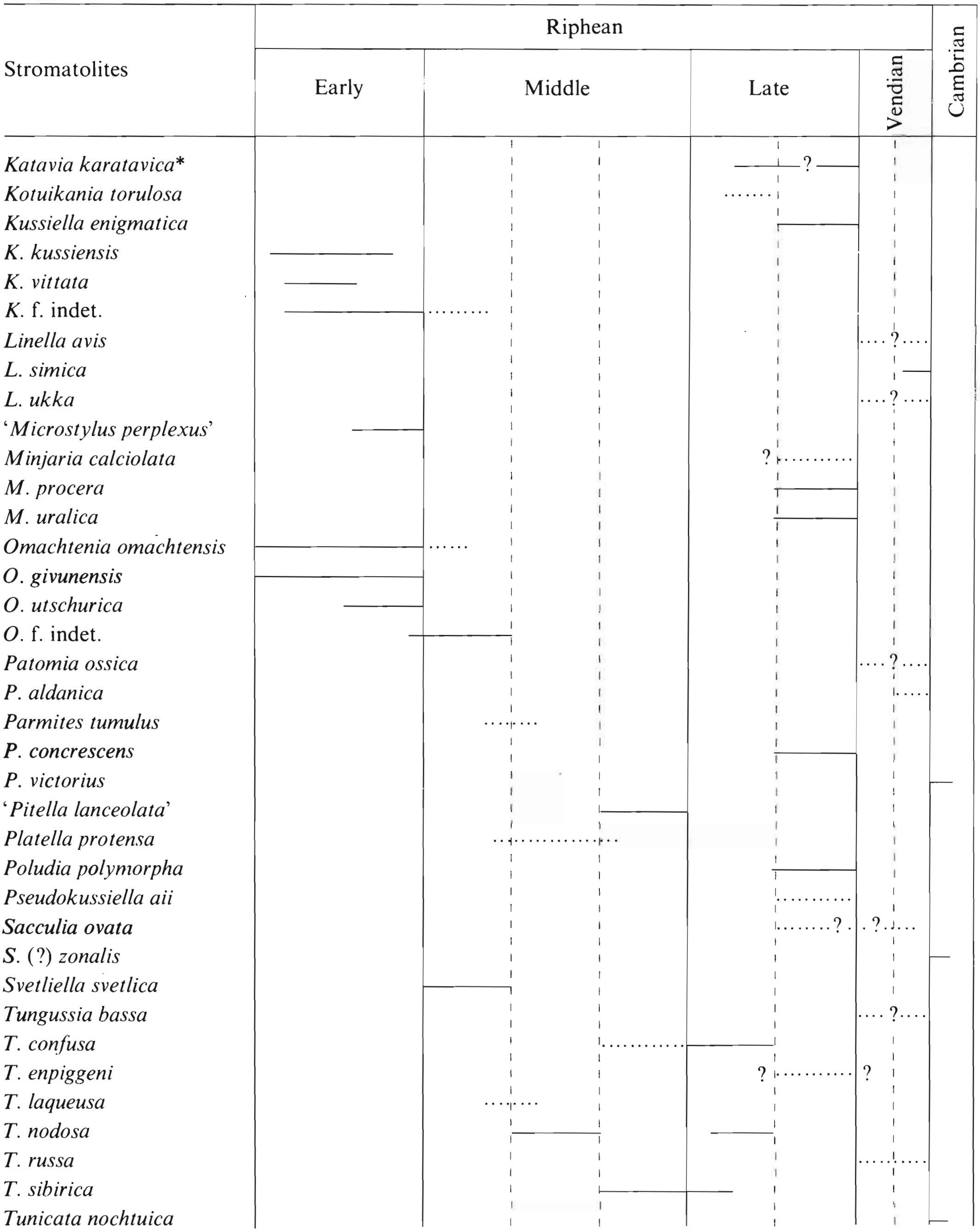
TABLE 6 (*cont.*)



* Komar and Semikhatov (1969) do not show *B. prima* in the early Middle Riphean.

† The name *Gymnosolen confragosus* Semikhatov originally applied to both Late Riphean and Vendian stromatolites, but is now restricted to a Vendian form, and the Late Riphean form is variously reclassified into the group *Inzeria* (Raaben 1969*a*) or the new group *Confragosia* (M. A. Semikhatov quoted in Krylov and Shapovalova 1970*b*).

TABLE 6 (*cont.*)



* In contrast to previous workers Raaben (1969*a*) places *K. karatavica* in the late Late Riphean rather than the early Late Riphean. However, Krylov and Shapovalova (1970*b*) reaffirm its occurrence in the early Late Riphean.

TABLE 6 (*cont.*)

Stromatolites	Riphean				Cambrian
	Early	Middle	Late	Vendian	
Turuchania arbora			···		
Uricatella urica					—
Vetella uschbasica					—
Colleniella singularis				—	
Gongilina differenciata	—				
G. mixta			···		
G. nodulosa				—	
G. urbanica				—	
G. zonata		···			
Nucleella cortinata			···		
N. fibrosa	—				
N. figurata	—				
N. inconformis		···	···		
N. simplex		···			
Paniscollenia emergens				—	
P. vulgaris					—
Planocollina serrata				··?··?··	
Stratifera ff.		—			
S. flexurata	—				
S. irregularia				···	
S. pseudocolumnata			···		
S. rara					—
S. undata	—				
Irregularia ff.		—		···	—

widely dispersed parts of Siberia. Of all the occurrences of *Tungussia* I have been able to relate to this new scheme, none is older than the middle subdivision. The youngest subdivision has several different forms of *Baicalia*. This unit is widespread in Siberia, but unknown from the Ural.

Conophyton metulum Kirichenko (emend. Komar, Raaben, and Semikhatov) is known only from the Middle Riphean and *C. garganicum nordicum* Komar *et al.* is restricted to the uppermost part of this interval (its range in terms of the threefold subdivision is unknown to me). *C. cylindricum* Maslov (emend. Komar *et al.*) occurs in North America in the Belt Supergroup and Apache Group, the former radiometrically dated as between 1100 and 1600 m.y. and the latter as about 1200–1400 m.y. (Cloud and Semikhatov 1969). The same authors report the occurrence of *Baicalia* aff. *B. rara* from possibly Middle Riphean rocks in South-West Africa.

Baicalia has recently been discovered in the Belt Supergroup of Montana (White 1970).

Late Riphean. This unit is defined by the most diverse assemblage of columnar stromatolites known. Particularly significant is the first appearance then of the widely occurring groups *Inzeria* Krylov, *Gymnosolen* Steinmann, *Minjaria* Krylov, and *Jurusania* Krylov; and less frequently the first *Katavia* Krylov, *Boxonia* Korolyuk, and others. The assemblage is widespread, occurring in Spitzbergen, the Ural, Tien-Shan, and several regions of Siberia.

Baicalia lacera Semikhatov, *B. prima* Semikhatov, and *B. maica* Nuzhnov persist into the earliest Late Riphean, and *B. unca* Semikhatov is known only from then (Semikhatov 1962; Semikhatov and Komar 1965; Nuzhnov 1967; Krylov *et al.* 1968; Raaben 1969*a*). Forms of *Tungussia* occur extensively and frequently. A new form of *Kussiella* is found in Late Riphean sediments of the Polud Range of northern Siberia (Raaben 1964).

Raaben (1969*b*) and Raaben and Zabrodin (1969) have proposed a two-fold subdivision of the Late Riphean, a possibility earlier noted by Semikhatov and Komar (1965). The temporal ranges of some of the stromatolites used by Raaben as index fossils of the subdivisions are given differently by Keller and Semikhatov (1967) and Komar and Semikhatov (1969). Raaben recognizes the older subdivision in Spitzbergen, the Ural, and central and northern Siberia. It is characterized especially by forms of *Inzeria*, although this group extends throughout the Late Riphean; *I. tjomusi* Krylov is considered particularly characteristic. Also present are *Jurusania* and several forms of *Gymnosolen*. The upper subdivision occurs in Spitzbergen, the Ural, Polud and Timan Ranges, and Cape Kanin, but is absent from Siberia where no carbonates of an appropriate age are known. Index stromatolites of the upper subdivision include *Gymnosolen ramsayi* Steinmann, *Minjaria uralica* Krylov, *Inzeria djejimi* Raaben, and *Conophyton miloradovici* Raaben. Krylov and Shapovalova (1970*b*) have proposed a similar subdivision.

A notable feature of the Late Riphean is the paucity of both forms and numbers of *Conophyton*, in contrast with the Middle Riphean (Komar *et al.* 1965). At the Middle–Late Riphean boundary disappear *Conophyton cylindricum*, *C. garganicum*, *C. lituum*, and *C. metulum*. Only *C. miloradovici* and *C. baculum* Kirichenko (emend. Komar, Raaben, and Semikhatov) are present, and then only in small numbers. *C. ressoti* Menchikoff from South-West and northern Africa may be Late Riphean (Cloud and Semikhatov 1969). No forms of *Jacutophyton* are reported from the Late Riphean of the U.S.S.R.

Vendian. This final Riphean division contains a less diverse and apparently a less prolific assemblage than the Late Riphean. The shorter time interval represented and the only recent palaeontological differentiation of the Vendian may account for the apparent lesser diversity. Several new stromatolite groups are considered in the U.S.S.R. to appear first in the Vendian: these are *Linella* Krylov, *Patomia* Krylov, and *Aldania* Krylov, Korolyuk, and Sidorov. The time ranges of *Linella* and *Patomia* are controversial.

Three forms of *Linella* have been described, all by Krylov (1967). *Linella avis* occurs in the same stratigraphic unit as *Patomia ossica* Krylov and *Conophyton* *gaubitza* Krylov, in the Tien-Shan and Karatau Ranges (Kirgizia and Kazakhstan). This assemblage occurs about 100 m above beds with *Inzeria toctogulii* Krylov, *Gymnosolen* cf. *ramsayi*, and *Minjaria calciolata* (Korolyuk) which Krylov (1967, p. 71) correlates with the upper Upper Riphean of the Ural. Unconformably above the *Linella* beds are carbonates with microphytoliths considered by Z. A. Zhuravleva to be Vendian, although according to Krylov they also occur in the Early Cambrian. Higher still are definitely Early Cambrian units with hyolithids and trilobites. One element of the *Linella* assemblage, *Patomia ossica*, also occurs in the Patom Mountains (eastern Siberia) in a unit immediately overlain by glauconitic sandstone dated at about 600 m.y. Krylov uses this to support his belief that the assemblage is Vendian. Keller and Semikhatov (1967, fig. 2) show the range of *Patomia* as spanning the Vendian–Late Riphean boundary. Krylov (in Rozanov *et al.* 1969, p. 217) reaffirms his belief that *Patomia* is exclusively Vendian but does note the occurrence of similar forms in the upper Minyar 'Suite' of the Ural, at least part of which contains Late Riphean stromatolites.

Krylov (1967) described *Linella ukka* and *L. simica* from only the Uk and Kliktan 'Suites' of the Ural, considered to be Vendian. Now *L. simica* is also known from the uppermost Yudoma 'Suite' (Semikhatov *et al.* 1970). Thus to the best of present knowledge the *Linella–Patomia–Conophyton gaubitza* assemblage in the U.S.S.R. is Vendian; but at least *Patomia* may have originated during the Late Riphean. In California *Linella* aff. *L. ukka* occurs in the Johnnie Formation below *Boxonia* aff. *B. gracilis*; the Johnnie Formation is of very old Palaeozoic or very young Proterozoic age (Cloud and Semikhatov 1969).

The genus *Conophyton* is poorly represented in the Vendian. Besides *C. gaubitza* there is only *C. circulum* which like *C. gaubitza* is geographically restricted, being known only from the Eastern Sayan Mountains of southern Siberia (Komar *et al.* 1965).

Gymnosolen confragosus Semikhatov (1962) was reported from the Dashkin 'Suite' before stromatolitic differentiation of the Vendian. The Dashkin 'Suite' is now considered to be Vendian (Krylov in Rozanov *et al.* 1969, p. 215). Semikhatov and Komar (1965) outline differences between these *G. confragosus* and the Late Riphean examples, but they do not reclassify them. Raaben (1969*a*) reclassifies the Late Riphean forms as *Inzeria confragosa*, and according to Krylov and Shapovalova (1970*b*) Semikhatov has designated it as the type form of the new group *Confragosia*, for which there is no published description or diagnosis.

Boxonia grumulosa Komar occurs extensively and exclusively in the early Vendian; it is known from northern, eastern, and southern Siberia, Spitzbergen, and possibly Byelorussia (Komar 1966; Semikhatov *et al.* 1967; Voronov *et al.* 1966; Raaben and Zabrodin 1969; Zhuravleva and Chumakhov 1968). It is one of the forms employed by Semikhatov *et al.* (1967, 1970) in a suggested two-fold subdivision of the Vendian. *Boxonia grumulosa* is the only form restricted to the lower subdivision. In the upper, the group is represented by *B. ingilica* Komar and Semikhatov. The only other forms restricted to the upper subdivision are *Linella simica*, *Aldania sibirica* (transferred from *Jurusania* to *Aldania* by Krylov, Korolyuk, and Sidorov in Rozanov *et al.* 1969) and *Jurusania allahjunica* (transferred from *Boxonia* by Raaben 1969*b*). This subdivision has been established in the Yudoma and Staraya Rechka 'Suites' in Siberia.

Cambrian. Cambrian stromatolites are not as intensively studied as those of the Riphean. Several exclusively Cambrian forms were described but not reconstructed by Korolyuk (1960). Sidorov (1960) described the Early Cambrian form *Ilicta composita*; reconstructions have recently been published (Krylov in Rozanov *et al.* 1969). *Vetella uschbasica* Krylov (1967) is restricted to the Early Cambrian of Kazakhstan. Reconstructions of *Uricatella urica* Sidorov and *Boxonia divertata* Sidorov (Korolyuk and Sidorov 1969) have yet to be published. They are considered Early Cambrian because they occur with 'renalcid' algae above sediments with Vendian microphytoliths and 200–300 m below rocks with the trilobite *Bulaiaspis*; they are also thought to have some features typical of Cambrian stromatolites.

CORRELATION BETWEEN AUSTRALIA AND THE RIPHEAN AND CAMBRIAN OF THE U.S.S.R.

The *Baicalia–Conophyton garganicum* assemblage of the Bangemall Group (Bangemall Basin) and Burra Group and possibly Callanna Beds (Adelaide Geosyncline) occurs in the U.S.S.R. abundantly, extensively and exclusively in Middle Riphean strata. Correlation of these units is clearly indicated (Table 3). Since the Middle Riphean extends from 1350±50 to 950±50 m.y., confirmation comes from a Rb-Sr shale dating of 1080±80 m.y. from the Bangemall Group, and support from a Rb-Sr dating of 1350±45 m.y. from below the Burra Group; an 867±32 m.y. dating on the Burra Group basement contradicts the correlation, but as yet receives little support from other geological data. The only pointer to a more precise correlation of the Bangemall Group is that *Conophyton garganicum australe* is very similar indeed to *C. g. nordicum* Komar, Raaben, and Semikhatov from within the later half of the Middle Riphean (the range of this form in relation to the three-fold subdivision of the Middle Riphean is unknown to me). The dating of 1080±80 m.y. supports a correlation with the upper Middle Riphean. The presence of *Conophyton garganicum* in the 1500–1600 m.y. old McArthur Group (McArthur Basin) is in accord with its occurrence in the U.S.S.R. in the Early and Middle Riphean (1600± 50 to 950±50 m.y.).

In the Amadeus Basin, stromatolites occur prolifically in the Bitter Springs Formation. The Gillen Member, the older of two subdivisions of the formation, is only known to contain *Tungussia erecta*. In the U.S.S.R. *Tungussia* extends from the Middle Riphean to the Vendian inclusive (but I have been unable to find a record of its occurrence in the early Middle Riphean). Therefore the Gillen Member is unlikely to be older than Middle Riphean. This is a useful confirmation of very tenuous conclusions drawn from equivocal radiometric datings which suggest for the Gillen Member an age no greater than 1200–1400 m.y., and also supports the conclusion that the Gillen Member is no older than the Burra Group of the Adelaide Geosyncline, for which a Middle Riphean age has already been determined (Glaessner *et al.* 1969).

Of the eight groups of stromatolites known from the upper (Loves Creek) member of the Bitter Springs Formation, three are new. Two others are restricted in the U.S.S.R. to the Late Riphean: these are *Inzeria* and *Minjaria*. The Australian

Inzeria intia closely resembles *I. tjomusi* Krylov which occurs in the U.S.S.R. only in the older subdivision of the Late Riphean. Two other groups, *Boxonia* and *Jurusania*, are found in the U.S.S.R. in the Late Riphean and Vendian, but the form of *Jurusania* present, *J. nisvensis* Raaben, is restricted to the early Late Riphean (Raaben 1969*b*). One of the new stromatolites, *Acaciella australica* (Howchin), closely resembles an as yet undescribed Late Riphean form from the Patom Mountains (Krylov 1967, figs. 11, 12). Thus far the assemblage is clearly Late Riphean. The last element is anomalous; it is *Linella avis* Krylov which in the U.S.S.R. is probably restricted to the Vendian. In the U.S.S.R. *L. avis* is known only from two adjacent areas of Kazakhstan and Kirgizia, and there its Vendian age is not yet certainly established. Because of its geographical restriction and the uncertainty of its age it cannot be given much weight in the correlation. The Loves Creek Member is therefore considered definitely to be Late Riphean, and possibly early Late Riphean. Such a correlation is supported by its occurrence below the lower tillite which probably is 740±30 m.y. old (the Late Riphean extends from 950±50 m.y. to 680±20 m.y.; the early Late Riphean assemblage zone is probably older than 760 m.y. according to Raaben 1969*b*).

Cloud and Semikhatov (1969) report the occurrence of a new form of *Anabaria* Komar in an unspecified part of the Bitter Springs Formation. This stromatolite is best classified as a new form of *Kotuikania*, a group which in the U.S.S.R. is restricted to the Late Riphean. In the Jay Creek section it occurs in the lower Loves Creek Member.

The firm correlations of the Loves Creek Member with the Upper Riphean and of the Skillogalee Dolomite with the Middle Riphean (Glaessner *et al.* 1969) confirm the conclusion earlier derived that the Loves Creek Member postdates the Skillogalee Dolomite.

The occurrence of *Tungussia inna* in the Pertatataka Formation of the Amadeus Basin adds nothing to the correlations. The youngest Amadeus Basin stromatolite is *Madiganites mawsoni* which is Middle and Late Cambrian. It closely resembles *Ilicta composita* Sidorov from the Early Cambrian of the U.S.S.R. Particularly notable is its very distinctive vermiform microstructure which in the U.S.S.R. is known only in Palaeozoic and Vendian stromatolites.

The Antrim Plateau Volcanics contain *Conophyton* cf. *gaubitza* Krylov and the new form *C. basalticum*. Since in the U.S.S.R. the group *Conophyton* is unknown from the Phanerozoic and *C. gaubitza* is probably Vendian, a Precambrian and probably Vendian age is indicated for the Antrim Plateau Volcanics. Other evidence restricts the age of the Volcanics to between early Vendian and Middle Cambrian.

At present no correlations can be made with the Late Precambrian of continents other than Eurasia, but we can note that of the groups *Boxonia*, *Linella*, and *Jurusania*, which occur in the Bitter Springs Formation, *Boxonia* and *Linella* also occur in the Johnnie Formation of California (Cloud and Semikhatov 1969) and *Jurusania* is known from an unnamed unit of possibly late Precambrian age in the western Sahara (Keller and Semikhatov 1967). The Johnnie Formation is late Precambrian or early Palaeozoic. Stromatolites of probable late Precambrian age resembling *Boxonia*, *Linella*, and *Jurusania* (among others) are described from the Sahara by Bertrand (1968, 1969).

PRE-RIPHEAN STROMATOLITE ZONATION

In the U.S.S.R. a stromatolite zonation has been established only in Riphean sequences, and older stromatolites, except for those from Karelia, are poorly known. A reading of the world literature reveals that stromatolites occur frequently in early Proterozoic sequences, but rarely in the Archaean. This is supported by observations in Australia which, together with other detailed studies of early Proterozoic stromatolites, provide the basis for a zonation of these rocks. The most informative studies are those of the Karelian stromatolites (Slodkevich *et al.* 1960; Sokolov and Butin 1961; Härme and Perttunen 1964; Krylov 1966), the wide-ranging study by Cloud and Semikhatov (1969), investigations in North America of stromatolites from the Animikie Group (Hofmann 1969*a*) and the Labrador Geosyncline (Donaldson 1963, 1966) and in South Africa from the Dolomite 'Series' (Young 1929 et seq.; Young and Mendelssohn 1949).

In Australia the oldest known stromatolites are in the early Proterozoic Fortescue Group of the Hamersley Basin, Western Australia, although there are Archaean rocks interpreted as pillow lavas replaced by carbonate (Noldart and Wyatt 1962, p. 111) and the possibility that some of these may be stromatolitic carbonates does not appear to have been investigated. The Fortescue Group is probably 2190±100 m.y. old (Compston and Arriens 1968) and contains the stromatolites *Alcheringa narrina*, described herein, and *Gruneria* f. nov. which was tentatively identified by Cloud and Semikhatov (1969) as *Gruneria biwabikia*. *Gruneria* f. nov. also occurs in the Ventersdorp 'System' of South Africa. Zircons from Ventersdorp lavas have been dated at 2300±100 m.y. (Niekerk and Burger 1964). The African stromatolites have been found only in bore cores and were first reported by Winter (1963). The similarly aged Ventersdorp 'System' and Fortescue Group both consist of interbedded volcanics and clastics with some carbonates and both underlie extensive banded iron-formations (Trendall 1968). Cloud and Semikhatov (1969) described *G. biwabikia* from the Biwabik and Gunflint iron-formations of North America, which they considered to be about 1900 m.y. old. *A. narrina* is a distinctive stromatolite unknown from younger rocks.

In the Hamersley Basin, dolomites of the Wyloo Group occur high in the sequence above the Fortescue Group. They contain two columnar stromatolites, *Pilbaria perplexa* and *Patomia* f. indet. The Wyloo Group is dated as 2020±165 m.y. old (Compston and Arriens 1968). A similar stratigraphic position is occupied in South Africa by the Dolomite 'Series', lying above the Ventersdorp 'System'. The intrusive Bushveld Complex sets its minimum age at 1950±50 m.y. Most Dolomite 'Series' stromatolites are not well enough described to allow more than superficial comparisons, but there are some resembling *P. perplexa* (Young 1941, text-fig. 1; Toens 1966, Pl. 5).

Among other stromatolites known from the Dolomite 'Series' and its correlative the Campbell Rand 'Series' are the small columnar forms with markedly divergent branching shown in plates 3 and 4 of Young (1934). These are very similar to Hofmann's (1969*a*) form C from the Gunflint Formation of Canada. In the available illustrations these two are indistinguishable, although form C may have more bridges than the African example. The age of the Gunflint Formation is not well determined; it may be between 1900 and 2500 m.y. or as young as 1635±24 m.y.

(Stockwell 1964; Trendall 1968; Faure and Kovach 1969), i.e. of a similar age to the Dolomite 'Series'. Stromatolites like form C are unknown from younger rocks. This Dolomite 'Series' stromatolite has now been named *Katernia africana* by Cloud and Semikhatov (1969). They do not comment on its similarity to the Gunflint stromatolite but consider that it may also occur in the early Proterozoic Nash Formation of Wyoming (see Knight 1968).

The affinities of one other Dolomite 'Series' stromatolite are noteworthy. The upper part of that in plate 25, figure 1 of Young (1943) is unusual, consisting of very small columns with numerous projections and slightly divergent branching. It is not well illustrated, but there is a marked similarity with the stromatolite shown in plate 5 of Donaldson (1963). This latter is from the Denault Formation in the Labrador Geosyncline of Canada and is between 1800 and 2440 m.y. old (Stockwell 1964). A stromatolite indistinguishable in longitudinal section from the Denault Formation example possibly is from the Koolpin Formation in the Pine Creek Geosyncline of Australia; this is 1830–2400 m.y. old (Compston and Arriens 1968). The labelling of this specimen is uncertain. Thus, possibly the same kind of particularly distinctive stromatolite occurs on three continents in rocks of a similar age; none similar is reported from younger rocks.

There is a growing body of evidence that several stromatolite groups have a disjunct temporal distribution, occurring in both the Early Proterozoic and the Late Riphean and Vendian. An example is *Patomia* Krylov, originally described from the Vendian or Late Riphean of the U.S.S.R., but now tentatively identified from the Early Proterozoic Duck Creek Dolomite. The Duck Creek *Patomia* is poorly preserved, but resemblances with other similarly ancient stromatolites are notable: firstly with the probably Early Riphean form from Queensland named *Eucapsiphora paradisa* by Cloud and Semikhatov (1969); and secondly with Hofmann's (1969*a*) forms B and F from the Gunflint Formation of Canada. As Hofmann notes, forms B and F closely resemble *Gymnosolen* Steinmann (emend. Krylov); lack of reconstructions prevents identification. There is a striking similarity between the Late Riphean *Katavia karatavica* Krylov from the Ural and a stromatolite that Hofmann (1969*b*) figures from early Proterozoic Manitounuk Group of Canada. Krylov (1966 and in Rozanov *et al.* 1969) has commented on the resemblance between Late Riphean and Jatulian stromatolites, but this does not appear to be close enough to allow identification of the Jatulian forms. These examples of probably disjunct distributions, the only ones known at present, are distinct from cases of range extensions. A stromatolite which may prove to have a long, continuous time range is Hofmann's (1969*a*) form D from the Gunflint Formation; a form identical in longitudinal sections occurs in the Jurassic of Poland (Szulczewski 1968) and superficially similar forms occur in many rock sequences.

It has been shown that the late Precambrian stromatolite sequence discovered in the U.S.S.R. also occurs in Australia in rocks of probably the same age, and thus that intercontinental correlation is possible. Stromatolites occur frequently in early Proterozoic rocks, and of the few studied, several are distinct from younger stromatolites and indicate the possibility of extending the zonal scheme to older sequences. Three groups of stromatolites seem to have a temporally disjunct distribution, occurring in both early Proterozoic and Late Riphean and Vendian sediments.

MAJOR EVENTS IN THE EVOLUTION OF STROMATOLITES

A broad survey of stromatolite evolution shows several major events worthy of discussion. Stromatolites with narrow, tall, erect, branching columns are common in the Precambrian and early Palaeozoic, but rare after the Ordovician. This is well illustrated by a comparison of the Precambrian assemblages here described with those from the Phanerozoic described or listed by Johnson (1937 et seq.) in his numerous comprehensive publications. A check of hundreds of references has confirmed the reality of this change. The youngest described 'old style' stromatolites are in the Ordovician of the U.S.A. (Howe 1966) although they possibly also occur in the Carboniferous of Canada (Schenk 1969). Such forms are at least moderately common in the Cambrian (e.g. Sidorov 1960; Korolyuk and Sidorov 1969). Cloud and Semikhatov (1969) have also noted that stromatolites are more abundant and more varied in gross form in Early Ordovician and older rocks than in younger sediments. Typical post-Ordovician columnar stromatolites have columns less than 15 cm high (often *much* less), e.g. from the Pennsylvanian (Johnson 1961, pl. 105), Jurassic (Szulczewski 1968), Eocene (Bradley 1929), and Oligocene (Johnson 1937). Broad, high, unbranched columns such as those of the mid-Tertiary of France (Bertrand-Sarfati *et al.* 1966) and the Devonian of north-western Australia (Playford and Cockbain 1969) occur infrequently; broad, erect, unbranched columns are currently forming in Shark Bay, Western Australia (Logan 1961). The rapid decline in the abundance and diversity of stromatolites during the Palaeozoic can be attributed to an increasing abundance and diversity of scavengers and burrowers. Not only do gastropods and other animals eat the algae but they also destroy the stromatolites by burrowing into them or scraping their surfaces (Brock *et al.* 1969; Davies 1970*b*; Garrett 1970; Awramik 1971; Walter *et al.*, in prep.). It is probable, as Fischer (1965) suggested, that in the past stromatolites formed in a wider variety of environments than at present, indicating the need for caution when using them for environmental analysis. This is supported by Playford and Cockbain (1969) who demonstrate that Devonian stromatolites grew in up to 45 m of water, deeper than any known extant forms (see also Walter 1970*b*).

The group *Conophyton* was thought to have become extinct near the Vendian–Lower Cambrian boundary, and Cloud (1968) used this event to define the end of the Precambrian. However, growing *Conophyton* has recently been found in the effluents of hot springs and geysers in Yellowstone National Park, Wyoming (Walter *et al.*, in press). This group is most diverse and abundant during the Middle Riphean. *C. basalticum* and *C.* cf. *gaubitza* Krylov from the Antrim Plateau Volcanics of northern Australia may be Lower Cambrian. The group *Georginia* is similar to *Conophyton* and *G. howchini* from the Georgina Basin of Central Australia is probably Early Cambrian. Maslov's (1938) early reports of *Conophyton* from the Palaeozoic resulted from incorrect correlation of sediments now known to be Precambrian. His identification of an Ordovician *Conophyton* (Maslov 1960) is unacceptable since this stromatolite lacks a crestal zone, a diagnostic feature of conophytons as presently defined (Komar *et al.* 1965, p. 29). Cloud and Semikhatov (1969) are of the opinion that no conophytons are younger than the early Vendian, but this is not true in Australia (pp. 46–49), and even in the U.S.S.R. it is not established, since the exact relative position of the occurrence of *C. gaubitza* Krylov is unknown (pp. 79–80).

Komar *et al.* (1965) discuss apparent parallel evolutionary trends in the three *Conophyton* subgroups. A striking and apparently real trend is the persistent increase with time in the ratio L_2/L_1 (thicknesses of dark laminae over those of contiguous pale laminae). Hundreds of measurements have revealed a distinct modal value for each form and variety of *Conophyton* (the groups are subdivided mainly on other criteria). For instance, in the *C. garganicum* subgroup the Early to Middle Riphean variety *C. g. garganicum* has a mode of about 1·0, the late Middle Riphean varieties *C. g. australe* and *C. g. nordicum* respectively have modes of 1·25 and 2·0, and that of the Late Riphean form *C. miloradovici* is about 2·5 (text-fig. 27). Thus *C. g. australe* from Australia conforms to the evolutionary trend first detected in the U.S.S.R. In the *C. garganicum* subgroup this trend largely results from an increase with time in the modal thickness of dark laminae, but in the *C. cylindricum* subgroup a decrease in the modal thickness of the pale laminae is the major factor. Komar *et al.* (1965, p. 67) speculate that the dark laminae represent originally alga-rich layers in which a relative increase in thickness would be advantageous since it would allow more photosynthesis per unit mass of column. In the Australian conophytons the dark colouration is due to the presence of iron oxides, which may have replaced organic matter. Presumably the pale laminae originally had less organic matter. Since during accretion of a column each pale lamina forms a barrier through which the algae must move or grow for continued existence, reduction in the thickness of these laminae is likely to be advantageous. Increase in the thickness of dark laminae could be due to the evolution of algae with thicker filaments.

Coarse, prominent, vermiform microstructures first appear in Vendian stromatolites and they are strongly developed in some Cambrian stromatolites such as *Cryptozoon proliferum* Hall (see Goldring 1938). This is in marked contrast with older stromatolites, which all lack the 30–60 μ wide, pale, sinuous, intertwined patches of carbonate so prominent in, for example, *Madiganites mawsoni* from the Middle and Upper Cambrian of the Amadeus Basin (Pl. 1). Vologdin (1962, pl. 61) figures a partly similar microstructure in stromatolites from the Uluntuy 'suite' of the Baikal region of the U.S.S.R., but these lack the long, sinuous patches of sparry carbonate common in the vermiform microstructure; they resemble Krylov's (1963) illustrations of the microstructure of some *Baicalia baicalica*, a stromatolite which occurs in the Uluntuy 'suite'; it is probably a grumous texture of secondary origin. The patches in *M. mawsoni* are similar to *Girvanella* but lack the microgranular walls of that form. Krylov (in Rozanov *et al.* 1969, p. 223) has independently also concluded that vermiform microstructures are an innovation typical of the Phanerozoic. He considered that they first appear near the base of the Cambrian. A specimen of the Vendian *Boxonia gracilis* Korolyuk from the U.S.S.R. available to me has this microstructure, but poorly developed. The Lower Cambrian form *Ilicta composita* Sidorov (1960) is another example. Such microstructures are common in Phanerozoic stromatolites (Johnson 1961; Vologdin 1962).

The microstructural differences between older and younger stromatolites cannot be explained as due to different preservation, since many Precambrian stromatolites are just as well preserved as those from the Phanerozoic having the vermiform microstructure. These structures could have been formed by carbonate-precipitating algae. This suggestion is supported by the fact that the first appearance of this microstructure in Vendian stromatolites nearly corresponds to the origin of *Girvanella*-built oncolites during the Cambrian (*Girvanella* is known from near the base of the Cambrian: Voronova and Missarzhevskiy 1969). The *Girvanella* tubules may have been formed by carbonate-precipitating algae. Vermiform microstructures may form in another way. As stromatolites grow, the algal trichomes move upwards leaving behind their mucous sheaths. Dissolution of modern stromatolites and oncolites frequently leaves a body of mucus the same size and shape as the originally calcareous structure (e.g. Fritsch and Pantin 1946). If these resistant mucous sheaths became calcified during diagenesis, or left cavities later filled with carbonate, a vermiform microstructure would result. A very similar microstructure is forming this way in modern stromatolites (Davies 1970*b*). The vermiform microstructure could be due to algal boring; Klement and Toomey (1967) show that at least some *Girvanella* tubules are made by boring organisms. This is unlikely because of the uniform distribution of the vermiform structure within laminae.

The filaments responsible for the vermiform microstructure were coarse, about 30–60 μ wide. The filaments of many extant blue-green algae are less than 10 μ wide; stromatolites are rarely well enough preserved to show such narrow structures and the only possible indications of them in Australian Precambrian stromatolites are faint, alternately dark and pale strips about 10 μ wide arranged normally to the lamination in some specimens; coarser structures in the early Proterozoic *Alcheringa narrina* are problematic, but could represent the bundles of filaments which occur in blue-green algae such as *Rivularia* (e.g. Monty 1967, pl. 16). Although the vermiform structures are unusually coarse for blue-green algae, they are finer than the coarsest extant blue-greens. They are comparable in size to the small filamentous red and green algae. The favoured explanation of their origin is that algae with coarse filaments first participated in stromatolite formation on a large scale during the Vendian. This is supported by the fact that the well preserved and diverse microfloras from the Precambrian Gunflint Formation and Bitter Springs Formation contain numerous algal filaments but none broader than 15 μ (Barghoorn and Tyler 1965; Schopf 1968; Cloud and Hagen 1965).

A broad survey shows three major events in the evolution of stromatolites: the first appearance of coarsely vermiform microstructures during the Vendian; the extinction of the group *Conophyton* at about the beginning of the Cambrian; and the abrupt decline of stromatolites with narrow, tall, erect, branching columns after the Ordovician. Predictably, two of these major events as well as numerous lesser changes happened during the period of flux near the beginning of the Cambrian.

BIOLOGICAL INTERPRETATIONS

The biological interpretation of stromatolite taxa is not essential to their use in biostratigraphy, since the biostratigraphic method is empirical: but for the confident use of the method interpretation is important. Although it is shown in this section that there must be a connection between algal and stromatolite evolution, this does not exclude the possibility that sequential environmental changes were a factor in stromatolite change. The compositional evolution of the atmosphere and hydrosphere could conceivably have had some effect on algal plant shape, particularly as it relates to gas exchange. Here I have chosen to emphasize biological control of stromatolite morphology because the following analysis indicates that it could have been the dominant mechanism in stromatolite evolution and because it has previously been virtually neglected. Critics of the biostratigraphic use of stromatolites frequently raise two major questions: 1. How can the gross shape of stromatolites be influenced by the algae which build them? 2. Modern evidence suggests that the evolution of blue-green algae through the Precambrian has been very slow—is it likely, therefore, that there is any direct connection between this evolution and observed changes in stromatolites? The first question is asked in a number of different ways by Hofmann (1969*b*), who leaves it unanswered. The rapidly expanding knowledge of both ancient and modern algae and stromatolites now allows both questions to be answered, although certainly not to the complete satisfaction of either party to this debate. The second question, on algal evolution, will be considered first. At once the question which algae built and still build stromatolites must be raised: too often only blue-green algae are mentioned in this regard.

THE ALGAE WHICH BUILD STROMATOLITES

The most fundamental division in the organic world is between procaryotes and eucaryotes (procaryotes are formally named the kingdom Monera; Whittaker 1969). Ranged across this division are the 'algae': to the Monera belong the blue-greens (the Cyanophyta), but all other algae are eucaryotic. A striking feature of the nine phyla (divisions) of algae (Prescott 1968) is the prevalence of convergent evolution (Fritsch 1935, p. 27). For instance, filamentous forms from the Cyanophyta, Chlorophyta (greens), Rhodophyta (reds), and Phaeophyta (browns) are quite similar: all can be about the same size, all can be encased in mucus, and all can form mats and tufts. Furthermore, calcium carbonate deposition occurs about the filaments and unicells of some species from all of these phyla (here and elsewhere I refer to the formation of carbonate moulds about cells rather than to intracellular or intramural precipitation of calcium carbonate, which are distinguishing characteristics of particular groups of algae and may preserve their cellular structure). The essential features of blue-green algae which cause them to build stromatolites are their sediment-trapping and sediment-precipitating abilities. They can trap sediment for several reasons, one of the more important being their phototaxis which causes them to move up through any covering sediment (Schopf 1970) thus binding it in place. Both filamentous and some unicellular cyanophytes are phototactic (Stanier *et al.* 1971). In addition, many have sticky mucous sheaths and form loose networks of filaments into which sediment falls. Since taxes occur in algae from other phyla and these also include filamentous and mucus-coated forms some of which precipitate carbonates, it is to be expected that they will also build stromatolites. A survey of the literature shows they do. Even diatoms (Bacillariophyceae) form mucilaginous colonies in which carbonate is precipitated, possibly by bacteria

(Monty 1967). The fresh-water filamentous brown algae *Pleurocladia lacustris* deposits carbonate between its erect filaments to form small, rigid, cushion-shaped colonies (Fritsch 1945, p. 55). Stromatolites formed on the coast of Normandy by the red alga *Rhodothamniella floridula* are described in detail by Hommeril and Rioult (1965). The erect filaments of this alga trap detritus mostly finer than 100 μ (because the gaps between filaments are mostly less than 100 μ wide). Another species, *R. rothii*, traps much finer sediment. *R. floridula* forms 'cushions' and 'mats' from several centimetres to several tens of centimetres wide and up to more than 5 cm thick. Tilden (1897) recorded carbonate deposits around filaments of the red alga '*Chantransia*' *pygmaea*. Kann (1940, 1941) described carbonate deposits formed by red algae, but his papers have not been available to me. Calcareous crusts formed about the red algae *Hildenbrandia rivularis* and *Pseudochantransia chalybaea* are described by Lingelsheim and Schroder (1918). A variety of subtidal stromatolitic algal mats are described from the Bahamas by Neumann *et al.* (1970); one of these has as its main components *Cladophoropsis membranacea* (Chlorophyta), *Gracilaria blodgetti* (Rhodophyta), *Schizothrix calcicola* (Cyanophyta), and diatoms. The green alga controls the structure of the mat. Sediment-trapping mats composed of the green alga *Enteromorpha* are described from the Bahamas by Scoffin (1970). Monty (1965*a*) mentions modern stromatolites formed by the green algae *Gongrosira incrustans* and *Chaetophora incrassata*. Fritsch (1945, p. 267) noted that several members of the Gongrosireae form cushion-like growths encrusted with carbonate (e.g. *Gongrosira scourfieldii* and *Chlorotylium*). Carbonate encrusted *Chaetophora calcarea* are described by Tilden (1897). The uni-cellular green alga *Palmella miniata* is very abundant in stromatolites presently forming in Green Lake, New York (Bradley 1929).

Although numerous examples of modern non-cyanophycean stromatolites can be found, it is still true that many, and probably the majority, of modern stromatolites are built by blue-green algae. But it is important to consider the past role of non-cyanophycean algae in stromatolite building. The obvious question is whether there is a connection between the evolution of new algal phyla and the observed changes in stromatolites, because although blue-green algae probably evolved during the Archaean other algal phyla did not appear until later.

In looking for examples of fossil stromatolites built by algae other than blue-greens the problem of properly identifying even well-preserved material arises. Eocene stromatolites in the Green River Formation of the U.S.A. contain very distinct, spherical, uni-cellular organisms of about 100 μ diameter. Bradley (1929) identified them as *Chlorellopsis coloniata* Reis which he compared to the extant *Chlorococcum infusionum* (Schrank) Meneghini (Chlorophyta). Although the fossils have no definitely eucaryotic features, they are much larger than any of the extant coccoid Cyanophyta (Drouet and Daily 1956) but similar in size to many coccoid Chlorophyta, and so Bradley's tentative identification of them as a green alga is reasonable. Cloud *et al.* (1969) have identified chlorophyceans and possibly chrysophyceans in possibly Middle Riphean stromatolites from California. In a study of algal limestones (including stromatolites) from the Phanerozoic of Europe Meijer (1969) found probable representatives of the Cyanophyta, Chlorophyta, Xanthophyta, and Rhodophyta; his paper is only a brief preliminary report with no information on the relative abundances of the different algae. Cambrian stromatolites from

Spain contain filaments which Meijer compares with the extant red alga *Conchocelis* (see his pl. D).

Having established that blue-greens are not the only algae which build stromatolites we must examine the fossil record to see what algal evolution occurred during the Precambrian: Schopf (1970) provides a comprehensive review of this subject. No definite eucaryotic microorganisms are known from the intensively studied and well preserved flora of the early Proterozoic Gunflint Formation and its correlatives (Barghoorn and Tyler 1965; Cloud and Hagen 1965; Cloud and Licari 1968; Hofmann and Jackson 1969). The oldest definite green algae with at least a moderately-well established age are the excellently preserved examples in the early Late Riphean (about 800–900 m.y.) upper Bitter Springs Formation of Central Australia (Schopf 1968). These are not associated with distinct stromatolites (although the laminae they form may be stromatolitic). Cloud *et al.* (1969) describe fossil eucaryotic algae from the Beck Spring Dolomite of California; this formation they tentatively consider on the basis of tenuous isotopic evidence to be about 1200–1400 m.y. old. The Beck Springs Dolomite contains a '*Baicalia*-like' stromatolite; in the U.S.S.R. *Baicalia* is Middle Riphean and early Late Riphean. They identify the probable eucaryotes as coccoid chlorophyceans, some of which occur in cumulate stromatolites, and possible chrysophycean cysts, also in stromatolites. Pflug (1966, 1968) has described microorganisms from the Belt Supergroup of North America; this unit is between 1100 and 1600 m.y. old (Cloud and Semikhatov 1969). The microorganisms include possible chlorophyceans and chrysophyceans (or dinoflagellates). Also present are what Pflug tentatively considers to be members of the Leiosphaeridaceae and the Diacrodiaceae; Downie *et al.* (1963) rename these taxa Sphaeromorphitae and Diacromorphitae, and include them with the Acritarcha, a polyphyletic group which probably includes many fossil algae; the systematic position of acritarchs is much disputed. The possible significant role of red algae in stromatolite building has already been noted. Their time of origin is very poorly known, but the Bitter Springs assemblage may include red algae (Schopf 1970) and they are well known from the Cambrian. Since many of Vologdin's stratigraphic correlations are disputed in the U.S.S.R., his reports of Precambrian red algae (Vologdin 1962) cannot be accepted until confirmed.

Comparison of differently aged fossil microfloras may indicate the rate and extent of the evolution of the blue-green algae during the Precambrian. First a note of caution: the classification of extant blue-green algae is in a state of flux which verges on chaos. In a revision of the cyanophycean family Oscillatoriaceae Drouet (1968) has grouped 2400 previously described specific and subspecific taxa into '23 autonomous species, some few of which may in the future prove to be ecophenes of others'; some of his synonymies run into almost forty pages. Drouet (1963*a*) considers that *Schizothrix calcicola* alone has been described as fifty-four different taxa, and he has come to similar conclusions in detailed and comprehensive studies of *Microcoleus chthonoplastes* (recte *Schizothrix arenaria*), *M. vaginatus* (Drouet 1962, 1963*b*), and all of the coccoid blue-greens (Drouet and Daily 1956). However, these views are not at all acceptable to all algologists familiar with the group (Desikachary 1959; Stanier *et al.* 1971). The difficulties lie in setting limits to the intraspecific variation, which may be great. In fossil material because of limited preservation these difficulties are increased. Even in the case of the excellently preserved Gunflint and Bitter Springs assemblages, when considering the taxonomy a little scepticism and caution are in order.

Schopf (1968) has made comparisons between the more ancient fossil microfloras and with the modern microflora, and notes that compared with the Gunflint assemblage, that of the Bitter Springs Formation 'includes a more diverse assemblage of procaryotic filaments, and seems more "modern" in composition with many more of the organisms being comparable to particular extant taxa'. Schopf considers that there are no taxa in common between the Bitter Springs and Gunflint floras. 'Microscopic algae and a variety of Problematica, assigned to fifteen species comprising nine genera, have also been reported from the late Precambrian Belt Series of south-central Montana. . . . These approximately 1100 million-year-old microorganisms . . . are generally rather dissimilar from those of the Bitter Springs assemblage.' With one possible exception these floras have no taxa in common. Recently Schopf and Barghoorn (1969) have found one alga in common between the Early Riphean (1350–950 m.y.) Skillogalee Dolomite (Adelaide Geosyncline) and the Bitter Springs Formation. These units have no known columnar stromatolites in common. Hofmann and Jackson (1969) tentatively consider that the early Proterozoic Belcher Group of Canada has in common with the Bitter Springs assemblage a bacterium and a fungal or algal microorganism.

The dissimilarities between these fossil microfloras may partly be due to differing original environments; Schopf (1968) has overstated the facies similarities between the Gunflint and Bitter Springs floras, and did not indicate that whereas many of the Gunflint organisms occur within columnar stromatolites those from the Bitter Springs Formation are in flat-laminated sediments. Nevertheless, extant blue-green algae have phenomenally wide environmental tolerances (if Drouet's taxonomy is accepted) so the differences in the fossil assemblages are probably due to evolution. As Schopf (1968, 1969, 1970) discusses at some length, algal evolution has been particularly slow, and the fossil microfloras show many similarities with their extant counterparts; but what is preserved as fossils is frequently insufficient to allow the degree of taxonomic differentiation possible with extant material (De Ley 1968). Furthermore, physiological differences, such as that which causes carbonate precipitation to be specific to particular taxa of blue-green algae (Monty 1967) will not be apparent in comparisons of cellular morphology but will affect the growth of stromatolites. A biological analysis of ancient stromatolites will reward the investigator with new data on algal evolution.

We may conclude that there was a marked amount of algal evolution during the Proterozoic. Many new taxa (e.g. *Epiphyton*, *Renalcis*) first appear at about the beginning of the Palaeozoic, and in particular red algae then become more and more prominent. Algae other than blue-greens can presently form stromatolites and did so in the past. Because of this, and the fact that green algae evolved during the late Lower Proterozoic, Early Riphean, or early Middle Riphean (i.e. between 2000 m.y. and 1200 m.y. ago), and that red algae evolved during the Riphean or Cambrian, it is apparent that the evolution of new algal phyla may be the cause of at least some of the stromatolite evolution now known. It would be premature to make specific correlations between algal and stromatolite evolution.

ALGAL PLANT SHAPE AND ITS RELATION TO STROMATOLITE SHAPE

The macroscopic shape of the algal plants (colonies) is particularly important because upon this depends the shape of the stromatolites they form. Unfortunately it appears to be a subject of little interest to algologists. The arrangement of unicells and filaments within plants is frequently described, but to the gross plant shape itself only scanty reference, or none at all, is made. Plant shape is rarely mentioned in the works of Drouet (1962, 1963*a*, *b*, 1968), Drouet and Daily (1956), Desikachary (1959), and Prescott (1968). Elenkin (1938) and Kosinskaya (1948) illustrate and briefly describe some cyanophyte plant forms which they consider specific to certain taxa. In his major works on the algae Fritsch (1935, 1945) gives numerous very brief descriptions of plant forms and indicates reasons for different filamentous algae forming differently shaped plants. For instance, whereas some filamentous blue-greens rarely branch those of the Rivulariaceae exhibit frequent 'false' branching: the resultant crowding of filaments often causes them to be radially distributed and thus to form globular or hemispherical plants (Fritsch 1945, pp. 837–841). Coccoid algae form sticky mats but not the open felted mats characteristic of many of the filamentous algae, and thus cannot so readily trap sediment (however, some of the coccoid algae are pseudofilamentous, and some form rugose mats the hollows of which trap sediment). Fritsch (1907) describes several plant forms among the Ceylonese blue-green algae he studied. Thin, sticky films are formed mainly by unicellular taxa, but also by some which are filamentous. The filamentous algae commonly form mats in which the filaments are tangled and unoriented; they may grow up from these into mats composed of erect filaments which may be arranged in tufts. In some the tufts are closely spaced but in others they are wide apart. Fritsch (1907, p. 211) suggests that the tufted growth form facilitates gas exchange and moisture adsorption. The available data indicates that there are different plant forms among the algae (even among the blue-greens) and that not all plant forms can be achieved by each algal taxon.

Support for this conclusion and an explanation of the connection between algal plant shape and stromatolite lamina shape is found in studies of algae made by several geologists. An excellent example occurs in Eardley's (1938) very detailed investigation of sedimentation in the Great Salt Lake of Utah. Stromatolites are common along the margins of the lake: most are built by the unicellular blue-green alga *Aphanothece packardii* (recte *Coccochloris elebens*) which forms nodose mats, and therefore the stromatolites have wavy, irregular laminae. Some are built by the unicellular *Pleurocapsa entophysaloides* (recte *Entophysalis deusta*) whose mats are smooth, and thus these stromatolites have smooth, continuous laminae. 'The *Aphanothece* live in . . . colonies of gel some of which are firmly attached, covering as a slime or mat small areas but leaving the intervening rock surfaces bare'; which simply explains the waviness and irregularity of the laminae they form. 'The *Pleurocapsa* as far as observed live in thin jelly mats entirely covering the areas they occupy and therefore their deposits are more regular and tabular.'

In the upper intertidal zone on the southern shores of the Persian Gulf the carbonate sediments are bound by three distinct cyanophyte communities, each forming distinctively shaped sediment layers: 1. a 'mamillate mat' dominated by coccoid algae, particularly *Entophysalis magna*; 2. a 'flat mat' dominated by filamentous algae, particularly *Microcoleus chthonoplastes*; and 3. a 'pinnacle-blister-wrinkle mat' also dominated by filamentous algae, particularly *Schizothrix 'schizothrix'* (Kinsman *et al.* 1971). Despite the correlation of cyanophyte communities and mat forms, these authors dispute the biological control of mat form.

In a very detailed thesis Monty (1965*a*) describes modern stromatolites and algal plants in the Bahamas; only a small part of this has been published (Monty 1965*b*, 1967). Monty concentrated on studying the microstructure of modern and ancient stromatolites, and only briefly describes their growth forms: but nevertheless he makes numerous observations of significance in this discussion. He notes that *Scytonema myochrous* may form a 'continuous turf-like cover' with scattered small protruding domes about 1 cm high; the domes result from the 'flabellate growth of more active clones [descendants of a single filament] raising their bundles over the general level. In other instances, the mats are discontinuous and confined to scattered small domes 0·5–1 cm high and reaching 2–3 cm in diameter.' In describing *Dichotrix bornetiana* he mentions that it may 'build either flat mats . . . or mamillated structures and small rounded heads 1–2 cm high . . .' (Monty 1967). Here are possible explanations for column-formation and branching, for in these processes in fossil stromatolites the formation of mamillae frequently precedes the separation of columns. The following extract from Monty (1965*a*, p. 343) is relevant in this regard:

> In upper infralittoral and intertidal areas, growth may be fairly irregular . . . commonly some parts of the [algal] dome stop their growth for a few days, while the adjacent areas keep on growing; as a result the external shape of the dome is ever changing; in the particular case where the cessation of growth is definitive, highs and lows progressively form. . . . Some *Schizothrix* domes show moreover a shifting of growth sites: some portions of a dome grow actively, rising above the rest as protuberances; then growth starts in the depressions which are rapidly filled with hyaline jelly. This introduces strong discordances in the lamination.

This mechanism is one which could lead to the formation of continually separated protuberances, and thus to branching. Monty (1965*a*, p. 377) argues, contrary to several previous workers, that it is wrong to attribute the formation and continuance of domes to the inability of the mat to traverse interareas: 'In the case of the *Schizothrix* domes it is clear that the initiation and maintenance of domes, or small columns depends only on the metabolism of algae and their growth characteristics'; Monty (1967, pl. 16) illustrates two domes formed by the local cessation of algal growth, stating that 'the initiation and maintenance of these domes relies on the presence of more active *clones*' (Monty 1965*a*, p. 378). Nevertheless it is likely that the inability of the algal mat to cross interareas is an important mechanism in column maintenance in some cases, such as at Shark Bay, Western Australia, where many columns are tens of centimetres high and where the sediment between them is continually moved by wave and tidal action (Logan 1961).

At Shark Bay the stromatolites grow largely by detrital sediment accretion (see Pls. 8–9) whereas in some environments in the Bahamas carbonate precipitation is important. Do the shapes of the stromatolites depend on the mechanical processes of their formation? Monty (1965*a*, p. 377) states: 'domes represent the growth form of the *Schizothrix* colonies; the degree to which they have incorporated particles of sediments seems to have no effect on their shape; I have shown that variation in this shape was explained by differential growth of an algal population . . .'; and on p. 388: 'in Andros the domes of *Schizothrix* show no difference whether they are loaded with, or devoid of, entrapped particles'. Thus the question is explicitly answered. However, this is only part of the answer because, as already shown, the same algae can form differently shaped plants. The form of the plant depends to some extent on the environment: for instance the Bahaman supratidal mats formed by mixed communities of *Scytonema myochrous* and *Schizothrix calcicola* consist of 'sub-continuous mats, so-called algal polygons, algal chips . . . raised discs or algal heads . . . etc. . . . These gross morphologic features result mostly from the moisture content of the substrate and the phases of desiccation that the mat underwent' (Monty 1967, p. 69). In these structures there is every gradation from mats architecturally controlled by *Schizothrix calcicola* (in the wetter or more saline environments) to those controlled by *Scytonema myochrous* (in drier environments). These two algae presumably are associated because during inimical conditions one finds refuge in the mat of the other and they flourish under the opposite conditions (Monty 1967).

Here it is appropriate to mention that, as Monty (1967) and Neumann *et al.* (1970) have shown, although there may be numerous different taxa of algae in a plant, only one or two control the microstructure and gross shape of the plant. Thus the oft-made criticism that it is ludicrous to formally name stromatolites because they are built by large, diverse, and variable assemblages of algae is unjustified. Furthermore, in at least some of the examples previously used to support this criticism, if Drouet's taxonomy is accepted many of the numerous taxa are found to be synonymous (Sharp 1969).

Monty (1967, p. 92) compares *Schizothrix calcicola* domes from Bermuda with *Symploca laeteviridis* domes from Florida which were described by Ginsburg (1960). They apparently are very similar, and he concludes that similar stromatolites can be built by different algae. Some of the force of this comparison has now been lost as Drouet (1968) places *Symploca laeteviridis* into synonomy with *Schizothrix arenaria*.

These observations on modern algae and stromatolites are consistent with my own on their fossil counterparts. Just as some algae may form mats or domes, so flat-laminated stromatolites frequently grade into columnar forms (without microstructural changes); Mawson and Madigan (1930) rightly concluded from this that the same algae may build differently shaped stromatolites. As the shape of modern algal plants is partially governed by their growth environment, so the shape of particular stromatolites varies to a limited extent, e.g. from the centre to the margins of a bioherm. Vertical gradations such as occur within *Inzeria intia* or between *Conophyton*, *Jacutophyton*, and *Baicalia* can be matched with the gradual replacement in dominance of one alga by another as the environment gradually changes, or by the change in plant-form of one alga under changing conditions. Just as one kind of stromatolite does not grade uniformly into all other kinds, so there are particular algal associations such as that of *Schizothrix calcicola* and *Scytonema myochrous* which are advantageous to the algae involved, and therefore stable.

A facet of lamina shape which must be considered is the significance of walls, peaks, and cornices. An obvious prerequisite for the growth of a wall is sufficient relief of the columns; but the presence or absence of walls means more than just this since the growing columns built only by rugose mats at Shark Bay have up to many tens of centimetres of relief, but no walls (Pl. 9, figs. 1–2, 6). My brief observation of these shows that they grow by the accretion of coarse sediment on to horizontal or gently sloping surfaces (tops of the columns and tops of ribs, peaks, and cornices). The algal mucus is rubbery and not sticky enough to hold sediment on steep slopes even though the algae are growing there; therefore no wall can form. In this case it is incorrect to argue that walls form when a column has sufficient relief and when the column occurs in a low energy environment where the walls would not be eroded off. These factors probably both apply, but the type of alga is important as well. The same Shark Bay stromatolites also indicate that caution is necessary when interpreting the significance of peaks and cornices. It seems reasonable to suggest that these are laminae which grew down on to and partly across the sediment in the interspaces, and thus give some indication of the growth relief of the columns. However, peaks and cornices (albeit rather thick) occur exposed on the sides of the Shark Bay columns (Pl. 9) and bear no relation to their present relief.

We have established that lamina shape varies between algal plants of different taxa just as it does between stromatolite taxa. Two possible mechanisms for branching have been outlined: 1. more active growth of particular parts of mats; 2. cessation of growth of parts of mats. Modern examples of these processes are known. A feature of major taxonomic significance in stromatolites is the kind of branching. How is this connected with the shape of algal plants? A clue comes from the examination of text-figures 6–8, on which the lamina shapes of different stromatolites are shown. On text-figure 6 are grouped stromatolites which predominantly have parallel, or no, branching. On the other two figures are stromatolites whose predominant mode of branching is slightly or markedly divergent. Thus grouped, it can be seen that stromatolites with parallel branching have laminae that generally are neither markedly wavy nor have frequent marked shape changes, in contrast to those on the other figures. On text-figure 6 there are two exceptions to this generalization: *Kulparia alicia* (Cloud and Semikhatov) is very wavy, but it is noticeable that few flexures are as wide as a branch would be. Stromatolites with projections are mostly shown on text-figures 7 and 8 because they also have complex branching (except for *Minjaria pontifera*). Here too there are exceptions to the generalizations. *Madiganites mawsoni* has slightly and markedly divergent branching but not very wavy or variable laminae; *Baicalia lacera* Semikhatov is similar. *Inzeria intia* III has very wavy laminae but does not branch at all; however it does have projections. Laminae from the base of *I. intia* III are also included (text-fig. 7); these are neither wavy nor markedly variable and this correlates with the fact that branching there is α–β-parallel. They were included simply because all of the examples from *I. intia* were put together.

The positive correlation between complex branching and lamina waviness and/or variability shows best for *Linella avis* Krylov, *Tungussia inna*, and *Kotuikania torulosa* Komar. It is reasonable to postulate that in such cases complex branching and projection formation result from the exaggeration of lamination irregularities. This may be due to the rapid growth of more active algal clones, as Monty suggested for dome formation, or to mechanical processes that concentrate accretion on the extremities of protrusions. It may be that the ends of these protrusions (branches or projections) get more light and more nutrients, and thus growth of the algae is favoured there; Fritsch (1907) has described such a process where blue-green algae growing on vertical surfaces form tiers, the lower of which project out the farthest to catch water dripping down from higher levels. One thing is clear: stromatolites frequently 'anticipate' branching by forming large flexures, one for each impending branch, and thus a fundamental process in at least some branching is the flexuring of laminae. Numerous authors have suggested (after Young 1935) that once such flexures have formed branching occurs when the hollows fill with sediment, preventing algal growth there, but Monty has shown that no such process is necessary. Tasch and Kidson (in Tasch *et al.* 1969) consider that erosive disruption of parts of an algal mat may initiate branching, but since laminae at column bases usually show no evidence of disruption, this appears unlikely to occur often. Very frequently branching occurs over large areas at particular levels or surfaces in biostromes and bioherms (e.g. *Acaciella australica*, *Inzeria intia*; text-figs. 29, 40). It seems likely that in these cases there was some external influence which caused simultaneous branching, i.e. that there was a subtle environmental change of some sort. The effect of this change may have been either to alter the percentages of species in an assemblage or to change the growth form (such as to cause more lamina waviness).

The case for the shape of stromatolites being partly controlled by the algae which build them would be greatly strengthened if it could be shown that there is a positive correlation between the shape of stromatolites and the taxa of microfossils within them. No detailed study of this type has been published, but Kaulback (in Kaulback and Veevers 1969) has made pertinent observations on Cambrian stromatolites from northern Australia. In his study of two kinds of stromatolites, one columnar and the other spherical, he found that spherical microfossils averaging 45 μ wide are abundant in and restricted to the columnar stromatolite, while rod-shaped microfossils averaging 100–150 μ wide are abundant in and restricted to the spherical stromatolites.

It was emphasized in an earlier section that stromatolite taxa are defined from groups of characters, and that knowledge of the occurrence of one or two of these characters frequently permits prediction of the occurrence of others. One of the taxonomically significant characters is lamina shape. Here we have established that lamina shape depends directly on algal plant shape, and that plant shape depends to some extent on the algal taxa involved. Hence we arrive at the conclusion, of great significance, that the gross shape of stromatolites depends at least to some extent on the algae which build them.

BIOLOGICAL INTERPRETATION OF STROMATOLITE MICROSTRUCTURE

As I have previously discussed, in some classifications microstructure is given great taxonomic significance. This is discussed at length in the Russian publications referred to previously. Monty's (1965*a*, *b*; 1967) research on modern stromatolites is devoted largely to their microstructure. The processes of growth of stromatolites are described in detail by Monty and by Neumann *et al.* (1970), Gebelein (1969), Sharp (1969), Black (1933), Pia (1933), and many others. Therefore these matters need not be discussed in detail but several points require emphasis: 1. the extent and effect of secondary alteration; 2. the taxonomic significance of the amount and coarseness of detritus incorporated in stromatolite laminae; 3. the calcification of particular algae; 4. the importance of bacteria in determining microstructure.

The fact that grumous textures frequently result from slight recrystallization of previously homogeneous laminae has already been noted (p. 14). Some clotty and grumous textures are primary (Monty 1967; Neumann *et al.* 1970). A point worth emphasizing is that the presence, amount, and distribution of non-carbonate minerals and 'impurities' has a marked effect on the pattern of recrystallization and thus on the final microstructure. Just as organic matter inhibits the conversion of aragonite to calcite (Kennedy and Hall 1967), so it may also inhibit recrystallization. The distribution of organic matter in a stromatolite depends on that in the original algal mats; in Bahaman stromatolites there are alternately organic-rich and organic-poor laminae (Monty 1967). In most fossil stromatolites there are alternately pale and dark grey laminae. To check whether the grey pigment is organic the columns from a specimen of *Acaciella australica* were dissolved in HCl until all of the carbonate had been removed. The residue was a pale grey powder consisting of unresolvable pigment coating very fine silt and clay-sized quartz and feldspar (totalling several per cent by weight of the original specimen). The powder was heated for several hours at 1000 °C during which its weight decreased by 0·7 per cent and it changed to a very pale yellow-grey colour. Thus the pigment was oxidized and driven off, indicating that it was organic. Another specimen of *A. australica* was analysed by D. M. McKirdy and found to contain 0·01 per cent (by weight) of organic carbon.

Several Bitter Springs Formation stromatolites were completely digested in HCl and yielded about 2–3 per cent (by weight) of insolubles which, as in the previous example, were very fine silt and clay-sized quartz and feldspar. Bausch (1968) has shown that clay minerals inhibit carbonate recrystallization, and has noted that quartz may have a similar effect. The presence of organic matter and detritus probably accounts for the fact that many of the Australian stromatolites are composed of carbonate with a grain size of less than 30 μ, and frequently less than 15 μ. Furthermore, the pigmented laminae are nearly always finer grained than contiguous pale laminae. Therefore even the microstructure of slightly altered stromatolites may be of diagnostic value since it reflects the structure of the original algal plant.

In most Australian stromatolites studied the only detritus present is the very fine-grained material just mentioned. However, the laminae of *Tungussia inna* consist largely of calcarenite (Pl. 6, fig. 4). This is a constant and unusual feature of this taxon, and is therefore of diagnostic value. Its possible biological significance is clearly shown in the works of Monty (1967) and Hommeril and Rioult (1965). In the Bahamas *Schizothrix calcicola* forms dense felted mats of filaments whereas *Rivularia biosolettiana* forms mats in which there are erect, separate bundles of filaments. 'As *Schizothrix* does not erect strong bundles of filaments, it cannot trap detrital particles as does *Rivularia*; hence, *fine-grained particles* only will be *agglutinated* on the mucilaginous surface of the mat and bound by further algal growth. Accordingly these structures are generally characterized by much smaller grains than the ones occurring in *Rivularia* mats . . . where a substratal sand is pervaded by filaments and bound' (Monty 1967, p. 86). The modern stromatolites described by Hommeril and Rioult (1965) are built by red algae. *Rhodothamniella floridula* has relatively coarse, widely-spaced filaments which trap coarse sediment, whereas the filaments of *R. rothii* are finer and closer and collect only fine sediment. Thus the presence of abundant coarse detritus may be taxonomically significant. Coarse detritus occurs sporadically in some stromatolites, for instance *Conophyton garganicum australe* in which the great majority of laminae lack any recognizable detritus, but there are occasional laminae of coarse sand and granules (Pl. 6, fig. 2). Since some of these laminae dip at 60–80° below the horizontal, the sediment-trapping ability of the algae must have been truly remarkable.

Stromatolites with well-preserved structures indicating the former presence of coarse algal filaments [i.e. uniseriate or multiseriate chains (trichomes) of cells] first appear in the Vendian and become abundant in the Palaeozoic. Because of this, comments by Fritsch (1945) and Lewin (1962) that only particular taxa of modern blue-green algae become calcified are especially significant. Monty (1965*a*, 1967) expands on this theme: in the Bahamas two blue-greens are important in the building of stromatolites, *Schizothrix calcicola* and *Scytonema myochrous*. Only *S. myochrous* deposits carbonate in its mucus to such an extent that *Girvanella*-like calcareous tubules form, even though it lives side by side with carbonate-free or only weakly calcified *Sch. calcicola*. Therefore the first appearance in the fossil record of *Girvanella* may mark the evolution of a carbonate precipitating alga (p. 87).

It is frequently suggested that bacteria play some part in the growth of stromatolites (e.g. Krylov 1963; Hofmann 1969*a*). Inevitably they do. Sorensen and Conover (1962) give an excellent detailed description of life processes in mats of *Lyngbya confervoides* (recte *Microcoleus lyngbyaceus*), in the lower parts of which bacteria occur abundantly. Although no carbonate deposition was reported in these mats there is a growing body of evidence that bacteria are significant carbonate precipitators. It is often suggested (e.g. Fritsch, 1945) that bacteria living in the sheaths of blue-green algae are the agents of carbonate precipitation there. Bacteria alone can cause, or at least modify, the precipitation of carbonate, leading to the formation of distinctive aggregates (Lalou 1957; Oppenheimer 1961; Greenfield 1963; Krumbein 1968; Maslov 1961). Therefore some elements of stromatolite microstructure (such as clots) may be of bacterial origin. Many bacteria precipitate metallic oxides and may be important in the colouring of stromatolite laminae.

One last point: some ancient stromatolites are widely distributed and this is also true of extant stromatolite building algae. *Schizothrix calcicola* is perhaps the most important extant stromatolite builder (Sharp 1969). According to Drouet (1963*a*) it is 'perhaps the most widely distributed and most frequently encountered blue-green alga on the earth'.

CONCLUSIONS

Columnar stromatolites can be used successfully for intercontinental and interregional correlation within the Precambrian and Cambrian. To enable the definition of temporally restricted taxa, a classification based on groups of characters must be used. The limits of variation of individual characters have been shown to be taxonomically unimportant, but each character has a distinct mode in its range of variation, and taxa in which all the diagnostic characters are modally developed are definable. In a detailed survey of previous work and of the variation of characters in the Australian material (as studied both in outcrop and the laboratory) the most stable and frequently useful characters were found to be the column arrangement, branching, and shape, and lamina shape; these are the characters most often used to define the highest taxonomic category, the group. For the next category, the form, small variations in these characters in combination with microstructure were most often useful. However, the importance given to different characters varies from taxon to taxon and in some cases microstructure was used as the prime characteristic of a group. Only by using the graphical reconstruction method developed by Krylov can the full range of taxonomically useful characters be studied.

It is recommended that in most cases all columnar ecologic variants of a particular stromatolite be included in the one taxon. For instance, columns from the flanks of bioherms should not be taxonomically separated from those in the bioherm centres. The grouping of these variants will give a more natural classification, will simplify nomenclature, and may reduce the time range of taxa such as *Tungussia* Semikhatov. In this study the pseudocolumnar and undulatory variants of each stromatolite are excluded from the taxonomy.

In a review of the literature on modern algae and stromatolites it is found that algal plant shape varies with the algae involved, and on plant shape depends the lamina shape of stromatolites. A study of the lamina shape of ancient stromatolites reveals a positive correlation between lamina shapes and the gross shapes of stromatolites and thus a connection is established between stromatolite and algal taxa. As yet this is very tentative because of a paucity of information on algal plant forms.

The stromatolites of the Loves Creek Member in the Amadeus Basin are composed of calcite or dolomite, or both. Two generations of dolomite are present: very early diagenetic and post-lithification. The stromatolites were originally probably wholly aragonite. Most of the stromatolites within this member occur as biostromes within which are small contiguous bioherms. The bioherms had a growth relief of up to 1·3 m but individual columns protruded less than 3 cm above their substrate. The extent of the growth relief, with the paucity of evidence for erosion within the biostromes, indicates subaqueous growth, which accords with an originally aragonitic composition. During growth the bioherms resembled those forming around the shores of Shark Bay, Western Australia, although their environment was probably more like that of the present Persian Gulf, but more humid. Stromatolites in the Antrim Plateau Volcanics probably grew in lakes on the surfaces of the basalt flows.

Using the methods mentioned above seventeen taxa have been identified or defined, and three have been tentatively identified. This includes sixteen groups, seven of which are new. Of the eighteen forms, twelve are new and two others are put into new combinations. One new variety (the lowest category) is defined. Eight of these taxa are from the upper (Loves Creek) member of the Bitter Springs Formation of the Amadeus Basin: they are *Acaciella australica* (Howchin) comb. nov., *Basisphaera irregularis* gr. et f. nov., *Boxonia pertaknurra* f. nov., *Inzeria intia* f. nov., *Jurusania nisvensis* Raaben, *Kulparia alicia* (Cloud and Semikhatov) comb. nov., *Linella avis* Krylov, and *Minjaria pontifera* f. nov. In the U.S.S.R. *J. nisvensis, Inzeria*, and *Minjaria* occur only in the Upper Riphean, *Boxonia* in the Upper Riphean and Vendian, and the range of *Linella avis* is uncertain but possibly only Vendian. Therefore the upper Bitter Springs Formation is best correlated with the Upper Riphean. From the lower (Gillen) member of the Bitter Springs Formation only *Tungussia erecta* f. nov. is known. In the U.S.S.R. *Tungussia* extends from the Middle Riphean to the Vendian and therefore this part of the Bitter Springs Formation is unlikely to be older than Middle Riphean. Above the Bitter Springs Formation is the tillitic Areyonga Formation followed by the Pertatataka Formation which includes another tillite. From between the tillites comes *Tungussia inna* f. nov. Stratigraphically higher is the Cambrian Pertaoorta Group with the distinctive stromatolite *Madiganites mawsoni* gr. et f. nov. which is different from Precambrian stromatolites but resembles one from the Cambrian of the U.S.S.R.; *M. mawsoni* has a vermiform microstructure which is a radical innovation occurring in many Vendian and younger stromatolites. Sediments of the Amadeus Basin are poorly dated radiometrically, but the datings available are consistent with the stromatolite correlations. Stromatolites give a more precise dating for the upper Bitter Springs Formation.

In the Hamersley and Bangemall Basins of Western Australia there is also a succession of stromatolite assemblages. The oldest there, and in Australia, is *Alcheringa narrina* gr. et f. nov. and *Gruneria* f. nov. from the Fortescue Group; this has been radiometrically dated at 2190 ± 100 m.y. *Gruneria* f. nov. also occurs in the Ventersdorp 'System' of South Africa, dated at 2300 ± 100 m.y. These stromatolites are unknown from younger rocks. Above the Fortescue Group in Hamersley Basin is the Wyloo Group with *Pilbaria perplexa* gr. et f. nov.; this is unknown from elsewhere. Also from the Wyloo Group is a badly preserved and therefore not fully identifiable form of *Patomia* Krylov; in the U.S.S.R. *Patomia* occurs only in the Vendian. The Bangemall Group, from which shales are radiometrically dated at 1080 ± 80 m.y., is unconformably above the Wyloo Group. It contains *Baicalia capricornia* f. nov. and *Conophyton garganicum australe* var. nov. In the U.S.S.R. *Baicalia* occurs abundantly in the Middle Riphean and sparsely in the Upper Riphean. *C. garganicum* is restricted to the Lower and Middle Riphean; *C. g. australe* closely resembles the upper Middle Riphean variety *C. g. nordicum.* Correlation with the Middle Riphean (1350 ± 50 to 950 ± 50 m.y.) is clearly indicated and is consistent with the radiometric dating.

Metacherts interbedded with the Antrim Plateau Volcanics of northern Australia contain *Conophyton basalticum* f. nov. and *Conophyton* cf. *gaubitza* Krylov. In the U.S.S.R. *Conophyton* is restricted to the Precambrian and *C. gaubitza* is probably Vendian. Thus a Vendian age is suggested for the Antrim Plateau Volcanics and this is consistent with other palaeontological and radiometric evidence. The McArthur Group of the McArthur Basin of the Northern Territory contains *Conophyton garganicum ?garganicum* which is consistent with radiometric datings suggesting for the sediments an Early Riphean age. The Mount Baldwin Formation of probable Early Cambrian age in the Georgina Basin of the Northern Territory contains in its lower part *Georginia howchini* gr. et f. nov. which is unknown from elsewhere (although this stromatolite closely resembles *Jacutophyton*).

On the bases of stratigraphic position and lithology the Bitter Springs Formation (Amadeus Basin) is usually correlated with the Burra Group (Adelaide Geosyncline). The abundant and diverse stromatolite assemblage in the upper Bitter Springs Formation has no taxa in common with that of the Skillogalee Dolomite of the lower Burra Group but is very similar to that of the Umberatana Group, unconformably above the Burra Group. The Umberatana Group and Loves Creek Member (Bitter Springs Formation) have six stromatolite groups but no forms in common. They clearly belong to the same assemblage zone (Late Riphean) but are not directly correlated because in their respective areas one is above and the other below the lower tillite. It has been shown, however, that the Umberatana Group, the Loves Creek Member, and the lower tillite correlate with the Upper Riphean of the U.S.S.R. The Burra Group contains a form of *Baicalia*, and *Conophyton garganicum* comes from either the Burra Group or the underlying Callanna Beds. This same assemblage (Middle Riphean) occurs in the Bangemall Group of the Bangemall Basin. The Bangemall Group is radiometrically dated at 1080±80 m.y. while the Burra Group and Callanna Beds are probably younger than 1345±50 m.y. Thus the stromatolite correlation accords with the radiometric datings. However, new data suggest an age of less than 867±32 m.y. for the Burra Group, which conflicts with the correlation of the Burra Group with the Middle Riphean.

While this work shows that in general columnar stromatolite taxa are temporally restricted, several examples of convergent evolution are known. Some early Proterozoic stromatolites are taxonomically indistinguishable from Late Riphean and Vendian groups: these are *Patomia* and possibly *Gymnosolen* and *Katavia*. Therefore it is unwise to base correlations on the occurrence of single taxa. This similarity of early Proterozoic and younger stromatolites warrants further study.

In summary: the shape of stromatolites depends on the algae which form them as well as on their growth environment. As the algae evolved so morphological features of stromatolites changed. Thus is explained the empirical observation, expanded and supported by this research, that a succession of stromatolite assemblage zones is recognizable, and permits intercontinental and interregional correlations within the Precambrian, including the early Proterozoic.

SYSTEMATIC DESCRIPTIONS

It may be helpful to briefly describe the format and order of the descriptions which follow. For simplicity the order is alphabetical except that the closely related groups *Conophyton* and *Georginia* are placed first.

Direct comparisons are not made in the diagnoses of new taxa but in a separate section after each description. Diagnoses are given for new groups only when more than one form is known; when this is the case a section with 'comparisons' occurs after the group diagnosis.

Within the descriptions the layout is as follows:

Mode of Occurrence—types of bioherms or biostromes.

Column Arrangement and Branching—orientation of columns, frequency and kinds of branching, structure of the bases and tops of the stromatolitic beds, frequency of coalescing and bridging.

Column Shape.

Lamina Shape—including waviness and wrinkling, and also column margin structures: walls, peaks, cornices.

Microstructure and Texture—thicknesses and continuity of laminae, the form of their borders, their shape on a small scale (e.g. lenticular); lamina thicknesses are given in microns. Mineral textures are described as an aid in interpreting how much of the microstructure is primary.

Following the description of the stromatolite the interspace fillings are briefly described. Then follows a discussion and description of the secondary alteration of the stromatolite, to enable correct interpretation of the significance of features previously described. Any special comments which are necessary or useful are put in a separate section after 'secondary alteration'. After this is a list of the localities and stratigraphic levels from which the stromatolite came and finally a statement on its age. The distribution and age are discussed in detail in the appropriate section on local stratigraphy.

Depositories. Depositories are as follows: specimens with numbers prefixed S or Ad F are in the Department of Geology and Mineralogy, University of Adelaide, South Australia, those with the prefixes CPC or BMR F are in the Bureau of Mineral Resources, Geology and Geophysics, Canberra, and those prefixed GSWA F are in the Geological Survey of Western Australia, Perth.

Group CONOPHYTON Maslov

Conophyton Maslov 1937*b*, Komar, Raaben, and Semikhatov 1965, Komar 1966, Krylov 1967, and Cloud and Semikhatov 1969.

Type Form. Conophyton lituum Maslov, which occurs widely in the U.S.S.R.

Diagnosis. Extremely rarely branching columnar stromatolites with conical laminae many of which are thickened in their crestal parts.

Content. C. cylindricum Maslov, *C. metulum* Kirichenko, *C. circulum* Korolyuk, *C. garganicum* Korolyuk, *C. miloradovici* Raaben, *C. lituum* Maslov, *C. baculum* Kirichenko, *C. gaubitza* Krylov, *C. ressoti* Menchikov, *C. cadilnicus* Korolyuk, and possibly *C. confertus* Semikhatov.

Age. Riphean and early Proterozoic.

Conophyton basalticum f. nov.

Plate 5, fig. 5; Plate 10, figs. 1-3

Collenia frequens Walcott (partim), Edgell 1964, pp. 238, 246, 252, 253, 255.

Material. Seven specimens from two localities.

Holotype. CPC 11314.

Name. The type material is from sediments interbedded within basalts of the Antrim Plateau Volcanics.

Diagnosis. Conophyton with a banded microstructure in which the laminae are not wrinkled or wavy and are of almost constant thickness (predominantly 30-150 μ); the crestal zones are type I of Komar *et al.* (1965) and text-fig. 4 herein.

Since I have not studied this stromatolite in the field, and the specimens available are small for a stromatolite with such large columns, only very limited information on the mode of occurrence and shape of columns can be given.

Mode of Occurrence. Traves (1954, 1955) studied *C. basalticum* at two localities. At Top Spring 'an algal bioherm is exposed for a length of many hundred yards. This outcrop has been surrounded by basalt so that it has been entirely silicified, and quartz veins, rock crystal, and basalt are found throughout the outcrop' (Traves 1955, p. 24). Since this bed outcrops over an area of many square miles (Randal and Brown 1967), it is a biostrome. Traves considered that the stromatolites at this and other localities are in silicified inliers of rocks older than the Antrim Plateau Volcanics, but they are now known to be interbedded in the upper part of the volcanic sequence (Randal and Brown 1967). Traves (1954) figured an outcrop of the *C. basalticum* bed at Top Spring; his plate 6, figure 1 showing the apices of conical laminae in contiguous columns, apparently on a horizontal surface, has the caption 'top of bioherm at Top Spring, N.T.'; but figure 2 of the same plate shows an apparently vertical surface also with what appear to be transverse sections of columns. He does not mention the orientation of the columns. Available specimens and Traves' (1954) description show that massive bridges occur frequently; so frequently in some cases that there are almost no interspaces and *C. basalticum* is pseudocolumnar.

Column Shape. Columns are straight and cylindrical (including having round transverse sections) for heights of at least 25 cm. Traves (1954) notes that columns are from less than 2·5 cm to more than 60 cm wide.

Lamina Shape. Laminae are conical, with hemispherical crests in which the radius of curvature is 2-10 mm (Pl. 10, fig. 1). They are not wrinkled or wavy. Away from the crests very frequently laminae are slightly concave outwards, but some are straight or slightly convex; often the straight or concave laminae are sharply deflexed near column margins. Away from their crests laminae dip at 60-90°. Laminae intersect column margins at very acute angles or parallel them (forming walls), and very frequently they form bridges. Shape changes within columns are gradational and minor, at least in the available specimens which are only short segments of columns. At column margins some laminae are contorted, indicating movement of columns or laminae relative to the interspace filling.

Crestal Zone. The crestal zones are so badly altered as to be rarely preserved. They are 4-20 mm wide (Pl. 10, figs. 1-3). The crestal lines are nearly straight. Within these zones laminae are hemispherical and almost everywhere symmetrical. Only one available thin section shows the crestal zone and even this is badly altered, but it is clear that in it many laminae are thickened at least several times; there may be some extra laminae in the crestal zone. Thickenings of about five times seem to occur frequently.

Microstructure and Texture. There are prominent macrolaminae 200–1500 μ thick but since the stromatolites have been greatly altered these may be of little significance. Many continue for several centimetres, or even up to 15 cm, before fading out. Their boundaries are indistinct but smooth and parallel (Pl. 5, fig. 5; Pl. 10, figs. 1–3).

Where well preserved, laminae can be traced without interruption or marked thickness change for several centimetres before fading out; but few are that well preserved. They are 30–150 μ thick and have moderately smooth boundaries which may be gradational over 10–20 μ; there often are irregularities within the outer 10–20 μ. Laminae are alternately pale and dark. Pale laminae are mostly quartz but dark laminae are quartz or carbonate or mixtures of these. In well preserved laminae both the carbonate and quartz is polygonal, xenotopic, equigranular, and of 5–30 μ grain size. Frequently the carbonate is in rounded segregations 30–100 μ wide; some laminae consist only of trains of these segregations. The pigment is a brown, limonite-like mineral.

Interspace Fillings. None of these has been seen in thin section, but where visible in specimens they seem to consist largely of limonite in which is embedded scattered tabular intraclasts up to several centimetres long. The intraclasts are of laminated calcareous chert the same as that forming the columns.

Secondary Alteration. The crestal zones especially have suffered extreme alteration: in most cases nothing remains and there is an open tube lined with quartz crystals; or there may be a solid core of quartz with a grain size of up to 3 mm. The presence of much carbonate (often as rounded segregations) in the columns indicates silicification of primarily calcareous stromatolites. But there is also secondary carbonate which forms both discordant and concordant patches.

Comparisons. The consistently conical shape of laminae and frequent crestal thickening are unique characters of the group *Conophyton* Maslov. *C. circulum*, *C. garganicum*, *C. miloradovici* (Komar *et al.* 1965), and *C. gaubitza* (Krylov 1967) also have a large percentage of laminae 30–150 μ thick. Only *C. cylindricum* (Komar *et al.* 1965) and *C. garganicum* have laminae approaching in constancy of thickness and lack of wrinkling and waviness those of *C. basalticum* (but this information is unavailable for *C. baculum* and *C. gaubitza*). Thus there are several similarities with *C. garganicum* which, however, has crestal zones of type III (text-fig. 4) whereas those of *C. basalticum* are type I. The combination of type I crestal zone with thin laminae also occurs in *C. circulum* which, however, has wavy laminae of variable thickness. The extreme constancy of thickness and lack of wrinkling and waviness in laminae of *C. basalticum* is unique among adequately described forms of *Conophyton*.

Distribution. Upper part of the Antrim Plateau Volcanics. Top Spring, at the junction of the Montejinnie and Murrenji tracks (near Victoria River Downs Station) and 7 miles west of Catfish Yard, south of Wave Hill Station; both localities are in the north-west Northern Territory of Australia.

Age. Early Cambrian or Vendian.

Conophyton garganicum australe var. nov.

Plate 6, figs. 1–3; Plate 10, figs. 4–5; Plate 11, figs. 1–2, 4–5; text-figs. 6, 26–27

Conophyton cf. *garganicus* (partim), Glaessner, Preiss, and Walter 1969, pp. 1057–1058, fig. 2.

Material. Five specimens from two localities.

Holotype. S188.

Name. The name *australe* is given because of the location of the type area.

Diagnosis. Conophyton garganicum Korolyuk (emend. Komar, Raaben, and Semikhatov) with prominent macrolaminae, frequent lenticular thickenings in laminae, and a pronounced mode between 1·0 and 1·5 in the ratio L2:L1 (thickness of dark laminae over that of contiguous pale laminae).

Mode of Occurrence. C. garganicum australe forms extensive biostromes; the two seen have eroded tops (Pl. 10, fig. 5) so their original shape is unknown, but they probably were tabular. The maximum thickness seen was 1·5 m.

Column Arrangement. Columns are erect, straight, parallel, and almost contiguous. Many are within 1 cm of their neighbours. At the base of the biostromes is flat-laminated carbonate. Columns start either as small conical projections within which are conical laminae continuous with those of the substrate, or as low rounded domes which upwardly become conical. Laminae of the lower parts of columns are continuous with those of the substrate (text-fig. 26A, C). No branching has been seen.

Column Shape. Columns are subcylindrical with round, oval, or lanceolate transverse sections 15–60 cm wide (Pl. 10, figs. 4–5; text-fig. 26). Most columns are straight but the crestal lines are frequently slightly wavy (with wavelengths of many centimetres; text-fig. 26A).

In the field, projections and very large bumps were seen to occur moderately frequently; one bump observed was 20 cm wide and several centimetres in relief (Pl. 10, fig. 4). Bumps grade into projections of which the largest seen protruded 15 cm from a column. Laminae in many projections are continuous with those in the columns.

The large size of the columns makes specimen collection difficult, and specimens were not collected with reconstruction in mind. However, it has been possible to make three reconstructions (text-fig. 26). The column margins are very uneven. Bumps 1–2 cm wide by several millimetres in relief are closely spaced over the margins. There are several large projections; one is transversely elongate, enclosing a pocket-like niche 8 cm long; another fuses into an adjacent column. There are numerous peaks on one column, few on the others; they are up to 3 cm long and dip at 30–90°. Longitudinal, deep re-entrants and furrows are present on one column.

Lamina Shape. Most laminae are conical (Pl. 11; text-fig. 6). At column bases some are gently or steeply domed. Their shape within columns is not markedly variable, although gradual changes in slope occur frequently. The slope of laminae on opposite sides of their crests is often different. Very frequently the slope increases away from the crestal zone, which results in laminae looking in longitudinal sections of columns like gothic arches; these have slopes of 30–60° within a few centimetres of their crests increasing outwards usually to about 80° but infrequently to 90°, and locally near column margins consistent slopes back in towards the crestal zone have been seen. The shape of many laminae is complicated by large flexures with a wavelength frequently in the range 1–6 cm, and relief of up to 1 cm.

Apices of the cones and 'gothic arches' are very rarely sharply pointed. They are rounded; the radius of curvature varies greatly from lamina to lamina, very frequently being 1–10 mm. With moderate frequency the slope initially increases rapidly away from a lamina crest, but then tends to flatten before increasing again (Pl. 11); thus there may be depressions in laminae, usually within 1 cm of their crests, which emphasize the crestal zone.

Most laminae are nearly straight over lengths of a centimetre or two, except for slight wrinkling or waviness caused by lenticular thickenings (which, of course, are most marked in the crestal zone). Laminae formed or modified by stylolites are exceptions.

Many laminae have been deformed (Pl. 11, fig. 4; text-fig. 26). Recumbent or nappe-like folds with down-column displacements of up to several centimetres are prominent in longitudinal sections of columns; in transverse sections these show as oval, concentrically layered structures up to 9 by 17 mm. The axial planes of the folds are variously inclined, from parallel to perpendicular to the general direction of the lamination. Most axial planes dip away from the crestal zones of columns, but examples of the opposite sense were seen. Many of the folded laminae also are fractured.

Infrequently crestal zone laminae transgress and intrude each other; the penetration always is directed upward. Boundaries remain abrupt and distinct. Usually the penetration is only 1–2 mm, but in one example a diapir-like body 5 mm wide intrudes 5 mm into the overlying laminae (Pl. 11, fig. 5); laminae within the diapir conform to its gross shape, but some are truncated at its margins. Between the diapir and the enclosing laminae is a zone up to 300 μ wide of apparently homogeneous carbonate presumed to be the brecciated and smeared remains of the intruded laminae.

At column margins there often is a 5–15 mm wide zone of bent and fractured laminae (Pl. 11; text-fig. 26B). Most folds are of an open, chevron style. Concordant areas of coarse detritus occur in the contorted zone. Only rarely is there a wall.

Crestal Zone. The crestal zone is a combination of types II and III of Komar *et al.* (1965) and text-fig. 4 herein. Its average width is 4·5 mm (45 measurements from five specimens). About 50 per cent of the laminae are thickened very little or not at all in the crestal zone (Pl. 6, fig. 1; Pl. 11, figs. 1, 5); of those laminae thickened more than 1·5 times the average thickening (in 24 examples) is 4·7 times (excluding one example thickened 25 times); in none but the latter was the thickening more than 10·2 times and the majority were less than five. On the average no one type of lamina is any more thickened than another. In some cases there is more than one thickening in a lamina in the crestal zone. The maximum thickness of a lamina is predominantly within its crest, but with moderate frequency it is several millimetres away. Where thickenings are more than two to three times, the lens formed is usually asymmetrical and the crestal line is sinuous; abrupt direction changes in the crestal line occur frequently. Small recumbent folds with crests directed away from the crestal zone occur very rarely.

Microstructure and Texture. Within columns are distinct macrolaminae 70–460 μ thick composed of laminae mostly 25–100 μ thick (text-fig. 27). Dark and pale laminae and macrolaminae alternate. Macrolaminae are not ubiquitous. Three lamina types are present (Pl. 6, figs. 1–3); dark, fine-grained pale yellow-grey, and coarse-grained colourless:

1. Dark laminae consist of polygonal, xenotopic, equigranular carbonate of 2–4 μ grain size, with several per cent (by volume) of orange-brown irregularly shaped grains, 1–3 μ wide. The dark macrolaminae are very continuous where well preserved, some continuing uninterrupted for several centimetres. Except for small interruptions most macrolaminae can be traced through the 10 cm height of the largest thin section studied. Infrequently they wedge out or are cut off at structural discontinuities. Interruptions are numerous where sparry carbonate is prevalent. Laminae often can be followed for over 1 cm (where well preserved) before merging into a macrolamina or fading into pale carbonate. Macrolaminae or laminae rarely converge and coalesce, but often an apparently homogeneous macrolamina grades laterally into several laminae with the same overall thickness. Such clearly laminated segments of macrolaminae are irregularly distributed and variously shaped, often being only part of the thickness of a macrolamina.

Usually the thickness of any one lamina or macrolamina varies little except where sparry carbonate projects into it. But many laminae consist of a series of conjoined, or even separated, lenses; others have widely-spaced lenticular thickenings (up to seven times thicker than the rest of the lamina). Most lenses taper out but some are blunt-ended; rarely they are subcircular in section. Some lenses have a concentric layering within them, indicating an origin by the deformation (rolling up) of a lamina (but this explanation is restricted to lenses with such a layering). Dark macrolaminae are 70–460 μ thick; 95 per cent of the laminae are less than 150 μ thick, 57 per cent are between 25–100 μ, and the modal thickness is 50–75 μ (text-fig. 27); the total number of measurements is 117. Away from the crestal zone laminae often vary 20–50 per cent above and below their usual thickness.

2. Pale, yellow-grey laminae and macrolaminae consist of polygonal, xenotopic to idiotopic, equigranular carbonate of 3–5 μ grain size, with about 2 per cent (by volume) of orange-brown, irregularly shaped grains

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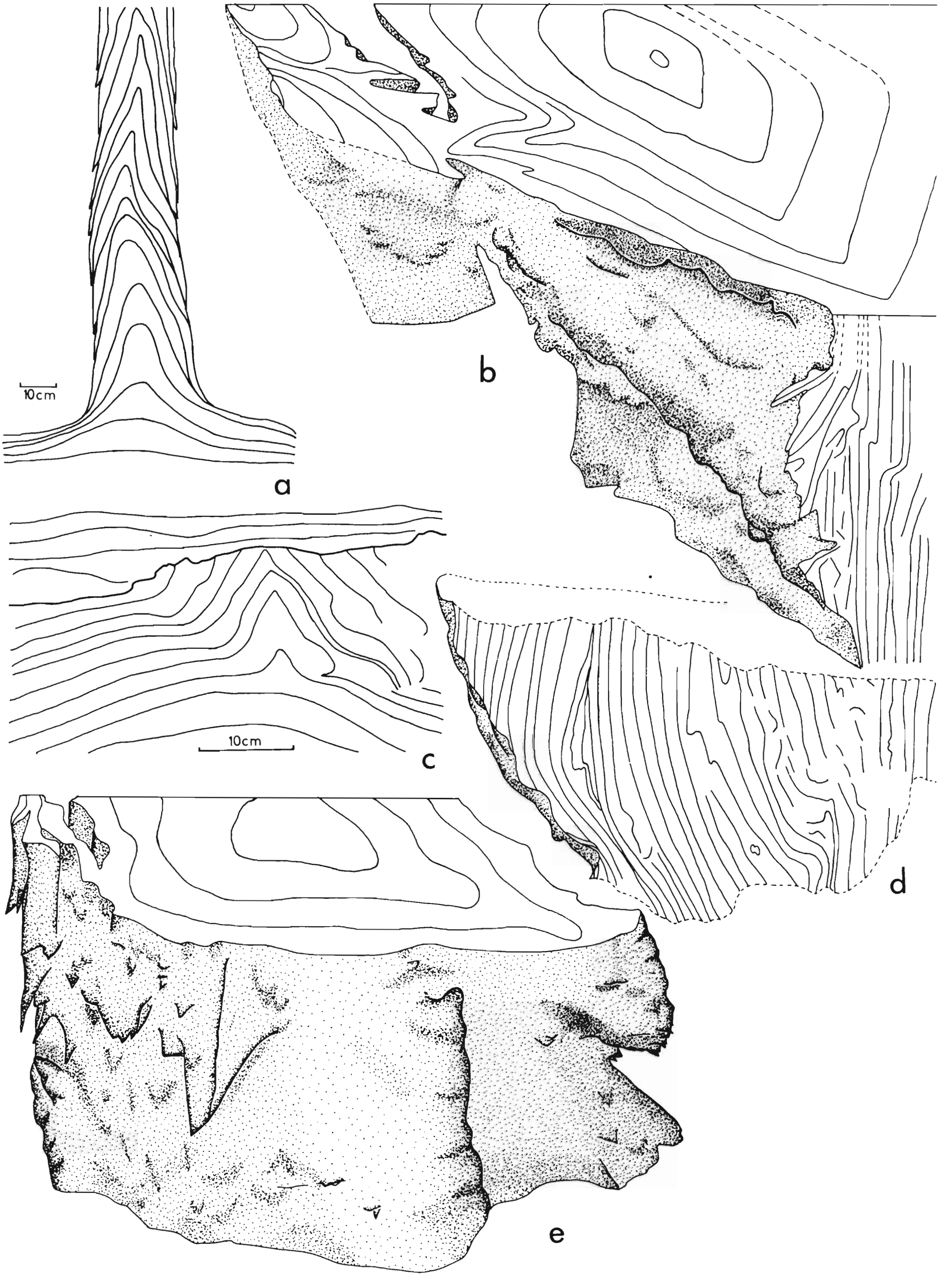
TEXT-FIG. 26. *Conophyton garganicum australe*, Irregully Formation, Irregully Creek, Bangemall Basin. A, C, Columns in sections normal to bedding; A, from a field sketch; C, traced from a field photograph. Almost the whole of the column in C was eroded away before the next bed was deposited. B, D, E, Reconstructions ×½. The laminae shown on the transverse section in B were traced from the specimen. All R_1 (reliability index; see p. 8).

Note. In these and all subsequent reconstructions only selected laminae are traced on to the front faces. The laminae shown on transverse sections are diagrammatic, unless stated otherwise in the captions. All reconstructions are of the 45° type unless otherwise specified.


10cm
a
b
10cm
c
d
e

1–3 μ wide. Their shape is largely controlled by that of the dark laminae (for which they form a matrix). Infrequently they form lenses unrelated to those in contiguous dark laminae. They are as continuous as dark·laminae and macrolaminae, but infrequently wedge out where dark layers converge. There often is interfingering at the ends of dark lenses, and short segments of pale laminae are visible in some lenses. Similarly, many dominantly dark macrolaminae contain 30 per cent or so (by volume) of pale carbonate in laminae and irregular areas. Lamina boundaries are mostly smooth, but there is some intertonguing with contiguous dark macrolaminae. Pale macrolaminae often abruptly change laterally into sparry carbonate. Pale macrolaminae are 70–450 μ thick; 99 per cent of pale laminae are less than 150 μ thick, 73 per cent are between 25 and 100 μ, and the modal thickness is 25–50 μ (text-fig. 27); the total number of measurements is 107.

Away from the crestal zone laminae often vary 20–50 per cent above and below their usual thickness. These figures include the sparry (type 3) laminae. The ratio L2:L1 in 117 determinations has a mode at 1·0–1·5 (32 per cent of determinations); 79 per cent of determinations are less than 2·0 (text-fig. 27).

3. Sparry laminae and macrolaminae consist of polygonal, xenotopic to hypidiotopic carbonate of 10–400 μ grain size (grains more than 100 μ wide predominate). Such carbonate forms 30–40 per cent of the volume of columns. It occurs as roughly concordant patches from about 0·5 mm to several centimetres in length which vary in thickness from that of thin laminae to that of macrolaminae. Many patches are slightly discordant. Frequently they have inclusions and borders of the pale carbonate; sparry macrolaminae usually are contiguous with dark macrolaminae. The patch margins are ragged and there are irregular thickness changes.

Transgressive veins filled with the same type of carbonate occur moderately frequently. Rarely the sparry carbonate forms very large transgressive areas with angular inclusions of pale and dark carbonate.

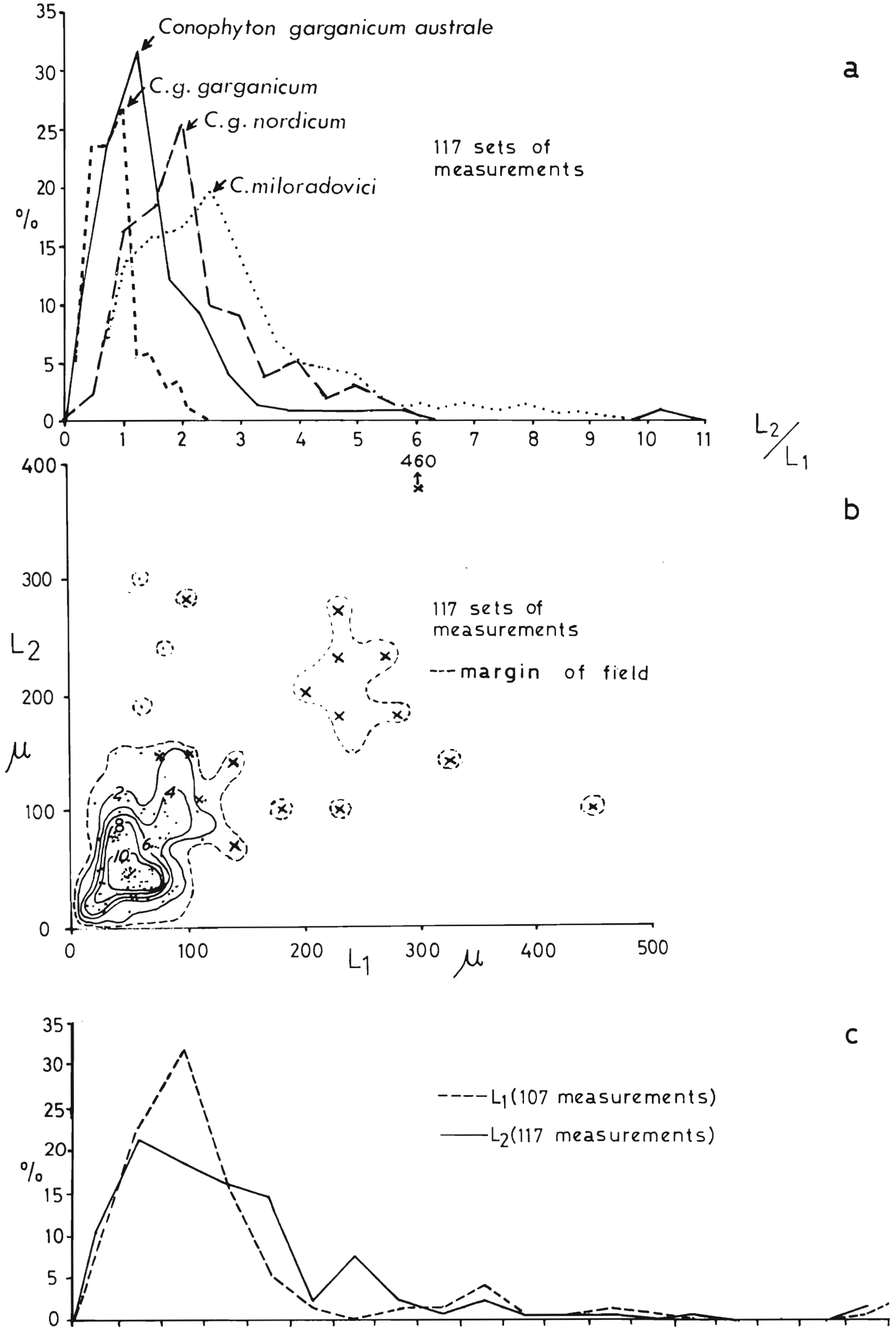
The irregular shape, coarse grain size, and presence of inclusions indicate a secondary origin for this carbonate; most is recrystallized or replaced pale carbonate.

Interspace Fillings. In the field many large, tabular intraclasts were seen in interspaces. The bulk of the filling is carbonate, with local concentrations of detrital quartz and feldspar (detrital, non-carbonate grains occur very rarely within columns except in the contorted marginal zones). The filling is laminated; some laminae resemble those of the columns. The laminae are contorted (Pl. 11).

Secondary Alteration. As already stated the sparry carbonate is secondary. Locally, formation of this carbonate was so pervasive that only small relics of laminae remain; but the pale laminae were favoured sites for its formation. Thus dark laminae are usually well preserved.

The folding and fracturing of laminae is clearly secondary. All of the deformations seen are consistent with an origin by compaction resulting from the weight of the upper parts of columns or the overlying sediment. This happened when some laminae were able to deform plastically but others were brittle, and fractured. Some of the crestal zone complexity could have resulted from this deformation: because of the need for differently shaped laminae to fit closer together during compaction, flow of carbonate to fill spaces below the crests of the more acutely conical laminae could occur. The patches of detritus in the marginal zones of some columns were probably incorporated from the interspace during deformation since they are restricted to deformed parts of the margins. There is no evidence of tectonic deformation; the containing formation dips consistently at only about 10° in the area from which the stromatolites were collected.

TEXT-FIG. 27. *Conophyton garganicum australe* statistics and comparisons; the measurements are from five specimens. A, Frequency distribution of the ratio L2:L1 (thicknesses of dark laminae over those of contiguous pale laminae); class interval 0·5. Also shown are graphs for the three other taxa in the *C. garganicum* subgroup for which statistics are available (from Komar *et al.* 1965). B, Thicknesses of dark (L2) laminae plotted against those of contiguous pale (L1) laminae. Thicknesses in microns. Dots = laminae, crosses = macrolaminae. For the contouring the number of points within squares with sides of 5 mm were counted (in this reproduction the same squares have sides of 4·25 mm). C, Frequency distribution of the thicknesses of dark (L2) and pale (L1) laminae. Thicknesses in microns.


a
Conophyton garganicum australe
C.g. garganicum
C.g. nordicum
C.miloradovici
117 sets of measurements
%
0
5
10
15
20
25
30
35
0 1 2 3 4 5 6 7 8 9 10 11
L_2/L_1
460
b
117 sets of measurements
---margin of field
L_2
μ
0
100
200
300
400
L_1
0 100 200 300 400 500
μ
2
4
6
8
10
c
----L_1(107 measurements)
——L_2(117 measurements)
%
0
5
10
15
20
25
30
35
0 50 100 150 200 250 300 350 400 450
μ

Comparisons. This stromatolite undoubtedly belongs to the group *Conophyton* since it has erect, parallel, non-branching columns built of conical laminae with upwardly directed apices and thickenings in the crestal zones. Its relatively continuous, smooth-bordered laminae which predominantly are thinner than 150 μ are characteristic of the *Conophyton garganicum* subgroup (*C. garganicum*, *C. miloradovici*, and *C. gaubitza*). Its laminae are much more continuous than those of *C. miloradovici*; furthermore, most dark (L2) laminae are thinner than in *C. miloradovici* and the ratio L2:L1 has its mode at 1·0–1·5 rather than at 2·5 as in *C. miloradovici*. The poor preservation of *C. gaubitza* makes detailed comparisons impossible.

The form of the crestal zones is indistinguishable from that of *C. garganicum*; the amount of thickening appears to be greater than in *C. garganicum garganicum* and more like that of *C. garganicum nordicum*. Another similarity with *C. g. nordicum* is the frequent presence of nodular or lenticular thickenings of laminae; these are mentioned in the diagnosis, but not description of *C. g. nordicum,* and are clearly shown in a figure (Komar *et al.* 1965, p. 46, pl. 7, fig. 4). Thickenings in laminae of *C. g. garganicum* are not so marked. The thicknesses of laminae in the Australian form have a unique distribution (text-fig. 27); the ratio L2:L1, with a distinct mode between 1·0 and 1·5, lies intermediate between that of *C. g. nordicum* (2·0) and *C. g. garganicum* (0·5–1·0). The mode of L2:L1 is little altered by excluding the macrolaminae of *C. g. australe* (macrolaminae are weakly developed or absent in the other two varieties). The strong development of macrolaminae is a characteristic of *C. garganicum australe*.

It is concluded that the Australian form is very similar to *C. garganicum nordicum* but is as different from *C. g. nordicum* as that variety is from *C. g. garganicum* and it is therefore described as a new variety, *Conophyton garganicum australe.*

Distribution. Irregully Formation of the Bangemall Group, ½ mile south of the north end of the gorge of Irregully Creek, Edmund 1:250 000 Sheet area; and from float in Fords Creek, Turee Creek 1:250 000 Sheet area; Western Australia.

Age. A little older than 1080±80 m.y. (Middle Riphean).

Conophyton garganicum ?garganicum

Plate 5, fig. 4; Plate 11, fig. 3; Plate 12, fig. 1

Material. Fourteen specimens from possibly eleven localities within the McArthur Basin. All of the specimens belong to the Commonwealth Bureau of Mineral Resources, Geology and Geophysics, whose officers collected them; some are poorly located.

Comments. Only five of the fourteen specimens have been studied, and all proved to be the same.

Occurrence and Column Arrangement. No significant information has been published. It is apparent from specimens that columns are subparallel at least for short distances (30 cm or so), and that massive bridging and coalescing occur frequently. Columns often are only a few millimetres apart.

Branching. No branching of *Conophyton* columns has previously been recorded (Komar *et al.* 1965, pp. 27, 28). One example of branching, which is possibly α-parallel and dichotomous, occurs among the specimens from the McArthur Basin (Pl. 11, fig. 3).

Column Shape. Since I have not seen this stromatolite in the field, and as it has columns too large to be adequately represented in normal specimens, the overall shape is not known. But at least for about 30 cm columns are straight and subcylindrical. Transverse sections are round, rounded polygonal, or lanceolate.

Lamina Shape. Laminae are conical, often with apical angles as small as 30° (Pl. 12, fig. 1). In one column, on the limbs of the cones the laminae are almost exactly straight for the full 15 cm height of the specimen; in other specimens many are straight for several centimetres, but frequently they are slightly wavy. The flexures are 0·5–4 cm wide by 2–5 mm in relief; laminae are waviest near their crests. The radii of curvature of laminae in the crestal zone are variable: many are only about 1 mm, so that these laminae have sharp crests, but in others they are 6–7 mm.

Crestal Zone. The crestal zones are a combination of types II and III of Komar *et al.* (1965) and text-fig. 4 herein. A large percentage of the laminae are thickened less than 1·5 times.

Microstructure. In the thin sections studied the microstructure is much altered by recrystallization (Pl. 5, fig. 4). Although there are differently altered thick layers no macrolaminae comparable with those in *C. garganicum australe* var. nov. are present. Laminae predominantly are 20–150 μ thick, possibly with a mode near 50 μ. They have smooth, parallel borders; thickness changes are not conspicuous although there are infrequent lenticular thickenings. Despite recrystallization many laminae can be traced for several millimetres.

Comparisons. The subcylindrical columns with conical laminae which are thickened in their crests are typical of the group *Conophyton* Maslov (Komar *et al.* 1965). Only forms of the subgroup of *C. garganicum* (*C. garganicum*, *C. miloradovici*, and *C. gaubitza*) have thin laminae and complex crestal zones comparable with those of the McArthur Basin form. The laminae of the form here described are much more even and continuous than those of *C. miloradovici* but are very similar to those of the varieties of *C. garganicum*. *C. gaubitza* is insufficiently known to allow detailed comparison. Insufficient specimens of the McArthur Basin material have been studied in detail to allow confident classification to the varietal level, but the known data allows no distinction from *C. garganicum garganicum*.

Distribution. Karns Dolomite at Calvert Hills Station (Calvert Hills 1:250 000 Sheet) and Foelsche River (Robinson River 1:250 000 Sheet); Emmerugga Dolomite (unpublished name) near Old McArthur River Homestead, Top Crossing, and Bauhinia Downs Homestead (all on the Bauhinia Downs 1:250 000 Sheet); Reward Dolomite (unpublished name) near Reward Lead Prospect (Bauhinia Downs 1:250 000 Sheet); and the Tooganinnie Formation near Rosie Creek (Mount Young 1:250 000 Sheet). All of these units belong to the McArthur Group of the McArthur Basin, north-east Northern Territory of Australia.

Age. The McArthur Group is less than 1750 m.y. old and possibly older than 1510 ± 120 m.y.; i.e. Early Riphean or possibly latest pre-Riphean.

Conophyton cf. *gaubitza* Krylov

Plate 5, fig. 3; Plate 12, figs. 2–3

Conophyton cf. *inclinatum* Rezak, Edgell 1964, p. 247, pl. 5, fig. 2.

Material. One small specimen (GSWA F 5022). Having only one specimen and not having seen this stromatolite in the field, I am unable to fully identify it.

Mode of Occurrence. Edgell (1964) variously states that this stromatolite has a 'subhorizontal axis' or 'a downward apex and an axis inclined or vertical to the bedding plane'.

Column Shape. The one available column is at least 13 cm wide with a circular transverse section. The specimen margins may not be the original column margins.

Lamina Shape. Laminae are conical, away from the crestal zone dipping at 70–80° (Pl. 12, figs. 2–3). Lines of flexures radiate up and out from the crestal zone, to which they are inclined at about 45°. These lines are unevenly spaced, in places being absent for several centimetres, whereas elsewhere several occur within 2–3 cm; they are not evenly matched across the crestal zone. Apart from these flexures there is no waviness or wrinkling except where laminae curve around lenses, and these are thin.

Crestal Zone. This is type III (text-fig. 4). Some laminae are greatly thickened (Pl. 12, fig. 2). The thickenings are not restricted to lamina crests but occur over a zone 5–15 mm wide. Consequently laminae frequently are wavy in the crestal zone. There are a few diagonal lines of flexures which die out after less than 1 cm; in these and the flexures described above many laminae are thickened.

Microstructure and Texture. Macrolaminae 0·5–1·5 mm thick are distinct in slabs but not in thin sections. The dark laminae are 30–130 μ thick except at lenticular thickenings, which occur frequently; many dark laminae are of almost constant thickness (Pl. 5, fig. 3). In lenses the lamina thickness reaches 250 μ or more. Contiguous lenses combine into abrupt thickenings about 500 μ thick. Disconnected lenses occur moderately frequently, partly as a result of alteration. Due partly, at least, to poor preservation, few laminae can be traced more than 1–2 cm. The dark laminae are set in a pale matrix. Where well preserved the pale laminae are about the same thickness as the dark.

The whole specimen is quartz which is xenotopic and equidimensional, of 10–20 μ grain size in dark laminae but frequently 60–70 μ wide and with serrated boundaries in pale areas. There are some very coarse-grained discordant or concordant patches.

Secondary Alteration. No carbonate was seen, but by analogy with *Conophyton basalticum*, also from the Antrim Plateau Volcanics, an originally carbonate composition is inferred. Many dark laminae end abruptly in pale areas, indicating secondary alteration.

Interspaces. None preserved.

Comparisons. The possession of laminae predominantly less than 150 μ thick is a diagnostic feature of the subgroup of *Conophyton garganicum*, which includes *C. g. garganicum*, *C. g. nordicum*, *C. g. australe*, *C. miloradovici*, and *C. gaubitza* (Komar *et al.* 1965; Krylov 1967). Like these forms it also has a type III crestal zone. With only one specimen, and that altered, identification is difficult. However, there is one notable similarity with *C. gaubitza* Krylov, and difference from all other forms: that is the possession of lines of flexures oblique to the crestal zone (Krylov 1967, pl. 7, fig. 2). There are other interesting similarities with *C. gaubitza*. The Kimberley form is silicified and is said by Edgell (1964) to have occurred with its axis inclined or parallel to bedding. *C. gaubitza* is silicified and occurs horizontally or gently inclined in beds. Krylov (1967) deduces that this is the growth position but his evidence is not compelling. Another *Conophyton* with inclined or prostrate columns, *C. inclinatum* Rezak, is now known to be *C. cylindricum* Maslov (Cloud and Semikhatov 1969) which has a microstructure different from that of the *C. garganicum* subgroup.

Distribution. Antrim Plateau Volcanics half a mile east of Mount Wittenoom (Gordon Downs Sheet area), Kimberley region of Western Australia.

Age. Vendian or early Cambrian.

Group GEORGINIA gr. nov.

Type Form. Georginia howchini f. nov. from the Mount Baldwin Formation, Georgina Basin.

Name. Derived from is occurrence in the Georgina Basin.

Characteristics. As for the type form.

Content. G. howchini only.

Distribution. Mount Baldwin Formation of the Georgina Basin.

Age. Probably early Cambrian, but may be late Vendian.

Georginia howchini f. nov.

Plate 6, fig. 5; Plate 12, figs. 4-5; text-fig. 28

Material. Three specimens from one locality.

Holotype. CPC 11316.

Name. Given in honour of Professor Walter Howchin, who pioneered the study of Australian stromatolites.

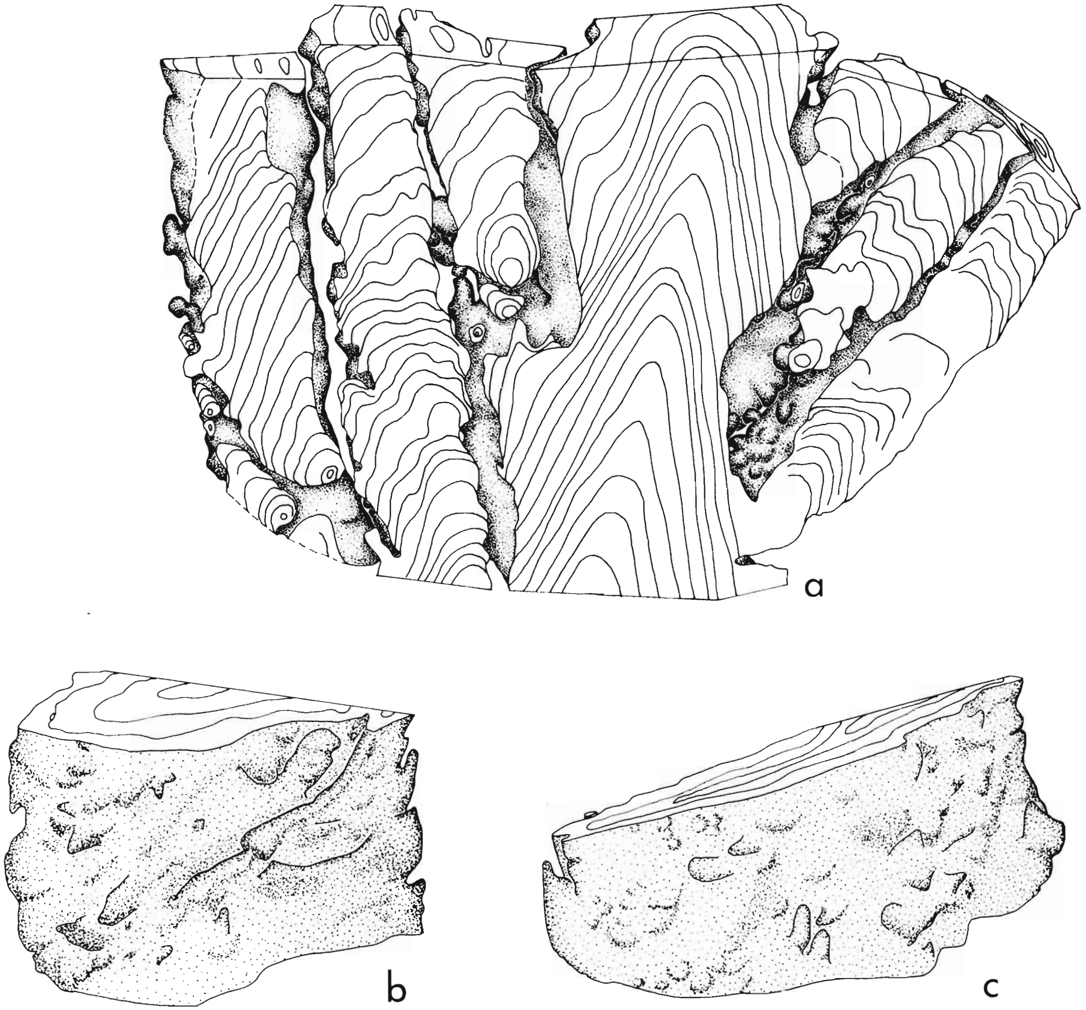
Diagnosis. Stromatolites with *Conophyton*-like columns from which numerous branches radiate upwards and outwards; the columns and branches bear many projections.

Mode of Occurrence. I have not studied this stromatolite in the field, and published data are minimal. Smith (1964) gives a meagre amount of information which may apply to this stromatolite: alongside part of a stratigraphic column in his figure 16 is the explanation 'algal *dolomite* (reef) with red dololutite'. The diagram is suggestive of a stromatolite bioherm possibly about 3 m thick embedded in red dololutite.

Column Arrangement and Branching. Two of the three available specimens are too small to show more than several parallel short segments of columns. The third is larger and has a central straight column which over a height of 13 cm branches off at least four new columns (Pl. 12, fig. 5; text-fig. 28); it is assumed that originally there were more branches, as only one side of the central column is preserved in the specimen. Other narrow columns parallel the branches, indicating origination from lower on the same central column. Laminae in the central column and its branches are roughly symmetrical about an axis through the central column, which suggests that it was vertical during growth.

Column Shape. Columns are subcylindrical but transverse sections often are elongate (text-fig. 28). At least for lengths of 10 cm or so they are straight. The margins are extremely bumpy and irregular but not ragged (i.e. overhanging laminae are rare or absent). There are numerous pustules several millimetres wide and in relief, as well as bumps a centimetre or more wide. But most characteristic are the frequent, variously oriented, and often contorted projections; many are bulbous and resemble arthritic fingers. They are 2–10 mm wide by up to almost 2 cm long. They have pointed or rounded ends and grew upwards, sideways, or downwards. Some are transversely or diagonally elongated into ridges up to several centimetres long.

Lamina Shape. Laminae are conical in most columns, but this shape is greatly modified in some of the branches in the large specimen (text-fig. 28). Usually the slope of laminae between their crests and the column margins is more or less constant at 60–80°. Laminae intersect the margins at very acute angles or, occasionally, parallel them for short distances, forming walls. In many columns the laminae are only very



TEXT-FIG. 28. *Georginia howchini*, Mount Baldwin Formation, 5·5 miles south-west of Huckitta Homestead, Georgina Basin. The columns B and C are from a small specimen, and whether they are branches from another column is not known. $\times\frac{1}{2}$; A (CPC11316), B–C (CPC11317). All R_2.

slightly wavy, with occasional flexures 3–4 mm (or even up to 12 mm) wide by 0·5–1 mm in relief. Flexures of similar width but much greater relief (reaching almost 1 cm) occur in the laminae of several branches of the large specimen. Often the crestal zone is well to one side of a column, and in extreme cases right on a margin.

Crestal Zone. Columns with conical laminae have *Conophyton*-like crestal zones which are type III of Komar *et al.* (1965) and text-fig. 4 herein, but with only a small amount of lamina thickening (Pl. 6, fig. 5). The thickening is slight or nil in many laminae, but reaches several times in others. The crestal zones are 2·5–7 mm wide and of almost constant width within a column. Within these zones laminae are gently domed, hemispherical, or almost rectangular.

Microstructure and Texture. The lamination is indistinct in thin sections. There are no macrolaminae.

Laminae are 50–200 μ thick and discontinuous; few can be traced as far as 5 mm; most are lenses or blunt-ended segments 1–5 mm long (Pl. 6, fig. 5). They are alternately pale and dark, and have diffuse or abrupt borders which are smooth in the best preserved examples. Some unlaminated areas are almost homogeneously dark or pale. Dark laminae coalesce where pale laminae lens out and vice versa. Both pale and dark laminae consists of polygonal, xenotopic, equigranular carbonate; in dark laminae the grain size is 10–20 μ but it reaches 30 μ in pale laminae.

Interspace Fillings. Coarse-grained sparry carbonate in large patches, veins, and coatings forms about 50 per cent of the interspace fillings; within some of this there are distinct relics of zoned rhombs up to 0·5 mm wide. There are many irregular, dark, fine-grained carbonate patches up to many millimetres wide; some of the smaller, angular patches may be intraclasts.

Secondary Alteration. In large areas of some columns much or all of the lamination has been obliterated; there the carbonate is of about 30–50 μ grain size with numerous large rhombs up to 250 μ wide. Structures and textures in both the columns and interspaces indicate a complex diagenetic history involving several generations of carbonate. Much of the discontinuity of laminae appears to be due to secondary alteration, especially the lateral gradation of dark laminae into pale areas; the diffuse nature of lamina borders and the blunt ends of many lamina segments are consistent with this interpretation. Some column margins may have been altered, and in any case are often indistinct, and therefore the reconstructions are not completely representative of the original stromatolites; but all the major features are accurate, as confirmed by thin section examination.

Comparisons. The possession of *Conophyton*-like columns from which radiate other columns was a unique characteristic of the group *Jacutophyton* Shapovalova. Compared with the described forms of *Jacutophyton*, *J. ramosum* and *J. multiforme* (Shapovalova 1968), *G. howchini* has thinner laminae, and also lacks their ragged column margins; but most characteristic of all is the possession by the columns of *G. howchini* of numerous contorted projections, apparently absent from *Jacutophyton* (no reconstructions of *Jacutophyton* have been published, but the projections are easily seen in sections of *G. howchini*, and would have been noticed if they occurred in *Jacutophyton*). Furthermore, conical laminae occur frequently in the branches of *G. howchini* but not in those of *Jacutophyton*. The same features distinguish this form from those described by Bertrand (1968) which appear also to be *Jacutophyton*.

Distribution. Mount Baldwin Formation in the Georgina Basin, 5·5 miles south-west of Huckitta Homestead (Huckitta 1:250 000 Sheet area), Northern Territory.

Age. Early Cambrian or Vendian.

Group ACACIELLA gr. nov.

Type Form. Acaciella australica (*Cryptozoon australicum* Howchin 1914).

Name. The name used by Howchin, *Cryptozoon* Hall, is inappropriate, and no existing group has the characteristics of the type form. The name *Acaciella* is derived from Acacia Well, near to which Dr. Charles Chewings collected the original specimens of *A. australica*.

Diagnosis. Nearly straight, parallel, or radially arranged subcylindrical columns with α-, β-, and rarely γ-parallel and very slightly divergent multiple branching. On column margins are numerous low bumps and occasional small cornices and peaks;

small areas of wall occur infrequently. Laminae dominantly are rectangular, rhombic, or gently domed and are not markedly wavy or wrinkled; the microstructure is streaky.

Content. Acaciella australica (Howchin) and several forms from the Adelaide Geosyncline (Preiss 1971) as yet only named in manuscript.

Comparisons. Stromatolites with a similar column arrangement and branching style are *Kussiella* Krylov, '*Microstylus*' Komar, *Boxonia* Korolyuk, *Katavia* Krylov, and *Tunicata* Sidorov. Comparison with *Tunicata* is hampered by the paucity of reconstructions of that group; Sidorov considers its most characteristic feature to be the possession of a selvage. No selvage occurs on *Acaciella* columns. The columns of *Katavia* are much bumpier than those of *Acaciella* and are walled. *Boxonia* is very similar in gross form but has smoother, walled columns.

Kussiella is the most similar group, but its columns have numerous well-developed cornices, a rarity in *Acaciella*, and only very infrequently have β-parallel branching, which is moderately frequent in *Acaciella*. '*Microstylus*' is probably a synonym for *Kussiella*, as apparently it differs from it only in size and microstructure; its microstructure is said to be distinctive (Komar 1966, p. 78) but appears to be the product of great alteration. Within beds of typical *A. australica* there are columns with numerous bridges, and columns which persist for only short lengths; by a decrease in the frequency of bridging and coalescing they grade into separate, long *A. acaciella* columns. The short and frequently bridged columns are indistinguishable from short segments of *A. australica* columns, and it is unnecessary to differentiate them nomenclatorially. The group *Omachtenia* Nuzhnov has been created for the *Kussiella* analogues of these columns. Its forms differ from *Acaciella* in having numerous remarkably well-developed cornices.

Distribution. Loves Creek Member of the Bitter Springs Formation, Amadeus Basin; various units in the Adelaide Geosyncline.

Age. Late Riphean (Adelaidean).

Acaciella australica (Howchin)

Plate 2, figs. 3-4; Plates 13-14; Plate 15, figs. 1-2; text-figs. 6, 21-22, 29-32

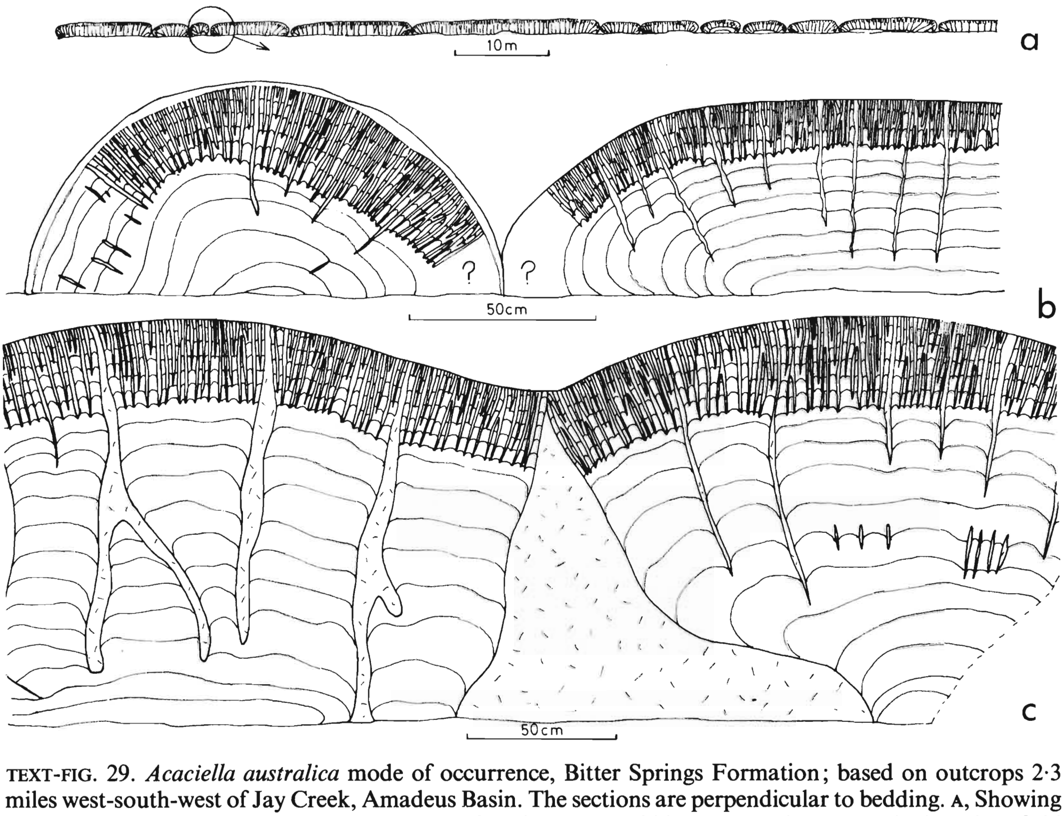
Cryptozoön australicum Howchin 1914, pp. 6-7, pls. 1, 2.
Cryptozoön tessellatum Howchin 1914, p. 7, pls. 3, 4.
Algal form, Mawson and Madigan 1930, pl. 45.
'*Cryptozoon*' *australicum* Glaessner, Preiss, and Walter 1969, pp. 1057-1058, figs. 2-3.
Not *Collenia australasica* (sic) Edgell 1964, pp. 244-245, pl. 5, figs. 4, 5.

Material. Forty-eight specimens from eight localities up to 290 km apart.

Lectotypes. As Howchin designated no holotypes, the following lectotypes are chosen: for *Cryptozoon australicum* specimen S16 shown in pl. 1, fig. 1 of Howchin (1914); for *C. tessellatum* specimen S20 shown in Howchin's pl. 4, fig. 2. The specimen of *C. australicum* figured by Howchin in his pl. 2 is missing. Chewings collected the syntypes from the Bitter Springs Formation about ½ mile west of Acacia Well, eastern MacDonnell Ranges, Northern Territory of Australia (Chewings 1914).

Diagnosis. Acaciella in which the characteristic narrow columns almost everywhere are formed from broad basal columns by α-parallel branching occurring predominantly at one smooth surface within each bioherm or biostrome; which forms all gradations from hemispherical bioherms to tabular biostromes; and in which coalescing and bridging occur moderately frequently.

Mode of Occurrence. A. australica usually forms tabular or domed biostromes; most biostromes consist of closely spaced or contiguous tabular, domed or hemispherical bioherms (text-figs. 29–30) which in plan (where seen near Williams Bore, east MacDonnell Ranges) are approximately circular or elliptical (text-fig. 22). Isolated bioherms occur very rarely. There are all gradations from small bioherms formed by a single individual (one 'bush') to tabular biostromes with numerous individuals. The biostromes are from less than 0·1 m up to 1·3 m thick. Bioherms range from 0·3 m to several tens of metres wide and up to 1·3 m thick.



TEXT-FIG. 29. *Acaciella australica* mode of occurrence, Bitter Springs Formation; based on outcrops 2·3 miles west-south-west of Jay Creek, Amadeus Basin. The sections are perpendicular to bedding. A, Showing contiguous hemispherical to tabular bioherms forming a domed biostrome. Diagrammatic, based on field observations, sketches, and photographs. B, Two contiguous bioherms, drawn from field photographs and sketches; that on the left is shown in Pl. 13, fig. 4. In these particular cases the structure of the bioherm margins is poorly known, but gently inclined columns often occur on bioherm margins where only queries are shown here. C, Two contiguous bioherms, drawn from a field sketch; these are in the same biostrome as those in B. The rock between the bioherms is intraclastic limestone. Note the different form of the bioherm margins in B and C: in C interbiohermal sedimentation probably almost kept pace with bioherm growth whereas in B the full height of the bioherms was exposed during growth (see text-fig. 22).

TEXT-FIG. 30. *Acaciella australica*, Bitter Springs Formation, Katapata Gap, Amadeus Basin. Tracing of a slab cut normal to bedding but slightly oblique to the columns. The specimen (S345) is from the bioherm shown in Pl. 14, fig. 3; the full width and height of the bioherm are not present in the specimen shown here. The stippled area represents a non-stromatolitic erosional mound.

Column Arrangement and Branching. From stratiform stromatolites of the substrate or from erosional mounds in the substrate (text-fig. 30) almost always there first grew broad columns; from these formed narrow columns by multiple α-parallel branching at a smooth surface which conforms to the outward shape of the whole structure, i.e. which is flat in tabular biostromes and domed in domed biostromes and bioherms (text-fig. 29). At the top of biostromes all columns are bridged over along flat or domed surfaces (Pl. 13, figs. 1, 4, 5; text-fig. 29). The relative thicknesses of the broad- and narrow-column zones in different beds are variable but change little within one bed (a domed biostrome at Jay Creek was followed for 2·5 km without finding any noticeable change); rarely, broad columns are absent, and—in contrast—in some beds they form three-quarters of the thickness. The thickness of the broad-column zone usually is 20–100 cm and that of the narrow-column zone usually is 20–40 cm; but some biostromes predominantly of narrow columns are only 10 cm thick.

The columns are 2–20 mm apart and most are approximately straight. In tabular biostromes they are parallel, but in hemispherical and domed bioherms they are radially arranged. Columns rarely are horizontal but are often only 20–30° above the horizontal (text-fig. 30). In the smallest bioherms the radial arrangement persists, but in larger bioherms sloping columns frequently curve upwards. At the junctions of contiguous bioherms many columns are crowded out (the bioherms do not coalesce).

Branching occurs moderately frequently within the broad-column zone; it is usually α-parallel but some β- to γ-parallel branching has been seen. Columns many tens of centimetres wide may, by successive branching, form columns 5–10 cm wide (text-fig. 29). Some 2–3 cm wide columns form in the broad-column zone but shortly are bridged over (where such columns are not associated with better developed *A. australica* they are difficult to identify). Branching in the narrow-column zone is randomly distributed, and is predominantly multiple, frequent and α- to β-parallel but rarely is γ-parallel. Where column arrangement is radial, branching predominantly is parallel to very slightly divergent. Coalescing and bridging occur moderately frequently; the bridges are delicate or massive.

Column Shape. The columns are subcylindrical and approximately straight. Transverse sections are rounded polygonal, circular, oval, or elongate and often are indented, occasionally markedly (text-figs. 31–32). On bioherm margins the shape is frequently less regular. In broad-column zones the columns are from 1 cm to many tens of centimetres wide (Pl. 13; Pl. 15, fig. 2) but the width is approximately uniform within a bed; frequently these columns are 10–20 cm wide. Column width in the narrow-column zones also is uniform within any one bed, and is frequently 1-5 cm; in some beds columns are consistently only 3–10 mm wide (Pl. 15, fig. 2).

Column margins are moderately bumpy; the bumps are large or small, rounded or angular. There are numerous short ribs and some longitudinal or diagonal furrows. Some columns have scalloped margins. Very short projections, infrequently in niches, occur rarely. In longitudinal sections of columns the margins appear finely ragged or smooth (Pl. 2, figs. 3–4; Pl. 15, figs. 1–2; text-figs. 31–32); laminae infrequently project more than 1 mm. Long cornices occur rarely, short ones moderately frequently. Peaks are small and sparse.

Lamina Shape. In broad columns laminae are almost flat or very gently domed, rarely steeply domed; occasionally they are sharply deflexed at column margins. In narrow columns laminae most frequently are rectangular, rhombic, or gently domed and often are steeply deflexed near column margins; steeply domed laminae occur infrequently. The ratio h/w predominantly is 0·3–0·5. Shape changes within columns are slight and gradational (text-figs. 6A, 31–32).

Laminae are smoothly curved, but slight flexures occur frequently: these reach 10 mm wide and 5 mm in relief, but most frequently are several millimetres wide and 1 mm or less in relief. In sloping columns laminae often are asymmetrical (text-fig. 30). There are occasional micro-unconformities.

At column margins many laminae end abruptly (blunt-ended) but others wedge out. There are occasional short patches of wall up to several millimetres high and formed by several laminae; these patches cover up to 10 per cent of the area of column margins and often form smoothly rounded bumps.

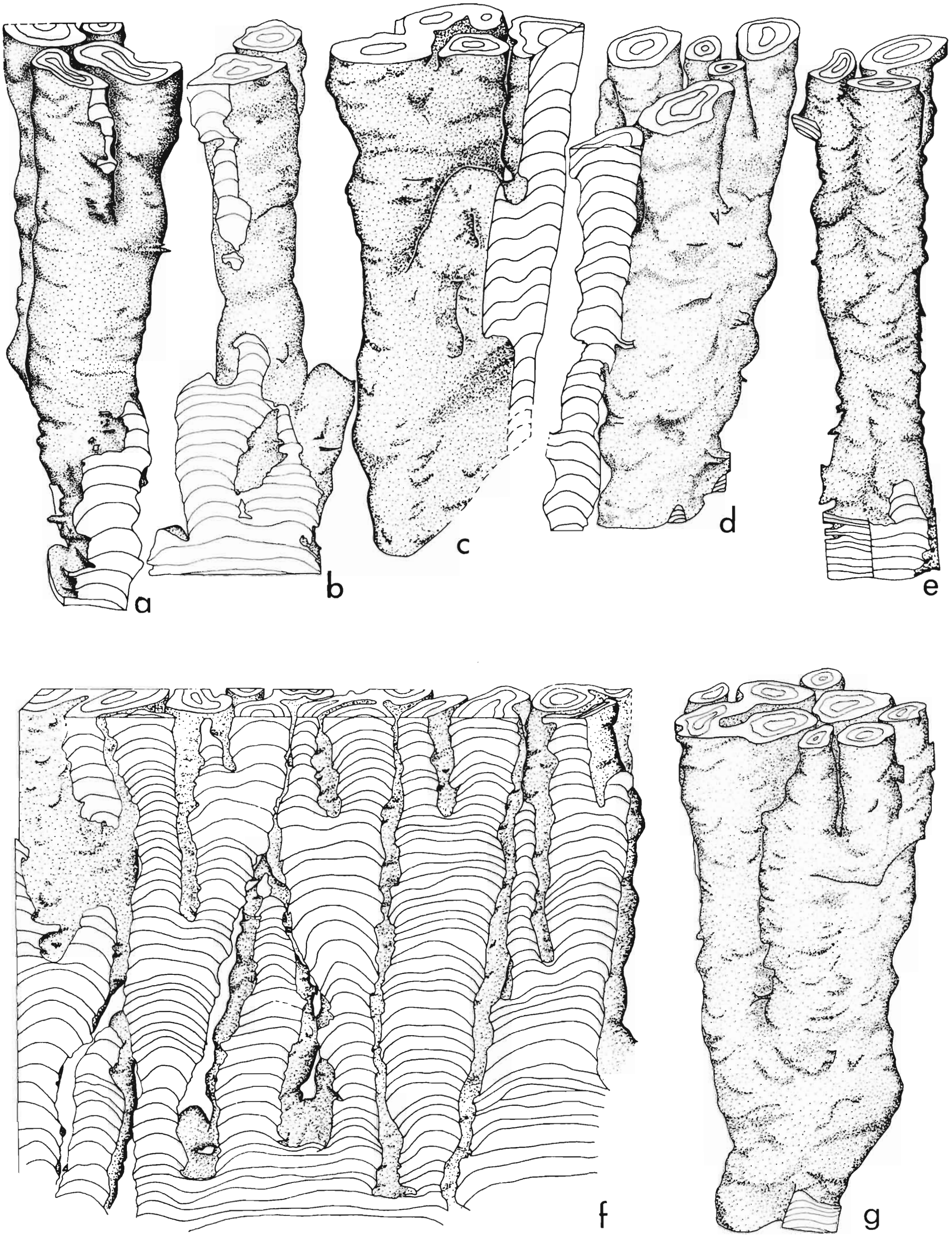
Microstructure and Texture. Lamination is most even and laminae are most homogeneous in specimens from Katapata Gap; these are pale brown and entirely dolomite. The microstructure of these (Pl. 2, fig. 3) is considered to be the best preserved available and hence is described below before that of the more usual calcite preservation (in which laminae are finely grumous and columns dark grey; Pl. 2, fig. 4).

In the dolomite preservation colour and textural contrast between laminae is low. The most prominent layering consists of macrolaminae and laminae 100–1000 μ thick; within macrolaminae the lamination is indistinct. Occasional thick pale macrolaminae and thin dark macrolaminae can be traced across the full width of a column. Most of these prominent layers are of almost constant thickness, although they thin towards column margins; but some fluctuate markedly. Their boundaries usually are abrupt but indistinct. Pigmentation within laminae is almost homogeneous, but is speckled on the same scale as the carbonate grain size. Three types of laminae can be distinguished (dark, pale, sparry), the first two predominating:

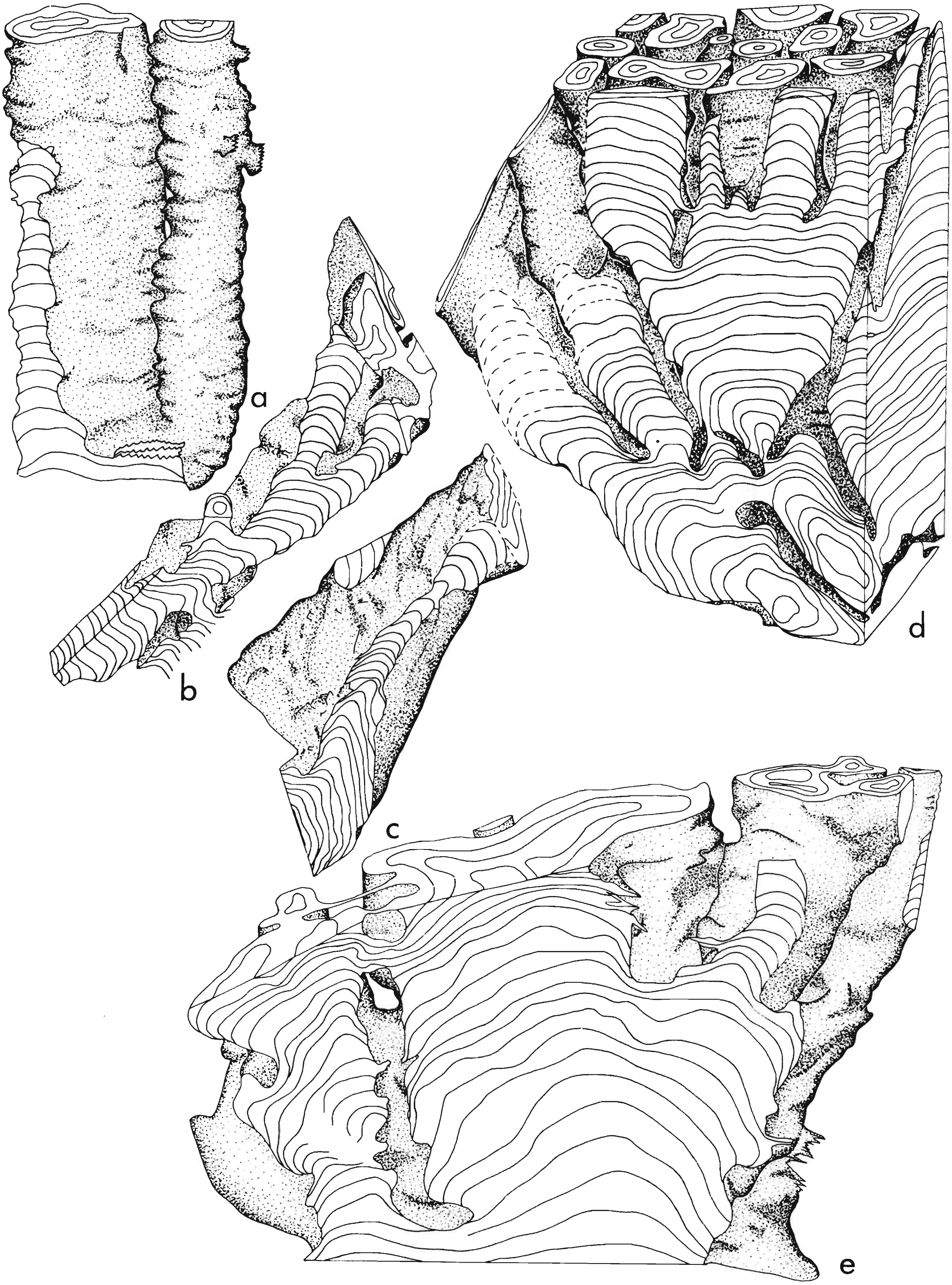
1. Relatively dark laminae consisting of fine grained (10–30 μ), equigranular, polygonal to interlobate, xenotopic dolomite, occasionally with numerous inclusions about 1 μ wide. They are 30–300 μ thick and have smooth boundaries which mostly are parallel; but there are abrupt thickness changes at indentations or where laminae dissociate into trains of rounded clots.

2. The carbonate of pale laminae is very similar in texture to that of the dark, but frequently it is slightly coarser grained (up to about 60 μ) and xenotopic to hypidiotopic; as in the dark carbonate there are numerous inclusions. The shape, where visible, is the same as for the dark laminae, as is their thickness, except that rarely they reach 450 μ.

3. The third type consists of concordant patches of sparry carbonate (grain size frequently 50–150 μ) up to several hundred microns thick, and some irregular, discordant patches of the same material. Some



TEXT-FIG. 31. *Acaciella australica*, Bitter Springs Formation, 2·3 miles west-south-west Jay Creek Aboriginal Settlement, Amadeus Basin, × ½ (S131). All R_1.



TEXT-FIG. 32. *Acaciella australica*, Bitter Springs Formation, Amadeus Basin. A, 2·3 miles west-south-west Jay Creek Aboriginal Settlement, × 1 (S132), R_1. B–D, Katapata Gap; this is the same specimen as in text-fig. 30. The columns in B and C are in their original orientation, × ½ (S345), R_1. E, ¼ mile west of Acacia Well, × ½ (S91), R_3.

of the lightest pale (type 2) laminae grade into sparry areas. Within the sparry grains are domains the same size as adjacent fine-grained dolomite.

In columns preserved in calcite, lamination is more distinct. Dark macrolaminae have a moderately sharply defined darker layer at their tops, usually 10–20 per cent of their thickness. The tops of dark macrolaminae usually are more sharply defined than their bases, where they often grade into the underlying light macrolaminae; but many dark macrolaminae are separated from the underlying pale macrolaminae by a persistent thin (50 μ) sparry lamina. The least grumous laminae span the whole of a column. Calcite in dark macrolaminae is extremely fine grained (several microns), xenotopic, and equigranular; pigment colours 50–60 per cent of the carbonate, forming clots 10–15 μ wide, irregular in shape, but often rounded. Very faint 10 μ thick laminae within dark macrolaminae are marked only by clot concentrations. Pigment occurs in 20–30 per cent of the cross-sectional area of pale laminae and is concentrated at grain boundaries, forming sinuous patches. In pale macrolaminae calcite grains are 5–30 μ wide, equidimensional, and hypidiotopic; there are some rhombs (dolomite?), up to 40 μ wide. As with dark macrolaminae they are unlaminated or only very faintly laminated: some laminae are 75–100 μ thick, others 5–10 μ. Pigmentation changes, not grain size differences, mark fine laminae.

In both types of preservation the prominence of macrolaminae is variable; with moderate frequency they are absent or indistinct. Rarely, alternating faint light and dark bands about 10 μ wide occur perpendicularly to the lamination. Intraclasts and other coarse detritus are extremely rare within columns.

Interspace Fillings. Intraclasts are abundant in the interspaces. Most frequently they are tabular (up to 8 mm long but usually only 1–2 mm) with the same microstructure and texture as adjacent columns (but rarely laminated). In addition, Katapata Gap specimens contain irregularly shaped calcarenite lumps consisting of cemented oolites and carbonate fragments (similar to '*Vesicularites compositus*' and '*V. flexuosus*'; Zhuravleva 1964), as well as many coated grains and oolites (some radially crystalline—'*Radiosus*'; ibid.). The matrix of the detritus has the same texture as pale laminae in the column. Laminae are absent or very coarse, and are gently concave or flat. The whole filling of the Katapata Gap examples is dolomite. Concordant patches of dolomite form about 30 per cent of the interspace volume between calcite-preserved columns. This dolomite is structureless. Dolomite (?) rhombs up to 60 μ wide are numerous in some interspaces.

Secondary Alteration. This is least in the dolomitic columns, where sparry carbonate in veins, discordant and concordant patches is secondary (not 'birdseyes'); stylolites, which are concordant, occur infrequently and are marked by concentrations of a limonite-like mineral (some laminae are lightly pigmented by the same mineral). The almost homogeneous condition of large patches of columns probably is secondary. Concordant stylolites also occur infrequently in the calcite-preserved columns; there they often have dolomite concentrations along them. But not all dolomite laminae in columns are along stylolites. Acicular carbonate fills some stylolites. Stylolites mark the edges of some calcite-preserved columns. Grumous textures often are best developed near column margins, and frequently the carbonate is coarser there, resulting in a pale zone along some column margins. Within columns homogeneous or very finely grumous laminae often grade laterally and vertically into paler coarsely grumous laminae and areas; these further may grade into areas with only sinuously pigmented patches. Grain size within these dark pigmented patches (e.g. 7–10 μ) is much less than in surrounding light areas (e.g. 30–100 μ); maximum grain size is at the centre of the light patches. The rhombs present within columns and interspaces often penetrate early structures (such as intraclast boundaries) and are secondary.

Comments. The maximum growing-relief of the columns indicated by bridges and vertically standing intraclasts is 1 cm.

The syntypes of *Cryptozoon australicum* Howchin and *C. tessellatum* Howchin are very small and no useful data on their mode of occurrence was given with the original descriptions (Howchin 1914), so identity with the widespread stromatolites now named *A. australica* was established on circumstantial evidence. Several visits to the type locality revealed no columnar stromatolites other than *A. australica*, and those present have the same preservation and size as the syntypes. Furthermore, the microstructure, lamina shape, column margin structure (Pl. 14, figs. 5–6) and, so far as they are present, the gross features of the syntypes, are indistinguishable from those of other *A. australica*. *Cryptozoon tessellatum* was characterized by the variability of the transverse-sectional shape of its columns and the invariability of its interspace widths; these features are common in beds of *A. australica* but are not consistently developed.

Comparisons. No reconstructions or detailed descriptions of an unnamed Russian stromatolite very similar to *A. australica* have yet been published, but three drawings of its form in outcrop are given by Krylov (1967, pp. 20, 21). In outcrop it is indistinguishable from some of the radiating varieties of *A. australica* which are common at Katapata Gap, near Ringwood, and at Acacia Well: compare Krylov's figure 12*a* with my text-fig. 32E, and his 11 with my 30.

Distribution. Loves Creek Member of the Bitter Springs Formation 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, 10 miles north-west of Undoolya Gap, ½ mile west of Acacia Well, and 1·1 miles north of Ross River Tourist Camp; ?Loves Creek Member 6 miles south-south-east of Ringwood and 'Gill's Pass' (several miles west of Jay Creek): Bitter Springs Formation at Katapata Gap, and the southern end of the Ross River valley (text-fig. 12), Amadeus Basin.

Age. Late Riphean (Adelaidean).

Group ALCHERINGA gr. nov.

Type Form. Alcheringa narrina f. nov.

Name. Alcheringa is an Australian Aboriginal name for the mythical 'dream-time' of long ago. The type species, *A. narrina*, is the oldest known Australian stromatolite.

Characteristics. As for the type form.

Content. A. narrina only.

Distribution. Various localities and levels within the Fortescue Group of the Mount Bruce Supergroup, Pilbara region of north-western Western Australia.

Age. About 2190±100 m.y.

Alcheringa narrina f. nov.

Plate 5, fig. 2; Plate 15, figs. 3-5; Plate 16, figs. 1-3; text-figs. 6, 33

Collenia sp. aff. *C. multiflabella* Rezak, Edgell 1964, p. 254, table 2.

Material. Seven specimens from one locality.

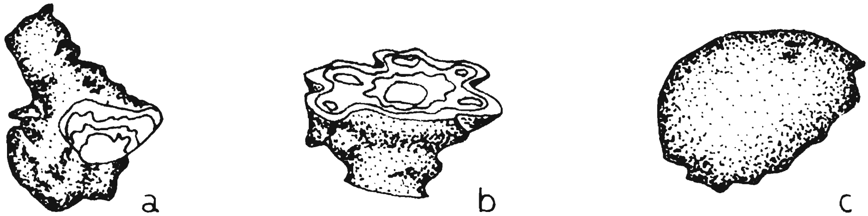
Holotype. S95.

Name. 'Narrina' is the name of a creek draining the type locality, Mount Herbert.

Diagnosis. Very small cumulate (non-columnar) or columnar individuals which widen upwards abruptly or gradually, becoming subspherical, loaf-shaped, heart-shaped, or clavate; these occur separately or coalesce into larger hemispherical or subspherical masses. The laminae often are wrinkled. The microstructure is banded.

Mode of Occurrence. A. narrina occurs as tabular biostromes or domed or subspherical microbioherms. A biostrome at Mount Herbert is 30 cm thick and most microbioherms apparently are less than 10 cm wide and high.

Shape of Individuals. The individuals are clavate, inverted conical, columnar, heart-shaped, loaf-shaped, or subspherical; or any of these with large projections altering the basic shape; or any of these coalesced into microbioherms which frequently are subspherical (Pls. 15, 16; text-fig. 33). Prominent in nearly all of these shapes is a rapid upward widening. Within individuals can be distinguished units each consisting of a stack of domed or parabolic laminae; the simplest individuals comprise one such unit. The units branch, but laminae within adjacent units usually remain joined; the domed surfaces of units project from the tops and sides of complex individuals. The branching-off of discrete new units occurs infrequently (Pl. 16, fig. 3). Margins of individuals are smooth or bumpy, with bumps a few millimetres wide by 1-2 mm in relief. There are occasional ribs. Bridging occurs moderately frequently.



TEXT-FIG. 33. *Alcheringa narrina*, Pillingini Tuff, Mount Herbert, Hamersley Basin, ×½ (S95). A–B, R_2; C, R_1.

Individuals range from 0·5 mm high and wide to 15 mm high and 12 mm wide. Where coalesced into microbioherms, heights and widths of 19 cm are reached.

Lamina Shape. In the smaller individuals and units laminae are gently domed, steeply domed, parabolic, or even almost elliptical or circular (in vertical sections); many 'parabolic' laminae have pointed crests, making them flame-shaped (Pl. 5, fig. 2; Pl. 15, figs. 3-5; Pl. 16; text-fig. 6H). In the wide, upper parts of individuals or units, and where individuals have coalesced, laminae mostly are gently convex (with deflexed edges), rectangular or rhombic (with lamina edges curving in as well as being deflexed). Frequently laminae continue down a margin for several millimetres forming a wall; walls consist of as many as about ten laminae but often less than five. About 30 per cent of the area of the margins is walled. Margins are smooth almost everywhere even where there is no wall. Many laminae are slightly wrinkled; most wrinkles are 50-600 μ wide by 50-300 μ in relief.

Microstructure and Texture. There are distinct, alternating pale and dark grey laminae 15-150 μ thick (Pl. 5, fig. 2). Dark laminae usually are thinner than contiguous pale laminae, and rarely exceed 100 μ in thickness. Apparently-detrital non-calcareous minerals, mostly in the clay and very fine silt to fine sand size range but reaching coarse sand size (Wentworth grades), are concentrated in parts of some columns; here lamination is indistinct or absent, and the detritus forms macrolaminae 150-1000 μ thick. The dark or pale laminae often grade into detrital laminae:

1. Pale laminae consist of equigranular, polygonal, xenotopic carbonate mostly of 5-10 μ grain size. Other mineral grains often are numerous: in particular there are many angular very pale green grains 3-4 μ wide of slightly higher refractive index than the carbonate (chlorite?), colourless or pale yellow grains less

than 1 μ wide with a very high refractive index, and opaque euhedra (cubic?) 1-6 μ wide (pyrite?). Faint clots about 20 μ wide cause a mottling.

The lamina boundaries are smooth and parallel. Thickness variations are minor, but at least the thicker examples thin gradually towards column margins. Frequently the thin laminae can be traced for only 1·5–2·0 mm before they fade into an area of unlaminated pale carbonate or into a concentration of detritus; but some cross the full width of a column.

2. Dark laminae have the same composition and texture as the pale examples except for concentrations of grey pigment and of the opaque euhedra. Predominantly they are 10–50 μ thick. They are distinct, but have slightly diffuse boundaries. The boundaries are parallel and smooth or slightly indented. Their continuity is the same as that of the pale laminae.

3. Detrital macrolaminae: 60–70 per cent of the volume of these is carbonate the same as that forming the dark and pale laminae. As well there is a concentration of chlorite(?) in 30–50 μ wide aggregates and separate, ragged grains, giving the laminae a speckled appearance. Occasional large mica flakes (up to 0·5 mm long) parallel the lamination. The macrolaminae predominantly are 150–1000 μ thick and often are crudely laminated on the same scale as the other laminae. The upper and lower boundaries of the macrolaminae vary from smooth and distinct to indefinite (where the content of detritus increases in contiguous laminae).

4. Radiating acicular structures: these occur in all individuals which include detrital non-carbonate grains. They are 20–100 μ wide by up to 3 mm long and converge towards the centre of an individual's base, varying from normal to the lamination to parallel to it (Pl. 5, fig. 2; Pl. 15, figs. 3–5; Pl. 16). Usually they are spaced 20–100 μ apart. They are particularly distinct in laminae rich in non-carbonate detritus and the laminae immediately overlying these. They are darker than the enclosing laminae; near the tops of detrital laminae and in immediately overlying laminae they are often black and opaque; the intense colouration is caused in many cases by concentrations of minute (about 1 μ wide) opaque euhedra (cubic?) and in others by concentrations of yellow grains about 1 μ wide and by yellow pigment. Many of the structures seem to be concentrations of the pale green flaky mineral described above and many consist only of leucoxene. They are more distinct under crossed nicols since the green grains appear to be isotropic (the distinctness is not due to a common orientation of the mineral grains). Some consist only of a concentration of grey pigment (which is probably organic). Laminae frequently bend upwards abruptly where these structures pass through them; this is the cause of some of the wrinkling.

Interspace Fillings. Most of the filling consists of chlorite-like and sericite-like minerals of about 30–150 μ grain size with local concentrations of a green to colourless mica in flakes up to 300 μ long. There probably is a considerable amount of fine-grained carbonate, but in thin sections this is difficult to distinguish from sericite. About 10 per cent of the filling consists of a xenotopic, opaque mineral of about 50–150 μ grain size. Patches up to 5 mm wide of xenotopic, polygonal, equidimensional carbonate of 100–750 μ grain size occur moderately frequently; most are not transgressive, but some project into the stromatolites. There is a crude lamination 0·15–3·0 mm or more thick caused by variations in the concentrations of dark minerals.

Secondary Alteration. Some individuals or parts of individuals have been silicified; the microstructure appears unaltered by this, but frequently the radial structures are more prominent.

There are occasional concordant patches of chert in the interspaces. These and the concordant or near concordant coarse carbonate patches may be primary.

Comments. A. narrina occurs interbedded in a dominantly volcanic sequence. The mineral assemblage is unusual for stromatolites and clearly results from the occurrence with volcanics. The micaceous minerals presumably are weathering products trapped by the stromatolite-forming algae.

The unusual radial structures may be explained by the trapping of detritus by radially oriented bundles of algal filaments (as, for instance, occurs in clumps of *Rivularia*; Monty 1967). Lack of non-carbonate detritus prevents the preservation of the radial structure.

Comparisons. Since *Collenia* is an oncolite (Hofmann 1969*b*), this is an inappropriate name for this form. There are similarities between *Alcheringa* and forms of *Colleniella* Korolyuk, particularly *C. calix* Korolyuk, but the variability in shape occurring within *Alcheringa narrina* and its very small size necessitate assignment to a new group. In gross shape *Alcheringa* closely resembles some examples of *Cryptozoon* (see Goldring 1938) which, however, are much larger and have the vermiform microstructure typical of Phanerozoic stromatolites. *Katernia africana* Cloud and Semikhatov (1969) from the Dolomite Series of South Africa is similar to *A. narrina* but predominantly is columnar and branches frequently.

Distribution. One hundred metres north of the Mount Herbert cairn, Yarraloola 1:250 000 Sheet area, Pilbara region of Western Australia; Pillingini Tuff, Fortescue Group, Mount Bruce Supergroup. Stromatolites which are probably similar have been reported from many localities in the Fortescue Group.

Age. About 2190±100 m.y. (Early Proterozoic).

Group BAICALIA Krylov

Baicalia Krylov 1963, 1967; Semikhatov 1962, Nuzhnov 1967, Cloud and Semikhatov 1969.

Type Form. Baicalia baicalica (Maslov), which occurs widely in the U.S.S.R.

Diagnosis. Stromatolites with tuberous to subcylindrical columns with frequent parallel to markedly divergent branching. The columns are naked or have patchy walls; in some forms peaks and bridges occur frequently.

Content. B. baicalica (Maslov), *B. prima* Semikhatov, *B. rara* Semikhatov, *B. lacera* Semikhatov, *B. unca* Semikhatov, *B. ampla* Semikhatov, *B. ingilensis* Nuzhnov, *B. aimica* Nuzhnov, *B. maica* Nuzhnov, *B. minuta* Komar, and possibly *B. kirgisica* Krylov. The paucity of published reconstructions of these numerous forms hinders their comparison, but since some are distinguished largely on microstructural features they may be found to be synonymous.

Age. Middle and Late Riphean.

Baicalia capricornia f. nov

Plate 5, fig. 1; Plate 17; Plate 18, figs. 1–2; text-figs. 6, 34–36

Algal stromatolites of *Cryptozoon*-type, Daniels 1966*b*, p. 50, pl. 21A.

Material. Ten specimens from three localities.

Holotype. S200.

Name. This stromatolite is best known from an outcrop close to the Tropic of Capricorn.

Diagnosis. *Baicalia* only rarely having peaks and cornices and predominantly with almost straight, subparallel columns; constrictions at the bases of branches are infrequent; the microstructure is banded.

Mode of Occurrence. At the type locality (Henry River area) a low hill hundreds of metres square consists entirely of beds of *B. capricornia* (Pl. 17). The shape of the beds, most of which are more than 1 m thick and some more than 2·5 m, is uncertain, but they may be tabular biostromes; the biostrome boundaries are taken at very extensive, massive bridges (which are nearly flat). The whole hill may be part of one huge bioherm (formed of superimposed biostromes) since a hill only 50 m away approximately along the strike is of a different rock type; but outcrop is insufficient to allow more than speculation on this. Near the base of the Irregully Formation at the northern end of the gorge of Irregully Creek there is a 1–1·5 m thick bed, apparently of this stromatolite (Pl. 17, fig. 3). At a third locality (20 miles north-north-east of Coodardoo Gap) it occurs only as disoriented or roughly oriented, fragmented columns in a slump breccia (Pl. 18, fig. 1); contrary to Daniel's (1966*b*) opinion, these columns are certainly not all aligned.

Column Arrangement and Branching. The columns predominantly are subparallel, vertical, nearly straight, and 0·5–3 cm apart; but column segments sloping at up to 40° from the vertical occur moderately often; rarely there are horizontal projections (text-figs. 34–36). Reconstructions and sections reveal much more irregularity than was expected from outcrop appearance.

At the bases of biostromes is wavy-laminated dolomite which resolves upwards either into broad columns up to 30 cm high which in turn form narrow columns (Pl. 17, figs. 1, 5), or directly into narrow columns. Branching occurs frequently: from the basal, broad columns apparently it predominantly is α-parallel or occasionally slightly divergent (this is based only on field observations) but elsewhere it is β- to γ-parallel to slightly divergent, dichotomous or multiple (Pl. 17, fig. 4; text-figs. 34–36). It appears to be infrequent in the upper parts of some biostromes (Pl. 17, fig. 2).

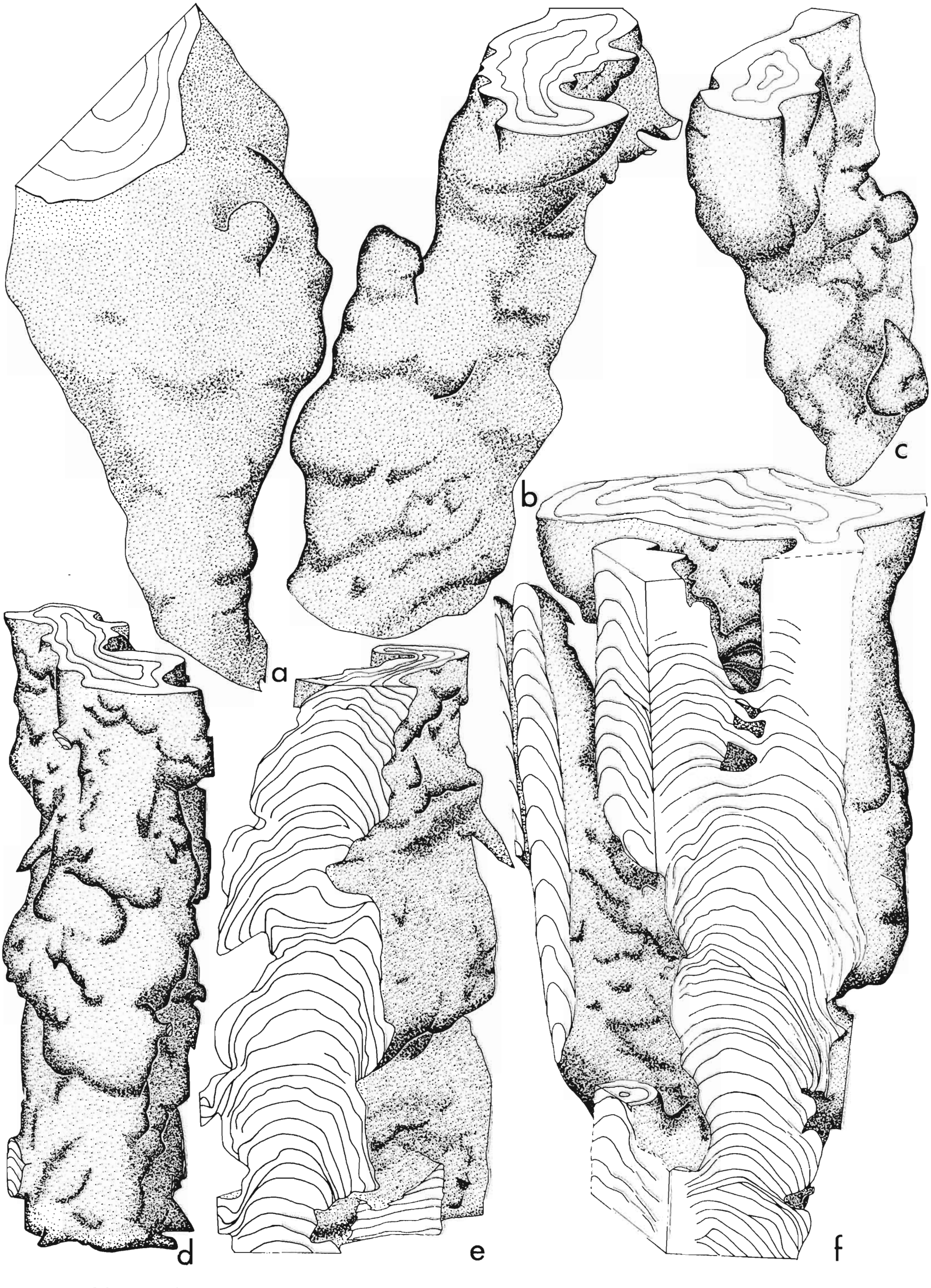
Bridging occurs frequently and is delicate or massive. In this feature the reconstructions are inaccurate because often it is difficult to distinguish interspace-filling laminae from bridges. Some 'bridges' abut against a column without joining its laminae although they are continuous with the laminae of the column from which they originate.

Column Shape. Columns are subcylindrical with rounded-polygonal, rectangular, oval, or round transverse sections, all with numerous large indentations, and are 1–10 cm wide. They are tuberous with numerous large and small bumps (text-figs. 34–36). Some constrictions resemble elongate niches; indeed, in some there are elongate small projections (text-fig. 34E). Large or small digitate projections occur infrequently to moderately frequently; some are at high angles to their parent columns. Peaks and cornices occur rarely.

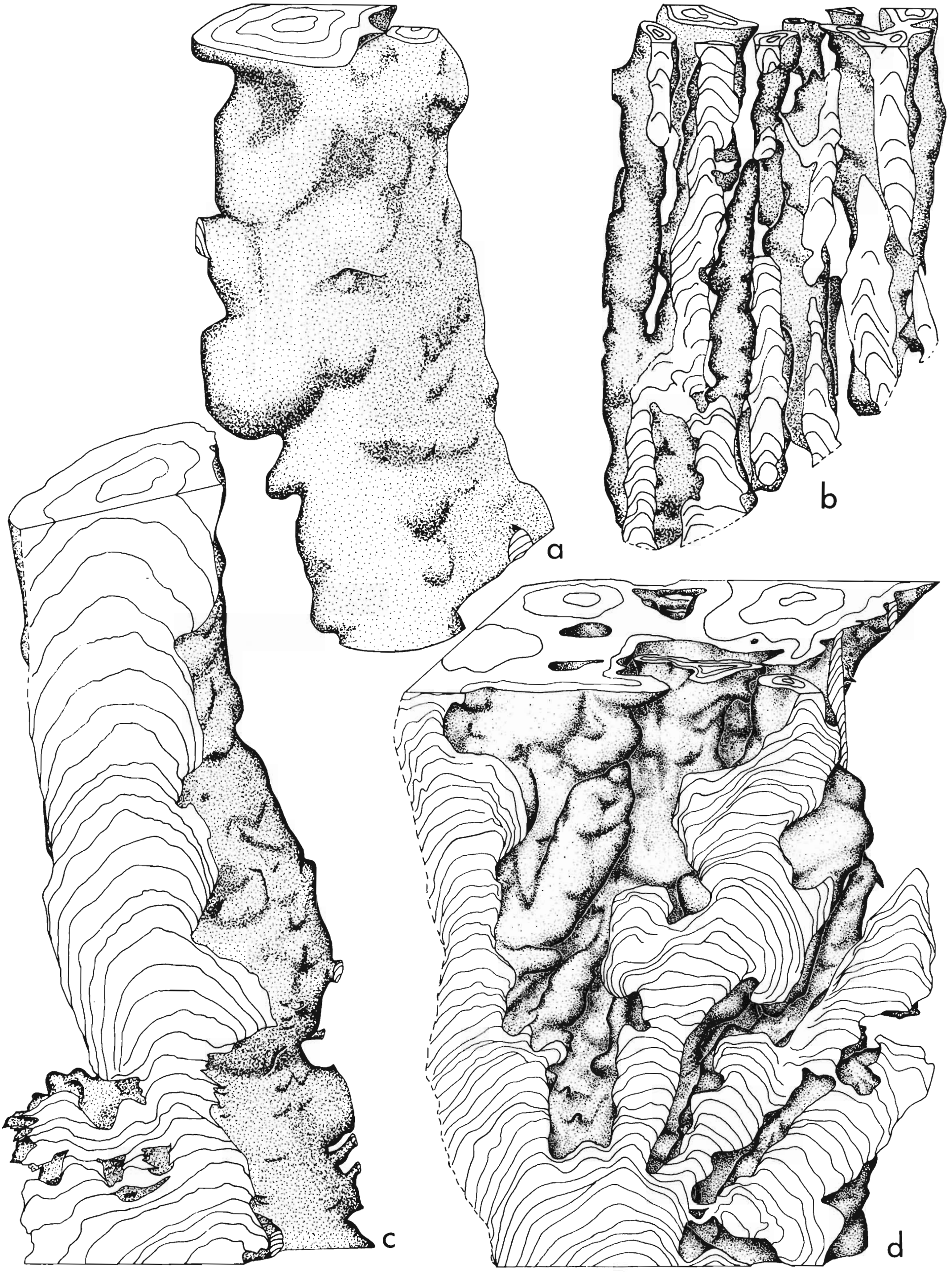
Lamina Shape. Laminae vary from almost flat or gently convex, through steeply convex infrequently to parabolic (h/w ranges from 0·2–0·7). Frequently they are asymmetrical, continuing much further down one side of a column than the other. Micro-unconformities occur moderately frequently. Some shape changes are abrupt, most are gradational (text-figs. 8B, 34–36).

Locally there is a multilaminate wall; it occurs where laminae are steeply convex or parabolic and frequently only on one side of a column, the same laminae on the other side ending abruptly at the column margin (Pl. 18, fig. 2; text-fig. 36A). Walls several centimetres long occur frequently. Locally they are unconformable on underlying laminae. Laminae frequently conform to the outer shape of columns, in some cases folding around and under bulbous expansions.

Laminae are slightly wavy, with flexures up to 10 mm wide by 4 mm in relief (Pl. 5, fig. 1; Pl. 18, fig. 2); some flexures result from doming over irregularities in micro-unconformity surfaces. Infrequently the flexures resemble symmetrical ripple marks or curled-up mud flakes (but those origins are not necessarily



TEXT-FIG. 34. *Baicalia capricornia*, Bangemall Basin. A–C, From a slump breccia in the Devil Creek Formation, 20 miles north-north-east of Coodardoo Gap, $\times \frac{1}{2}$; A (S194), B–C (S195); R_2. D–F, Irregully Formation, 21 miles east-south-east of Maroonah Homestead, $\times \frac{1}{2}$ (S200), R_2. E is a 60° reconstruction of part of the column in D, drawn to show the constriction and projection about one third of the way up the column.



TEXT-FIG. 35. *Baicalia capricornia*, Bangemall Basin. A, From a slump breccia in the Devil Creek Formation, 20 miles north-north-east of Coodardoo Gap, $\times\frac{1}{2}$ (S195), R_2. B–D, Irregully Formation, 21 miles east-south-east of Maroonah Homestead, $\times\frac{1}{2}$; B (S197—from the uppermost part of a biostrome), R_3; C–D (S200), R_2.

TEXT-FIG. 36. *Baicalia capricornia*, Irregully Formation, 20 miles north-north-east of Coodardoo Gap. A, Longitudinal section through the same columns as shown in text-figs. 34D–F, 35C–D, and 36B; × $\frac{1}{3}$ (S200). B, × $\frac{1}{2}$ (S200), R_2, 60° reconstruction.

attributed to them). Wrinkling occurs frequently and is prominent. Most wrinkles are about 1 mm wide and less than 1 mm in relief (often about 0·5 mm).

Microstructure and Texture. Macrolaminae 1-5 mm thick are prominent in the field and in slabs; but in thin sections they are indistinct and instead laminae 100–1000 μ thick predominate (Pl. 5, fig. 1). The laminae alternately are pale and dark grey:

1. Dark laminae are 100–1000 μ thick. The thickest examples can usually be resolved into thin dark laminae with the intervening pale laminae greatly reduced. They are distinct but their boundaries are irregularly indented, and often gradational over about 70 μ; the indentations are almost contiguous and 40–80 μ deep by the same width. Lamina boundaries are nearly parallel and many laminae cross almost the full width of a column. Continuous laminae predominate, but some lens out. In most laminae thickness changes are minor but occasionally there are lenticular thickenings. Some of the thinnest laminae consist of discontinuous zigzag wisps of pigment.

Very fine-grained carbonate forms 80–90 per cent of the volume of the dark laminae, slightly coarser quartz the rest. The carbonate is of 3–5 μ grain size, xenotopic to hypidiotopic, equidimensional, and polygonal. The quartz is 15–150 μ grain size, xenotopic, equidimensional, and polygonal to interlobate.

2. Pale laminae form about 40 per cent of the volume of the columns. Most are the same thickness as the dark laminae, but some reach 2·5 mm; within the thickest are greatly reduced dark laminae. Although most pale laminae cross at least half of the width of a column, wedging out is more frequent than for the dark laminae. Wisps and spots of dark pigment 30–150 μ wide by up to several hundred microns long occur very frequently in pale laminae; similarly, pale spots less than 100 μ wide occur moderately frequently in dark laminae.

Pale laminae vary from 90 per cent carbonate to 90 per cent quartz. The carbonate has the same texture as in dark laminae but often is slightly coarser grained (7–35 μ). In predominantly carbonate laminae the quartz is equidimensional, polygonal, xenotopic, and 15–75 μ in grain size. Laminae predominantly of quartz are the palest and have the smoothest boundaries; the quartz in these is acicular, with crystals 15–60 μ wide by up to 350 μ long arranged normally to the lamination; much of the included carbonate also is acicular.

Interspace Filling. Up to 50 per cent of the filling is platy intraclasts reaching 2 cm in length and with the same microstructure and texture as the columns. Most of the filling is unlaminated. It is about half and half quartz and carbonate, with the carbonate in discrete 100–250 μ wide patches in the quartz. There possibly are relict carbonate euhedra in the quartz.

Secondary Alteration. The spotty texture in pale laminae is due to incomplete silicification leaving relics of pigmented carbonate. Relict carbonate textures occur in some of the quartz. Some of the wrinkling of the laminae may be due to the crystallization of acicular quartz but quartz is not ubiquitous in areas of wrinkling.

Carbonate at the Henry River locality is cleaved and some of the stromatolites are strongly deformed; those reconstructed are not much deformed. Sections used in reconstruction were cut parallel to the cleavage. The possibility of the cleavage causing the wrinkling and waviness was considered, but specimens from 20 miles north-north-east of Coodardoo Gap are not cleaved but still have wrinkled and wavy laminae (and also are silicified but the quartz is not acicular).

Occasional areas of coarse, sparry carbonate cross laminae.

Comments. The variable lamina shape reveals considerable variation in relief during growth: from about 1 cm at some bridges to at least 5 cm elsewhere (text-fig. 36A).

Comparisons. A number of features clearly indicate that this stromatolite is properly classified as *Baicalia*: 1. The irregularly tuberous and bumpy columns. 2. The patchy wall (see Krylov 1963). 3. The variability of lamina shape and the presence of micro-unconformities (see Semikhatov 1962, pl. 2, fig. 3). Furthermore, the similarity in shape with the asymmetrical, wavy and wrinkled laminae of *B. baicalica* figured by Krylov (1963, pl. 7, fig. 2) is striking, as is that between the 'lamellar-stripy' microstructure of

B. baicalica (Krylov 1963, pl. 10, figs. 2, 3; pl. 11, figs. 1, 2) and that of *B. capricornia.* That form of microstructure appears the best preserved of those figured by Krylov.

Many *Baicalia* are described as having bent columns, to some extent variously inclined; but *B. aimica* and *B. prima* have straight, generally parallel columns (Nuzhnov 1967; Raaben 1969*a*) as do large segments of *B. baicalica* (Krylov 1967, fig. 9). Krylov's diagnosis of *Baicalia* included the possession of constrictions at the bases of columns, only infrequently present in *B. capricornia.* In some other forms of *Baicalia* this feature also occurs infrequently (Komar 1966, fig. 19) or is absent from many columns (Nuzhnov 1967, pl. 9, fig. 1; pl. 11, fig. 4; Krylov 1963, figs. 20B, 21A; Semikhatov 1962, pl. 2, fig. 2; pl. 5, fig. 1). Many described forms of *Baicalia* have, in contrast to *B. capricornia,* numerous peaks and cornices; but these are not ubiquitous (e.g. Nuzhnov 1967, pl. 8, fig. 1; Raaben 1969*a*, figs. 10, 11) and in many cases occur infrequently. The parallelism and straightness of columns and the rarity of peaks and cornices distinguishes *B. capricornia* from all other forms.

The similarity between some forms of *Inzeria* Krylov and *Baicalia* Krylov was noted by Krylov (1963, p. 63) and is emphasized by this study. Particularly notable are the infrequent occurrence in *B. capricornia* of niche-enclosed projections and poorly developed ribbing. The prevalence of prominent constrictions, expansions, and large bumps precludes classification as *Inzeria*, but short segments of columns are 'inzeriform' and the arrangement of columns resembles that of *Inzeria.*

Distribution. Irregully Formation, 21 miles east-south-east of Maroonah Homestead and north end of the gorge of Irregully Creek, Capricorn Ranges; Devil Creek Formation, 20 miles north-north-east of Coodardoo Gap: all are Bangemall Group, Edmund 1:250 000 Sheet area, Western Australia.

Age. Middle Riphean (Adelaidean).

Group BASISPHAERA gr. nov.

Type Form. Basisphaera irregularis f. nov.

Name. The name alludes to the shape of column bases and of individuals occurring scattered between clusters of columns.

Characteristics. As for the type form.

Comparisons. See below.

Content. Basisphaera irregularis only.

Distribution. Loves Creek Member of the Bitter Springs Formation, Amadeus Basin.

Age. Late Riphean (Adelaidean).

Basisphaera irregularis f. nov.

Plate 2, fig. 1; Plate 18, figs. 3-4; Plate 19, figs. 1, 3-5; text-figs. 6, 24, 37-38

Material. Four specimens from one locality.

Holotype. S346.

Name. The name '*irregularis*' is given because of the shape of the columns.

Diagnosis. A stromatolite having broad, erect, straight columns which by multiple α-parallel branching, predominantly at one level, form numerous narrow columns. Subspherical, hemispherical, or small columnar individuals formed where incipient column bases failed to develop further. The columns have many bridges and short cornices, small peaks, occasional short transverse or oblique ribs, and numerous small bumps; swellings and constrictions are prominent. In broad columns laminae are dominantly steeply domed; those of narrow columns are very variable.

Mode of Occurrence. Only one bed is known. Within it are isolated clusters of erect columns up to 1·3 m high. Gaps between clusters may reach several metres wide and contain only scattered hemispherical, subspherical, and small columnar individuals (up to 25 cm wide) identical with column bases (text-figs. 24, 38B).

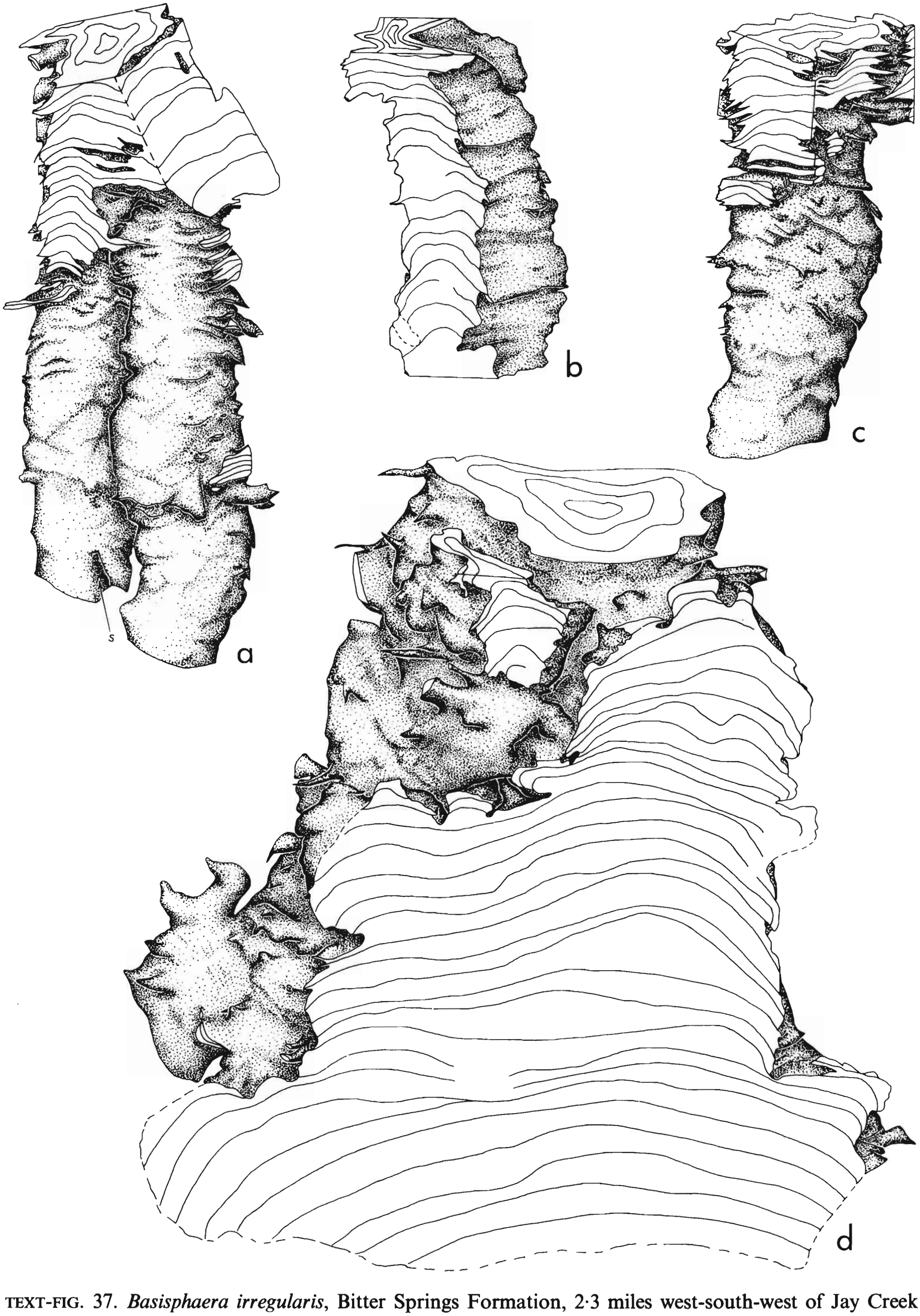
Column Arrangement and Branching. In the lower 60–100 cm of the bed are erect, subparallel columns 30–50 cm wide and mostly less than 3 cm apart. These, by α-parallel branching, form columns 1·5–4 cm wide, less than 1 cm apart, and up to 25 cm high (text-figs. 37D, 38B) all at nearly the same level. The branching occurs within a zone, rather than at a single level (text-fig. 37D); in the example reconstructed, through a 10 cm high zone the broadest column branches into one narrow column and two other columns both several centimetres wide (only one of which could be shown). Examples seen in the field show that in such cases the columns of intermediate width persist for a few centimetres before branching into narrow columns. Branching of the narrow columns is rare and could not be sampled. The narrow columns also are erect and subparallel but one was seen slightly inclined. The only branching seen well within the broad-column zone was that in which three broad columns formed from one large, hemispherical individual (text-fig. 38B). Coalescing and bridging (massive and delicate) occurs frequently in both zones.

The basal columns start from a flat-laminated substrate as mounds a centimetre or two wide which expand upwards and outwards, forming subspherical, hemispherical, or small columnar individuals (which have not been seen in transverse section). Many of these continue upwards to form broad columns but some do not (Pl. 19, figs. 4–5; text-fig. 38B). The top of the bed is irregular, with adjacent narrow columns finishing at various heights (up to 25 cm) above the top of the broad columns.

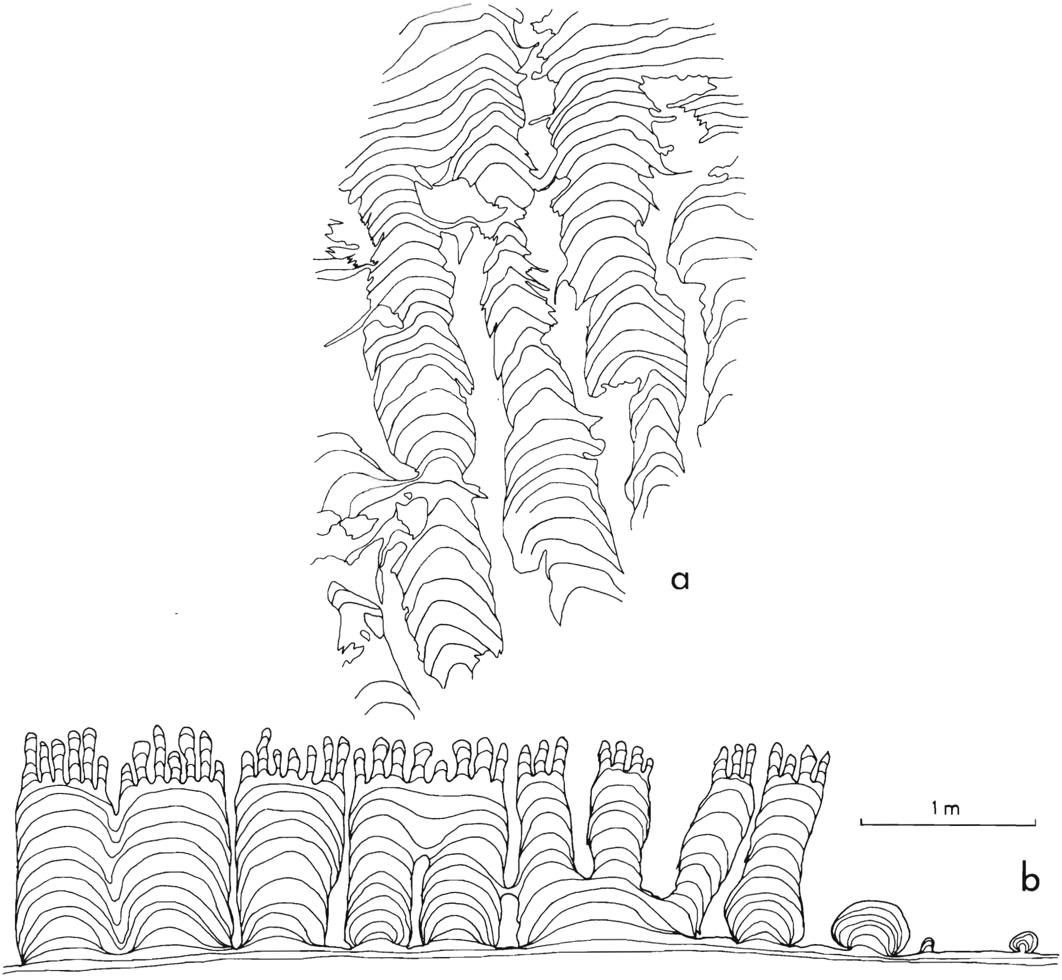
Column Shape. The columns are more or less straight. The basal columns are 30–50 cm wide; their shape in transverse sections is unknown. The margins of the broad columns are nearly straight, although slightly ragged, or have broad, low bumps many centimetres wide; on them are numerous small bumps, peaks, short cornices, and irregular small projections (Pl. 19, fig. 1; text-fig. 37D). The uppermost columns are 1·5–4 cm wide and crudely cylindrical, but in transverse section often they are elongate and markedly indented (text-fig. 37). Their margins are smooth to very ragged with numerous peaks, short cornices, and bridges; broad, low bumps several centimetres wide by about 5 mm in relief occur frequently and there are numerous smaller bumps; there are occasional ribs, often oblique.

Lamina Shape. Within the broad columns most laminae are hemispherical or flattened hemispherical (h/w about 0·6) but some are almost flat (Pl. 19, text-figs. 37D, 38B). Often laminae in subspherical individuals are themselves subspherical (Pl. 19, figs. 4–5); in these individuals many laminae are slightly wavy with flexures 5–10 mm wide by up to 2 mm in relief (there are occasional broader flexures but these have less relief); wrinkling occurs rarely, as do micro-unconformities and wedge-outs. This description probably also applies to laminae in the broad columns, but these have not been studied in thin section.

In the narrow columns laminae are gently domed, rectangular, rhombic, or steeply domed, and infrequently are conical (Pl. 18, figs. 3–4; text-figs. 6D, J, 37, 38); h/w is 0·2–1·0. Many conical laminae are contorted in the crestal area. Shape changes are abrupt or gradational. Most laminae are uniformly curved, but there are occasional flexures up to 7 mm wide by 1 mm in relief. Micro-unconformities occur rarely. Where laminae are steeply domed column margins are smooth and locally walled; usually the wall consists of several laminae and is only a few millimetres high, but rarely patches up to several centimetres long are present.



TEXT-FIG. 37. *Basisphaera irregularis*, Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin. D is from a specimen of the broad to narrow columns branching zone. In A the letter s indicates a stylolite. ×$\frac{1}{2}$; A, C (S346), B (S136), D (S351); R_2.



TEXT-FIG. 38. *Basisphaera irregularis*, Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin. A, Tracing of a longitudinal section of the narrow columns, $\times\frac{1}{2}$ (S346). B, Diagrammatic representation of the mode of occurrence, based on field sketches and photographs (see text-fig. 24).

Microstructure and Texture. Laminae are continuous and of even thickness (Pl. 2, fig. 1). Three major types (dark, pale, and sparry) are distinguishable, with the first two about equally frequent and the third much less so:

1. Relatively dark grey laminae of equigranular, polygonal, hypidiotopic carbonate of 10–80 μ grain size. They are 30–700 μ thick and often occur as lenses 5–15 mm wide. The lens boundaries are smooth and hence the lenses are probably primary. Some laminae almost cross their columns. Some change laterally into laminae of irregular (often angular) dark patches set in a paler matrix like that forming pale laminae. Others grade laterally into pale laminae. Upper and lower boundaries vary from distinct to diffuse. The darkest laminae are almost homogeneous but slightly paler ones are patchily coloured, the patches being irregular and about the same size as the carbonate grains, often forming a reticulate pattern.

2. Pale grey laminae of equigranular, equidimensional (10–80 μ) hypidiotopic carbonate, 30–700 μ thick. These are moderately even and continuous (like the dark laminae); where dark laminae fade out, pale

ones coalesce. Lamina boundaries are smooth except where sparry carbonate is present. The pigment occurs between grains, and forms a finely reticulate pattern clearly visible at 100× magnification. There is often a slightly grumous texture.

3. Colourless laminae of hypidiotopic to xenotopic, equigranular, equidimensional (50–170 μ) carbonate. These occur sporadically. Mostly their thickness is even and 50–100 μ. Some continue across half a column but often they wedge out after only a few millimetres. Some larger, irregular patches of identical carbonate cross and obliterate the lamination.

Many of the thicker dark and pale grey layers described are in fact macrolaminae; in parts of some columns these are conspicuous.

Interspace Fillings. Locally there are numerous small platy intraclasts (up to 6 mm long), indistinguishable from segments of the stromatolite columns, set in a matrix of sparry carbonate (type 3 above). Elsewhere the filling is more nearly homogeneous carbonate with a texture and colour like that of the pale laminae, but cloudy. In parts of the filling are crude laminae 1–4 mm thick.

Secondary Alteration. Since the sparry laminae have discordant apophyses and are identical in texture with carbonate in discordant patches they probably are secondary. Recrystallization of dark laminae is likely to be the cause of the lateral gradation of these into pale laminae. Many irregularities in lamina margins, particularly where the carbonate is coarse grained, are secondary.

Comparisons. Basisphaera irregularis resembles *Acaciella australica* (Howchin), forms of *Kussiella* Krylov, *Boxonia* Korolyuk, and *Jurusania* Krylov. Only the narrow columns of *B. irregularis* resemble *Jurusania*, which lacks the broad basal columns of *Basisphaera*. The gross shapes of *B. irregularis* and *Acaciella australica* are similar, with broad basal columns which branch into narrow columns, but *B. irregularis* has many features lacking in *A. australica*: these include numerous peaks and cornices, abruptly and greatly variable lamina shape in the small columns, and predominantly steeply domed laminae in the broad columns. Forms of *Kussiella* Krylov have more numerous and continuous cornices, and in them branching from broad to narrow columns is randomly distributed; and the laminae of their broad columns are not predominantly steeply domed (Krylov 1967, figs. 2–7); further study may indicate more similarity with *Kussiella* than is presently apparent. In gross shape *B. irregularis* resembles some *Boxonia*, but it lacks the extensive walls and smooth columns which characterize that group and has more abruptly and greatly variable lamina shape.

Distribution. Loves Creek Member of the Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin.

Age. Late Riphean (Adelaidean).

Group BOXONIA Korolyuk

Boxonia Korolyuk 1960, Komar 1966, Cloud and Semikhatov 1969, Raaben 1969*a*.

Type Form. Boxonia gracilis Korolyuk from the Bokson 'suite' of Eastern Sayan, U.S.S.R.

Diagnosis. Stromatolites with subparallel, subcylindrical columns which are walled and have few bumps. Branching is α–β-parallel and frequent.

Content. B. gracilis Korolyuk, *B. grumulosa* Komar, *B. lissa* Komar, *B. krasivica* Golovanov, and *B. bianca* Raaben. Since these forms are distinguished largely by their microstructure it is likely that some will be found to be synonymous; Raaben (1969*a*) places *B. grumulosa* into partial synonymy with *B. gracilis*. *B. divertata* Sidorov is excluded because it lacks all but a patchy wall.

Age. Late Riphean and Vendian.

Boxonia pertaknurra f. nov.

Plate 2, fig. 2; Plate 19, fig. 2; Plate 20, figs. 1–3; text-figs. 6, 39

Boxonia sp. nov. Glaessner, Preiss, and Walter 1969, p. 1057, figs. 2–3.

Material. Five specimens from two localities 110 km apart.

Holotype. S350.

Name. The aboriginal word '*pertaknurra*' was used by Dr. C. T. Madigan as the name for a stratigraphic unit comprising the Heavitree Quartzite and Bitter Springs Formation (from which *B. pertaknurra* comes). It means high range; the Heavitree Quartzite forms such a range.

Diagnosis. Boxonia in which branching predominantly is α-parallel but with moderate frequency β-parallel and rarely γ-parallel; with an almost continuous wall except near the base of beds. Rectangular or rhombic laminae occur moderately frequently; the microstructure is streaky and clotty structures are rare.

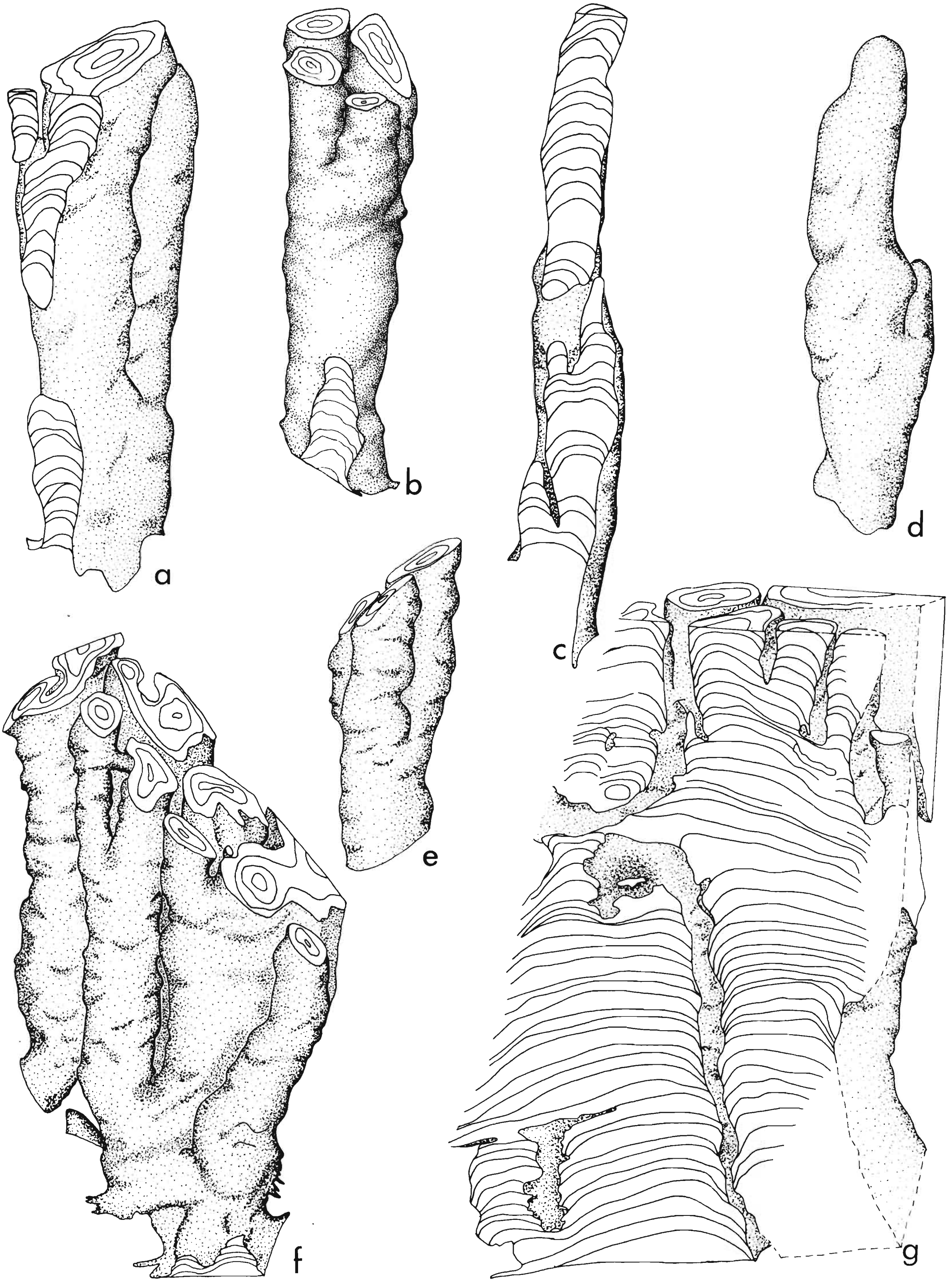
Mode of Occurrence. Two beds are known but due to poor outcrop neither could be traced for more than a few metres. That at Jay Creek is at least 1·7 m thick (Pl. 20, fig. 2), and the Ross River example reaches at least 1·5 m (Pl. 20, fig. 1).

Column Arrangement and Branching. Columns are erect, subparallel, and less than 1 cm apart. Broad columns locally prevail in the lower 20 cm of the beds but narrow columns frequently start directly from the base of a bed; most broad columns persist for less than 20 cm before forming narrow columns by multiple α-parallel branching (text-fig. 39F, G); this branching is randomly distributed within the lower 20 cm of the beds. At Jay Creek the bed covers an erosional surface on which there is local relief of several centimetres. Many columns stand on erosional highs; wavy laminated carbonate is draped over both highs and lows but on highs it is thicker. Within 1 cm of height the basal 'mat' resolves into interconnected columns and within a further centimetre or two into discrete columns. Branching of the narrow columns is frequent, dichotomous or multiple, predominantly α-parallel, with moderate frequency β-parallel, and rarely γ-parallel; up to four new columns are formed (text-fig. 39). Bridging between narrow columns occurs infrequently.

Column Shape. The broad basal columns are 5–10 cm wide with irregular transverse sections; bridging and coalescing occur frequently. Narrow columns are straight and subcylindrical, 1–5 cm wide. In transverse section most are round to rounded indented polygonal, but some are irregularly elliptical, especially near their bases. The columns are relatively smooth, but have numerous bumps 5–10 mm wide by up to 2 mm in relief, and some short transverse and diagonal ribs. Abrupt irregularities with greater relief are rare; many that are present on the reconstructions are seen in thin sections to have formed by stylolitization. Parts of columns are featureless and smooth.

Lamina Shape. In the broad, basal columns laminae are rectangular or rhombic, their edge portions forming a multilaminate wall even on overhanging segments of column margins (Pl. 19, fig. 2); locally stylolites mark column margins and here walls are absent; infrequently there is no wall although the margins are preserved. The tops of some laminae are slightly concave (such laminae also occur in the narrow columns).

In narrow columns laminae are hemispherical, rectangular, rhombic or, rarely, nearly conical (Pl. 2, fig. 2; text-figs. 6B, F, 39). Flattened (rectangular or rhombic) laminae are especially prominent below



TEXT-FIG. 39. *Boxonia pertaknurra*, Bitter Springs Formation, Amadeus Basin. B, E–G, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement. F and G are from the base of a biostrome; note the absence of broad, basal columns in F. B is an excellent example of α-parallel branching, ×½; B, E, F (S350), G (S354); R_1. A, C–D, 1 mile north-north-west of Ross River Tourist Camp, ×½ (S391), R_3. Poor preservation makes identification uncertain.

places of branching. A wall is almost always present; often it consists of ten to fifteen 20 μ thick laminae. Most shape changes are gradational. The laminae are relatively smooth, with infrequent large flexures. Flexures 1-3 mm wide by 0·5-1·0 mm in relief are locally numerous. Micro-unconformities are rare.

Microstructure and Texture. In thin sections of columns with either calcite or dolomite preservation the lamination is indistinct. In the central parts of columns laminae are 100-700 μ thick; dark laminae frequently are thicker than contiguous pale laminae (Pl. 2, fig. 2). In both calcite- and dolomite-preserved columns three types of laminae (dark, pale, and sparry) can be distinguished. The following description of a calcite-preserved example applies with very little modification also to dolomite-preserved columns:

1. Relatively dark laminae of xenotopic, equigranular carbonate of 10-35 μ grain size. Many continue across most of the width of a column and the majority can be traced for about 1 cm; almost always they grade laterally into pale carbonate, or break up into a grumous texture with pale carbonate as the matrix, or end abruptly against a patch of pale carbonate. The most continuous and homogeneous laminae have very smooth, abrupt, or diffuse borders; the others have irregular borders. They are coloured by a pale brown pigment which could not be resolved at 1200× magnification, and 1-3 μ wide patches of orange coloured matter were seen in some laminae. In the walls there is a concentration of diffuse green-grey pigment not resolvable at 1200× magnification.

2. Very pale grey laminae of xenotopic, equigranular carbonate of 10-35 μ grain size. These form the matrix to darker laminae and their shape depends on the shape of the included dark laminae. Where dark laminae fade out paler laminae coalesce; many patches of columns are largely pale carbonate. Laminae of these first two types prevail.

3. Colourless 50-200 μ thick laminae of xenotopic to idiotopic carbonate which often is acicular. The acicular crystals, up to 70 μ by 170 μ, are perpendicular to the lamination. These laminae often cross most of a column, but frequently the same carbonate forms elongate, concordant lenses, or irregular, discordant patches up to 500 μ wide. Grains reach a width of 170 μ in the larger patches. The lenses and patches grade into dark or pale laminae. In the areas of intergradation faint clotty or grumous textures occur; the clots are up to 300 μ wide and have indistinct boundaries.

Interspace Fillings. Interspaces between the calcite-preserved columns are filled with almost homogeneous, inequigranular, xenotopic to idiotopic dolomite of 15-50 μ grain size. Here and there are remnants of platy intraclasts up to 3 mm long. The dolomite grains project into column margins as if parts of the columns have been obliterated by dolomitization.

Interspaces between the dolomite-preserved columns are filled with 7-50 μ wide xenotopic to idiotopic carbonate the same as that forming the columns. Intraclasts up to 2·5 mm long are locally numerous, especially near column bases; many are of the '*Vesicularites*' type (Zhuravleva 1964). Many intraclasts have a darker marginal zone 50-100 μ wide. Parts of the fillings are laminated.

Secondary Alteration. Lamina shape shows that in the specimens from the Ross River area the greater part of the walls and up to half of the width of the columns were obliterated or removed during dolomitization and stylolite formation. Roughly concordant stylolites occur within columns but are much less common than in some other stromatolites (e.g. *Inzeria intia*). Occasional discordant patches and veins of coarsely crystalline (up to 170 μ), xenotopic carbonate are clearly secondary, and no clear distinction between these and the sparry laminae is possible; the veins cut all three lamina types. The lateral gradation of dark and pale laminae into sparry laminae suggest that the sparry carbonate is secondary, as does its coarse grain size. Similarly, dark laminae grade laterally into the pale laminae; relationships between these types suggests that much of the pale carbonate formed by recrystallization of the darker material. It follows that the grumous and clotty textures are secondary.

Comparisons. In gross shape this stromatolite resembles *Acaciella*, *Kussiella* Krylov, *Boxonia* Korolyuk, and to a much lesser extent *Katavia* Krylov. The columns are much less bumpy than those of *Katavia* and the presence of a continuous multilaminate wall clearly distinguishes it from *Kussiella* and *Acaciella*.

In most features it is a typical form of *Boxonia*; the one exception is that in all other forms clotty or grumous textures apparently are ubiquitous (and are considered taxonomically significant). Reconstructions only of *B. lissa* Komar and *B. gracilis* Korolyuk have been published and they are indistinguishable from those of *B. pertaknurra*. The significance of the clotty and grumous textures is obscure: some of the illustrated specimens of *B. lissa* obviously are much recrystallized; in at least two of the described forms clotty and grumous textures occur in interspace fillings as well as columns. A specimen of *B. gracilis* from the Bokson suite, near the River Bokson, sent by M. A. Semikhatov and I. N. Krylov, has a clotty texture consisting of pigment accumulations around detrital carbonate grains. However, in our specimen of *B. grumulosa* Komar from the U.S.S.R. the clots are unrelated to grain sizes and grain boundaries, and may predate the present grains. The well-preserved laminae of *B. pertaknurra* are evenly pigmented; until other forms are fully described and sufficiently reconstructed this feature must serve to distinguish *B. pertaknurra* as a new form. In addition, the laminae are not wrinkled or as steeply domed as those of *B. lissa*. The original description of *B. krasivica* Golovanov has not been available to me.

Distribution. Loves Creek Member of the Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement and 1 mile north-north-west of Ross River Tourist Camp.

Age. Late Riphean (Adelaidean).

Group INZERIA Krylov

Inzeria Krylov 1963, 1967, Cloud and Semikhatov 1969.
Inseria (partim) Raaben 1964, 1969*a*.

Type Form. Inzeria tjomusi Krylov from the Katav 'suite' of the Southern Ural and Demin 'suite' of the Polud Mountains, U.S.S.R.

Diagnosis. Stromatolites with subparallel, subcylindrical, usually ribbed columns, frequently with niches containing projections. Branching α–β-parallel or slightly divergent, infrequently γ-parallel or markedly divergent; some branches start in niches. The columns are naked or walled.

Content. I. tjomusi Krylov, *I. toctogulii* Krylov; possibly *I. nimbifera* (Semikhatov), *I. confragosa* (Semikhatov), *I. djejimi* Raaben, *I. nyfrislandica* Raaben, *I. macula* Golovanov, and *I. variusata* Golovanov. Golovanov's descriptions of *I. sovinica* and *I. chunnbergica* have not been available to me. *I. djejimi* would possibly be better classified as *Baicalia*.

Age. Late Riphean.

Inzeria intia f. nov.

Plate 3, figs. 1–5; Plate 20, figs. 4–5; Plates 21–23; text-figs. 7, 40–43

Inzeria sp. nov. I Glaessner, Preiss, and Walter 1969, p. 1057, figs. 2–3.

Material. Fifteen specimens from two localities 117 km apart.

Holotype. S372.

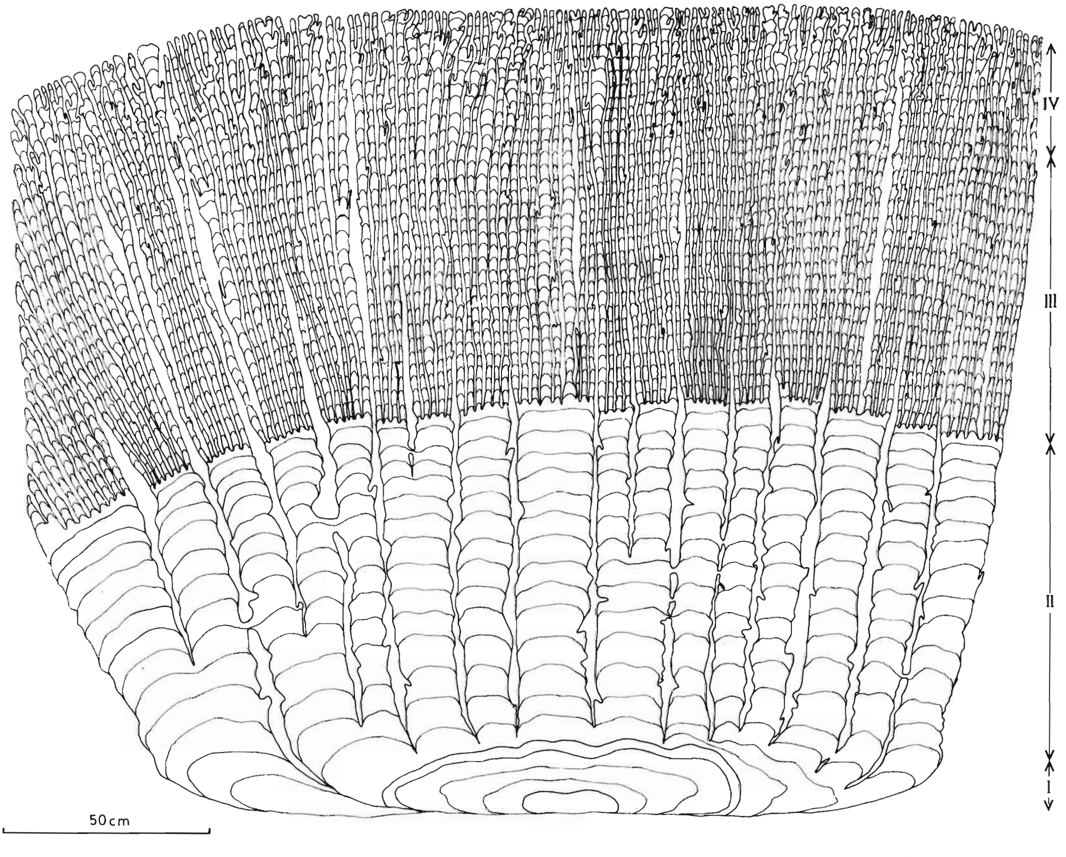
Name. In the language of the Aranda (Arunta) tribe of Aboriginals who lived in the Macdonnell Ranges *intia* means cave. In the columns of *I. intia* there are numerous niches.

Diagnosis. *Inzeria* in which predominantly the niches and projections are transversely elongate, even in subcylindrical columns, and whose columns have very irregular margins, with or without a wall.

Mode of Occurrence. *Inzeria intia* is well known from one biostrome (Pl. 21, fig. 1) which probably is domed; this biostrome varies gradually in thickness from 1–2 m over the 1 km for which it has been traced (without finding its ends). Two *I. intia* beds of uncertain shape each about 1 m thick occur about 2 m above and 1 m below the main biostrome in two separate small areas.

Column Arrangement and Branching. In the field there is an obvious division of the main biostrome into two parts, upper and lower, of similar thicknesses. Closer investigation allows two-fold subdivision of each of these. For convenience the resulting four divisions are numbered upwards I–IV (text-fig. 40):

I: The basal 30 cm or so of the biostrome consists of irregular columnar-bedded, pseudocolumnar or



TEXT-FIG. 40. *Inzeria intia* mode of occurrence. Diagram showing one bioherm from within a biostrome, 1 mile north-north-west of Ross River Tourist Camp, based on occurrences such as that in Pl. 20, fig. 5; Bitter Springs Formation, Amadeus Basin. Stage I is frequently more complex than shown here (see Pl. 21, figs. 4–5). Note the different forms of the two bioherm margins shown.

cumulate stromatolites (Pl. 21, fig. 5). The columnar units are 1·5–15 cm wide, oriented at from 20° above the horizontal to vertically, often radially arranged about one centre at the base of each dome and curving upwards to become more nearly vertical. Possibly most often the column arrangement is more complex than that just described, there being frequent branching of new columns from the sides of others (Pl. 21, fig. 4), as also occurs in stage II. *I. intia* I forms contiguous domes usually a metre or more wide and 30 cm in relief; the domed shape persists upwards through the biostrome, but the shape of the biostrome top is uncertain. *I. intia* I can exist alone and is not always found at the base of the main biostrome, i.e. locally *I. intia* II forms the base of the biostrome.

II: From the irregular stromatolites of stage I or directly from basal flat laminae protrude straight, mostly erect, 2–12 cm wide columns. These are arranged perpendicularly to their substrate which usually is domed, so they fan out over the domes (Pl. 20, fig. 5; Pl. 21, fig. 3; text-fig. 40). Locally over the flanks of stage I mounds separate columns are impersistent (bridging and coalescing occur frequently; Pl. 21, fig. 3). Bridges between columns occur moderately frequently and are delicate or massive. Interspaces are mostly less than 1 cm wide. Infrequently or moderately frequently columns divide by α-parallel branching: the columns formed from one trunk are often of different widths. More often new columns form by the upward growth of projections originating from niches in column margins. Initially these new columns may be inclined at up to 40° to the axis of the parent column, but they curve upwards to become parallel; many end after only a few centimetres (text-fig. 41F). Longitudinal sections through columns with such branches are often hand-shaped (Pl. 22, figs. 4–5).

The thickness of stages I + II gradually decreases south-westerly along the main biostrome and in addition the proportions of the stages vary. Over much of the length for which the biostrome was traced stage I is 30 cm thick and stage II 60–70 cm, but locally stage I is over 40 cm thick and stage II only 15 cm. Between adjacent domes stages I and II may both be thin. Nowhere except possibly in the hollows between some domes is stage II absent, and *I. intia* II can occur independently. A bed 2 m above the main biostrome is formed only of *I. intia* II (text-figs. 41B, F, 43J) overlying a domed substrate in which the lamination is continuous. Another bed just below the main biostrome also appeared to consist only of *I. intia* II but was poorly exposed.

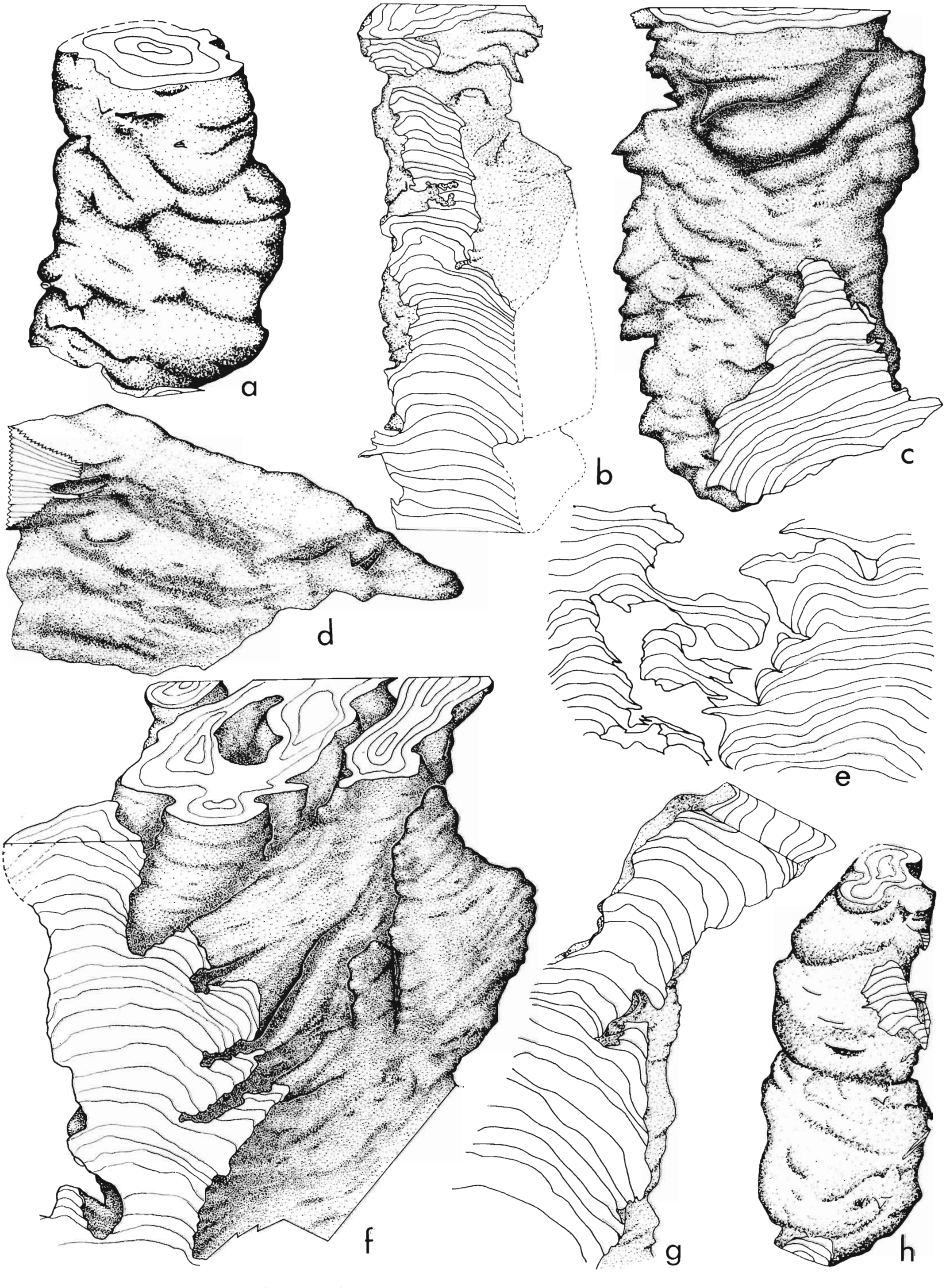
III: Over a zone about 10 cm wide, by successive α- or β-parallel multiple branching, the broad columns of stage II form numerous columns 1–3·5 cm wide (Pl. 20, figs. 4–5; text-figs. 40, 42). The branching zone within each biohermal unit is domed. One broad column may branch into over twenty narrow columns (an estimate based on text-fig. 42). Stage III is about 70 cm thick. Most columns are straight, erect, and parallel but near their bases they are perpendicular to the domed surface of *I. intia* II, and, consequently, radially arranged; the radial arrangement results in the crowding out (but not coalescing) of some columns on the margins of domes. The columns curve upwards to become erect. Locally groups of columns are bent. Columns are only several millimetres apart. Branching is rare and apparently α- or β-parallel and dichotomous; it was not possible to sample this but incipient branching in which columns failed to separate was seen in thin sections.

IV: The columns of stage III continue up into stage IV but there the structure changes. Branching and coalescing occur frequently, some columns expand (to as wide as 7·5 cm), crowding out others, and columns often bend so that adjacent columns may be differently oriented (Pl. 22, fig. 1). The branching is α- or β-parallel and dichotomous, or possibly slightly divergent (text-fig. 43A, H). At the top of stage IV all of the columns are bridged over; whether the upper surface is domed or flat is unknown.

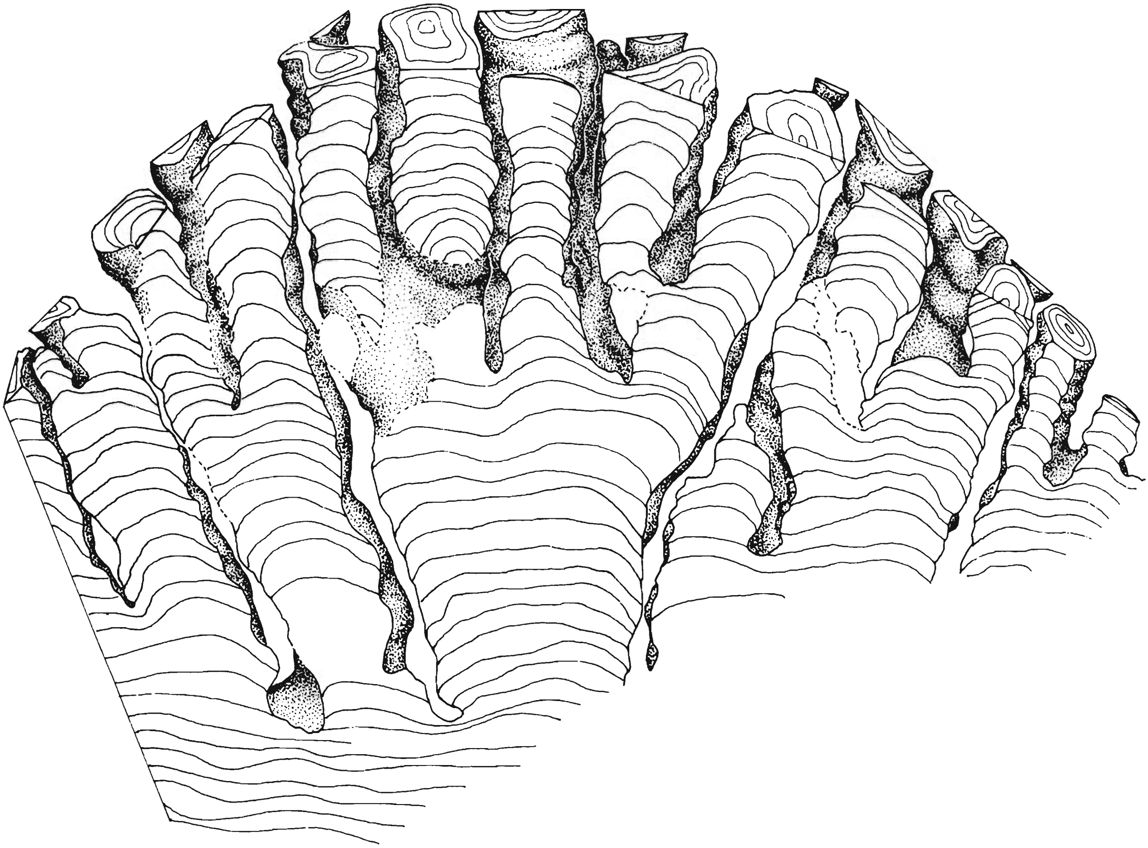
Column Shape. Two features are consistently developed throughout the complex biostrome; columns in all four stages have ribbed margins and niche-enclosed projections, which predominantly are transversely elongate.

I: Little can be added to the description given above. Columns are 1·5 cm to 15 cm or more wide, often crooked; transverse shape mostly is unknown, but one example is elongate. Projections about 1 cm wide and high, with rounded tops, are enclosed in niches; the one example reconstructed is elongate (text-fig. 41G). Column margins are ribbed, and there are occasional cornices.

II: The straight or curved columns of stage II are 2–12 cm wide; transverse sections are round, rounded polygonal, elliptical, or rectangular, always with numerous indentations of various sizes (text-figs. 41, 43J). Ribbing is prominent; ribs range from about a millimetre to almost 2 cm wide; some continue halfway



TEXT-FIG. 41. *Inzeria intia*, Bitter Springs Formation, Amadeus Basin. A, H, 1 mile north of Ross River Tourist Camp. B–G, 1 mile north-north-west of Ross River Tourist Camp. A–D, F, H, Stage II columns; B and F occurred separately but the others are from the complex biostrome. E, G, Stage I; E is a tracing of a section normal to bedding—note the niches. Both are from the complex biostrome. A–H, $\times\frac{1}{2}$; A, H (S94), B (S369), C–D (S372), E, G (S142), F (S138). All R_1.



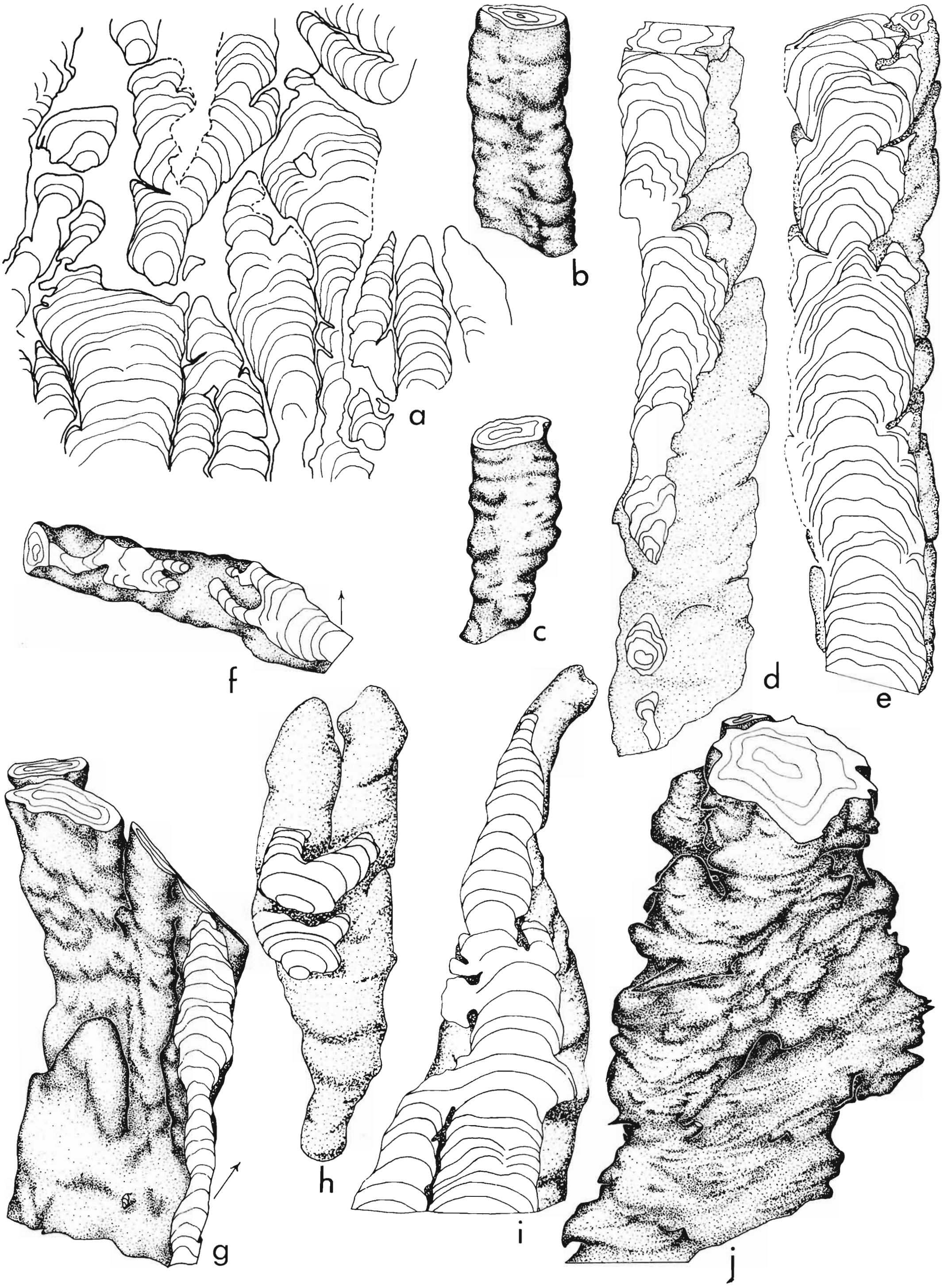
TEXT-FIG. 42. *Inzeria intia*, Bitter Springs Formation, 1 mile north-north-west of Ross River Tourist Camp, Amadeus Basin. The branching zone from stages II–III. $\times\frac{1}{2}$ (S141), R_2.

around a column, or even further, but most are less than 3 cm long. Frequently the indentations between ribs deepen into transversely elongate niches ('pockets'), one or both ends of which may be closed; concomitantly the ribs grade into elongate projections. Most, but not all, projections and niches are elongate, even in columns which are not. Infrequently, the projections grow upwards into new columns (Pl. 22, fig. 4; text-fig. 41F). Rarely projections are not in niches. Small peaks and cornices occur with moderate frequency.

III: Columns in stage III are subcylindrical with rounded polygonal transverse sections except near their bases where some are elongate (text-figs. 42, 43B, C, F, G). Column margins are ribbed and bumpy. Although no niches or projections are present on reconstructions of this stage they occur moderately frequently, as can be seen in thin sections (Pl. 22, fig. 2). Alteration of column margins hampers reconstruction, but peaks and cornices appear to be absent except possibly near the base of the stage.

IV: Again alteration hampers precise reconstruction, but elongate niches and projections are prominent, as are broad, low bumps. Ribbing is present but not prominent and peaks and cornices apparently are absent. Some columns are elliptical in transverse section. Gradual upward expansions or contractions of columns occur frequently (text-fig. 43A, D, E, H, I).

Lamina Shape. Laminae in columns of similar width from the different stages of *I. intia* have very similar shapes (text-figs. 7A–E, 41–43). Those in the broad columns in stages I and II, at the base of stage III, and in parts of stage IV are mostly gently convex, almost flat, rectangular or rhombic; i.e. laminae in broad columns rarely are steeply domed. Most laminae in narrow columns are steeply domed, rectangular,



TEXT-FIG. 43. *Inzeria intia*, Bitter Springs Formation, 1 mile north-north-west of Ross River Tourist Camp, Amadeus Basin. A, Stage IV columns—tracing of a longitudinal section, $\times\frac{1}{3}$ (S371). B–C, Stage III columns. No well-formed niches are present in these examples but they do occur in stage III columns (see Pl. 22, fig. 2), $\times\frac{1}{2}$ (S143), R_1. D–E, H–I, Stage IV columns, $\times\frac{1}{2}$; D–E (S370), R_1; H–I (S371), R_2. F–G, Base of stage III, from near a bioherm margin—the arrows indicate original vertical, $\times\frac{1}{2}$ (S379), R_2. J, Stage II column from a simple biostrome, $\times\frac{1}{2}$ (S369), R_1.

rhombic, or, infrequently, conical. Asymmetrical laminae are prominent in columns of stages I and II. There is an essential difference in lamina shape between the lower and upper two stages. Columns of stages I and II often have slightly ragged margins due to projecting laminae; some laminae turn upwards into interspaces or are slightly concave upwards near column margins (Pl. 3, fig. 3). In the lower stages small areas of wall are sparsely distributed (covering about 5 per cent of the area of column margins), but at the base of stage III, in the multiple branching zone, columns become more and more continuously walled upwards until they are coated by a continuous multilaminate wall (Pl. 22, fig. 2; Pl. 23, fig. 1). This continues into stage IV but there column margins are poorly preserved and so the continuity of the wall is not well established (Pl. 23, figs. 2, 4). In stage III the wall is 0·05–2·0 mm thick and formed from several to more than ten laminae; individual laminae can be traced down column margins for up to 1 cm.

Most lamina shape changes within columns are gradational, but some are abrupt. Laminae in all stages are slightly wavy, with flexures several millimetres wide and mostly less than 2 mm in relief. Laminae in stages III and IV are wavier than those in the lower stages. A slight wrinkling of laminae is almost always a secondary effect associated with stylolite-formation and recrystallization.

Columns of stage II are often coated with a homogeneous layer of fine-grained carbonate 0·5–2·0 mm thick; this is unconformable on the column laminae.

Microstructure and Texture. There are many features in common in the microstructure of all four stages (Pl. 3).

The most prominent layering is a macrolamination 0·5–2·0 mm thick. Many of these have pale bases grading up into dark upper parts with sharply defined tops. Many macrolaminae can be traced for several centimetres (i.e. right across narrow columns). Gradual thickness changes eventually leading to wedge-outs are numerous; discrete lenses less than 1 cm wide occur moderately frequently. Occasionally macrolaminae are cut off at micro-unconformities. Where well preserved, the macrolamina boundaries are smooth.

Laminae are variously very faint or prominent, and mostly 50–150 μ thick, although some are as thin as 15 μ; few continue for more than 2–3 mm before fading out. Where well preserved their boundaries are abrupt and smooth. The darkest are formed of equigranular, polygonal, xenotopic carbonate of 3–20 μ grain size whereas in the paler varieties, especially in the pale lower parts of macrolaminae, the texture tends to be hypidiotopic and a little coarser grained, up to 30 μ wide. As is usual the paler carbonate forms a matrix for the dark laminae, i.e. dark laminae grade laterally into pale carbonate.

Intraclasts occur infrequently to moderately frequently within the columns. Most are about 150 μ wide; the largest seen is 600 μ long by about 150 μ thick. Tabular forms lie parallel to the lamination.

As well as these features common to all stages there are marked differences. In stages I and II concordant stylolites and thin concordant laminae of sparry carbonate occur prolifically in most columns. Concordant stylolites are much less common in the upper stages; very pale and sometimes sparry laminae are numerous in the upper stages but less conspicuous than below. Related to the occurrence of these features is the irregular shape of lamina borders in the lower stages.

Interspace Fillings. Where not completely obliterated by secondary processes (as throughout much of stages III and IV) the fillings contain numerous intraclasts, mostly tabular, or consist largely of crudely laminated fine-grained carbonates. One 2 cm long intraclast stands vertically (base of stage III) indicating at least this much relief during growth; the wall also indicates about 2 cm of relief.

Secondary Alteration. Concordant stylolites, which are concentrated in the lower stages, frequently have along them concentrations of brown pigment; as a result many look like thin, wrinkled laminae. The concentration of concordant stylolites in stages I and II may be related to the near absence of a wall on these columns, i.e. a wall may inhibit fluid movement thus hampering stylolite formation; or there may have been compositional differences, with soluble materials concentrated in stages I and II. The sparry laminae which constitute up to 30 per cent of the volume of a column are composed of hypidiotopic to idiotopic carbonate of 50–120 μ grain size; they have numerous apophyses which transgress contiguous laminae. Locally such carbonate is not concentrated along laminae but forms numerous small patches, or forms the coarse component of a grumous texture. Grumous textures of this type obliterate much of the lamination near the margins of stage IV columns; in addition stylolites follow many of these margins. Grumous textures composed only of the dark and pale fine-grained carbonates occur in many of the slightly altered parts of columns.

Comments. Evidence from intraclast orientation, bridge shape, and walls indicates up to at least 10–15 mm of relief during the growth of stages I and II and at least 20 mm of relief during that of the upper stages. This does not imply that there was always more relief during the growth of the upper stages. The homogeneous carbonate covering (selvage) on stage II columns may be due to late growth of algae on column margins, as occurs at Shark Bay, Western Australia, on modern stromatolites.

The acquisition of continuous walls seems to occur concomitantly with the branching into narrow columns at the base of stage III; the surface at which this happens is domed and thus these two changes (branching and acquisition of a wall) were not caused by upward growth into shallower water.

Comparisons. This stromatolite can readily be classified as *Inzeria* because of the consistent and frequent possession of niches with projections, of long, straight, ribbed columns and of parallel branching and branching by the growth of the niche-enclosed projections.

Longitudinal sections of columns from stage II (Pl. 22, fig. 4) are indistinguishable from those of *Inzeria tjomusi* (Krylov 1963, pl. 13). Their microstructures and lamina shapes are remarkably similar. However, *I. intia* has predominantly elongate niches and projections, in contrast to those of *I. tjomusi*, and the column margin structure of *I. intia* apparently is more irregular than that of *I. tjomusi* (even as broadly employed by Raaben 1969*a*). The complexly biostromal form of *I. intia* is unique (but the upper part of *I. tjomusi* is not well known; Krylov 1963). The same features differentiate *I. intia* from all other described forms. In addition, niches are more frequent than in *I. toctogulii* Krylov and the γ-parallel and slightly divergent branching common in that form are lacking. The columns of *I. djejimi* Raaben and apparently also *I. nyfrislandica* Raaben tend to be tuberous and crooked; it is interesting that they are described as being walled (Raaben 1964, 1969*a*) whereas other Russian forms (except in the broad usage of Raaben 1969*a*; Golovanov 1966) are not, but they do have a covering homogeneous layer of carbonate (a 'selvage', Semikhatov and Krylov, pers. comm., 1969) as does *I. intia* II. Semikhatov's (1962) illustrations of *I. nimbifera* show columns with smooth margins, in contrast to other forms of *Inzeria*. Raaben (1969*a*) places *I. nimbifera* into synonymy with *I. tjomusi* but the reconstructions apparently of *I. nimbifera* shown in her figure 20 do not support this. These reconstructions show irregular, almost tuberous, columns quite different from those of *I. intia* and the original *I. tjomusi*.

Distribution. Loves Creek Member of the Bitter Springs Formation, 1 mile north-north-west of Ross River Tourist Camp, east MacDonnell Ranges. Bitter Springs Formation(?), 'Gills Pass' ('Rudd's Gap') several miles west of Jay Creek, west MacDonnell Ranges (collected by Dr. C. T. Madigan on 4 June 1930), Amadeus Basin.

Age. Late Riphean (Adelaidean).

Group JURUSANIA Krylov

Jurusania Krylov 1963, Raaben 1964, Semikhatov, Komar, and Serebryakov 1967, and Rozanov *et al.* 1969.

Type Form. Jurusania cylindrica Krylov from the Katav 'suite' of the Southern Ural and Demin 'suite' of the Polud Mountains, U.S.S.R.

Diagnosis. Stromatolites with subcylindrical, subparallel columns which are naked or have patchy walls. Branching is infrequent and usually α–β-parallel.

Content. J. cylindrica Krylov, *J. nisvensis* Raaben, *J. tumuldurica* Krylov, *J. allahjunica* (Komar and Semikhatov), *J. judomica* Komar and Semikhatov. Krylov and Shapovalova (1970*b*) note that *J. nisvensis* may be a synonym of *J. cylindrica.*

Age. Late Riphean and Vendian.

Jurusania nisvensis Raaben 1964

Plate 4, figs. 1, 3; Plate 24, figs. 1–4; text-figs. 8, 44

Material. Four specimens from one locality.

Mode of Occurrence. Only one bed with this stromatolite is known (it could occur more frequently, but when preserved as dolomite is inconspicuous in the field). Within the bed are isolated domed bioherms up to 3–4 m wide and nearly 2 m high (Pl. 24, fig. 1; Pl. 31, fig. 1; text-fig. 44G). These are spaced several metres apart (only three bioherms were seen, but the bed was not investigated over more than a few tens of metres).

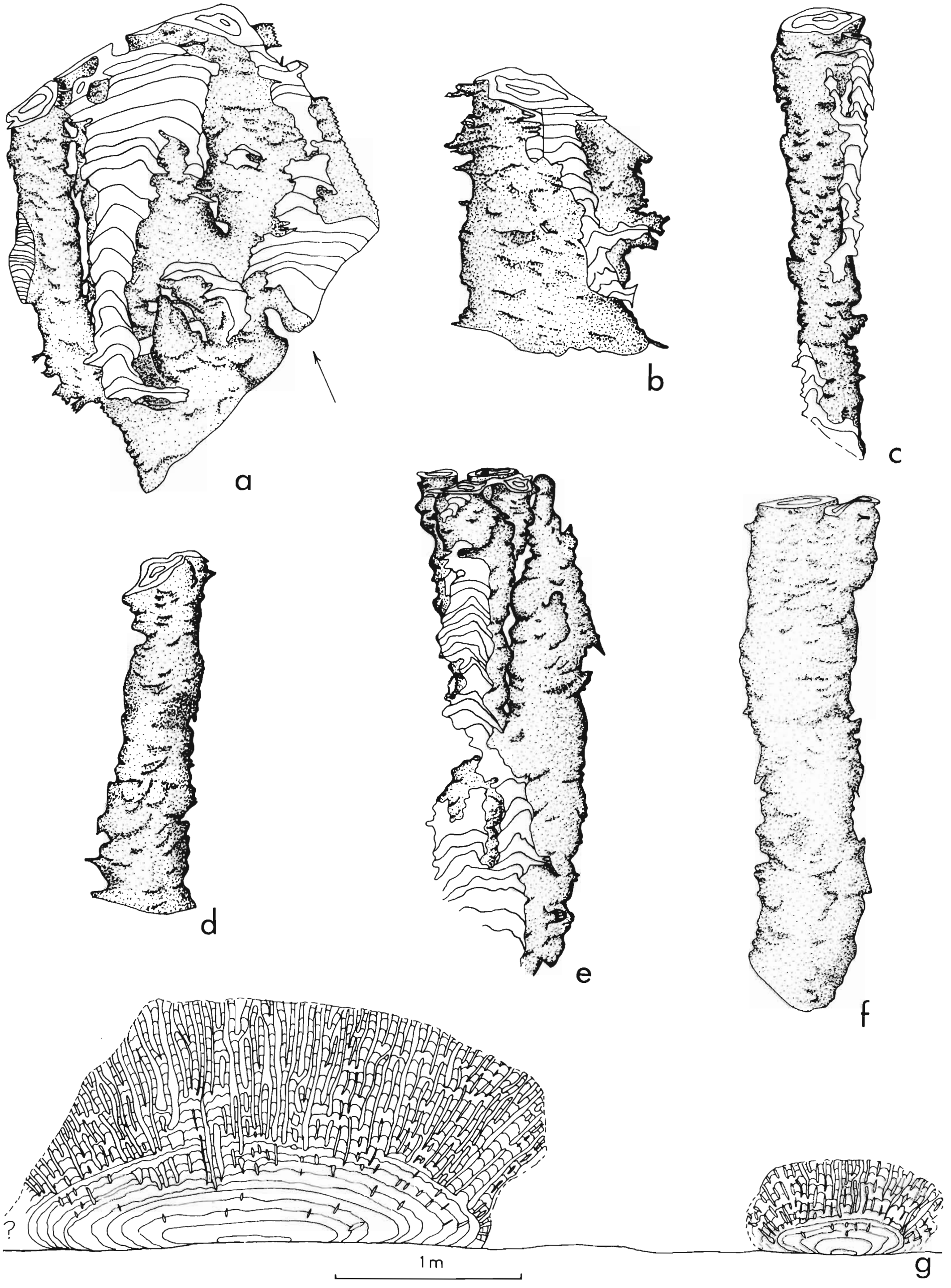
Column Arrangement and Branching. One bioherm, typical of the three, was studied in detail; within it there are superimposed zones, a lower stratiform zone overlain by a columnar zone (text-fig. 44G). The boundary between the two zones is gradational, columns becoming more and more discrete upwards. The lower zone is about 60 cm thick with laminae gently convex in the central part of the bioherm and re-entrant around its margins. Within this zone layering is mostly continuous but is broken occasionally to form columns a centimetre or two high and of a similar width. Over an interval of several tens of centimetres columns become more and more numerous and bridges fewer and fewer. The upper metre of the studied bioherm is largely columnar, although bridging still occurs frequently (particularly where columns are inclined, on the bioherm margins), and some bridges join many columns. Individual columns continue through the full 17 cm height of one specimen.

The columns are less than 1 cm apart and almost straight. Near the central part of the bioherm they are parallel but on the margins are radially arranged. The degree to which columns are inclined on the bioherm margins is uncertain because in the field they are indistinct, but in a specimen from the upper part of one margin they are 25° below the vertical.

Branching occurs infrequently. New columns may branch off the side of a column (text-fig. 44E); this is similar to, but strictly not, γ-parallel branching. Some α- and β-parallel branching is present.

Column Shape. Columns are almost straight and are 1–5 cm wide with irregular transverse sections which are rounded but indented and often elongate (text-fig. 44). Margins are irregular, with numerous discontinuous small cornices and ribs, infrequent peaks, and many small bumps. Longitudinal furrows occur infrequently. Rarely there are small, blunt-ended projections.

Lamina Shape. In the lower zone of the bioherm laminae are wavy with numerous interspaces and depressions (Pl. 24, fig. 3). Pseudocolumns about 1 cm wide are present. At interspaces laminae are sharply deflexed but no wall is present.



TEXT-FIG. 44. *Jurusania nisvensis*, Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin. A–B, ×½ (S352), R_1. Arrow in A indicates original vertical. C–F, ×½ (S134), R_1. G, Mode of occurrence; diagram based on field photographs and sketches and on laboratory examination of specimens. The bioherm on the left is that in Pls. 24, fig. 1 and 31, fig. 1. The details are diagrammatic. The broken lines show the limits of good outcrop.

Within columns the lamina shape is very irregular (text-figs. 8A, 44), varying from almost flat through gently domed, steeply domed to conical (with apical angles as small as 45°); h/w is 0·2–0·7. Abrupt shape and thickness changes occur frequently. Locally laminae are folded, contorted, and fractured. Column margins often are indistinct but where visible laminae end abruptly at the margin. No wall was seen.

Microstructure and Texture. It is convenient to discuss the column laminae as three basic types (dark, pale, and sparry), although these intergrade (Pl. 4, fig. 1):

1. Dark grey to brown-grey laminae of idiotopic to hypidiotopic carbonate of 30–50 μ grain size, coloured by unresolvable pigment. They are 100–200 μ thick, often discontinuous, and frequently grade laterally into pale laminae. The darkest examples have within them a finely braided pattern of roughly concordant stylolites. Lamina boundaries vary from abrupt and distinct (smooth or irregular) to diffuse. The laminae are moderately continuous: they can often be traced almost across a column. Thickness variations are irregular and abrupt, especially where sparry carbonate predominates.

2. Indistinct pale grey laminae and irregular patches of idiotopic to hypidiotopic carbonate of 20–70 μ grain size. Within these there is a mottled distribution of pigment with uneven patches about 30 μ wide. The laminae are 50–2000 μ thick, most being about 500 μ; but their thicknesses vary greatly since they grade laterally and vertically into dark and sparry laminae. Where their boundaries are abrupt and distinct they often consist of contiguous lenses and blunt-ended segments which sometimes overlap as if thrust across each other. Some pale laminae extend for the full width of a column. Patches of sparry carbonate occur frequently within these laminae. Locally lamination is indistinct and lamina boundaries diffuse; here occur tabular or irregular patches composed of all three carbonate types.

3. Laminae and patches of colourless, coarse-grained (up to 700 μ) xenotopic, equidimensional, interlobate, or amoeboid carbonate, grains of which often include small idiomorphic grains of grey carbonate of the types described above. Such coarse carbonate rarely forms whole laminae but is the matrix enclosing finer-grained patches, i.e. is a component of grumous laminae. The finer-grained patches are 10–25 μ wide, closely spaced and irregular in shape, with distinct boundaries. Some of these laminae cross most of a column but patchy and grumous textures are restricted and only vaguely related to the lamination. Some irregular patches up to 5 mm wide consist of a single grain.

Sparry carbonate is scarce in the lower part of the bioherm, where columns are fewer (Pl. 4, fig. 3). Here the lamination is distinct and may reasonably be interpreted as more nearly like the original structure. It is formed by an alternation of pale and dark grey laminae:

1. Dark grey laminae, of fine-grained (about 10 μ) xenotopic carbonate, which are continuous for several millimetres and vary little in thickness. Their thickness is 50–450 μ, and they have distinct, smooth boundaries. They are slightly wavy and locally slightly wrinkled. Many resemble the dark grey laminae of the columns.

2. Pale grey laminae of xenotopic to hypidiotopic 10–40 μ grain size carbonate. The palest have numerous 30–40 μ wide carbonate rhombs. In size, continuity, and boundary structure they are similar to the dark laminae, but occasionally are thicker than contiguous dark laminae. Locally they are indistinct and have a grumous texture.

Interspace Fillings. The interspaces are filled with pale grey-brown, almost homogeneous, equigranular, polygonal, xenotopic to hypidiotopic carbonate of 15–50 μ grain size. Locally there are diffuse darker patches which may be intraclast remnants. In places sparry carbonate is prominent and there grumous textures are common.

Secondary Alteration. The even, smooth, moderately continuous laminae of the basal part of the bioherm are taken as most nearly original. Even there they grade into grumous laminae but it is only in the columns that sparry carbonate becomes prominent. As sparry carbonate and grumous textures become more extensive laminae become more irregular and less distinct. The fracturing, displacement, and considerable contortion of some laminae may be secondary and due to replacement processes accompanied by volume changes, or to compression by overlying sediment; or they could be desiccation structures. But secondary processes are unlikely to account for all of the lamina shape variability.

Comparisons. There are similarities with the groups *Acaciella*, *Katavia* Krylov, *Kulparia* Preiss and Walter, *Patomia* Krylov, *Aldania* Krylov, and *Parmites* Raaben. The lack of a wall excludes *Katavia*, *Kulparia*, and *Patomia*. Furthermore, branching is less frequent and projections much less frequent than in *Patomia*; and *Katavia* has few, or no, bridges. The branching of *Acaciella* is more frequent and the column shape more regular than in *J. nisvensis*. The columns lack the numerous well-developed cornices of *Parmites* (see Rozanov *et al.* 1969). Compared to *Aldania* Krylov (which is very similar indeed to *Inzeria toctogulii* Krylov) the columns are less regular, not as ribbed, and branch less frequently.

The possession of long, narrow, naked, infrequently branching columns indicates classification as *Jurusania* Krylov. Peaks occur less frequently and the columns are bumpier than in *J. cylindrica* Krylov. The columns are less regularly cylindrical and less distinctly ribbed than those of *J. tumuldurica* Krylov. Identification as *J. nisvensis* is indicated by the irregular column shape, the presence of much bridging and coalescing and the upwardly increasing separation of the columns.

Distribution. Loves Creek Member of the Bitter Springs Formation, 2·3 miles west-south-west of the Jay Creek Aboriginal Settlement, Amadeus Basin.

Age. Late Riphean (Adelaidean).

Group KULPARIA Preiss and Walter gr. nov.

Type Form. Kulparia kulparensis Preiss (MS name = *Patomia* sp. nov. Glaessner, Preiss, and Walter 1969), Etina Formation equivalent (Umberatana Group), Yorke Peninsula, South Australia.

Name. The type form comes from near the township of Kulpara.

Diagnosis. Stromatolites having long, nearly straight, erect, and parallel or radially arranged bumpy columns; coalescing and bridging are very frequent; branching is α- and β-parallel; projections are rare to moderately frequent; a wall is almost always present between bridges.

Content. K. kulparensis Preiss (MS name) and *K. alicia* (Cloud and Semikhatov).

Comparisons. Forms of the group *Kulparia* closely resemble some examples of *Patomia ossica* Krylov, particularly those illustrated in Krylov's (1967) figure 27A–Z: these differ from the Australian forms of *Kulparia* only in lacking bridging and coalescing and in the possession of some slightly divergent branching. They have a very similar mode of occurrence, column arrangement, and margin structure. Possibly they could be grouped with *Kulparia* and the name *Patomia* restricted to those of Krylov's examples from the Patom Mountains. The examples of *Patomia ossica* from the Patom Mountains and a specimen we have, which resembles those in plate 5 of Krylov (1967), differ from forms of *Kulparia* by having branching predominantly slightly or markedly divergent and in the very frequent occurrence of projections.

The columns of *Kulparia* are not gnarled and tuberous like those of *Linella* Krylov and lack the γ-parallel branching which characterizes *Gymnosolen* Steinmann. In the mode of branching, column arrangement, and possession of bumpy walled columns *Kulparia* resembles *Katavia* Krylov. *Katavia* lacks the frequent bridging and coalescing and has more distinct bumps.

In the column arrangement, branching, and possession of a wall *Kulparia* resembles *Boxonia* Korolyuk. But *Boxonia* columns are smoother, have no projections and coalesce and bridge much less frequently. *Kulparia* is differentiated from *Minjaria* Krylov by its bumpier columns and more frequent branching and coalescing.

From *Inzeria intia* IV *Kulparia* differs by the lack of elongate projections and in the possession of bridges. Forms of *Acaciella* differ in lacking walls and projections.

Cloud and Semikhatov (1969) grouped *K. alicia* with *Jurusania* Krylov, but branching is much more frequent than in described examples of that group, and in *Jurusania* apparently a wall is absent or very sparsely distributed. Their specimen of *K. alicia* lacks a wall, but, as their illustrations show, the columns are poorly preserved and the interspaces are dolomitized; in stromatolites from the Bitter Springs Formation secondary alteration often obliterates walls.

Distribution. Etina Formation equivalent, Umberatana Group, Adelaide Geosyncline; near Kulpara, Yorke Peninsula, South Australia. Loves Creek Member of the Bitter Springs Formation, Amadeus Basin; near Jay Creek, MacDonnell Ranges, Central Australia.

Age. Late Riphean (Adelaidean).

Kulparia alicia (Cloud and Semikhatov)

Plate 1, fig. 3; Plate 24, figs. 5-6; Plate 25, figs. 1-2; text-figs. 6, 45

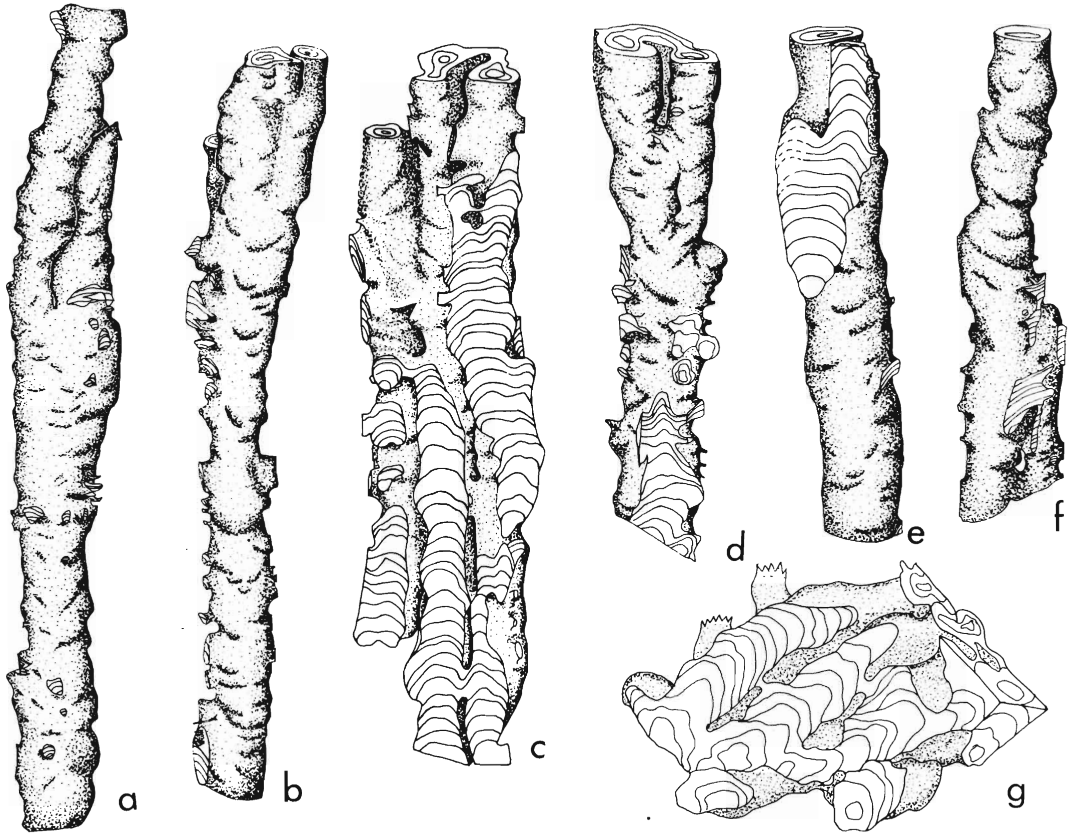
Jurusania alicia Cloud and Semikhatov 1969, pp. 1045-1046, pl. 5, fig. 12.

Material. Two specimens from one locality.

Diagnosis. Kulparia having dominantly rectangular or rhombic laminae; columns are moderately bumpy, with some ribs; projections are rare; there are numerous massive bridges; coalescing occurs frequently.

Mode of Occurrence. K. alicia is known definitely from only one bed. This is 2·5 m thick; at its base are flat-topped mounds with a relief of several tens of centimetres and a width of at least several metres. Columns are arranged perpendicularly to the surfaces of the mounds and thus are vertical throughout much of the bed, but at mound edges are inclined as much as 40–50° from the vertical. Between adjacent mounds columns are crowded out (Pl. 24, fig. 5). The mounds are composed of laminated carbonate in which the laminae conform to the overall shape.

Column Arrangement and Branching. Columns are more or less straight and parallel or radially arranged according to their position in the bioherm. Most are less than 5 mm apart. Near the base of the bed, columns are rarely discrete for more than 2–3 cm and frequently persist for only 0·5–1·0 cm; coalescing and bridging occur very frequently (Pl. 25, fig. 1). Columns become more discrete upwards, but bridging (both delicate and massive) and coalescing remain frequent; the bridges vary in shape from thin and knife-edged to rectangular or circular in vertical section. Extensive bridges occurring randomly within the bed join many columns. Branching is β-parallel, often with only slight expansion before division, i.e. almost α-parallel (text-fig. 45).



TEXT-FIG. 45. *Kulparia alicia*, Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin. A–F, *Kulparia alicia*, × ½ (S347), R_1. G, *Kotuikania ? juvensis* (see Pl. 25, fig. 3), × 1 (S349), R_2.

Column Shape. Columns are straight and subcylindrical, mostly 1–3 cm wide but near the base of the bed some are only a few millimetres wide. Transverse sections are round, rounded polygonal, or, where columns coalesce, U-shaped. Most are several tens of centimetres long (text-fig. 45). Because of poor preservation irregular marginal features smaller than 2–3 mm wide have mostly been obscured. Short transverse ribs with a relief of 1–3 mm, and bumps, the largest nearly 10 mm wide by several millimetres in relief, occur frequently. Projections are rare. There are occasional longitudinal furrows. Bridges rarely grade laterally into short cornices. No peaks were seen.

Lamina Shape. Laminae predominantly are rectangular or rhombic but in narrow columns many are steeply domed (text-figs. 6G, 45). Where the carbonate is fine grained and there are no concordant stylolites, most are uniformly curved; but some are slightly wrinkled or wavy with flexures up to 5 mm wide by 1 mm in relief. Column margins are rarely well preserved, but where they are a thin wall is usually present (Pl. 1, fig. 3); laminae have been traced as far as 7 mm down column margins. The thickest walls (250 μ) are formed by about ten laminae, but often only five participate. Laminae intersect some apparently original margins lacking walls at angles of up to 50°. The shapes of bridging laminae indicate relief during growth of up to 1 cm.

Microstructure and Texture. In slabs there is a prominent coarse macrolamination in which pale yellow-grey layers about 1 mm thick alternate with darker layers of about half that thickness. Their thicknesses are irregular; dark layers often end abruptly, or dissociate into a series of angular dark patches surrounded by pale carbonate. There has been much secondary alteration.

Only in thin sections is lamination distinct and where well preserved it can be seen to consist of an alternation of relatively paler and darker grey laminae about 250 μ thick which, at least for short distances, have smooth boundaries and maintain their thickness; but many are lenticular, wedging out after only 3-4 mm (Pl. 1, fig. 3; Pl. 25, fig. 2). The dark laminae consist of equigranular, polygonal, xenotopic calcite of 10-35 μ grain size. Pale laminae have the same texture except that much of the calcite is hypidiotopic. Concordant patches of still paler calcite are common; in these the calcite is equigranular, polygonal to acicular, idiotopic to xenotopic, with a grain size of 30-150 μ. Locally superimposed over both pale and dark laminae and especially prominent in pale parts of columns is an acicular texture with crystals up to 2 mm long by 0·5 mm wide arranged perpendicularly to the lamination.

Interspace Fillings. The two main types of filling are both pale, homogeneous calcite. One consists of tightly packed 30-40 μ wide rhombs in which there are numerous 3-10 μ wide pale-coloured inclusions; adjacent to this material, columns frequently have serrated margins, indicating some alteration. The other is equigranular, polygonal, xenotopic calcite of 5-30 μ grain size; there are occasional intraclast-like structures preserved in this type of filling. The fillings are unlaminated.

Secondary Alteration. In large, indistinctly laminated areas of columns there are numerous irregular discordant patches of sparry, coarse-grained (50-200 μ) carbonate. The coarse acicular crystals cross laminae and are unlikely to be primary. Stylolites are numerous within and at the margins of columns. Veins of sparry carbonate cut columns and interspaces. Only the relatively continuous, smooth-bordered laminae can be considered as nearly original; secondary processes have been pervasive.

Comparisons. K. alicia predominantly has much flatter laminae than *K. kulparensis* and lacks the numerous relatively large projections of that form. Bridges mostly are delicate in *K. kulparensis* but massive in *K. alicia*. *K. alicia* differs from *Patomia ossica* in lacking numerous projections and possessing frequent coalescing and bridging. Comparisons with other groups and the reasons for transferring *alicia* from *Jurusania* to *Kulparia* are given after the group diagnosis.

Distribution. Loves Creek Member of the Bitter Springs Formation, Amadeus Basin; 2·3 miles west-south-west of Jay Creek Aboriginal Settlement.

Age. Late Riphean (Adelaidean).

Group LINELLA Krylov 1967

Type Form. Linella ukka Krylov from the Uk 'suite' of the Southern Ural.

Diagnosis. Bumpy subcylindrical or tuberous more or less parallel columns with parallel to markedly divergent branching and frequent projections which are often pointed.

Content. L. ukka Krylov, *L. simica* Krylov, and *L. avis* Krylov.

Age. In the U.S.S.R. the time-range is uncertain, but probably only Vendian.

Linella avis Krylov 1967

Plate 4, fig. 5; Plates 26-27; text-figs. 7, 23, 46

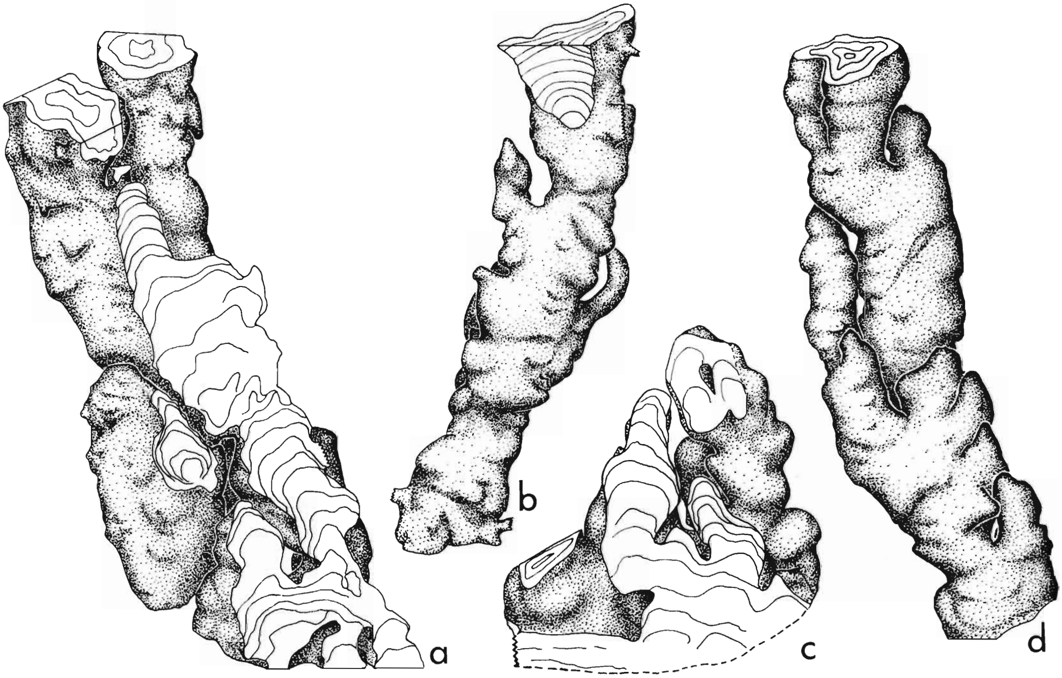
Linella avis Glaessner, Preiss, and Walter 1969, pp. 1057-1058, figs. 2-3.

Material. Seven specimens from one locality.

Mode of Occurrence. It occurs in tabular or domed biostromes 0·3 to 1·0 m thick within which are contiguous or almost contiguous bioherms of various shapes. Often the narrow *L. avis* columns start directly from a flat substrate (Pl. 26, figs. 2–3); here bioherms are not definable. Elsewhere, columns radiate from irregularities in the substrate (Pl. 26, fig. 4), or form broad columns or cumuli at the base of a bed (Pl. 27, fig. 4; text-fig. 23); columns are crowded out between the centres of radiation (Pl. 26, fig. 1). For descriptive purposes lines of crowding are taken as bioherm margins; frequently these are nearly straight and vertical. Two biostromes are known (text-fig. 14).

Column Arrangement and Branching. Columns are approximately perpendicular to their substrate and radiate or are subparallel. They start directly from the substrate or from a dark mass of wavy-bedded stromatolitic carbonate of the same appearance and microstructure as that in the columns and in extreme cases up to 30 cm thick; this basal mass frequently is resolved into broad columns from several centimetres to several tens of centimetres wide. Branching from the broad columns varies from multiple α-parallel to radial (Pl. 27, fig. 4). Branching of the narrow columns is complex and moderately frequent, forming two to four new columns (text-fig. 46). Some branching can be considered as α- to β-parallel, other slightly to markedly divergent (but with the columns returning to parallelism shortly after branching).

Massive bridges occur moderately frequently; the form of preservation resulted in the obliteration of most delicate bridges but they probably are infrequent to moderately frequent. At the top of the biostromes all columns are bridged over at about the same level (Pl. 27, fig. 1). Coalescing occurs infrequently to moderately frequently; in some cases the resultant column is no wider than either of the originals.



TEXT-FIG. 46. *Linella avis*, Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin. A–D, are all from the biostrome shown in Pl. 26; C is from the biostrome base and the others are from above the base. × $\frac{1}{2}$; A–B (S127), C (S377), D (S375); R_1.

Column Shape. The columns are crudely cylindrical but are crooked, tuberous, and gnarled (Pls. 26, 27; text-fig. 46); transverse sections are rounded polygonal, elliptical, or irregular with large indentations (but roughly equidimensional). They are 1-5 cm wide (but some basal columns are broader). On the column margins are numerous small bumps, some of which are pointed. Digitate and irregular projections from a few millimetres to several centimetres long with rounded or pointed ends are abundant; the larger of these can be regarded as new columns formed by branching, but soon crowded out. Some projections are partly enclosed in niches. Infrequently the projections point downwards. There are occasional longitudinal or diagonal flutes.

Lamina Shape. Laminae are steeply convex, gently convex with deflexed edges, rectangular or rhombic (Pl. 4, fig. 5; Pl. 27, figs. 2-3; text-figs. 7G, 46). Within columns the shape is moderately and gradually variable. In nearly all cases laminae continue down column margins forming walls. Continuation down for about 1 cm is frequently observed; it is probably often more than this, and may reach 2·5 cm, but laminae are indistinct near column margins. A multilaminate wall occurs everywhere except at bridges and where stylolites separate columns from interspace fillings; only rarely is it unconformable on underlying laminae. Where counted at one spot the wall consisted of about ten macrolaminae comprised of fifty or more 20 μ thick laminae. The laminae coat, and form, large bumps, continuing around the undersides of these.

Many laminae are uniformly curved with only occasional several millimetre wide flexures up to 1 mm in relief; locally flexures are numerous. Some laminae have many coarse wrinkles.

Microstructure and Texture. Macrolamination is prominent in most columns. Dark macrolaminae are 1-4 mm thick, pale mostly 1-2 mm; both thin markedly towards column margins, but this is inconspicuous for the pale macrolaminae because of the paleness of column margins (Pl. 4, fig. 5). Both types often continue across almost the full width of columns. Macrolamina borders frequently are irregular; patches of pale carbonate up to 1 mm or so wide project into dark macrolaminae, which grade laterally and vertically into pale carbonate. But frequently, one or both boundaries of dark macrolaminae are distinct and abrupt.

In contrast with macrolaminae, most laminae are discontinuous and indistinct. Darker lenses and laminae locally are prominent, particularly in dark macrolaminae and other dark parts of columns. These lenses vary from about 200 μ long by 50 μ thick to almost 1 mm thick by 3 mm long; some occur in trains and these may grade into almost continuous laminae. Their boundaries are diffuse and indistinct. They consist of equigranular, polygonal, xenotopic calcite of 5-25 μ grain size, surrounded by calcite with the same texture and the same or slightly coarser grain size. Diffuse, unresolvable pigment occurs throughout dark macrolaminae but is concentrated in the darker laminae and lenses. Rarely is there a distinct alternation of dark and light laminae; even here laminae consist of trains of conjoined or isolated lenses; they are 100-1200 μ thick. Their boundaries are abrupt and distinct or diffuse and indistinct, and dark laminae often grade laterally or vertically into pale carbonate. Within some laminae is a faint, thinner lamination on a scale of 15-30 μ.

Many pale laminae consist of equigranular, xenotopic, polygonal carbonate of 5-25 μ grain size and have abrupt, distinct upper and lower boundaries. Most of these are 50-100 μ thick. Some continue for three-quarters of the width of a column but most are less persistent.

The majority of pale macrolaminae (and hence the laminae within them) are composed of acicular carbonate with crystals 50-250 μ wide by 5 mm or more long, arranged perpendicularly to the lamination. Most, but not all, laminae within acicular macrolaminae have diffuse, indistinct boundaries. Lamina boundaries are within acicular crystals, and are marked by changes in the concentration of unresolvable grey-brown pigment and minute inclusions less than 5 μ wide. Frequently the acicular crystals extend into contiguous dark macrolaminae.

Column walls are formed dominantly of pale, acicular carbonate but where lamination is most distinct xenotopic texture dominates. Some prominent laminae are composed of acicular carbonate but it is finer than elsewhere.

Interspace Fillings. The interspaces are filled with equigranular, polygonal, xenotopic dolomite of 30-60 μ grain size. Locally this has a grumous texture. There are many patches of coarsely crystalline (up to 1 mm) carbonate. No primary structures were seen.

Secondary Alteration. The acicular crystals cross laminae and are associated with irregularities such as lamination discontinuities and indented macrolamina boundaries; therefore they are considered to be secondary. How much of the lenticular microstructure is of primary origin is uncertain. In many cases contiguous laminae are domed over and under lenses, which may indicate a primary origin. But many bumps on lamina surfaces can be accounted for by different degrees of penetration into laminae of carbonate crystals. Patches and veins of xenotopic sparry carbonate are secondary.

Comments. Since most laminae continue down column margins for at least 1 cm, and some for as far as 2·5 cm, relief during growth must have been at least 1 cm and up to more than 2·5 cm.

One *L. avis* biostrome at Jay Creek was followed for 2·5 km without any significant variation being found except that several clusters of *Minjaria pontifera* columns occur within it; these occurrences are discussed with the description of *M. pontifera.*

Comparisons. Only forms of the groups *Linella* Krylov, *Gymnosolen* Steinmann, *Patomia* Krylov, and *Vetella* Krylov have subparallel bumpy columns with numerous projections.

The columns are more gnarled and bumpy than most *Gymnosolen* columns, which also have fewer and more regular projections, and possibly straighter columns. But they are very similar to some reconstructions of *Gymnosolen confragosus* (in particular pl. 17, fig. 8 of Semikhatov 1962). They have a multilaminate wall which is continuous or nearly so, as does *Gymnosolen.* Small pieces may be indistinguishable from *Gymnosolen.*

Patomia columns are straighter and their bumps proportionately smaller than in the Australian *L. avis*; furthermore, the wall of *Patomia* is patchy.

It is not clear how the gross forms of *L. avis* and *Vetella uschbasica* Krylov differ except in size. Possibly *L. avis* has a slightly more complex shape. Their margin structure apparently is very similar, but the microstructure of *Vetella* is distinctly banded, whereas that of *L. avis* is streaky. The Australian form clearly belongs in the group *Linella*, but in having a nearly continuous wall and lacking ribs it differs from *L. ukka* and *L. simica.* The Russian *L. avis* forms biostromes with vertical subparallel columns and bioherms with radiating columns, like the Australian form; the field appearance of the two is identical (see Krylov 1967, fig. 22) except that in Krylov's figure 22D the columns are more widely spaced. Although Semikhatov and Krylov (pers. comm., 1969) consider that a small sample sent to them has more regular columns than *L. avis*, a comparison of published reconstructions with mine shows no essential differences. Similarly, lamina shape and (apparently) margin structure are the same (no section showing the margin structure of the Russian form has been published but it has been described). Furthermore, examination of a specimen of the Russian *L. avis* kindly supplied by M. A. Semikhatov and I. N. Krylov confirms comparisons made from published data (it is noteworthy that the Russian specimen is badly altered and has small fractures across the columns; displacements on these fractures produce many irregularities in column shape). Hence the conclusion that *L. avis* and the Australian form belong to the same group is inescapable, and the published literature and available specimens reveal no reason for differentiating them at the form level.

Distribution. Loves Creek Member of the Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, western MacDonnell Ranges, Amadeus Basin.

Age. Late Riphean (Adelaidean).

Group MADIGANITES gr. nov.

Type Form. Madiganites mawsoni f. nov.

Name. Given in honour of Dr. C. T. Madigan, who made a very extensive study of Amadeus Basin stromatolites and whose collection was used as a basis for the study of the type form of this group.

Content. Madiganites mawsoni only.

Distribution. In the Pertaoorta Group throughout the north-eastern Amadeus Basin.

Age. Middle and Upper Cambrian.

Madiganites mawsoni f. nov.

Plate 1, figs. 1–2; Plate 28, figs. 1–3; text-figs. 8, 47

Material. Eleven specimens from four localities up to 110 km apart.

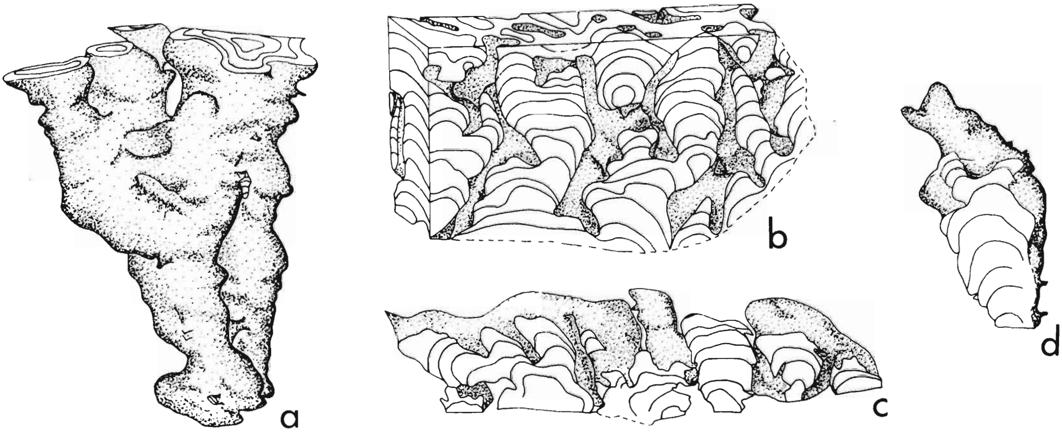
Name. Given in honour of Sir Douglas Mawson, an eminent pioneer in the study of stromatolites.

Holotype. S46.

Diagnosis. Gnarled, impersistent, crooked columns having α–γ-parallel and slightly and markedly divergent branching, a patchy wall, and vermiform microstructure.

Mode of Occurrence. At Jay Creek in the Jay Creek Limestone *M. mawsoni* forms tabular biostromes 15–30 cm thick. In the Shannon Formation of the Ross River valley it forms the upper part of a 60 cm thick domed biostrome with domes a metre or so wide (these may be closely spaced domed bioherms). Domed bioherms probably formed by *M. mawsoni* are illustrated by Wells *et al.* (1970).

Column Arrangement and Branching. Columns are subparallel and vertical in tabular biostromes and radially arranged in domed biostromes; but they are crooked and diverge at up to 50° from their general direction of growth (text-fig. 47). Bridging and coalescing are very frequent in some beds; columns often persist for



TEXT-FIG. 47. *Madiganites mawsoni*, Pertaoorta Group, Amadeus Basin. ×½, R_2. A, D, Possibly Jay Creek Limestone, Jay Creek (collected by Dr. C. T. Madigan), S46. B, Shannon Formation, several miles south of the Ross River Tourist Camp, S146. C, Jay Creek Limestone, near the junction of the Glen Helen and Hermannsburg roads (Jay Creek); arbitrary top at a lamina, S364.

only a few centimetres before being bridged over, often merging into pseudocolumns; a bed usually consists of a number of thin, columnar units separated by extensive bridges (Pl. 28, fig. 2).

Branching varies from parallel to markedly divergent; the latter occurs infrequently; when parallel it is of α, β, or γ type.

Column Shape. The columns are 5–30 mm wide and from several millimetres to at least 10 cm high (Pl. 28; text-fig. 47). They are basically cylindrical; transverse sections vary from circular to irregular with large indentations, but most are roughly equidimensional. They are crooked but lengths of up to 4 cm can be straight. On the margins are numerous bumps up to 15 mm wide and 5 mm in relief; there are also occasional longitudinal or diagonal furrows.

Lamina Shape. Laminae are hemispherical, rectangular, rhombic, conical, or, infrequently, gently convex (the range of h/w is from about 0·4–1·1); often they are slightly asymmetrical (text-figs. 8, 47). Many of the shape changes are abrupt. They are smooth or wavy with flexures up to 6 mm wide. The presence of stylolites hampers the interpretation of margin structure, but now short patches of column margins are walled; this is likely to be nearly the original condition. Most margins are smooth; infrequently a lamina projects a few millimetres into an interspace.

Microstructure and Texture. The vermiform microstructure of *Madiganites mawsoni* (Pl. 1, figs. 1–2; Pl. 28, fig. 1) is unique among described Australian stromatolites.

There is a prominent banding consisting of alternating pale and dark laminae 0·5–1·5 mm thick; with moderate frequency these laminae are themselves layered. Most of the pale and dark thick laminae have the same structure and will be described together, but in addition there is another lamina type with pale and dark variants:

1. Pale or dark thick laminae with a distinct vermiform or clotty structure form about 80 per cent of the volume of columns. Branching, 30–50 μ wide intertwined vermiform patches of pale carbonate are separated by irregular dark clots most of which are slightly wider (30–250 μ). Some pale patches have been traced for over 1 mm. The boundaries of the dark clots are distinct and abrupt even in dark laminae but especially in the pale examples. Dark patches infrequently are sinuous; some dark patches have darker borders. The carbonate both within and between the clots is equigranular, polygonal, xenotopic to hypidiotopic with a grain size of 5–15 μ; but in pale laminae the texture often is grumous and grain size between the pigmented patches reaches 100 μ.

The laminae are themselves layered where the pale vermiform structures parallel lamina borders for some distance (up to 1 mm); such occurrences are moderately frequent, usually only as patches within a lamina. The laminae often continue across the full width of a column, and with only minor thicknesses variations. Frequently they have pale bases and dark tops, and many grade laterally and/or downwards into nearly homogeneous pale laminae of equigranular, polygonal, hypidiotopic carbonate mostly of 10–40 μ grain size but with some larger grains; there is a faint clotty structure in these laminae.

2. Pale or dark nearly homogeneous laminae 70–2000 μ thick. The thinner examples separate thick vermiform laminae. Many continue, with little variation, across the full width of a column. Vermiform structures occur sparsely within them and infrequently they intergrade with vermiform laminae. Many are not homogeneous but consist of large irregular light and dark patches, as though dark laminae have patchily altered.

Pale examples consist of equigranular, polygonal, xenotopic to hypidiotopic carbonate of 5–20 μ grain size. Dark laminae consist of equigranular, polygonal, xenotopic carbonate of about 5 μ grain size.

Interspace Fillings. The fillings are crudely laminated; laminae about 2 mm thick crowded with intraclasts alternate with relatively dark laminae of xenotopic to idiotopic equigranular, polygonal carbonate of 10–40 μ grain size. The intraclasts are set in a matrix of xenotopic to hypidiotopic, equigranular, polygonal to elongate carbonate of 7–40 μ grain size; or in carbonate the same as that forming the dark (non-vermiform) laminae. There are some patches of coarse sparry carbonate.

Secondary Alteration. Concordant stylolites are common; stylolites are almost ubiquitous along column margins. Discordant patches of pale or sparry carbonate, much of which is idiotopic, are secondary.

Comments. The vermiform structure is more distinct than the clotty structures common to many stromatolites, and the dark parts of the structure have more distinct boundaries. The structure is very similar to that of *Girvanella* but lacks the microgranular boundaries of that form. Vermiform laminae grade into ones with the common clotty or grumous structure, a paler colour, and more nearly idiotopic carbonate; thus clotty and grumous laminae can form by slight alteration of vermiform laminae. But in all other stromatolites available for study clotty or grumous laminae grade into more nearly homogeneous laminae (except *Boxonia gracilis* Komar which also has a vermiform microstructure): along with other relationships this indicates that in most stromatolites such laminae were primarily homogeneous.

The thick vermiform laminae are thicker than laminae in most stromatolites; they may be interpreted as having formed from thick algal mats with intertwined filaments between which fine detritus was trapped and/or precipitated (dark parts of vermiform structure), which on decay left tubes later filled by carbonate or during diagenesis were replaced by carbonate.

Comparisons. The vermiform microstructure is distinctive and unusual, but since stromatolite classification is based largely on gross features these are considered first. The bumpy, crooked column shape and the mode of branching distinguish *M. mawsoni* from forms of all groups except *Baicalia* Krylov, *Linella* Krylov, *Ilicta* Sidorov, *Kotuikania* Komar, and *Uricatella* Sidorov. But forms of *Linella* have projections and multilaminate walls, both absent in *Madiganites*. All forms of *Ilicta*, *Kotuikania*, and *Uricatella* have multilaminate walls. In addition, *Ilicta* and *Uricatella* appear to have smoother columns than *Madiganites*, although no reconstructions of *Uricatella* have been published. On the basis of gross shape the most discrete columns of *Madiganites* cannot be distinguished from forms of *Baicalia*. But laminae of well-preserved *Baicalia* and all other Precambrian stromatolites (except to some extent *Boxonia gracilis*) available to me for study are quite unlike the thick, vermiform laminae of *Madiganites*. It is because this feature is so unusual and distinctive that a new group is defined. A similar microstructure is patchily developed in *Boxonia gracilis* Komar (in a specimen from the Bokson 'Suite' available to me) and may occur in *Collumnacollenia tigris* Korolyuk, *Ilicta composita* Sidorov, and other Phanerozoic stromatolites. *Boxonia* and *Collumnacollenia tigris* can be distinguished from *Madiganites* by their straight smooth-margined columns. As stated above there are many similarities in gross structure between *Madiganites* and *Ilicta* but they are distinguishable on gross features. Similarities of microstructure and lamina shape also are notable, but in *I. composita* (the only form in that group) vermiform laminae are subordinate in volume to other types, in contrast with the situation in *Madiganites*; and the vermiform structures are slightly larger in *I. composita*.

A similarity in gross shape, size, and margin structure with *Anomalophycus compactus* Fenton and Fenton is notable; but no reconstructions have been published and the description is very brief, preventing further comparison.

Distribution. Columnar stromatolites occur frequently in the Pertaoorta Group of the Amadeus Basin: every available example (of which there are eleven) has proved to be *M. mawsoni*. Specimens came from the Jay Creek Limestone at Jay Creek (near the junction of the Hermannsburg and Glen Helen roads) and probably from the Jay Creek Limestone at Ellery Creek, both in the western MacDonnell Ranges;

from the Jay Creek Limestone(?) in the Waterhouse Ranges; and from the Shannon Formation in the Ross River valley, 1–2 miles south of Ross River Tourist Camp, eastern MacDonnell Ranges.

Age. Middle and Upper Cambrian.

Group MINJARIA Krylov

Minjaria Krylov 1963, 1967, Semikhatov 1962.

Type Form. Minjaria uralica Krylov which is widely distributed in the U.S.S.R.

Diagnosis. Stromatolites with even, subparallel, subcylindrical columns which infrequently branch in a β-parallel or slightly divergent manner and which are covered by a multilaminate wall.

Content. M. uralica Krylov, *M. calciolata* (Korolyuk), and possibly *M. procera* Semikhatov. *M. procera* is distinguished from *M. uralica* only by microstructural features which may be secondary, and hence the two may be synonyms. Raaben's (1969*a*) placing of *Minjaria* into synonymy with *Gymnosolen* is not accepted.

Age. Late Riphean.

Minjaria pontifera f. nov.

Plate 2, fig. 5; Plate 28, figs. 5–6; text-figs. 6, 48–49

Minjaria sp. Glaessner, Preiss, and Walter 1969, pp. 1057–1058, figs. 2–3.

Material. One specimen.

Holotype. S374.

Name. From the Latin *pons*, meaning bridge.

Diagnosis. Minjaria with numerous small projections and massive bridges.

Comments. In the field the extent of the difference of this stromatolite from *Linella avis* Krylov, with which it occurs, was not recognized and only one small specimen was collected. However, the two reconstructions that were made from this specimen along with field photographs provide sufficient information for the description of a new form.

Mode of Occurrence. Within the upper *Linella avis* biostrome at Jay Creek (text-fig. 14), along the strike length of about 2·5 km over which it is exposed, are several clusters of broad, straight, and parallel columns, much more regular than *L. avis* (Pl. 28, fig. 6; text-figs. 48–49). Each cluster has a strike length of several metres. Most columns are erect but in the lower part of one cluster the columns are uniformly inclined. Definite *L. avis* and *M. pontifera* are closely juxtaposed (text-fig. 48); subordinate numbers of columns of intermediate shape may occur between the two forms, but this is not known.

TEXT-FIG. 48. *Minjaria pontifera* field occurrence, Bitter Springs Formation, 2·3 miles west-south-west of the Jay Creek Aboriginal Settlement, Amadeus Basin. Column outlines traced from a field photograph; laminae diagrammatic. Gaps are left where no detail is visible in the photograph. The section is almost normal to bedding; the base of the biostrome is marked by a broken line. The same biostrome is shown in Pls. 26 and 28, fig. 6. On the left there is a mound in the substrate from which radiate columns which are probably *Linella avis*.

Column Arrangement and Branching. Columns mostly are straight, erect, and parallel, up to 1 cm apart. Branching is rare: none is present in the small specimen and it is visible at only one point in field photographs (Pl. 28, fig. 6); there it appears to be β-parallel. Massive bridges occur frequently. The columns are all bridged over at the same level at the top of the biostrome.

Column Shape. In transverse section the columns are 3–6 cm wide and rounded polygonal, approximately round, or irregular (text-fig. 49). The biostrome is 0·3–1·0 m thick and most columns appear to persist for the full thickness. Column margins are relatively smooth with occasional broad, low, short ribs and some small irregularities, but the exact shape is uncertain since stylolites mark the edges of the sampled columns. Small peaks are rare. Numerous small pointed or ridged projections up to 15 mm high have axes making a very acute angle with those of their parent columns and almost touch them; all reconstructed have bases less than 1 cm wide.

Lamina Shape. Laminae predominantly are approximately hemispherical (Pl. 28, fig. 5; text-figs. 6c, 49). There is little variation within or between columns. They are slightly wavy, with flexures up to 3 mm wide by 0·7 in relief. Near column margins lamination is very indistinct and stylolites are present; laminae either parallel the margins or strike into the bounding stylolite at a very acute angle (Pl. 2, fig. 5). It is likely that originally there was a multilaminate wall continuous except at bridges.

Microstructure and Texture. There are three main types of laminae (Pl. 2, fig. 5):

1. Dark grey laminae and lenses of equigranular, polygonal, xenotopic to hypidiotopic, fine-grained (10–20 μ) calcite commonly 300–700 μ thick, but ranging from 100–1000 μ; the calcite reaches a grain size of 30 μ in grumous textures. Homogeneous laminae have abrupt, distinct boundaries, but boundaries of grumous or lenticular laminae often are gradational and indistinct; the boundaries often are emphasized by contiguous sparry (type 3) laminae. There are all gradations from homogeneous to grumous laminae.

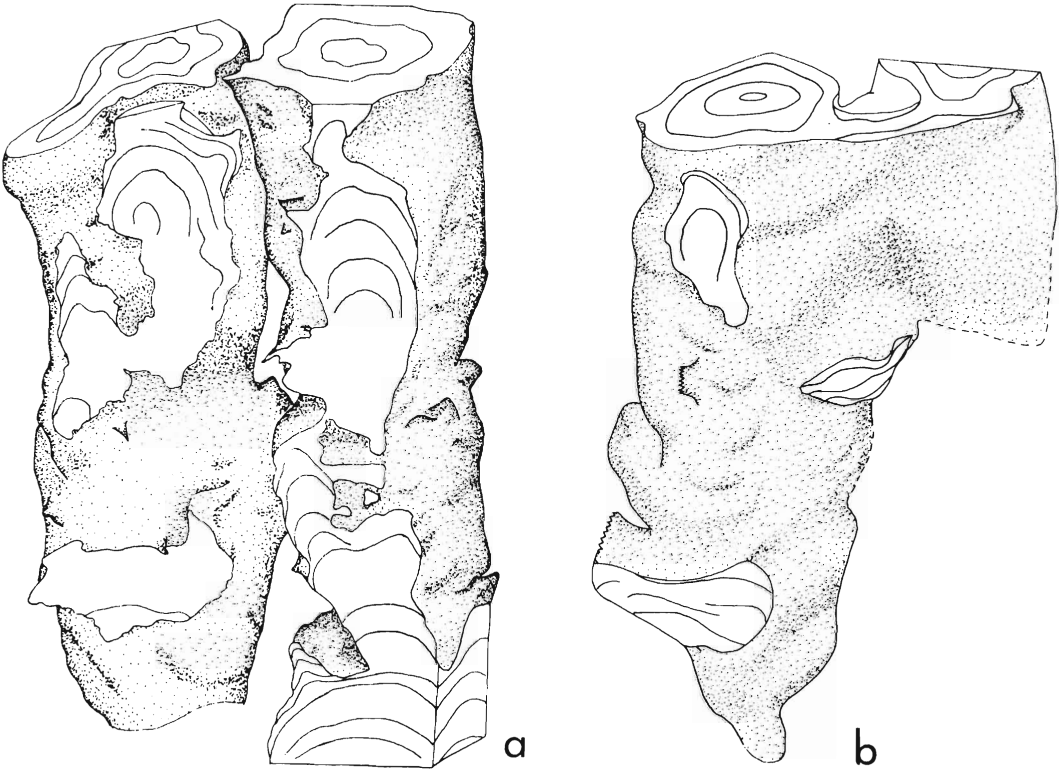
Within the darkest, most continuous laminae are indistinct microlaminae about 20 μ thick of alternating paler and darker carbonate. The dark laminae often continue across most of a column but some change laterally into pale laminae. Some thin slightly towards column margins.

2. Pale laminae of equigranular, polygonal, xenotopic to idiotopic, fine-grained (20–40 μ) carbonate 150–2500 μ thick; these are thickest in areas where dark laminae are grumous and lenticular. This type of carbonate forms about 60 per cent of the volume of each column, being the matrix in which dark laminae are suspended. Hence the shape of the pale laminae depends on that of the enclosed dark laminae. Many pale laminae persist across most of a column, but commonly they grade laterally into grumous or lenticular laminae. They thin gradually towards column margins.

3. Thin (40–120 μ) colourless laminae of xenotopic to idiotopic carbonate of 20–100 μ grain size. These occur sporadically, always contiguous with the upper or lower boundaries of dark laminae. Some continue across most of the width of a column; most are impersistent and local.

Within the columns near their margins is a zone 0–10 mm wide in which sparry carbonate is concentrated. The inner boundary of the zone is irregular but frequently abrupt. Sparry carbonate forms up to 50 per cent of the volume of the zone; much is acicular, with crystals 50–100 μ wide and up to 700 μ long. Carbonate like that of the sparry (type 3) laminae also is prevalent. In this zone dark and pale laminae consist only of lenses, spots and irregular patches and the lamination is very indistinct.

Interspace Fillings. The bulk of the filling is pale grey, slightly turbid carbonate which is equigranular (20–50 μ) and hypidiotopic. In veins, irregular patches, and as a component of a grumous texture, is colourless, idiotopic carbonate of 35–100 μ grain size. These two carbonates are the same as those forming the



TEXT-FIG. 49. *Minjaria pontifera*, Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin. × ½ (S374), R_2.

pale and sparry laminae, and have the same textures. Patches of very coarse-grained (up to 1·5 mm) colourless, xenotopic carbonate probably are secondary.

As well as the grumous structures there are small (150–300 μ) rounded pellets of dark grey carbonate which have abrupt, distinct boundaries. They may be primary; but similar structures occur in the column-margin zones where they almost certainly are secondary. There are also some intraclast-like structures.

Secondary Alteration. Several facts indicate that the grumous texture is secondary: there is a gradation in dark laminae from homogeneous to grumous; homogeneous dark laminae are the most distinct and continuous; grumous dark laminae have indistinct boundaries, fluctuate in thickness, and occasionally wedge out.

The carbonate of the pale laminae appears to be secondary because: dark laminae often abruptly change laterally into pale laminae; patches of pale carbonate transgress dark laminae; pale carbonate forms the matrix in grumous dark laminae. The sparry carbonate of type 3 laminae and the marginal zone is often idiotopic and coarse grained; remnants of darker laminae are enclosed by sparry carbonate in the marginal zone. Clearly this carbonate is secondary. There are some concordant and discordant stylolites within columns, and stylolites mark every column edge.

Much of the texture and some of the structure (pale marginal zone, shape of lamina boundaries, lamina discontinuities) is secondary.

Comparisons. M. pontifera differs from the associated *Linella avis* as follows: *M. pontifera* columns are broader, straighter, and smoother-margined than those of *L. avis*, whose columns are crooked and gnarled. Branching is complex and moderately frequent in *L. avis* but simple and rare in *M. pontifera*; but both have pointed projections. The waviness of laminae notable in *L. avis* was not seen in *M. pontifera*; how much of this is due to differences in preservation is uncertain. The texture of the most altered *L. avis* is similar to that of *M. pontifera* marginal zones, but the lamination remains more distinct in *L. avis*. The secondary acicular carbonate common in *L. avis* occurs only in the marginal zones of *M. pontifera* (perhaps because the columns are broader and hence not as pervasively altered).

The only other stromatolite group with such straight, even, walled columns is *Boxonia*; branching in that group is much more frequent than in *M. pontifera*, and *Boxonia* columns lack projections.

Minjaria uralica Krylov only rarely has pointed projections such as are common in *M. pontifera*, and according to Krylov (1963) peaks and bridges are absent, although Semikhatov (1962) includes in *M. uralica* forms with infrequent peaks and bridges. The microstructure of *M. pontifera* resembles that of *M. uralica*.

Semikhatov (1962) distinguishes *M. procera* by its texture; in other features it is identical with *M. uralica* (but it has some peaks). *M. procera* has clotty laminae and its wall is formed of only one lamina type. Krylov (1963) disputes the distinctiveness of this form.

M. pontifera most resembles *M. calciolata* (Korolyuk), whose characteristic feature, Krylov (1967) considers, is the presence of short, digitate projections. Korolyuk (Medvedev and Korolyuk 1958) considered characteristic the presence in each column of a pale marginal zone into which merge dark laminae. *M. pontifera* has such a zone, but not formed of the same carbonate which forms the dominant pale laminae within the columns as is that of *M. calciolata*. In summary, *M. calciolata* and *M. uralica* appear quite similar to each other and to *M. pontifera*, but neither have the numerous massive bridges of *M. pontifera*. Further study may necessitate reclassification into one of the Russian taxa. Raaben (1969*a*) places

Minjaria into synonomy with *Gymnosolen*, but her arguments for this are not compelling.

Distribution. Loves Creek Member of the Bitter Springs Formation, 2·3 miles west-south-west of Jay Creek Aboriginal Settlement, Amadeus Basin.

Age. Late Riphean (Adelaidean).

Group PATOMIA Krylov

Patomia Krylov 1967, Krylov in Rozanov *et al.* 1969.

Type Form. Patomia ossica Krylov from the Zherbin 'suite' of the Patom Mountains and Kurgan 'suite' of the Talasska Range, U.S.S.R.

Diagnosis. Stromatolites with narrow, subparallel, subcylindrical, bumpy columns having frequent α-β-parallel and slightly divergent branching and numerous long, pointed projections. Most columns are covered by a multilaminate wall.

Content. P. ossica Krylov and *P. aldanica* Krylov.

Age. Probably Vendian.

Patomia f. indet.

Plate 29, figs. 1, 8; text-fig. 50

Material. One specimen. The rock has a weakly developed cleavage and column margins are extensively secondarily altered and obscured. Consequently, details of the reconstructions are unreliable.

Mode of Occurrence. Unknown. The specimen was collected by geologists of the Geological Survey of Western Australia from an isolated outcrop about 3 m square in which no bedding planes were visible (J. H. Lord, pers. comm., 1969).

Column Arrangement, Shape, and Branching. Columns are approximately straight and parallel, and are subcylindrical with oval, circular, or rounded polygonal transverse sections (Pl. 29, fig. 1; text-fig. 50). Columns are 3–25 mm wide, 3–5 mm apart, and up to at least 15 cm high. Margins appear to have broad bumps. There may be bridges.

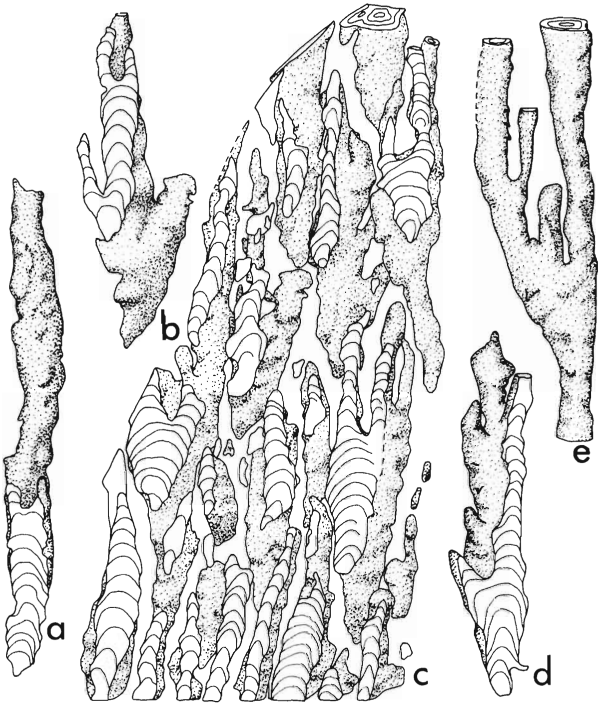
Branching occurs frequently, is α-β-parallel to slightly divergent, and forms two to three new columns. Some branches end after lengths of from several millimetres to 15 mm, forming projections, some of which may be pointed.

Lamina Shape. Laminae are indistinct in the central parts of columns, and invisible or nearly so in the marginal altered zones. It is possible to tell that most laminae are steeply domed or rectangular, and that some are gently domed (Pl. 29, figs. 1, 8; text-fig. 50). Many are asymmetrical. Some are wavy. There appears to be a patchy wall.

Microstructure. Where laminae are distinct they are 40–120 μ thick and have parallel, smooth boundaries (Pl. 29, fig. 8).

Interspace Fillings. The pale grey carbonate fillings are laminated on a scale of 0·1–3·0 mm. There are numerous rounded carbonate intraclasts 0·1–6 mm wide.

Secondary Alteration. The pale marginal zone of columns is a secondary feature, as is the clotty and grumous texture common in the columns. Many structures, such as the clots and intraclasts, are aligned parallel to the cleavage.



TEXT-FIG. 50. *Patomia* f. indet., Duck Creek Dolomite, 26 miles east-north-east of Mount Breshnehan, Hamersley Basin. The reconstruction C has a cut back. ×½ (GSWA F8134), R_3.

Comparisons. Comparisons based on one greatly altered specimen are obviously tentative and of limited significance. In all of the features preserved, this stromatolite is indistinguishable from *Patomia ossica* Krylov. It is also similar to *Vetella uschbasica* Krylov which, however, has a continuous wall. Krylov (1966) describes from Karelia a stromatolite very similar in gross shape (his 'second type') but larger, apparently lacking a wall, and having predominantly gently convex laminae.

In column shape as seen in sections and in lamina shape there is a strong resemblance to form B of Hofmann (1969*a*). This is *Collenia* (?) *ferrata* of Grout and Broderick (1919) which in his plate 2 caption Hofmann classifies as *Gymnosolen* (?) *ferrata*. No proper comparisons are possible until his form B has been reconstructed.

Distribution. Duck Creek Dolomite (Wyloo Group of the Mount Bruce Supergroup), 26 miles east-north-east of Mount Breshnehan, Turee Creek 1:250 000 Sheet area, Western Australia.

Age. About 2020 ± 165 m.y. (Early Proterozoic).

Group PILBARIA gr. nov.

Type Form. Pilbaria perplexa f. nov.

Name. The type species comes from the Pilbara region of Western Australia.

Content. Pilbaria perplexa only.

Distribution. Duck Creek Dolomite of the Wyloo Group (Mount Bruce Supergroup): Duck Creek area, Hamersley Ranges, Western Australia.

Age. About 2020±165 m.y. (Early Proterozoic).

Pilbaria perplexa f. nov.

Plate 4, fig. 4; Plate 29, figs. 2–7; text-figs. 7, 51–52

Material. Eight specimens from two localities.

Holotype. S206.

Name. In Latin *perplexus* means confused, obscure, ambiguous; it was given because of difficulty in deciding on the classification of this stromatolite.

Diagnosis. Columns are subcylindrical, long, mostly straight, subparallel, and mostly very smooth with proportionately very small transversely elongate niches with projections; near the bases of beds branching varies from parallel to markedly divergent, but above that level it is α–β-parallel or slightly divergent; laminae predominantly are steeply convex and form a patchy wall.

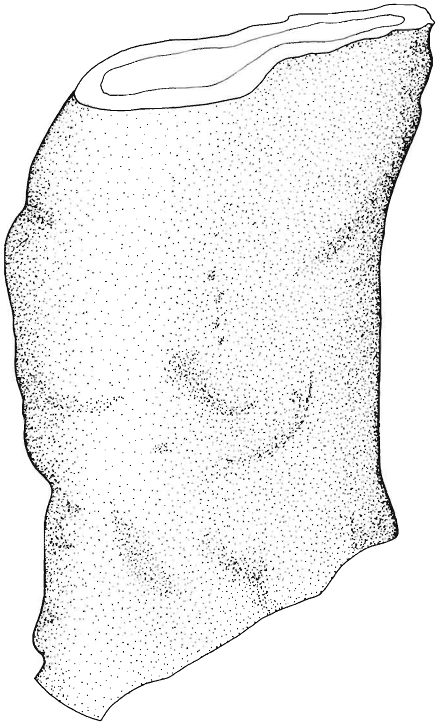
Mode of Occurrence. P. perplexa forms tabular biostromes about 0·5 m thick and much thicker (several metres) beds of unknown shape (Pl. 29).

Column Arrangement and Branching. At the base of beds columns start either directly from continuous flat laminae or from cumuli up to several tens of centimetres wide and high. Low (10–20 cm), broad columns which branch upwards into narrower columns occur frequently at the bases of beds, but many narrow columns start directly from the substrate. Near the bases of beds some groups of columns are variously inclined, but elsewhere columns are erect and subparallel. The top of only one biostrome was seen: all columns ended at nearly the same level (with variations up and down of several centimetres); they did not appear to be bridged over.

Broad, basal columns are up to several tens of centimetres wide but others are mostly 4–10 cm wide. Many are continuous for 50 cm. They usually are spaced 0·5–3 cm apart. Coalescing and bridging occur frequently; most bridges are massive. Besides the common forms of coalescing where adjacent columns unite for long distances with dumbbell-shaped transverse sections throughout or where two columns merge upwards into one, another form occurs in this stromatolite: projections, sometimes in niches, extend laterally and/or vertically to become bridges or to coalesce with an adjacent column (text-fig. 52A, E).

Because of the large size of *P. perplexa*, specimens include little branching. In outcrop, branching was seen to be frequent near the bases of beds and moderately frequent elsewhere. Near the base branching is variously parallel (apparently α–β) or slightly to markedly divergent, multiple or dichotomous. The divergent branching is most frequently from broad cumuli from which radiate new columns. Above the basal parts branching apparently is α–β-parallel or slightly divergent and probably dichotomous (Pl. 29, figs. 4, 6; text-fig. 52B).

Column Shape. Columns predominantly are straight or nearly so, and subcylindrical; transverse sections are subcircular or elliptical, with small indentations. Margins are relatively very smooth (text-figs. 51–52); this is particularly noticeable in longitudinal sections. Large and small bumps occur moderately frequently



TEXT-FIG. 51. *Pilbaria perplexa*, Duck Creek Dolomite, 20 miles east along the track from Mount Stuart Homestead, Hamersley Basin. $\times\frac{1}{3}$ (S201), R_1.

but nearly all are of low relief; the relief of even the widest bumps (which are several centimetres wide) rarely reaches 1 cm. There are occasional short, discontinuous ribs. Longitudinal furrows occur infrequently.

Proportionately small, transversely elongate niches and niche-enclosed projections occur moderately frequently. Most consist of pocket-like depressions several millimetres deep and closed at both ends; most openings are about 1 cm long. Rarely they run obliquely across a column. As described above some niche-enclosed projections participate in bridging and coalescing, as do rare, large projections.

Lamina Shape. Laminae predominantly are steeply domed to parabolic or even conical with deflexed edges (Pl. 4, fig. 4; Pl. 29, figs. 2-7; text-figs. 7, 52); gently domed or rectangular laminae occur infrequently. Shape changes are gradational. Most laminae are smoothly curved but some are wavy; the flexures usually are 5-15 mm wide by up to 5 mm in relief. The waviest laminae are in two columns which have more niches and ribs than usual. No laminae overhang column margins. About 30 per cent of the area of column margins is walled; elsewhere laminae intersect the margin at angles of 15° or less.

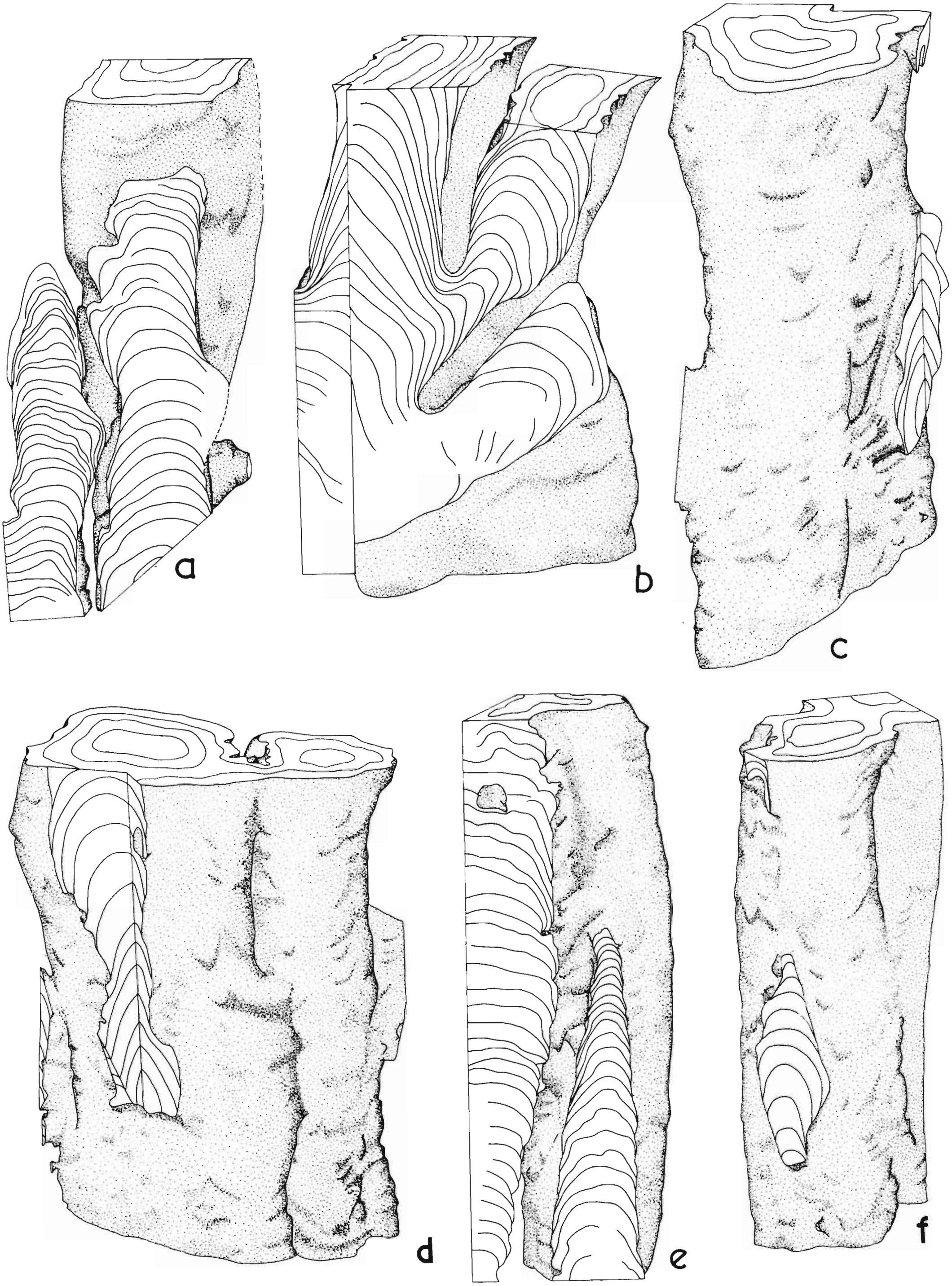
Microstructure and Texture. The lamination is very indistinct; boundaries are diffuse and laminae often grade laterally or transversely into areas of more or less homogeneous carbonate (Pl. 4, fig. 4). The laminae are 50-300 μ thick, with most at the thinner end of the range; they can never be traced for more than a few millimetres but over such distances have approximately constant thicknesses. They are alternately pale and dark:

1. Dark laminae consist of trains of dark, subcircular, lenticular, or irregular clots mostly 50-300 μ wide and frequently also dark tabular segments the full thickness of a lamina and continuous for 1 mm or so (the latter is probably most nearly the original form of the lamina). The clots, but not the tabular segments, have irregularly-shaped boundaries. The dark areas consist of hypidiotopic to xenotopic, equigranular, polygonal carbonate of about 20 μ grain size. There are many irregular dark patches up to many millimetres wide with a dense, clotty structure, which laterally grade into laminated areas.

2. In the apparently least altered areas there is a pale matrix enclosing the dark laminae. The carbonate texture and grain size in this is the same as in the dark laminae. Irregular 20-50 μ wide patches of pigment the same as that colouring dark laminae are scattered through the carbonate, but obviously are neither as dense nor as numerous as in the dark laminae.

Interspace Fillings. Interspaces are filled with almost homogeneous, pale grey, hypidiotopic to idiotopic, equigranular, polygonal carbonate of 15-75 μ grain size.

Secondary Alteration. About 60 per cent of column volumes is cherty carbonate in which the quartz is of about 5 μ grain size. Thick, roughly concordant patches of cherty carbonate are concentrated about the crestal zones of columns; they are up to 1 cm thick in their crests but thin markedly outwards. Margins of the patches have angular indentations and protrusions which cross laminae. A crude lamination within them is formed by inclusions of the dark carbonate prominent in well-preserved parts of columns. From 50-100 per cent of the volume of the patches consists of carbonate rhombs 20-130 μ wide; all of these are roughly aligned parallel to column axes (probably because of the incipient development of a cleavage parallel to the axes). There are also some approximately concordant patches of coarsely crystalline quartz with a grain size reaching 1 mm.



TEXT-FIG. 52. *Pilbaria perplexa*, Duck Creek Dolomite, 20 miles east along the track from Mount Stuart Homestead, Hamersley Basin. ×$\frac{1}{3}$; A (S205), B (S201), C–F (S206); R_1.

In the marginal parts of the columns is a zone several millimetres to 1 cm thick of pale pinkish grey carbonate. Within this, laminae are extremely indistinct, but are marked here and there by lenses of dark carbonate and by slight colour variations. This zone is not always present; in places laminae are moderately distinct. It consists of hypidiotopic to idiotopic, equigranular, polygonal carbonate of 15–60 μ grain size.

Comparisons. In having long, straight columns *Pilbaria* resembles *Jurusania* Krylov, *Minjaria* Krylov, *Boxonia* Korolyuk, *Kussiella* Krylov, *Acaciella*, *Kulparia* Preiss and Walter, and *Inzeria* Krylov. The consistent presence of a patchy wall, niches, and niche-enclosed projections excludes all but *Inzeria*, although the resemblance to some forms of *Minjaria* necessitates further discussion.

The smooth columns are very similar to those of forms of *Minjaria*. Projections occur in several forms of *Minjaria*, but most are not enclosed in niches and elongate niches are absent. The coalescing and massive bridging of *Pilbaria perplexa* is like that of *Minjaria pontifera*, but in *Minjaria* branching is infrequent whereas in *Pilbaria* it is moderately frequent.

The strongest resemblances are with forms of *Inzeria*, but differences are considered sufficient to warrant distinction as a new group. The ribbing which characterizes forms of *Inzeria* is only weakly developed in *Pilbaria*; in fact most columns of *P. perplexa* are notably smooth. But not all columns of *I. toctogulii* Krylov are ribbed (Krylov 1967, fig. 15). The few published reconstructions of *I. nimbifera* (Semikhatov) show very smooth columns; but it does have small, discontinuous ribs and many small bumps, as well as crooked columns (M. A. Semikhatov, pers. comm. 1969). There are also many resemblances with *I. intia* IV which, however, has much bumpier columns and proportionately much larger niches and projections than *P. perplexa*. This last feature, that the niches and projections of *P. perplexa* are very small compared with the column size, is an important difference from all forms of *Inzeria*. Raaben (1969*a*) uses a broad definition of *Inzeria* and allows considerable morphologic variation within forms; she gives little or no significance to the presence or absence of niches. Even using *Inzeria* in her broad sense *Pilbaria perplexa* cannot be classified into this group.

Stromatolites of a similar age from other continents which may be comparable with *Pilbaria* are described or figured by Baragar (1967), Donaldson (1963), Lausen (1929), Toens (1966, pl. 5), and Young (1941, text-fig. 1). None are sufficiently described or figured to enable further comparison.

Distribution. Gillen Member of the Bitter Springs Formation, Amadeus Basin, adjacent to a permanent large pool in Duck Creek, 18 miles east of Mount Stuart Homestead, beside the track 2 miles east of the previous locality and 'between Wyloo and Homestead, 10 miles west of Wyloo', all in the Wyloo 1:250 000 Sheet area, Hamersley Ranges, Western Australia. The third locality is that of a specimen loaned by the Geological Survey of Western Australia.

Age. About 2020 ± 165 m.y. (Early Proterozoic).

Group TUNGUSSIA Semikhatov

Tungussia Semikhatov 1962, Nuzhnov 1967, Krylov 1967, Raaben and Zabrodin 1969.

Type Form. Tungussia nodosa Semikhatov from several rock units in the Turukhan region of Siberia.

Diagnosis. Stromatolites with nonparallel, tuberous, or subcylindrical columns and frequent markedly divergent branching which commonly is multiple.

Content. T. nodosa Semikhatov, *T. confusa* Semikhatov, *T. sibirica* Nuzhnov, *T. bassa* Krylov, *T. laqueusa* Golovanov, and possibly *T. enpiggeni* Raaben and *T. russa* Raaben; the descriptions and illustrations of the last two are insufficient to allow any decision on their affinities. The description of *T. arctica* Raaben is not available to me. This whole group is in urgent need of revision.

Age. Middle and Late Riphean and probably Vendian.

Tungussia erecta f. nov.

Plate 4, fig. 2; Plate 30, figs. 1, 3–5; text-figs. 8, 53

Material. Two specimens.

Holotype. S357.

Name. The name *erecta* is given because in the upper part of individuals the columns are vertical.

Diagnosis. Tungussia with gnarled, tuberous, walled columns which are mostly erect and subparallel, but are horizontal and inclined near the bases of individuals.

Mode of Occurrence. T. erecta is known from one tabular biostrome about 70 cm thick (Pl. 30, fig. 1).

Column Arrangement and Branching. Within the basal 15–20 cm of the biostrome there are cumuli as well as columns (Pl. 30, fig. 4; text-fig. 53B). Here the columns vary from slightly declined to vertical; many are bent. Several columns branch off the upper surface of one cumulus; branching of the columns is frequent and varies from parallel to markedly divergent, with the latter predominating. Commonly from the upper surface of inclined columns project upwards several new columns which themselves may branch again, often dichotomously. Columns become vertical upwards so that the upper 50 cm or so of the biostrome consists of subparallel, erect columns (but in the upper few centimetres all are uniformly inclined). Interspaces are about 1 cm wide.

Column Shape. Columns are roughly cylindrical, crooked, gnarled, and tuberous; most are 2–5 cm wide (text-fig. 53). Transverse sections are elliptical, rounded rhombic, rounded polygonal, or, rarely, irregularly elongate. Bumps grade into rounded and digitate projections similar in width to the columns. Some irregularities shown on the reconstructions undoubtedly are artifacts of preservation, but the large bumps are primary since laminae within them conform to their shape. Within the basal part of the biostrome are cumuli up to 10 cm wide by 6 cm high.

Lamina Shape. Laminae are slightly wavy and dominantly steeply domed, hemispherical, parabolic, or conical (Pl. 4, fig. 2; Pl. 30, figs. 3–5; text-figs. 8H, 53). Rectangular and rhombic shapes occur in cumuli and the widest columns. Where column margins are least altered there is a wall (Pl. 30, fig. 3). There may be occasional peaks, cornices, and bridges, but because of very poor preservation this is uncertain.

Microstructure and Texture. Laminae are indistinct and discontinuous, consisting of dark grey carbonate layers, lenses, clots, and irregular bodies embedded in pale grey to colourless carbonate (Pl. 4, fig. 2). Most

TEXT-FIG. 53. *Tungussia erecta*, Gillen Member of the Bitter Springs Formation, 3 miles south-west of Alice Springs, Amadeus Basin. $\times\frac{1}{2}$, R_2. A, D, From the upper part of the biostrome (S357). B, C, From the lower part of the biostrome (S356). B is a tracing from a thin section cut normal to bedding. The section at the front of C is parallel to but not the same as that in B.

laminae are 100–200 μ thick but dark carbonate patches, many of which are crescent-shaped, reach a thickness of several millimetres. Boundaries vary from abrupt and distinct to diffuse and obscure. Within dark patches and laminae the texture is fine grained (10–35 μ) and hypidiotopic to xenotopic. The pale carbonate is coarse grained (35–170 μ) and xenotopic to hypidiotopic.

Interspace Fillings. Predominantly pale, grey, xenotopic to hypidiotopic, equigranular carbonate of about 35 μ grain size, with numerous large, irregular patches of finer, darker carbonate. Some dark patches resemble tabular intraclasts, and rounded bodies several millimetres wide may have been clastic grains. Grumous textures are common.

Secondary Alteration. Large parts of columns appear to have been replaced by the type of carbonate which also fills the interspaces; this obliterates most earlier structures although some patches remain less altered. Parts of columns are completely unlaminated, but these grade laterally into darker, laminated areas. Very little of the original microstructure has been preserved. Stylolitic solution has added to the column destruction.

Comparisons. The possession of markedly divergent branching and gnarled and tuberous columns, some of which are gently inclined, are similarities with forms of the groups *Baicalia* Krylov, *Tungussia* Semikhatov, and *Linella* Krylov. At least near the base of its biostrome *T. erecta* has variously inclined columns with markedly divergent branching, which distinguishes it from forms of *Linella* (but *L. ukka* grades into *Tungussia bassa*). The consistent and at least moderately frequent occurrence of gently inclined columns is used to characterize *Tungussia* and distinguish its forms from those of *Baicalia*. Thus this form is classified as *Tungussia*.

In the possession of long, vertical columns and only subordinate horizontal or gently inclined columns *T. erecta* resembles *T. confusa* Semikhatov. Semikhatov (1962) describes *T. confusa* as having a patchy wall; in our specimen of *T. confusa* most column margins are marked by stylolites: where these are absent there seems to be a wall (the lamination is sometimes indistinct). *T. erecta* also has a wall. But columns of *T. confusa* are not gnarled and tuberous, and laminae within them are only gently convex.

T. nodosa Semikhatov differs in having gently domed laminae, irregular large protrusions on columns, more frequently horizontal and gently inclined columns than *T. erecta*; and also it apparently lacks a wall.

The gross form of *T. bassa* Krylov resembles that of the lower part of *T. erecta* but lacks the upper, erect columns. *T. erecta* lacks large, horizontal columns with multiple branching at their distal ends. *T. laqueusa* Golovanov apparently lacks the vertical columns of *T. erecta*.

In contrast with *T. erecta*, *T. sibirica* Nuzhnov is characterized by its numerous horizontal columns with upturned, goblet-shaped ends, and by the ragged margins of its columns. Very poor illustrations make comparison difficult. *Tungussia inna* has more horizontal and gently inclined columns which also are more crooked, and in it coalescing and bridging occur frequently.

Distribution. Gillen Member of the Bitter Springs Formation, Amadeus Basin, 3 miles south-west of Alice Springs, Central Australia.

Age. Uncertain; probably Late Riphean, may be Middle Riphean (Adelaidean).

Tungussia inna f. nov.

Plate 6, fig. 4; Plate 30, fig. 2; text-figs. 8, 54

Tungussia sp. nov. I Glaessner, Preiss, and Walter 1969, p. 1058, figs. 2–3.

Material. Three specimens from one locality.

Holotype. S358.

Name. In the language of the Aranda (Arunta) tribe of Aboriginals who lived in the MacDonnell Ranges *inna* means trees and bushes: *T. inna* is bushy.

Diagnosis. Tungussia having crooked bumpy columns and almost continuous wall, frequent coalescing and bridging and wavy laminae; it occurs independent of other stromatolites.

Mode of Occurrence. T. inna forms tabular biostromes 30–45 cm thick and isolated rounded bioherms several tens of centimetres wide; it may also form tabular bioherms but inadequacy of outcrop makes this uncertain. Within the biostromes there are occasional discrete hemispherical bioherms several tens of centimetres wide: between these are individuals and columns not divisible into bioherms.

Column Arrangement and Branching. Columns radiate from a basal cumulus or start directly from a substrate consisting of flat laminated, pseudocolumnar, or short columnar stromatolites. The contact with the substrate is often gradational, bridging becoming less and less frequent upwards. Columns are variously inclined and crooked (text-fig. 54). Many columns are horizontal or gently inclined for several centimetres before turning upwards. Most branching is markedly divergent; possibly as many as ten columns radiate from some pillow-shaped cumuli. Interspaces are up to 1 cm wide.

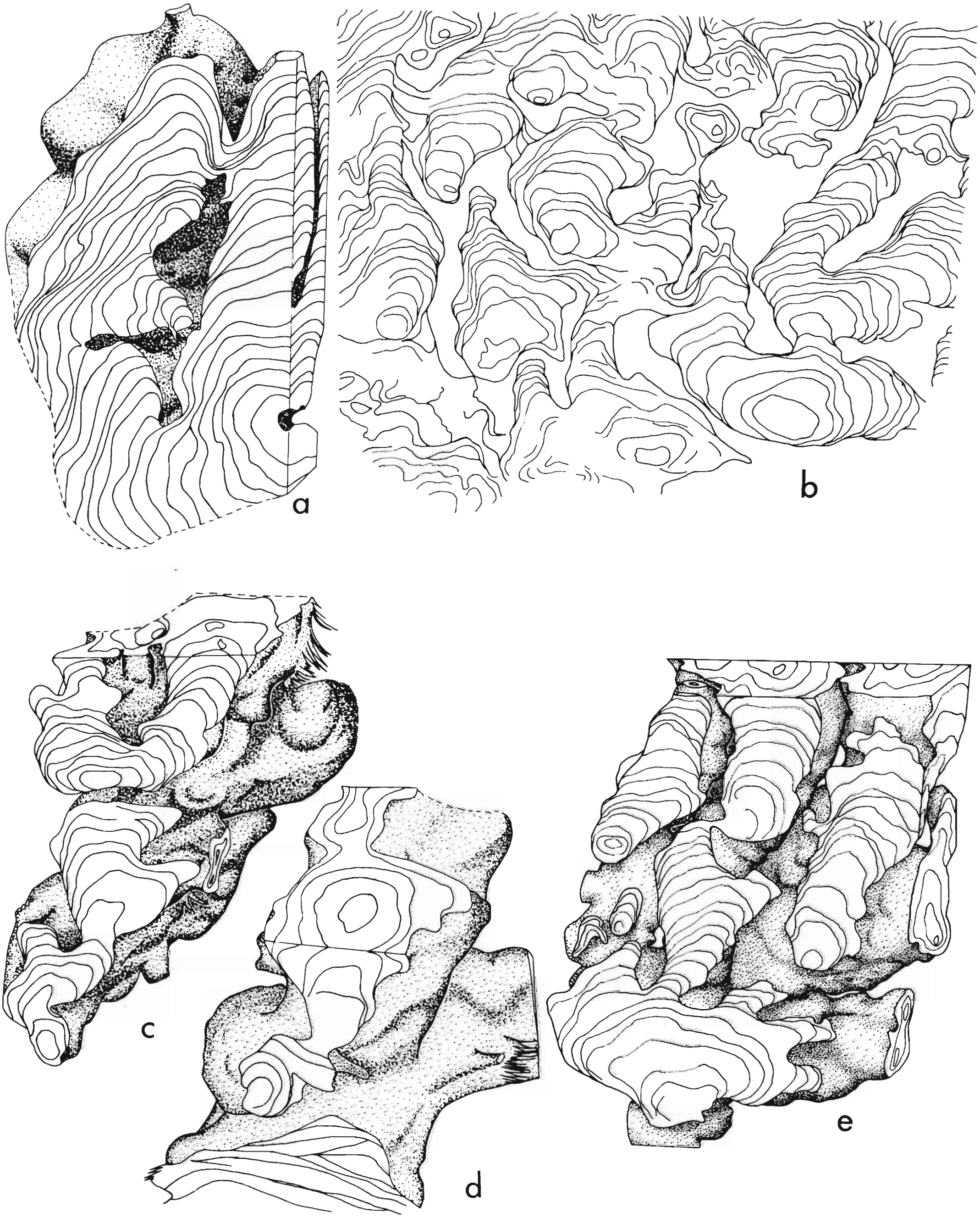
At the top of rounded and hemispherical bioherms all columns are roofed over by continuous bridges. Some bioherms consist largely of pseudocolumns (text-fig. 54A).

Column Shape. Column shape is very irregular and moderately tuberous but basically is cylindrical (text-fig. 54). Transverse sections are more or less equidimensional, with numerous indentations, and 1–3 cm wide. The columns are crooked, with abrupt direction changes of up to 70°. Many columns are only a few centimetres high. On the margins are numerous bumps up to 1 cm wide by 5 mm in relief. Infrequently there are digitate projections as well as occasional ribs and furrows.

Lamina Shape. Basically laminae are hemispherical, rectangular, or rhombic; but they are wavy, and the flexures cause considerable departure from the basic shapes (Pl. 6, fig. 4; Pl. 30, fig. 2; text-figs. 8G, 54). The flexures are up to half the width of columns, with amplitudes as great as their widths; more frequently they are smaller, each lamina having several flexures a few millimetres wide and in relief. Lamina shapes within columns vary moderately and gradually; occasional abrupt changes are caused by lenses. At column margins there usually is a wall, varying from 2 mm thick and formed by fifty laminae to a 0·15 mm thick coating of only two or three laminae. Most often ten or more laminae form the wall. Where there is no wall column margins are smooth, except where there are peaks and bridges; these are largely restricted to the lowermost and uppermost parts of bioherms and biostromes.

Microstructure and Texture. A striking feature of the texture of *T. inna* is the large amount of calcarenite, including oolites, incorporated in many laminae (Pl. 6, fig. 4). In this it is unique among Amadeus Basin columnar stromatolites. It is also one of the best preserved stromatolites from the basin (no connection between preservation and the presence of detritus is implied). Laminae about 400 μ thick are prominent. Three types of laminae can be distinguished:

1. Calcarenite cemented by sparite. Often these are not distinct laminae, but only patches within the pale or dark micritic laminae; some patches are irregularly tabular and conformable. They are identical with the interspace filling. Up to 50 per cent, but usually 10–20 per cent, of the volume of a column is formed of



TEXT-FIG. 54. *Tungussia inna*, Ringwood Member of the Pertatataka Formation, Amadeus Basin. × ½, R_1. A, 3 miles north-north-west of Olympic Bore (Alice Springs Sheet area). Part of a hemispherical bioherm about 30 cm wide (CPC 11517). B–E, 5·5 miles south-east of Ringwood Homestead. All four drawings represent almost the full thickness of a biostrome. B is a tracing from a section cut normal to bedding. B, C, E (S358), D (S359).

these patches and laminae. The patches are of very irregular shape but tend to be tabular; their boundaries vary from diffuse and gradational to abrupt and serrate. The bulk of this material is oolites and coated grains packed edge to edge, with sparite filling the interstices. The concentric oolitic lamination is sometimes faint, and some sparite patches at first appear homogeneous. The oolites and coated grains vary from spherical to tabular, with greatest dimensions from 40–500 μ; often their nucleii are opaque in thick sections and cream in reflected light. Very few grains lack a halo of sparite. The sparite is in grains 15–75 μ wide, usually at the smaller end of this range.

2. Semi-opaque pale micrite laminae. These commonly are 150–1500 μ thick and can be traced almost across a column; occasional lenses and clots up to 3·5 mm thick and 3·5–7 mm wide—some with an indistinct, contorted internal lamination—are formed of the same material. Abrupt 40–50 per cent thickness variations are numerous, as are wedge-outs. These laminae form 20–60 per cent of the volume of a column. Gradation into sparry calcarenite occurs frequently. Except for moderately numerous sparite patches and a few included oolites and coated grains they are relatively homogeneous, with a grain size of 7–18 μ. In transmitted light they are off-white, in reflected light colourless to slightly milky.

3. Dark micrite laminae. These vary from 150–700 μ thick laminae traceable across most of a column to a pattern of anastomosing thin (100–200 μ) stringers interspersed with laminae and patches of the sparry calcarenite. They form 20–50 per cent of the volume of a column. The carbonate is xenotopic to hypidiotopic and of 5–7 μ grain size. They are slightly mottled, with clots 50–100 μ wide. At 1200× magnification numerous 1–7 μ wide, irregularly shaped, black to amber particles are visible; many of the carbonate grains have pale amber coatings. In transmitted light these laminae are dark brownish grey, in reflected light pale brown.

In all three lamina types, but especially the micritic ones, there are faint laminae about 10 μ thick. The three major lamina types intergrade by the inclusion of patches of one type in another; the two micritic types are not always divisible. The wall is formed mainly of micritic laminae, with occasional thin calcarenitic laminae.

Interspace Filling. This is the same as the calcarenite laminae with the addition of platy intraclasts up to 17 mm long. The filling is unstratified except for occasional micritic laminae. Included are a few coarse (0·7 mm) rounded grains of sparry carbonate. The orientation of some intraclasts indicates at least 17 mm of relief during column growth.

Secondary Alteration. Stylolites and thin sparite veins occur infrequently. Some sparite has formed by recrystallization, as shown by relic structures within it. Patches of coarse sparite are rare; some may be open-space fillings.

Comparisons. Because of its dendritic shape with frequent markedly divergent branching and many columns which are horizontal or gently inclined for short distances, this form belongs to the group *Tungussia* Semikhatov.

Horizontal columns are less common than is suggested by Semikhatov's (1962) description of *T. nodosa*, which also apparently lacks a wall (at least this seems to be so because the margin structure is not described). *T. nodosa* has no laminae or patches of coarse detritus. The description of *T. laqueusa* Golovanov is brief and insufficiently illustrated, so comparison is difficult. It may be very similar to *T. inna*, but it has laminae of lesser convexity.

Tungussia confusa Semikhatov is described as having horizontal columns only rarely, but Semikhatov's (1962) illustrations and our specimens show numerous gently inclined columns which turn up into or branch into erect columns. In this *T. confusa* resembles *T. inna* but its columns are straighter and more nearly parallel, at least in the upper parts of individuals. The smooth columns of *T. confusa* contrast with those of *T. inna*. Semikhatov describes *T. confusa* as having a patchy wall; in our specimen of *T. confusa* most column edges are marked by stylolites: where these are absent there seems to be a wall (lamination is sometimes indistinct).

Hence *T. confusa* probably had a wall, as does *T. inna*. *T. confusa* lacks arenaceous laminae and patches.

T. bassa Krylov occurs on the flanks of bioherms of *Linella ukka* Krylov. *T. inna* occurs independently. *T. inna* lacks the long, horizontal columns with multiply-branched ends of *T. bassa*. Laminae of *T. bassa* apparently are not as wavy as those of *T. inna*. Arenaceous laminae and patches are absent from *T. bassa*.

T. sibirica Nuzhnov is characterized by its numerous horizontal columns with upturned, goblet-shaped ends and its ragged column margins, features lacking in *T. inna*. *T. inna* lacks the regularity of the upper part of *T. erecta*, and its columns are not as gnarled and tuberous. Raaben and Zabrodin's (1969) *T. russa* and *T. enpiggeni* are too poorly described to allow comparisons to be made.

Distribution. Ringwood Member of the Pertatataka Formation, 5·5 miles south-east of Ringwood Homestead, east MacDonnell Ranges, Amadeus Basin.

Age. Vendian or late Late Riphean (Adelaidean).

Unnamed Stromatolite

Plate 28, fig. 4; text-fig. 55

Collenia australasica Edgell 1964, p. 244, pl. 5.

Material. One specimen. This is the same (and only) specimen identified by Edgell (1964) as '*Collenia australasica* (Howchin)' (recte *Acaciella australica* (Howchin)). It is too small to be identified.

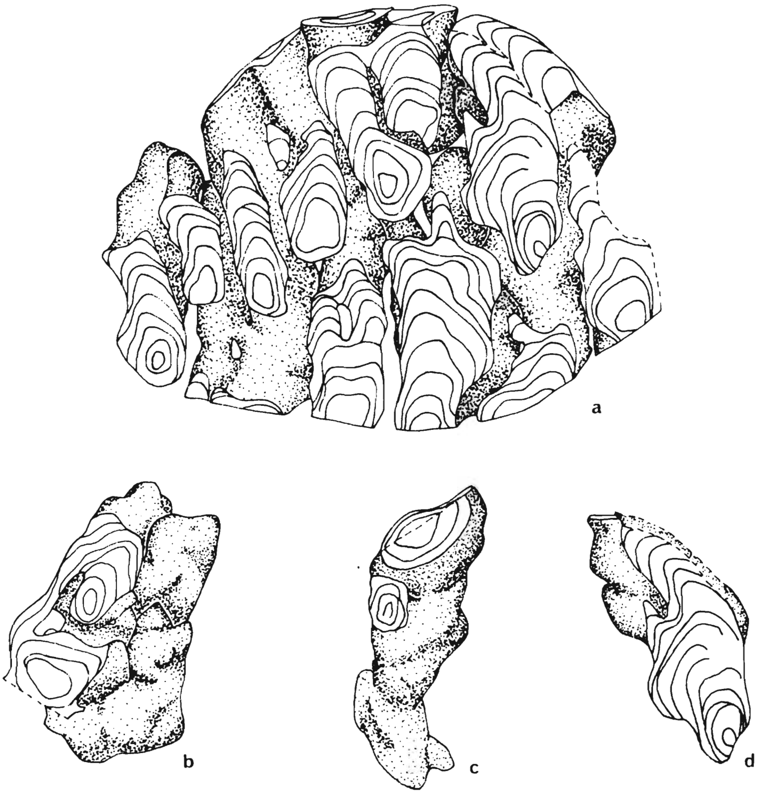
Mode of Occurrence. 'To the best of my recollection the small stromatolite "fingers" are independent growths and are not protuberances from a larger body. The columns are not parallel and the beds or bed in which they occur is only a few inches thick' (from the finder, W. N. MacLeod, pers. comm. 1969).

Column Arrangement and Branching. Columns are subparallel, and 2–5 mm apart. Branching is parallel (apparently α–β), dichotomous, and ?frequent. Coalescing and bridging occur moderately frequently (text-fig. 55).

Column Shape. Columns are slightly crooked, 1–2·5 cm wide, at least 8 cm high, and subcircular to rounded polygonal in transverse sections (text-fig. 55). There are numerous large bumps up to 15 mm wide by 5 mm in relief. Niches (not elongate) with projections occur moderately frequently.

Lamina Shape. Laminae are steeply domed to parabolic. Many are slightly wavy, with moderately frequent flexures up to several millimetres wide and mostly less than 1 mm in relief, but reaching reliefs of several millimetres (Pl. 28, fig. 4). Laminae do not overhang column margins. Over about 40 per cent of the area of column margins laminae intersect the margins at angles of up to 15°; elsewhere there is a wall, variously multilaminate or formed of only one or two laminae, infrequently lying unconformably on underlying laminae.

Microstructure and Texture. Laminae are indistinct (Pl. 28, fig. 4). The most prominent are 100–500 μ thick with smooth, locally distinct, subparallel boundaries. Boundaries are marked by dark lines, or by the abutment of a dark lamina against a pale one. Rarely can laminae be traced more than a few millimetres before fading or wedging-out. Many have dark bases which grade up to light tops. Locally discernible are alternating pale and dark laminae 20–100 μ thick which can be traced for up to 500 μ before fading out; their boundaries are parallel and smooth.



TEXT-FIG. 55. '*Collenia australasica*' of Edgell (1964); unnamed here. Reconstructions from the one and only specimen available and studied by Edgell. ×1 (GSWA F5015). A, The whole specimen, R_2. B–D, Columns from A. D is a 60° reconstruction, R_1.

Almost all of the columns consist of acicular carbonate with crystals perpendicular to the lamination. The crystals are 50–100 μ wide by about 300 μ long. An anastomosing pattern of quartz-filled cracks 15–350 μ wide is prominent in the central parts of columns and penetrates to their margins; they cause the carbonate to be divided into dark segments 20–150 μ wide making lamination almost indistinguishable.

Interspace Fillings. In the interspaces are numerous rounded carbonate grains 50–100 μ wide, some of which have within them 15–20 μ wide strips of pale carbonate up to 150 μ long. The strips may be replacement structures or have been formed by boring algae. Sparry carbonate surrounds the grains. There are occasional intraclasts up to 2 mm wide with a different texture from that of the columns. Detrital grains and intraclasts form about 70 per cent of the filling.

Comparisons. Adequate material for meaningful comparisons is lacking. There are some similarities with the *Patomia* f. indet. and *Pilbaria perplexa*, also from the Duck Creek Dolomite. It resembles Hofmann's (1969*a*) form F from the Gunflint Formation of Canada. No reconstructions of form F have been published but illustrated sections show columns frequently with steeply domed, slightly wavy laminae, a thin wall over most of the column margins, and bumpy, subparallel, coalescing columns which branch. The specimen shows none of the diagnostic characters of *Cryptozoon australicum* (recte *Acaciella australica*), and in addition has more steeply convex laminae than that form.

Distribution. Duck Creek Dolomite, Wyloo Group, Mount Bruce Supergroup 'south of June Hill, in the broad valley of Duck Creek' (Edgell 1964), Wyloo 1:250 000 Sheet area, Western Australia.

Age. About 2020±165 m.y. (Early Proterozoic).

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Revised typescript received 20 February 1972

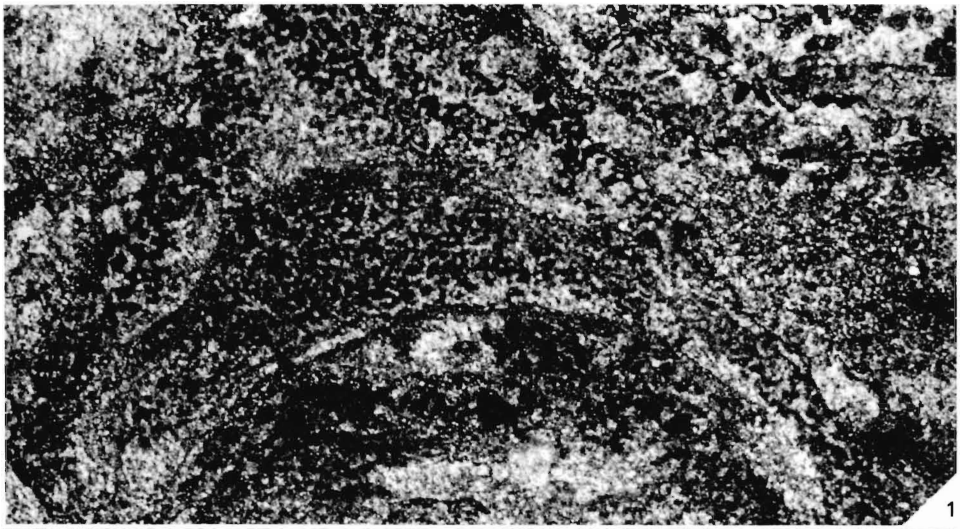
PLATES

EXPLANATION OF PLATE 1

Microstructures in thin section.

Figs. 1–2. *Madiganites mawsoni* vermiform microstructure, grading into areas with only a grumous structure, ?Jay Creek Limestone, Jay Creek, Amadeus Basin. 1, S46, × 12. 2, S46, × 25.

Fig. 3. *Kulparia alicia*, the least altered column margins have walls, Loves Creek Member, Jay Creek, Amadeus Basin, S347, × 3·2.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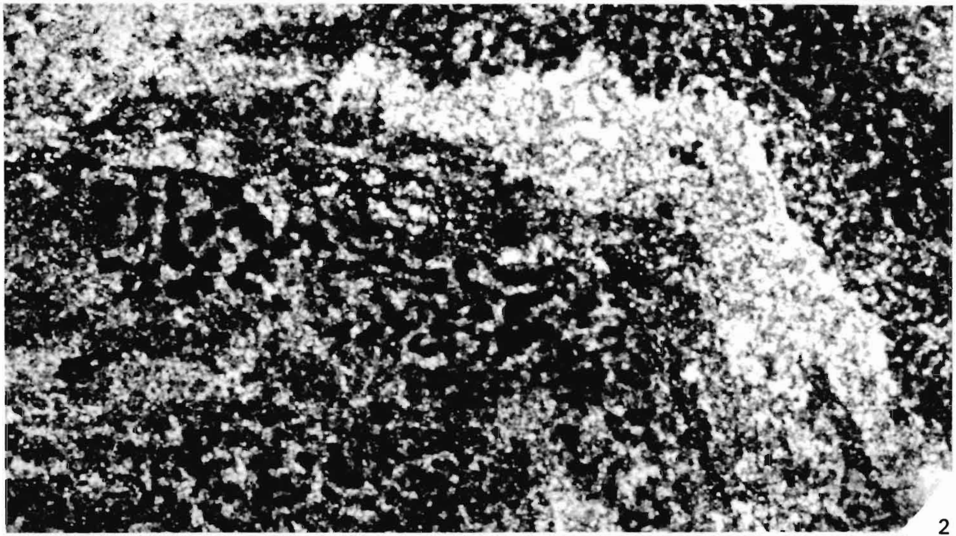
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WALTER, Stromatolite microstructure

EXPLANATION OF PLATE 2

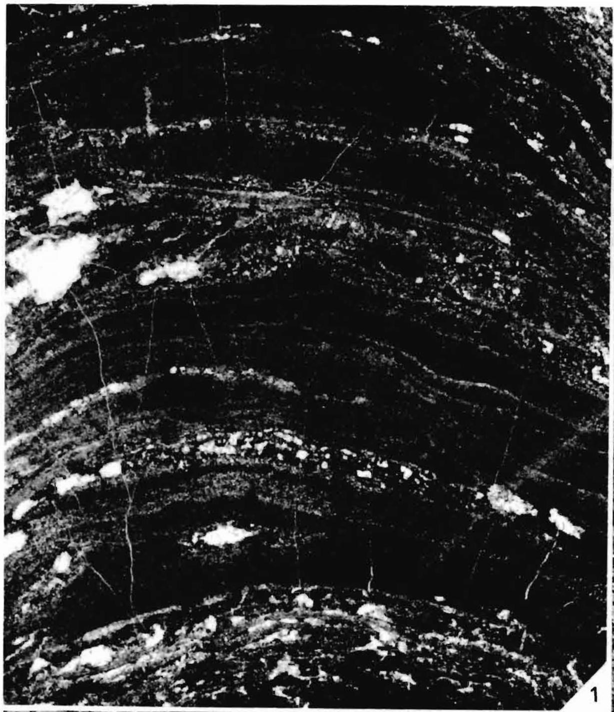
Streaky microstructures in thin section; all specimens except that in fig. 3 are from the Loves Creek Member at Jay Creek, Amadeus Basin.

Fig. 1. *Basisphaera irregularis* narrow column, S136, ×3.

Fig. 2. *Boxonia pertaknurra*, S137, ×3.

Figs. 3–4. *Acaciella australica*; 3, dolomite preservation, Bitter Springs Formation, Katapata Gap, Amadeus Basin, S345, ×3·3. 4, calcite preservation—note concordant stylolites and gradations from homogeneous to grumous laminae, S131, ×4.

Fig. 5. *Minjaria pontifera*; note that laminae become parallel to or strike acutely into the altered column margin—the now patchy wall is probably the remnants of a more continuous wall, S374, ×3·5.



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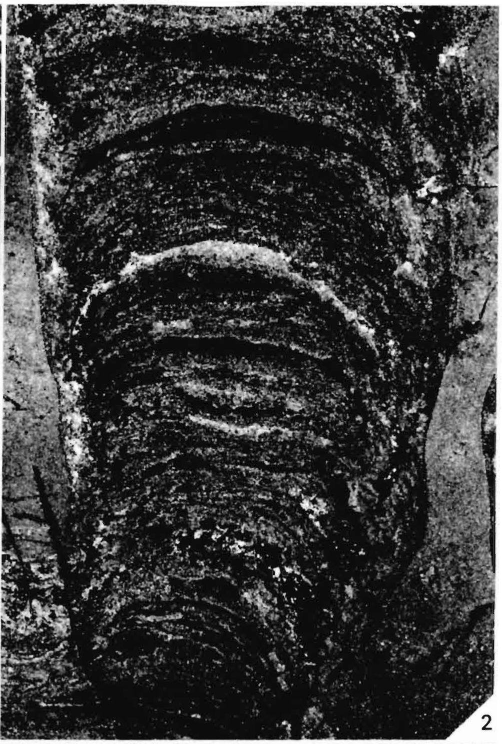

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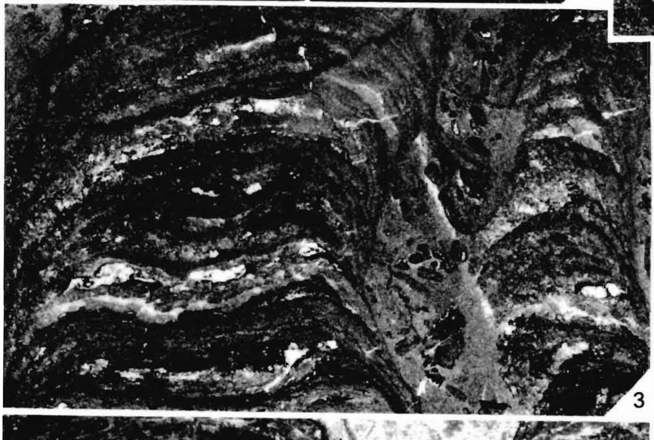

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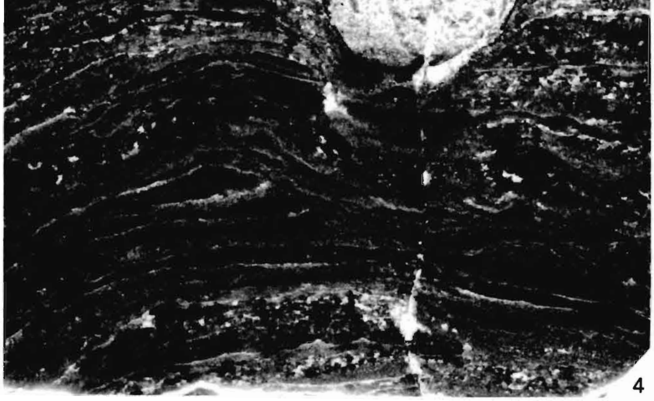

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WALTER, Stromatolite microstructure

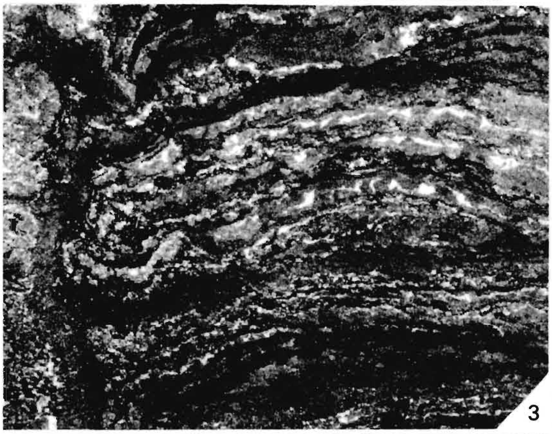
EXPLANATION OF PLATE 3

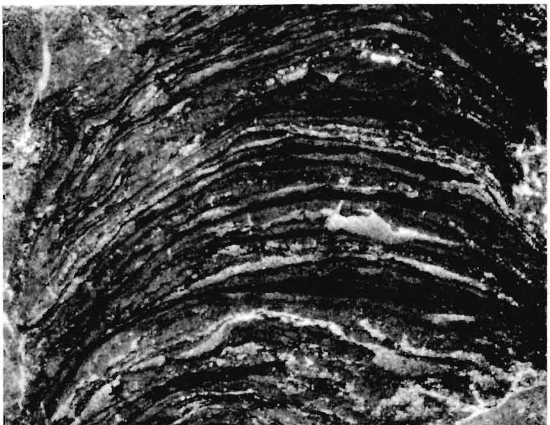
Microstructures of *Inzeria intia* in thin section; all specimens are from the Loves Creek Member, Ross River Tourist Camp, Amadeus Basin.

Fig. 1. Base of stage III; note lateral gradation from homogeneous to grumous laminae, wall, and intraclasts in the interspace, S141, ×4.

Fig. 2. Stage IV, showing a niche in one column, S370, ×3.

Figs. 3–5. Stage II in differently altered specimens, 5 being the least altered; 3 and 4 have numerous concordant stylolites; 3 has a selvage; 3, S138, ×4. 4, S369, ×2·8. 5, S372, ×3.





WALTER, Stromatolite microstructure

EXPLANATION OF PLATE 4

Microstructures in thin section.

Figs. 1, 3. *Jurusania nisvensis*, Loves Creek Member, Jay Creek, Amadeus Basin. 1, from upper columnar part, S134a, ×3·1. 3, from lower, pseudocolumnar, and many-bridged columnar part, which appears to be better preserved than the other, S134b, ×3·5. It is uncertain how much of the lamina shape irregularity visible in fig. 1 is secondary.

Fig. 2. *Tungussia erecta*, upper part, badly preserved, Gillen Member, Alice Springs, Amadeus Basin, S357, ×3.

Fig. 4. *Pilbaria perplexa*, Duck Creek Dolomite, Duck Creek, Hamersley Basin, S203, ×3·2.

Fig. 5. *Linella avis* showing the streaky microstructure, the well-developed walls and bumpy column margins, Loves Creek Member, Jay Creek, Amadeus Basin, S127, ×3·2.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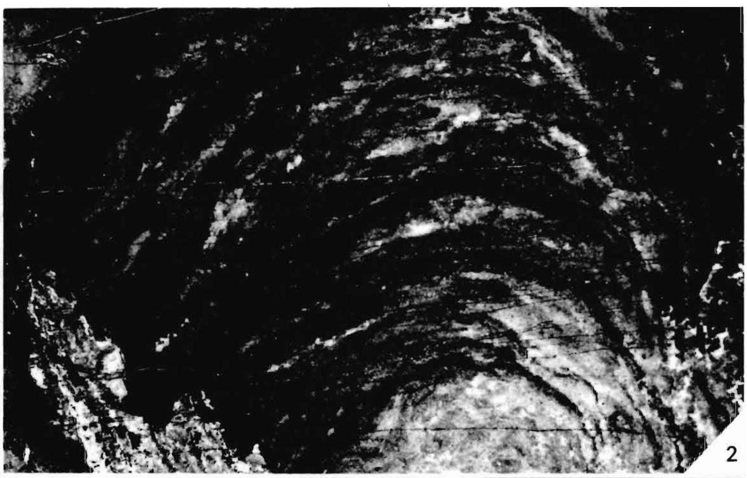
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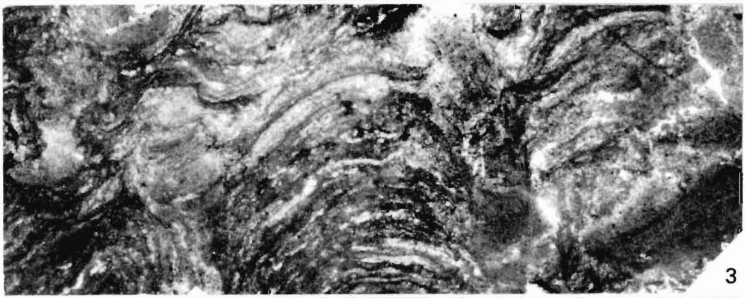
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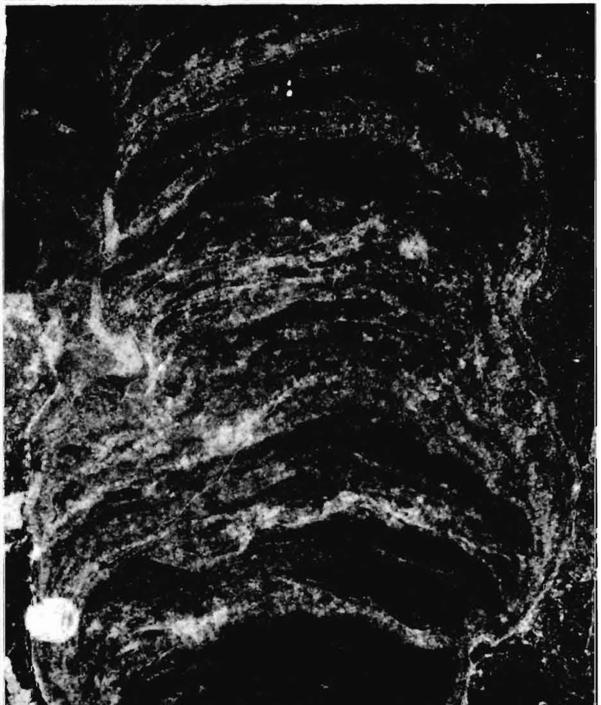
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WALTER, Stromatolite microstructure

EXPLANATION OF PLATE 5

Microstructures in thin section.

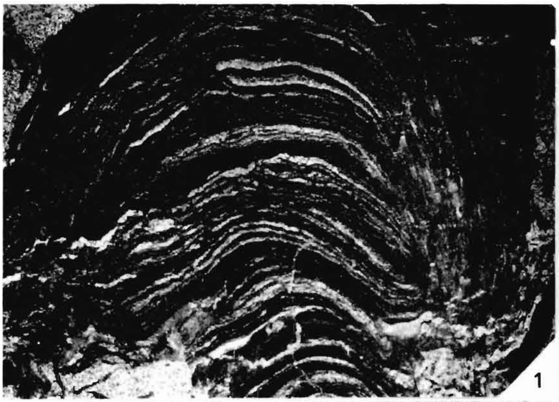
Fig. 1. *Baicalia capricornia*, note the banded microstructure, Irregully Formation, near Maroonah H.S., Hamersley Basin, S200, × 1·4.

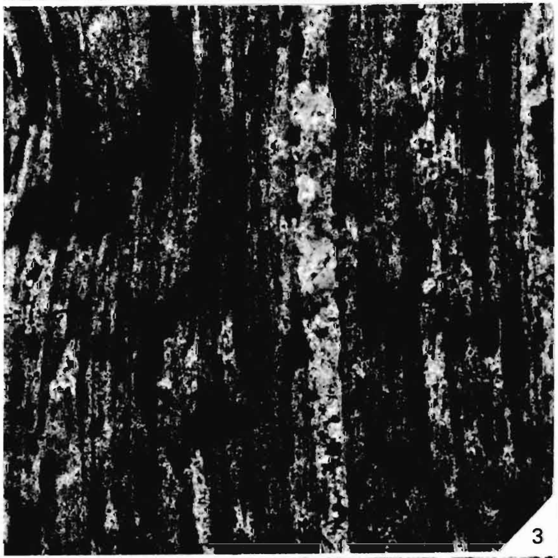
Fig. 2. *Alcheringa narrina*. The banded microstructure and radial structures are clearly visible. The speckling is caused by the inclusion of micaceous or clayey detritus, Pillingini Tuff, Mount Herbert, Hamersley Basin, S95c, × 10.

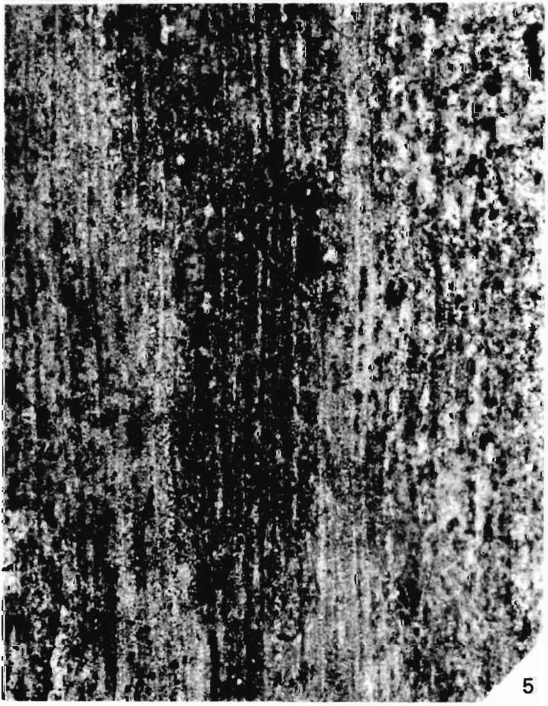
Fig. 3. *Conophyton* cf. *gaubitza*, Antrim Plateau Volcanics, Mount Wittenoom, Western Australia, GSWA F5022, × 3·5.

Fig. 4. *Conophyton garganicum* (*garganicum*?), McArthur Group, McArthur Basin, BMR F23519, × 7.

Fig. 5. *Conophyton basalticum*, note the banded microstructure, Antrim Plateau Volcanics, Northern Territory, CPC11314, × 2.







WALTER, Stromatolite microstructure

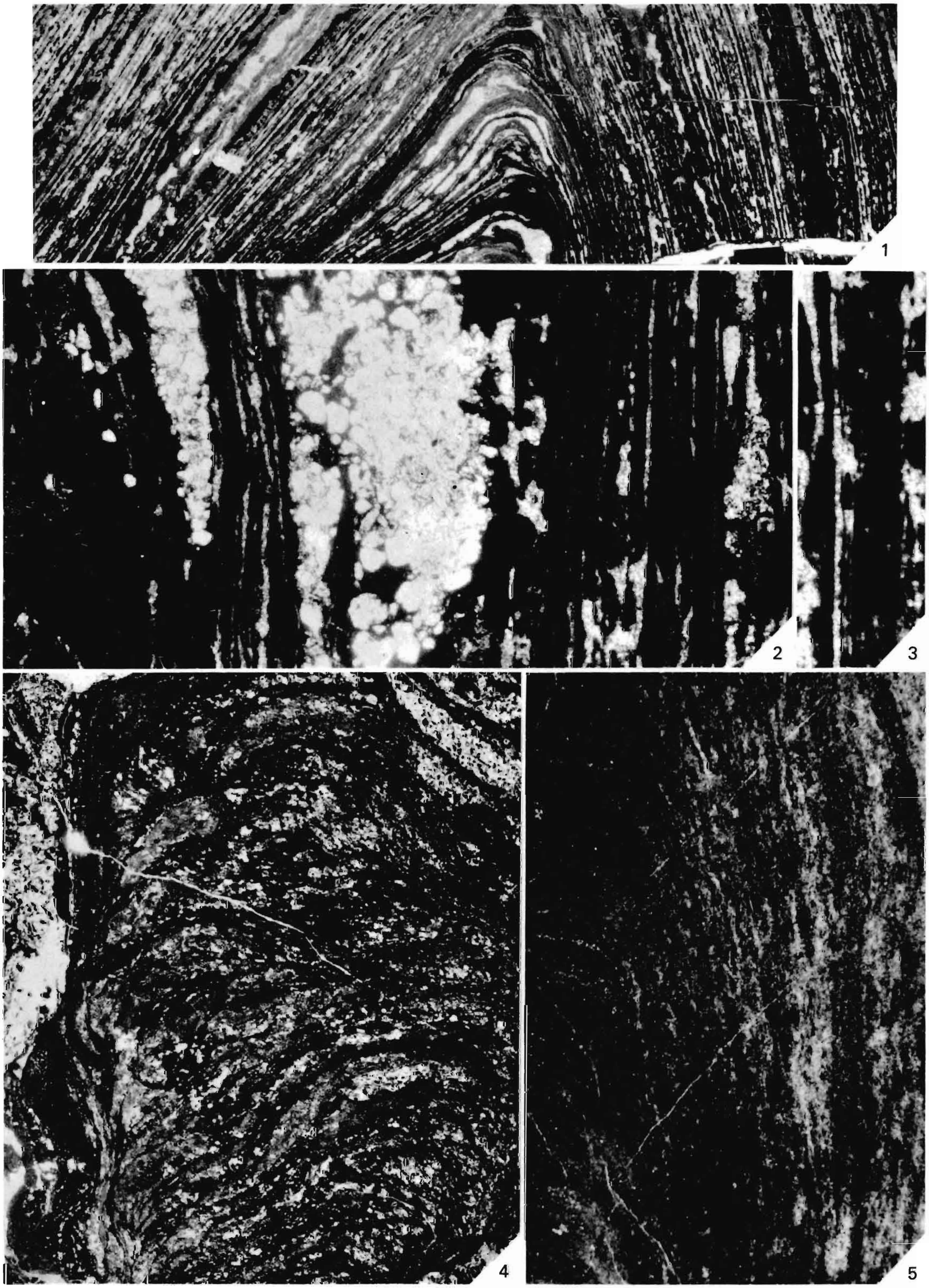
EXPLANATION OF PLATE 6

Microstructures in thin section.

Figs. 1–3. *Conophyton garganicum australe*, Irregully Formation, Irregully Creek, Bangemall Basin. 1, S188, ×1·5. 2, many lenses are visible, as is much included sand-sized detritus, S189, ×9. 3, shows a macrolamina, S188, ×20.

Fig. 4. *Tungussia inna*; the unique, spotty microstructure of this form results from the inclusion in the columns of a large quantity of sand-sized detritus; note also the column walls, Ringwood Member, Ringwood, Amadeus Basin, S358, ×3.

Fig. 5. *Georginia howchini*; some thickening of laminae is visible in the crestal zone, on the left, Mount Baldwin Formation, Huckitta, Georgina Basin, CPC11316, ×4.



WALTER, Stromatolite microstructure

EXPLANATION OF PLATE 7

Dead stromatolites in the intertidal zone of Shark Bay, Western Australia.

Fig. 1. Looking baywards, north of Goat Point; elongate cumuli grade into scattered columns; there are some growing stromatolites in the foreground and middle distance.

Fig. 2. Looking shorewards, north of Goat Point; the large stromatolite in the left foreground is about 2 m wide, and in front of it are two growing stromatolites.

Fig. 3. Looking shorewards, Goat Point; the dark flats in the background are covered by algal mats such as that in Pl. 8, fig. 3.


1


2


3

WALTER, Recent stromatolites

EXPLANATION OF PLATE 8

Growing stromatolites in the intertidal zone of Shark Bay, Western Australia.

Figs. 1–2. Mamillose algal mats trapping calcilutite; Gladstone area; between the stromatolites is ripple-marked coquina and calcarenite. 1, knife handle is about 15 cm long. 2, close-up showing foetid sediment below the few millimetres of living algal mat.

Fig. 3. Eroded rugose algal mats trapping calcarenite, north of Goat Point. Here erosion of continuous algal mats leads to the formation of discrete stromatolites. Pencil for scale (lower right).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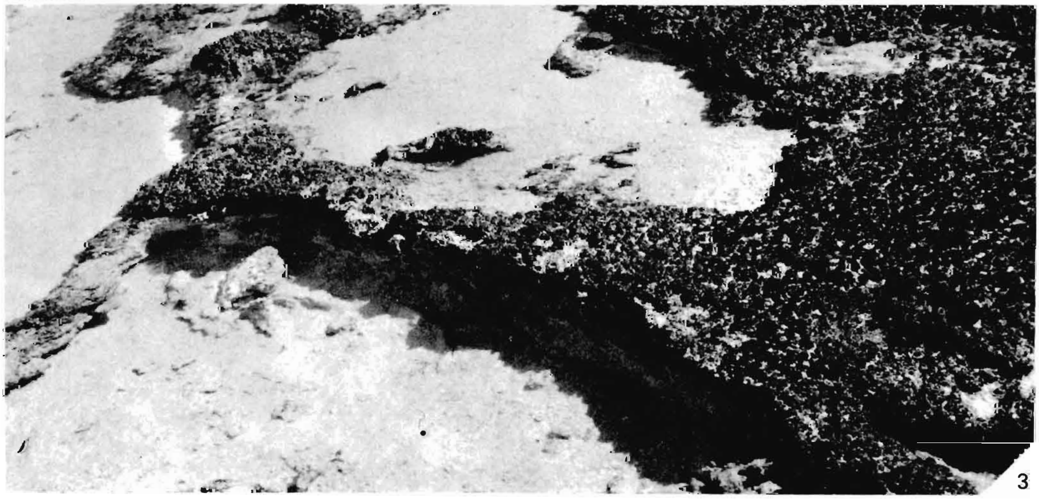
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WALTER, Recent stromatolites

EXPLANATION OF PLATE 9

Stromatolites and sediment, Shark Bay, Western Australia.

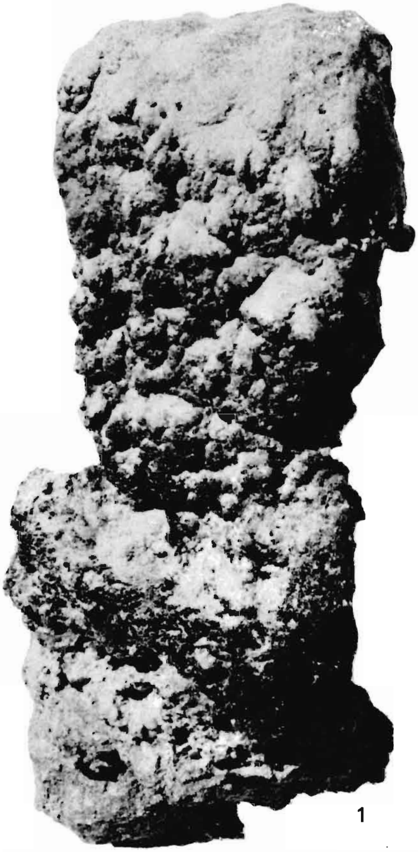
Figs. 1–2. Growing columnar stromatolites built by rugose algal mats; 1 is 33 cm high, 2 about 30 cm; the lower quarter of the column in 1 was buried in sediment. The dark patches are living algae. Upwardly directed surfaces are coated with calcarenite.

Fig. 3. Longitudinal section of growing columnar stromatolite built by smooth algal mats, × 1.

Fig. 4. Dead stromatolite with a prominent ribbing formed by overhanging coarse laminae, north of Goat Point.

Fig. 5. Eroded dead stromatolites with large intraclasts between them, wavecut platform, uppermost intertidal zone, north of Goat Point. Height of field of view about 25 cm.

Fig. 6. Longitudinal section of a growing columnar stromatolite like those in figures 1 and 2, built by rugose algal mats. Note the crude, coarse layering (cf. fig. 3) included shell debris and lack of a wall. S534.



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WALTER, Recent stromatolites

EXPLANATION OF PLATE 10

Figs. 1–3. *Conophyton basalticum*, Antrim Plateau Volcanics, Northern Territory. 1, crestal zone, despite the very poor preservation marked lamina thickening is visible, CPC11314, ×3·1. 2, longitudinal section of the same specimen as in 1, ×0·6. 3, longitudinal section showing the full width of a column, CPC11315, ×0·5.

Figs. 4–5. *Conophyton garganicum australe*, Irregully Formation, Irregully Creek, Bangemall Basin. 5, disconformity surface almost parallel to bedding, showing transverse sections of columns. Hammer handle 32 cm long. 4, close-up of one of the columns in 5; note the irregular lamina shape and the grit in several parts of the column.

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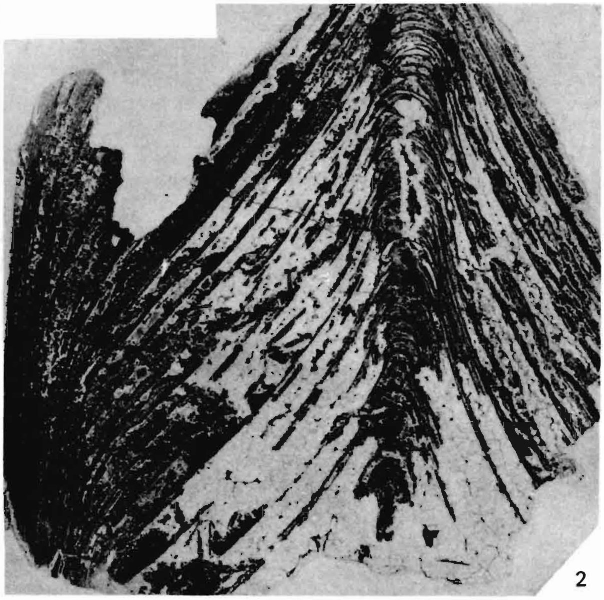

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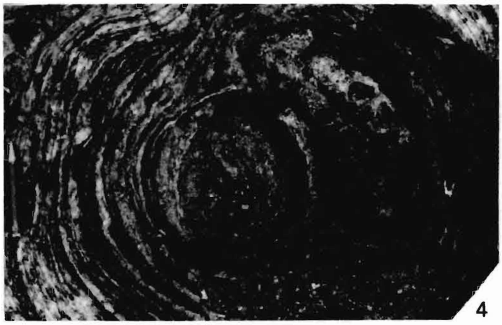

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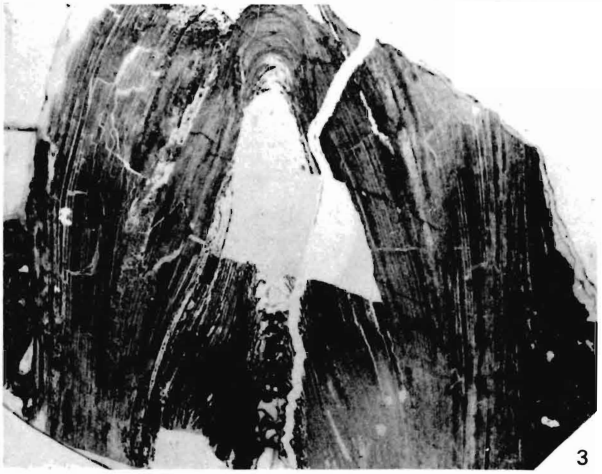

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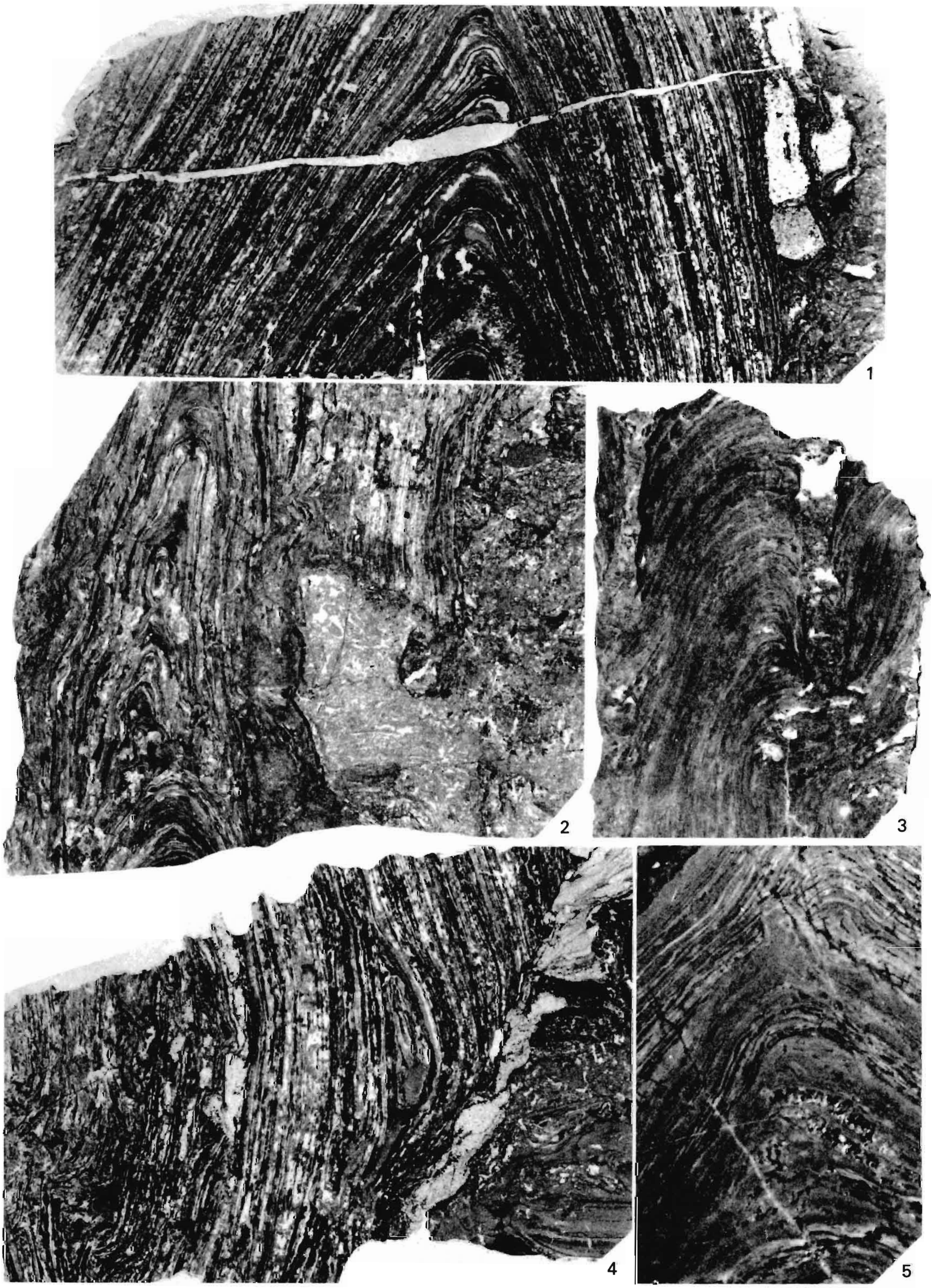
WALTER, *Conophyton*

EXPLANATION OF PLATE 11

Figs. 1–2, 4–5. *Conophyton garganicum australe*, Irregully Formation, Irregully Creek, Bangemall Basin; longitudinal sections. 1, crestal section; note contorted laminae and patches of coarse detritus at column margin, thin section of S188, ×0·7. 2, crestal section of a column with very steeply dipping and locally deformed laminae, and a very irregular margin, thin section of S187, ×0·7. 4, outer third of a column; note the folded laminae on the left, nappe-like fold on the right and coarse detritus along the margin, thin section of S189, ×0·8. 5, crestal section showing a small diapir near the top, cut face of S190, ×1·4.

Fig. 3. *Conophyton garganicum* (*garganicum*?), ? Tooganinnie Formation, McArthur Basin. The only known example of branching in conophytons. The section is not crestal, cut face of BMR F23520, ×0·3.



WALTER, *Conophyton*

EXPLANATION OF PLATE 12

Fig. 1. *Conophyton garganicum* (*garganicum*?), Reward Dolomite, McArthur Basin. Crestal section, cut face; silicified specimen, CPC11319, ×0·7.

Figs. 2–3. *Conophyton* cf. *gaubitza*, Antrim Plateau Volcanics, Mount Wittenoon, Western Australia; crestal sections of GSWA F5022. 2, crestal zone, ×3·5. 3, almost the full preserved width of the same column; note the lamina flexures, ×0·6.

Figs. 4–5. *Georginia howchini*, Mount Baldwin Formation, Huckitta, Georgina Basin; longitudinal sections. 5, central *Conophyton*-like column from which radiate branches, CEC11316, ×2. 4, column which was possibly a branch, with small digitate projections (which are not the result of secondary alteration), CPC 11317, ×1·1.

WALTER, *Conophyton* and *Georginia*

EXPLANATION OF PLATE 13

Acaciella australica in outcrop, Bitter Springs Formation, near Jay Creek, Amadeus Basin; the sections are approximately perpendicular to bedding and are all parts of one biostrome.

Figs. 1–3, 5. Parts of wide bioherms with broad basal columns which by α-parallel branching form numerous narrow columns. Text-figure 29C is a sketch which includes the bioherm shown here in 1.

Fig. 4. A hemispherical bioherm with radially arranged columns. The sketch of the hemispherical bioherm in text-figure 29B is based on this photograph.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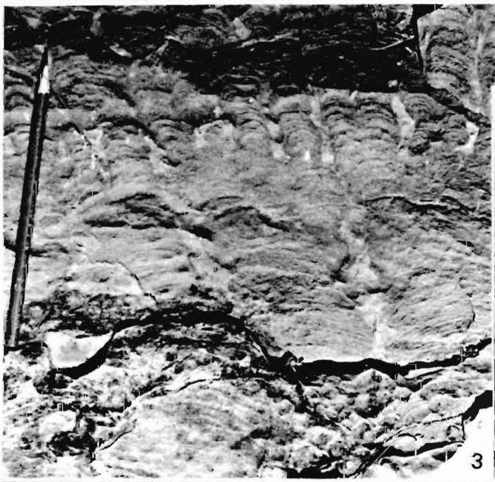
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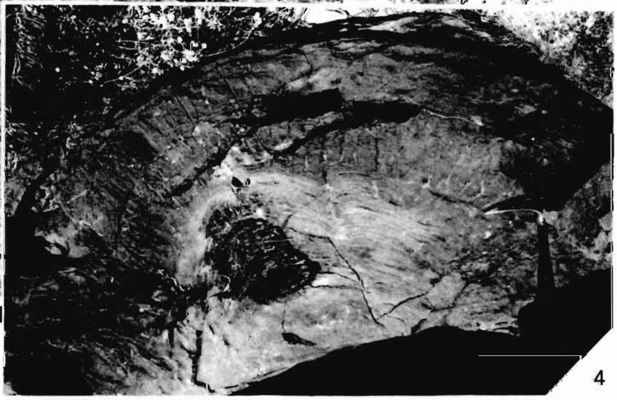
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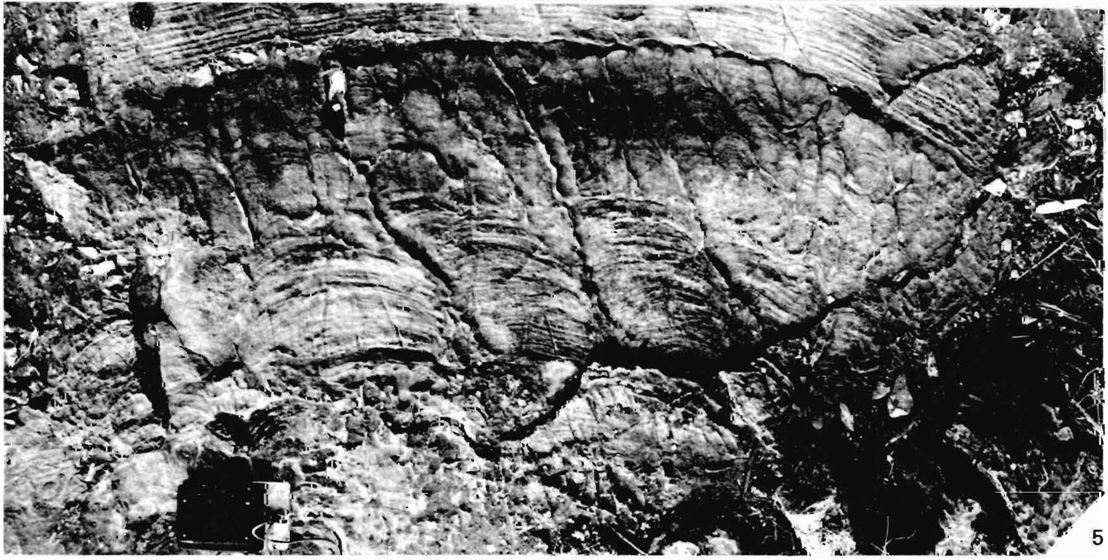
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WALTER, *Acaciella*

EXPLANATION OF PLATE 14

Acaciella australica, Bitter Springs Formation, Amadeus Basin.

Fig. 1. Two contiguous bioherms near Chewing's locality, about ½ mile west of Acacia Well; section perpendicular to bedding. Hammer handle 32 cm long.

Fig. 2. Longitudinal thin section; specimen from near Jay Creek, S131, ×0·5.

Figs. 3–4. Bioherms in one biostrome in Katapata Gap. The specimens of text-figures 30, 32B, C, D, are from the bioherm in 3.

Fig. 5. Syntype of *Cryptozoon tessellatum*; thin section, S22, ×1·4.

Fig. 6. Syntype of *Cryptozoon australicum*; thin section, S20, ×0·8.


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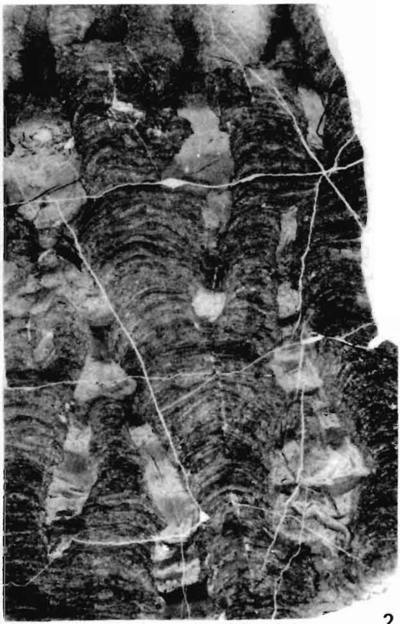
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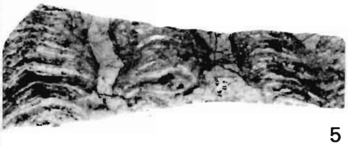
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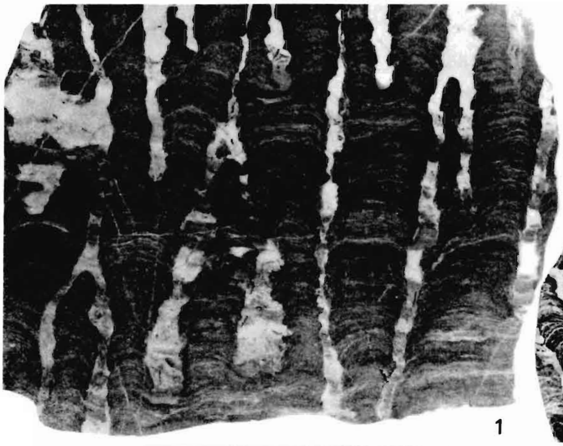
WALTER, *Acaciella*

EXPLANATION OF PLATE 15

Figs. 1–2. Longitudinal slabs of *Acaciella australica*, Bitter Springs Formation, Jay Creek, Amadeus Basin. Note the α- and β-parallel branching. 1, S131, ×0·4. 2, S132, ×0·5.

Figs. 3–5. *Alcheringa narrina*, Pillingini Tuff, Mount Herbert, Hamersley Basin; thin sections. 3, S95a, ×3. 4, note the microbioherms, S95b, ×1·1. 5, S95c, ×0·9.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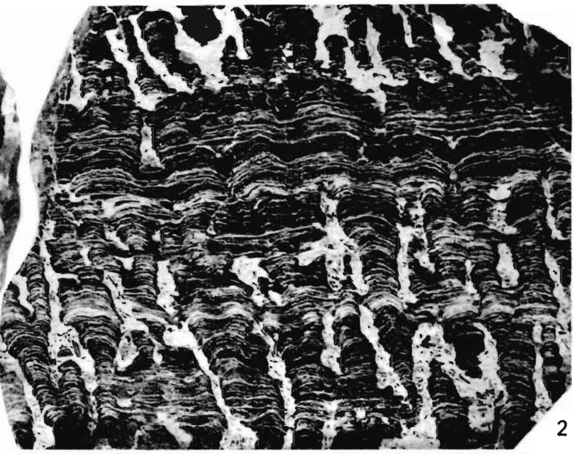
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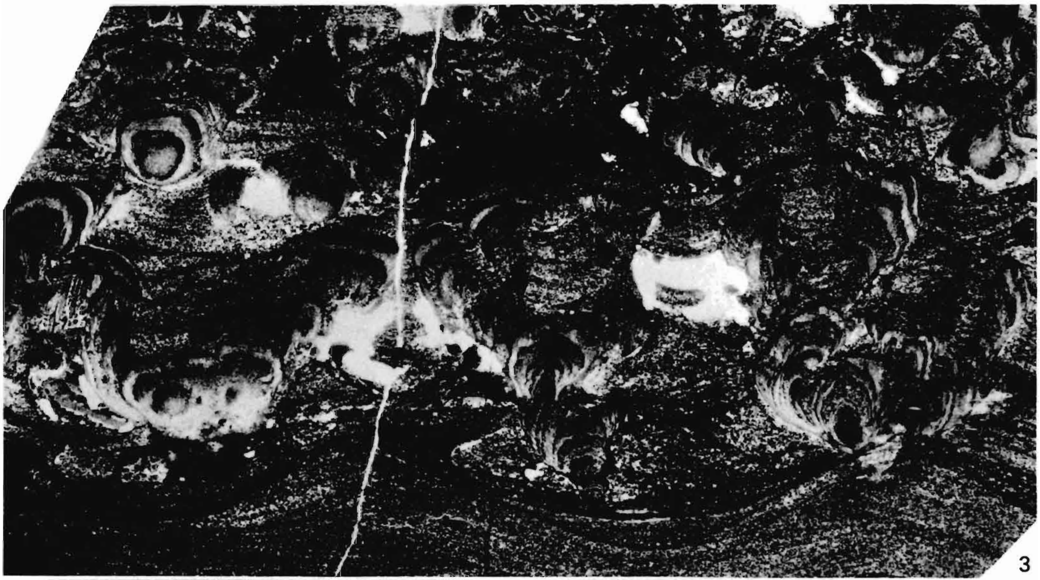
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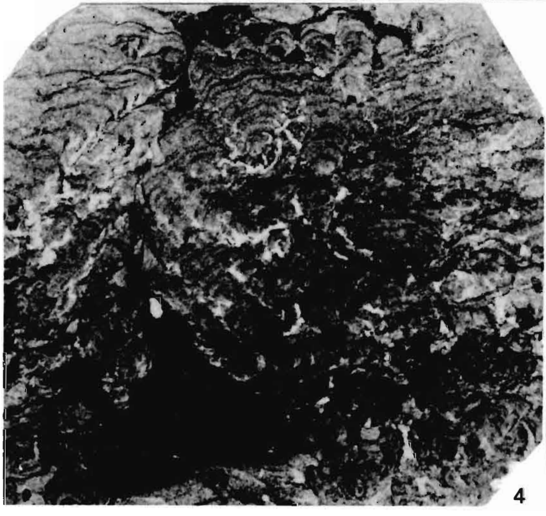
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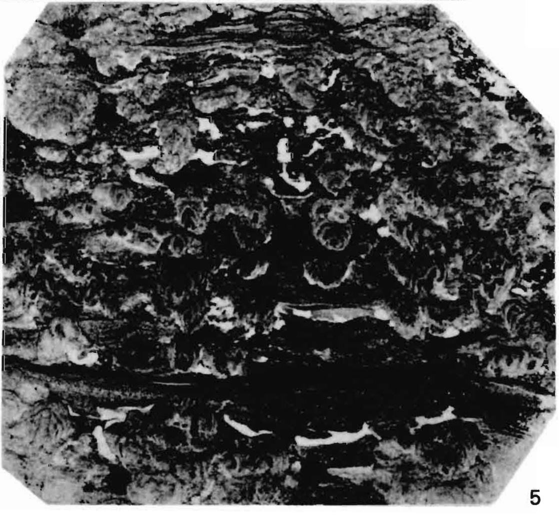
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WALTER, *Acaciella* and *Alcheringa*

EXPLANATION OF PLATE 16

Figs. 1–3. *Alcheringa narrina*, Pillingini Tuff, Mount Herbert, Hamersley Basin. 1, cut face normal to bedding showing a microbioherm GSWA F11487, ×1·1. 2–3, thin sections, normal to bedding. 2, S95b, ×16. 3, S95a, ×6.

Figs. 4–5. *Gruneria* f. nov., Ventersdorp 'System', Orange Free State, South Africa; thin section of S535. The pale lenses in 5 are coarse, sparry carbonate which probably infilled gas cavities. 4, ×3. 5, ×3·5.


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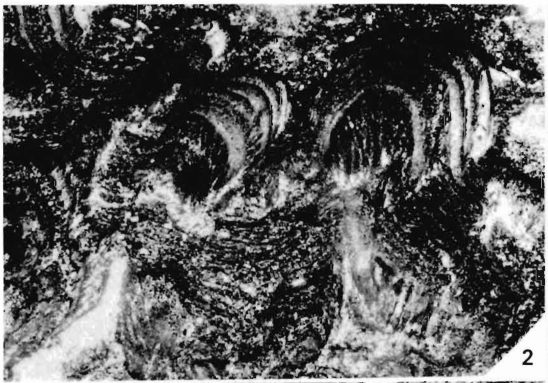
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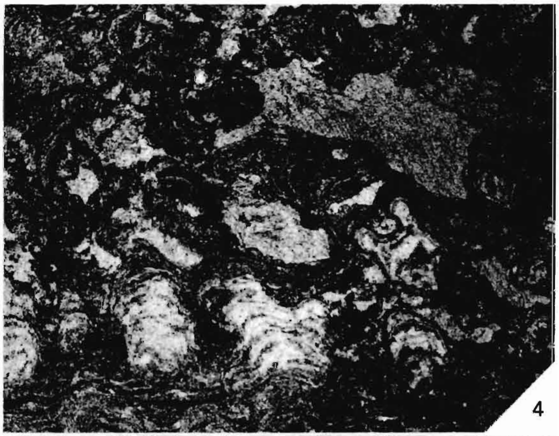
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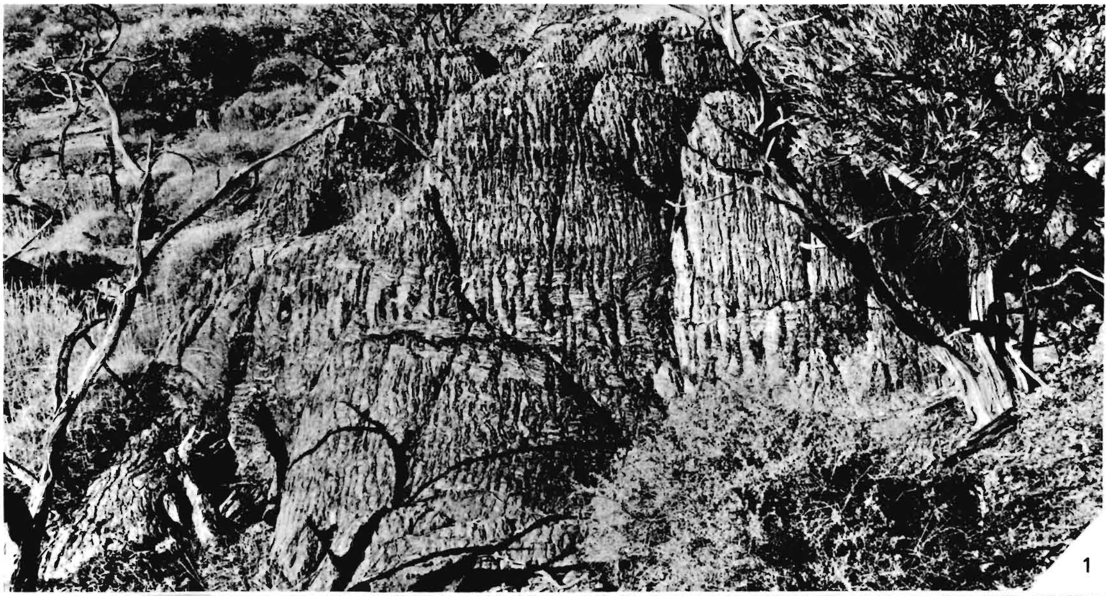
WALTER, *Alcheringa* and *Gruneria*

EXPLANATION OF PLATE 17

Baicalia capricornia in outcrop, Irregully Formation, Bangemall Basin; all sections are normal to bedding.

Figs. 1–2, 4–5. East of Maroonah Homestead. The outcrop in 1 is about 2·5 m high; note the broad columns in the middle, where there are also extensive bridges. 2 is the upper part of a biostrome. 5 shows α-parallel branching near the base of a biostrome.

Fig. 3. Northern entrance to the gorge of Irregully Creek; identity not certain.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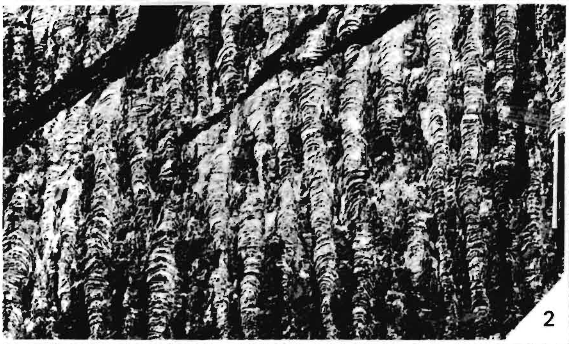
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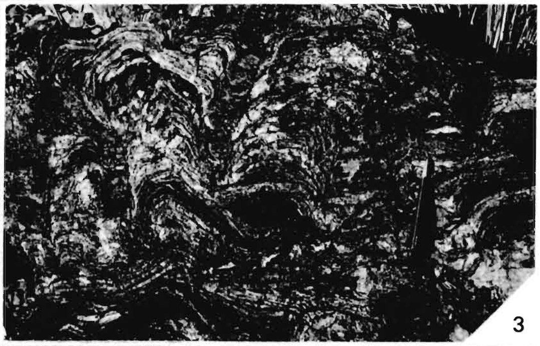
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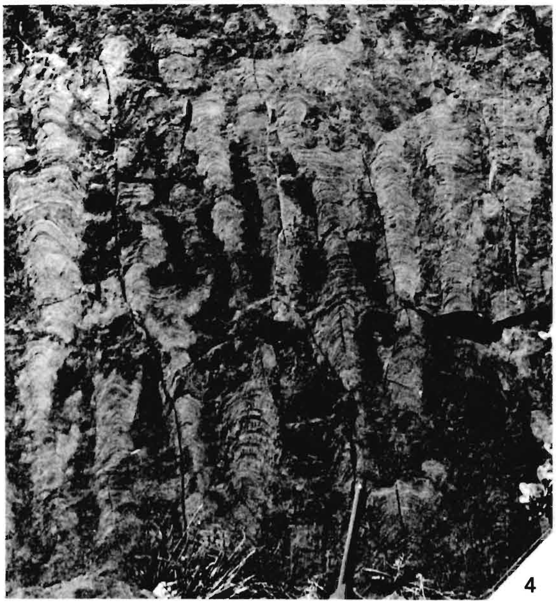
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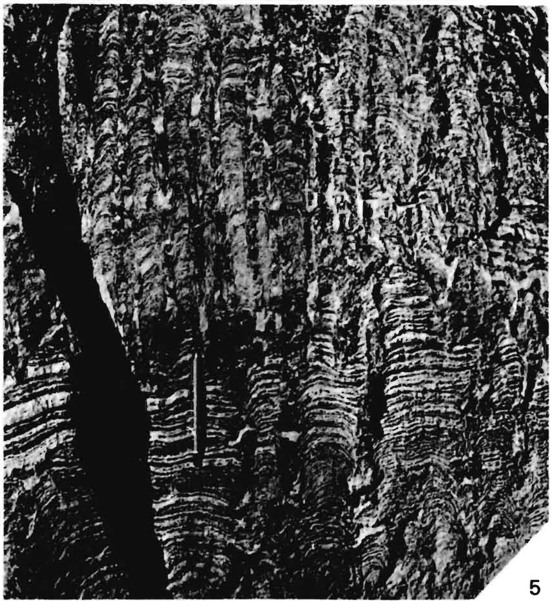
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WALTER, *Baicalia*

EXPLANATION OF PLATE 18

Figs. 1–2. *Baicalia capricornia*, Bangemall Basin. 1, face probably parallel to bedding showing brecciated, disoriented columns in the Devil Creek Formation. 2, longitudinal thin section of a specimen from the Irregully Formation, east of Maroonah Homestead, S200, ×0·6.

Figs. 3–4. *Basisphaera irregularis*, Bitter Springs Formation, Jay Creek, Amadeus Basin; longitudinal thin sections. 3, S346, ×0·7. 4, S136, ×0·1.

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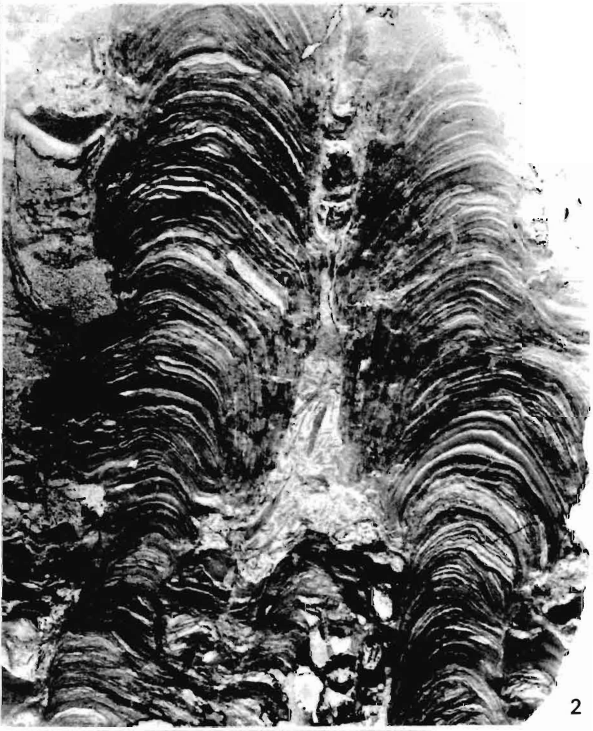

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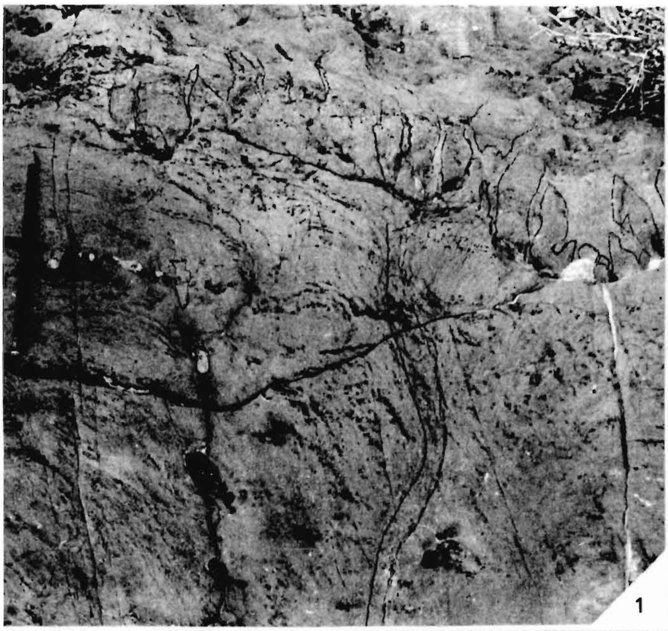
WALTER, *Baicalia* and *Basisphaera*

EXPLANATION OF PLATE 19

Stromatolites from the Bitter Springs Formation, Jay Creek, Amadeus Basin.

Figs. 1, 3–5. *Basisphaera irregularis*, field and cut sections normal to bedding. 1, broad columns branching into narrow columns (all columns outlined in ink). 3, several contiguous broad columns; compass is about 6 cm wide. 4–5, cumulate individuals at the base of the same bed which contains the columns in 1 and 3. 4, S135, ×0·5.

Fig. 2. *Boxonia pertaknurra*, thin section normal to bedding of broad, basal columns. Note the wall on the overhanging edge of the column on the left, S354, ×0·8.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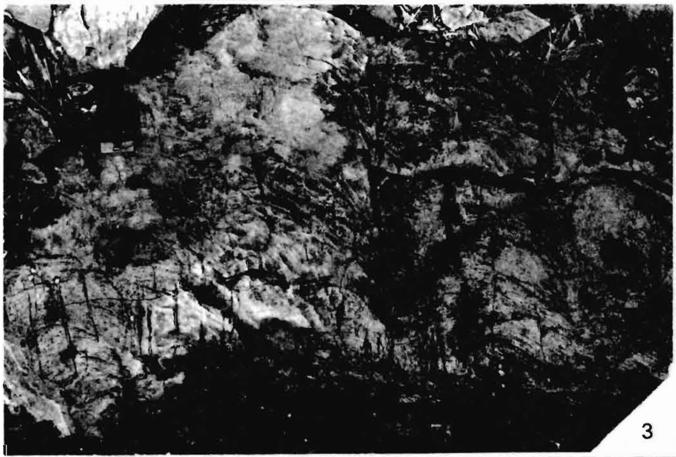
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WALTER, *Basisphaera* and *Boxonia*

EXPLANATION OF PLATE 20

Stromatolites from the Bitter Springs Formation, Amadeus Basin.

Figs. 1–3. *Boxonia pertaknurra.* 1–2, sections normal to bedding of biostromes. 1, column shape greatly modified by stylolites, near Ross River Tourist Camp. 2, near Jay Creek. 3, longitudinal slab of a Jay Creek specimen showing branching from broad columns; the columns in the upper right are slightly oblique to the section; S137, × 1.

Figs. 4–5. *Inzeria intia*, outcrops normal to bedding near the Ross River Tourist Camp. 4, contact between stages II and III. 5, a bioherm, with the broad columns of stage II outlined in ink; these branch into the narrow columns of stage III, forming the upper part of the photograph.


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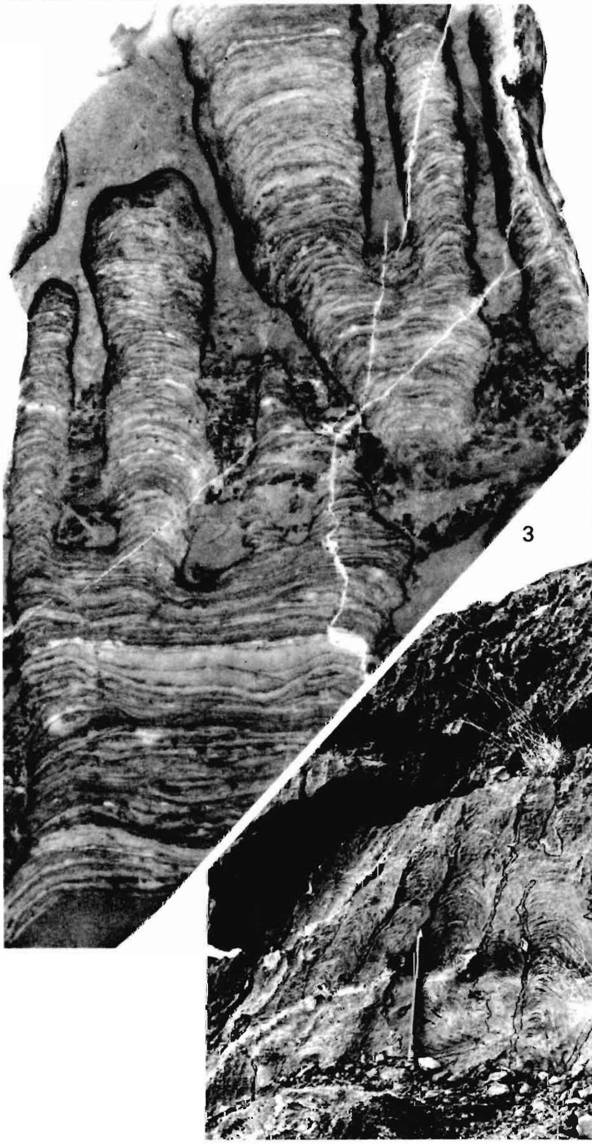
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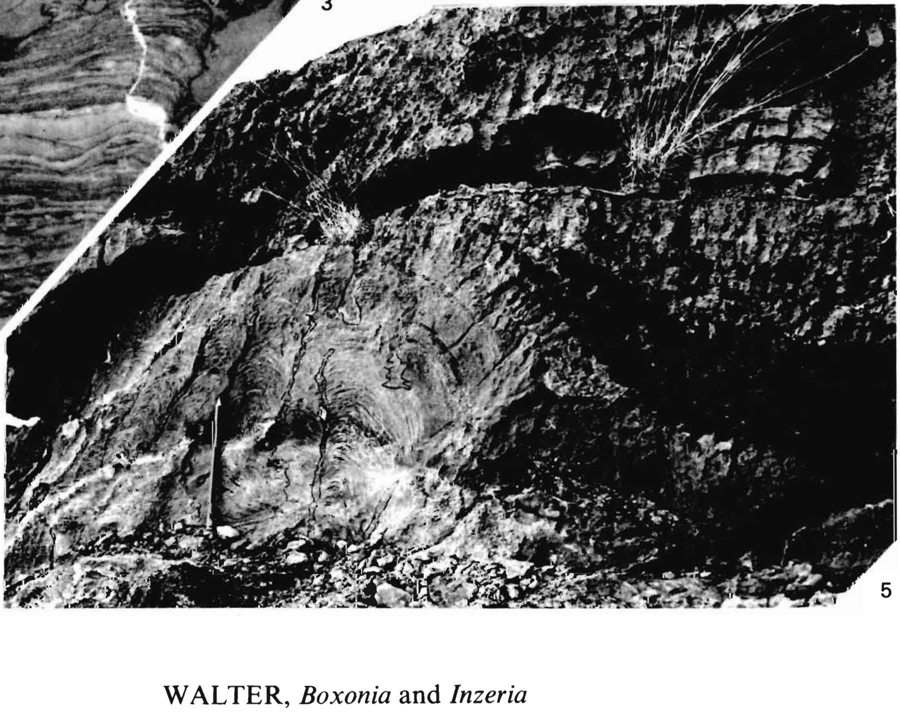
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WALTER, *Boxonia* and *Inzeria*

EXPLANATION OF PLATE 21

Figs. 1-5. *Inzeria intia* in outcrop, Bitter Springs Formation, near Ross River Tourist Camp, Amadeus Basin. 1, looking west along the north side of the ridges arrowed in Pl. 33, fig. 2. The narrow columns of stages II and III in the main *I. intia* biostrome make horizontal bands across the middle of the photograph; here they are not perpendicular to the bedding, which dips south (left) at about 40°. 2-3, bioherms within the biostrome in 1. 2, the margins of two bioherms are visible; stages I and II columns are invisible. 3, stage II columns outlined in ink; the curved branching zone is visible. 4, *I. Intia* I at the base of the biostrome shown in 1. 5, isolated *I. intia* I just below the main biostrome.


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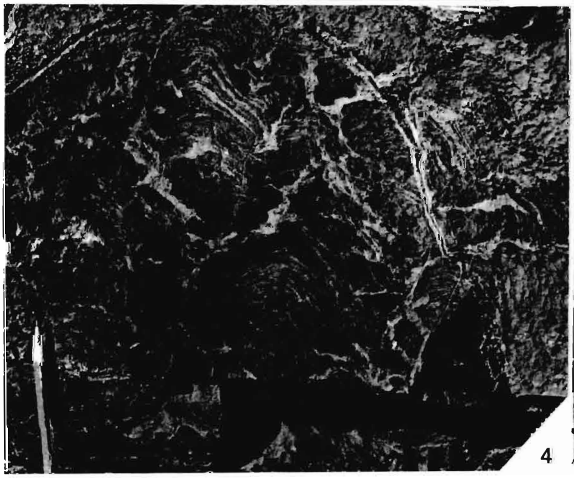
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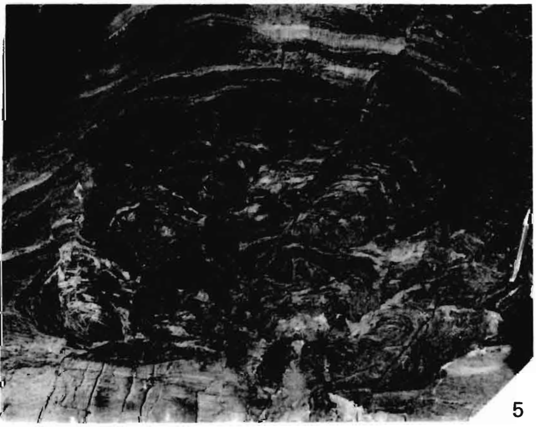
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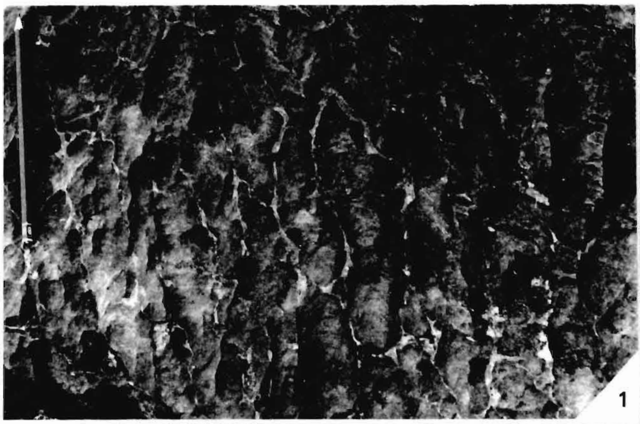
WALTER, *Inzeria*

EXPLANATION OF PLATE 22

Figs. 1–5. *Inzeria intia*, Bitter Springs Formation, near Ross River Tourist Camp, Amadeus Basin. 1, *I. intia* IV in outcrop, top of the main biostrome; arrows indicate projections. 2, *I. intia* III longitudinal thin sections. Note walls and niches, S143, × 0·8. 3, outcrop showing transverse sections of *I. intia* III columns. These resemble desiccation cracks but the column laminae are convex-up, not the reverse as in desiccation cracks. 4–5, two slabs from several centimetres apart in the same specimen of *I. intia*, S138; reconstructed in text-figure 41F, × 0·7.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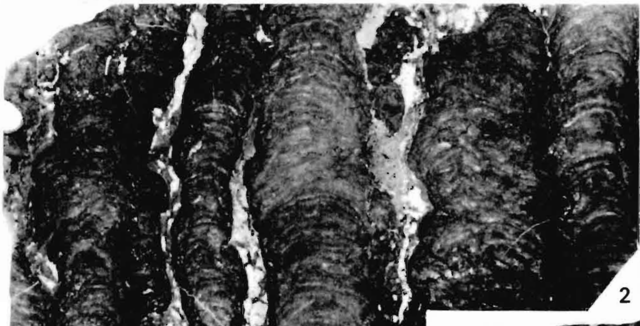
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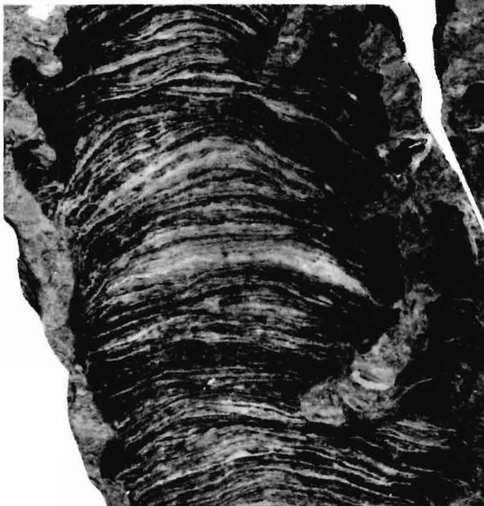
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WALTER, *Inzeria*

EXPLANATION OF PLATE 23

Figs. 1–5. *Inzeria intia*, Bitter Springs Formation, near Ross River Tourist Camp, Amadeus Basin. 1, columns from the branching zone between stages II and III shown in 3. Note the wall and partial alteration from homogeneous to grumous laminae; the column on the right is greatly altered, S141, ×3·2. 2, 4, stage IV columns. 2, ×0·9. 4, a niche is clearly shown, S370, ×3. 3, branching zone between stages II and III. 5, example of stage II which occurred separately in a thin biostrome lacking other stages, S369, ×0·8.


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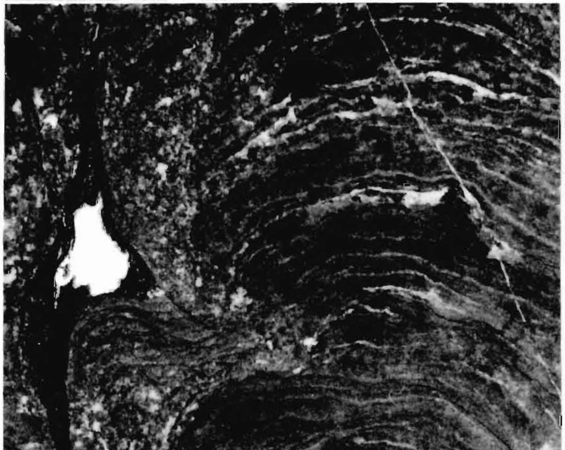
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WALTER, *Inzeria*

EXPLANATION OF PLATE 24

Bitter Springs Formation stromatolites, near Jay Creek, Amadeus Basin.

Figs. 1–4. *Jurusania nisvensis*; 1 and 2 are the same bioherm visible next to the figure in Pl. 31, fig. 1. 1, a section of the whole bioherm normal to bedding (which dips away from the observer at about 70°). 2, the gradational zone from the lower, flat-laminated part to the upper, columnar part (which forms the pale grey upper half of the photograph). 3, thin section parallel to the columns of the gradational zone (columns originally vertical), S134b, ×0·7. 4, longitudinal thin section of a specimen from the columnar part of the bioherm shown in 1, S134a, ×0·7.

Figs. 5–6. *Kulparia alicia*, in outcrop sections normal to bedding. The specimens reconstructed came from the areas shown here. 5, the bases (one at the bottom of the pencil) and junction (vertical line in the centre of the photograph) of two bioherms. 6, columns in the middle of the bioherm on the left in 5.


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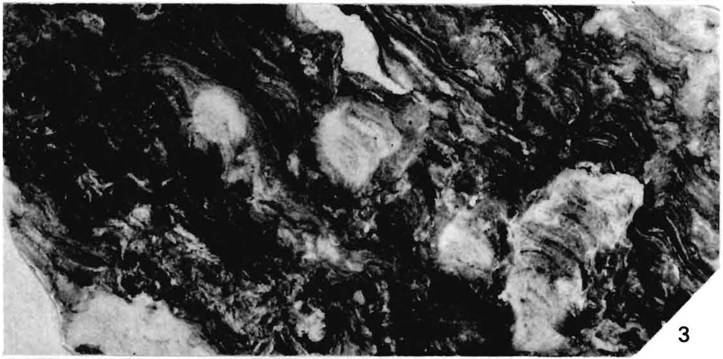
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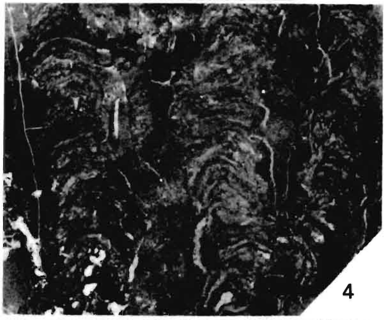
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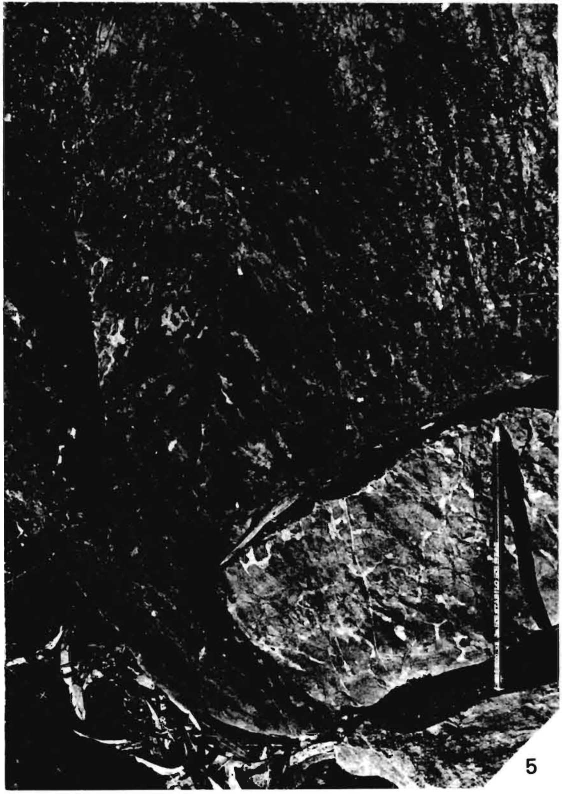
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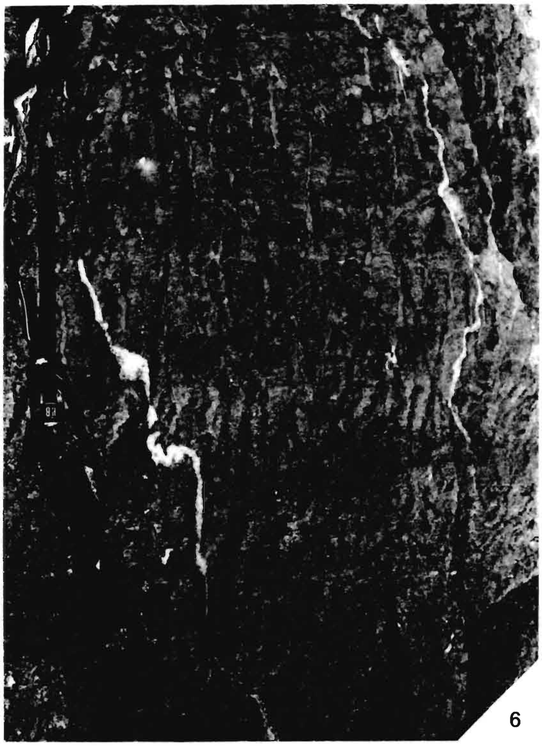
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WALTER, *Jurusania* and *Kulparia*

EXPLANATION OF PLATE 25

Sections of stromatolites from the Bitter Springs Formation, Jay Creek, Amadeus Basin.

Figs. 1–2. *Kulparia alicia*, longitudinal thin sections, ×1. 1, from near the base of a bioherm, showing narrow columns and numerous bridges, S348. 2, from the central part of a bioherm, S347.

Figs. 3–4. *Kotuikania*? *juvensis* (Cloud and Semikhatov) from the margin of a bioherm. The form of the columns from the central part of the same bioherm is uncertain. 3, approximately the same orientation as the field occurrence, i.e. a horizontal line is parallel to bedding, ×1. 4, S349, ×3·5.

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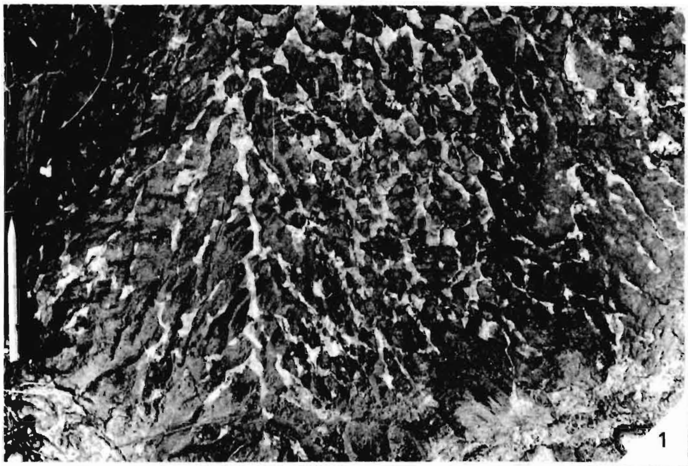
WALTER, *Kulparia* and *Kotuikania*?

EXPLANATION OF PLATE 26

Figs. 1–4. *Linella avis* in outcrop, Bitter Springs Formation, near Jay Creek, Amadeus Basin; sections are perpendicular to bedding, and are parts of the same biostrome. 1, contact between two bioherms. 2, almost the whole thickness of the biostrome. 3, the whole thickness of the biostrome, showing a flat-laminated, slightly irregular substrate. 4, columns radiating from a mound in the substrate.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WALTER, *Linella*

EXPLANATION OF PLATE 27

Figs. 1–4. *Linella avis*, Bitter Springs Formation, near Jay Creek, Amadeus Basin. 1, outcrop section normal to bedding, showing the top of a biostrome. 2, slab cut parallel to columns (columns are largely calcite, interspace fillings largely dolomite), S127, ×0·5. 3, longitudinal thin section; note the gnarled, tuberous columns, S127, ×0·75. 4, cut normal to bedding, showing columns branching off a cumulus, S378, ×0·4.

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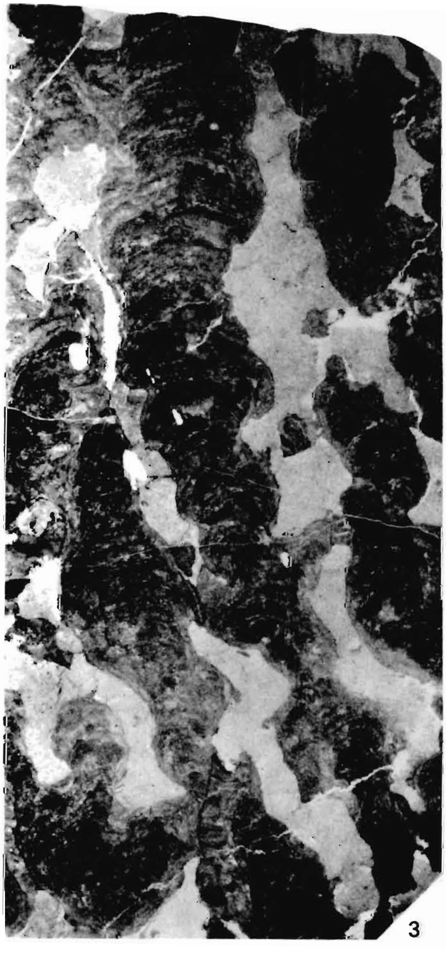

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WALTER, *Linella*

EXPLANATION OF PLATE 28

Figs. 1-3. *Madiganites mawsoni*, Jay Creek Limestone, Pertaoorta Group, Amadeus Basin; longitudinal thin sections. 1, the left central column visible in 3; note the thick laminae and slightly altered column margins, S46, ×2. 2, a pseudocolumnar and many-bridged columnar specimen, S364, ×0·9. 3, specimen with well-developed branching columns, S46, ×0·9.

Fig. 4. '*Collenia australasica*' of Edgell (1964)—unnamed here; longitudinal thin section. Note the steeply convex laminae, Duck Creek Dolomite, Hamersley Basin, GSWA F5015, ×1·5.

Figs. 5-6. *Minjaria pontifera*, Bitter Springs Formation, near Jay Creek, Amadeus Basin. 5, slab cut parallel to the columns; the pale grey is dolomite, dark grey calcite, S374, ×0·5. 6, outcrop normal to bedding from within the same biostrome as shown in Pl. 26. Note the regularity and parallelism of the columns (on the left they are curved). The third and fourth columns left of the pencil branch from a single broad column.

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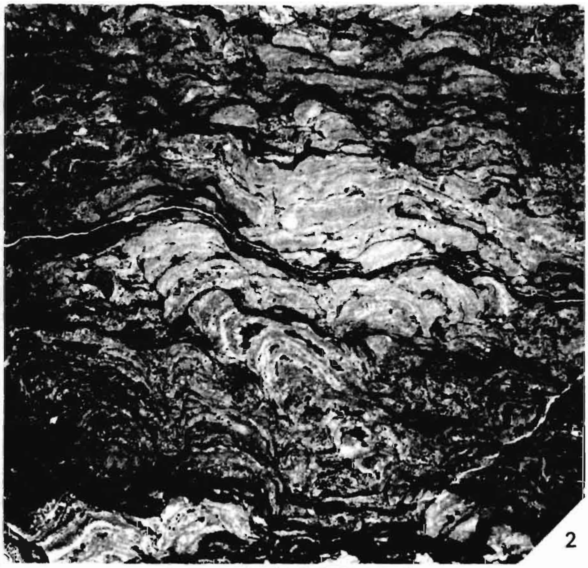

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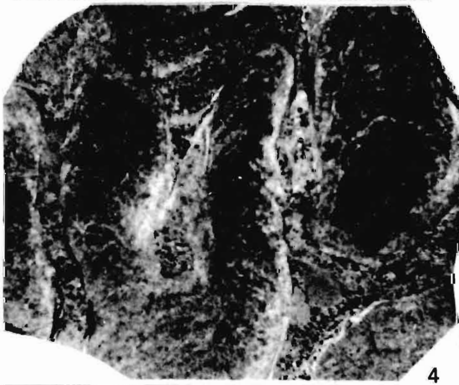

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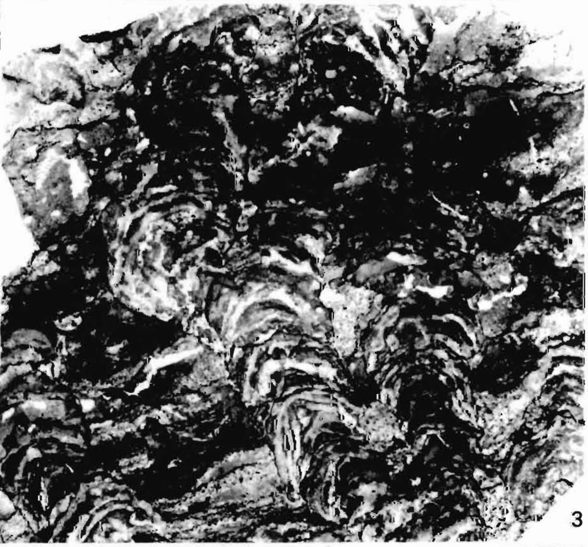

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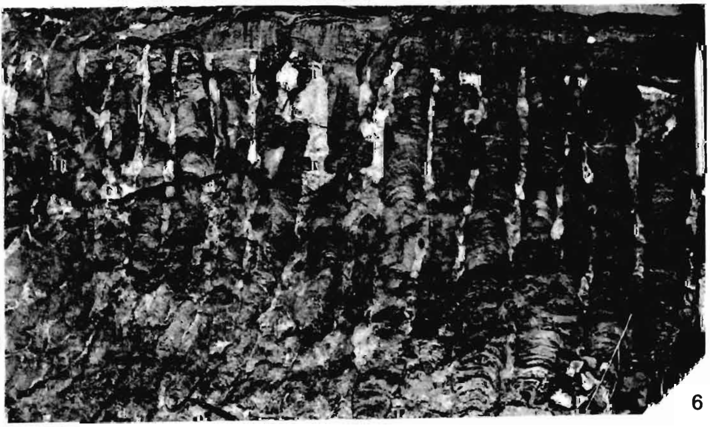

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WALTER, *Madiganites* and *Minjaria*

EXPLANATION OF PLATE 29

Columnar stromatolites, Duck Creek Dolomite, Hamersley Basin.

Figs. 1, 8. *Patomia* f. indet., longitudinal thin sections of GSWA F8134. A patchy wall is visible in 8, which is from the lower left of the section in 1. 1, ×0·5. 8, ×5.

Figs. 2–7. *Pilbaria perplexa.* 2, 7, longitudinal thin sections. The laminae most frequently are steeply convex but in 7 many are gently convex. 2, S203, ×0·6. 7, S206, ×0·7. 3–6, outcrop sections normal to bedding. 5, outcrop showing basal part of biostrome, adjacent to a permanent large pool in Duck Creek, east of Mount Stuart Homestead. 3, 4, 6, several miles east of the previous locality. Branching visible in 4 and 6.

PLATE 29


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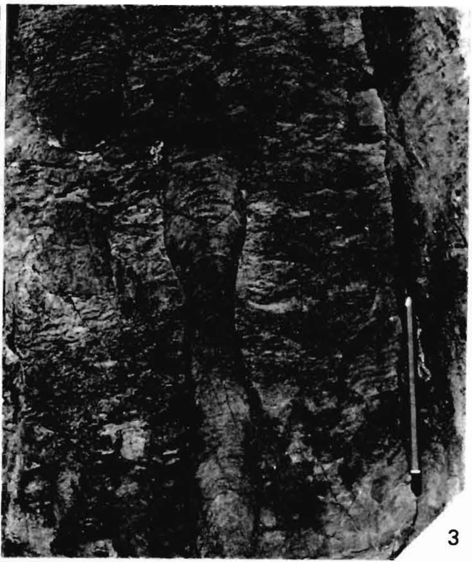
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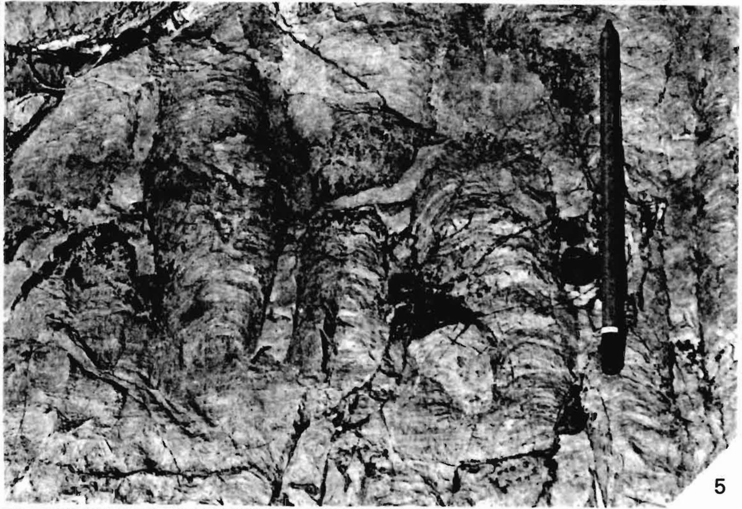
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WALTER, *Patomia* and *Pilbaria*

EXPLANATION OF PLATE 30

Figs. 1, 3–5. *Tungussia erecta*, Gillen Member, Bitter Springs Formation, near Alice Springs. 1, outcrop normal to bedding showing almost the whole thickness of the biostrome. The specimen shown in 5 came from near the top of the pencil, that in 4 from under the bottom of the pencil. 3, enlargement of portions of the two parallel columns on the left of 4, showing the walls, S356, ×3. 4, thin section normal to bedding showing irregular columns and cumuli. Text-fig. 53B, C, shows other illustrations drawn from this specimen, S356, ×0·5. 5, longitudinal thin section of the upper, parallel column part of *T. erecta*. The column margins are greatly altered, S357, ×0·8.

Fig. 2. *Tungussia inna*, Ringwood Member of the Pertatataka Formation, near Ringwood Homestead. Thin section normal to bedding, S358, ×1.


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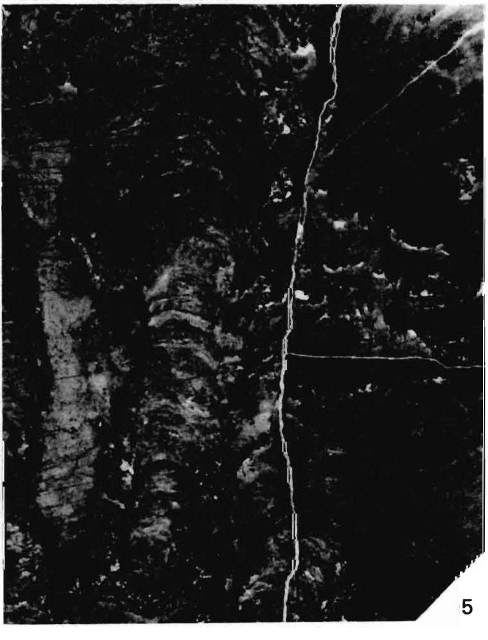
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WALTER, *Tungussia*

EXPLANATION OF PLATE 31

Amadeus Basin.

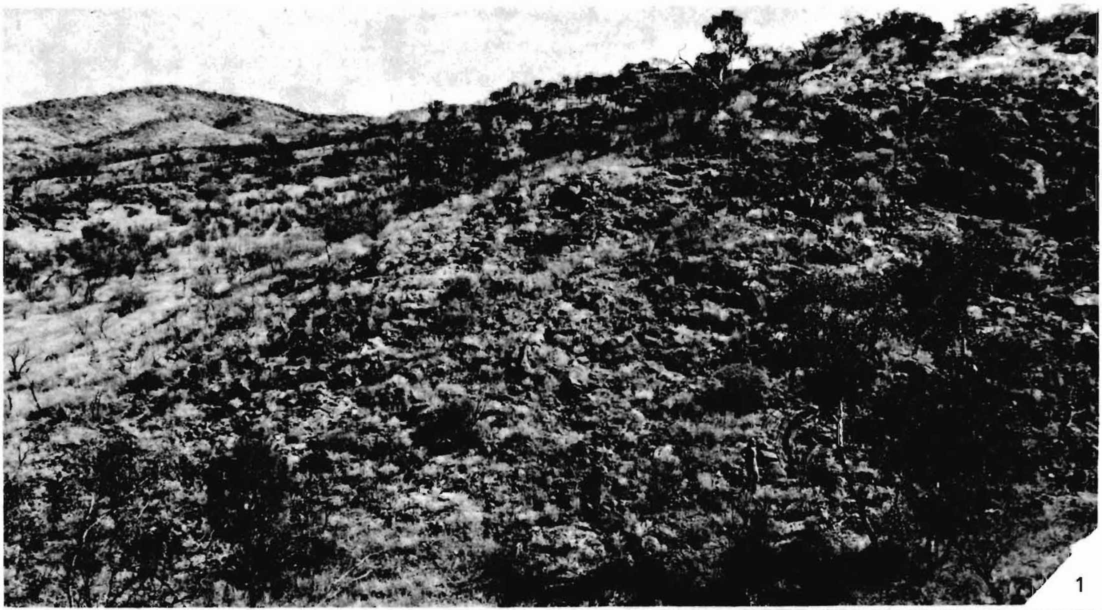
Fig. 1. Upper part of the measured section in the Loves Creek Member of the Bitter Springs Formation, near Jay Creek (Pl. 33, fig. 1; text-fig. 14). Looking slightly south of west, almost along strike, dip 70–80° south. The first small valley on the left is on white-spotted red silty dolomite; the figure to the lower right of centre is next to a bioherm of *Jurusania nisvensis*. The Arumbera Sandstone forms the ridge on the far left.

Fig. 2. An unidentified stromatolite from the Bitter Springs Formation, near Jay Creek; figure reproduced from Banks (1964); field of view 20 cm wide. This could be a form of *Inzeria*, but no specimens are available for study. Also figured by Murray (1964).

Figs. 3–4. Stromatolites in the Bitter Springs Formation in the Bonython Ranges, westernmost Amadeus Basin. The coin in 3 is about 3 cm wide. Photographs by courtesy of A. T. Wells.

Fig. 5. Oncolites in thin section; possibly from the Inindia Beds, but poor outcrop makes this uncertain; BMR locality BR21, 24 miles north of South Range, Bloods Range Sheet area, ×3·5.

Fig. 6. Oolites overlying a cumulate stromatolite; thin section normal to bedding. Loves Creek Member of the Bitter Springs Formation in the measured section near Jay Creek, ×0·9.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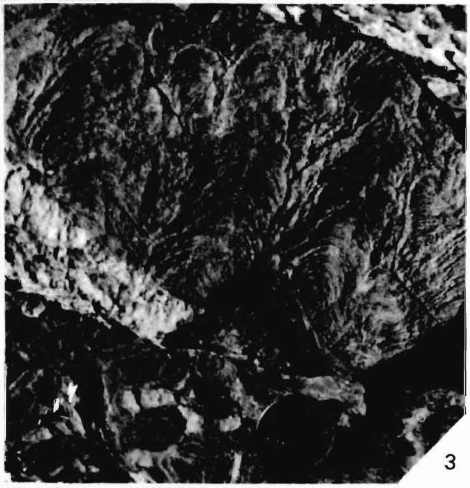
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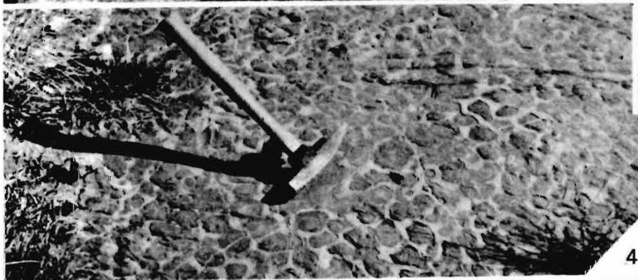
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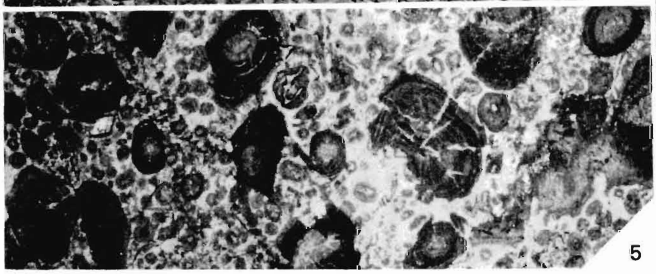
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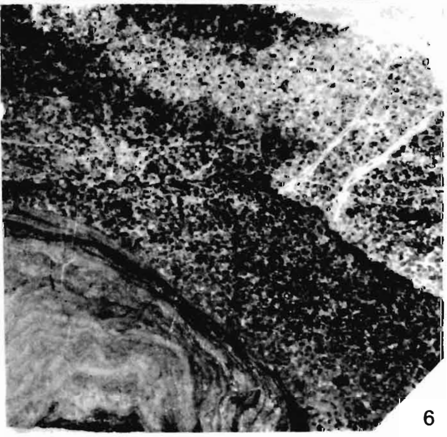
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WALTER, Stromatolite occurrence

EXPLANATION OF PLATE 32

Fig. 1. Cumulate stromatolites in the basal Irregully Formation, northern entrance to the gorge of Irregully Creek, Bangemall Basin. The stromatolite on the right grew over an upturned intraclast. Pencil for scale (right centre).

Fig. 2. Large oncolites at the same locality as above.

Fig. 3. A cumulate stromatolite in the Julie Member of the Pertatataka Formation, near Acacia Well in the Amadeus Basin. Pencil for scale (right centre).

Fig. 4. Linked cumuli in the Duck Creek Dolomite adjacent to a permanent large pool in Duck Creek, west of Mount Stuart Homestead, Hamersley Basin. Pencil for scale (left centre).

Fig. 5. Pseudocolumnar stromatolites developed on peaked stromatolites, Duck Creek Dolomite, locality as for 4. Stratigraphic top towards the top of the photograph.

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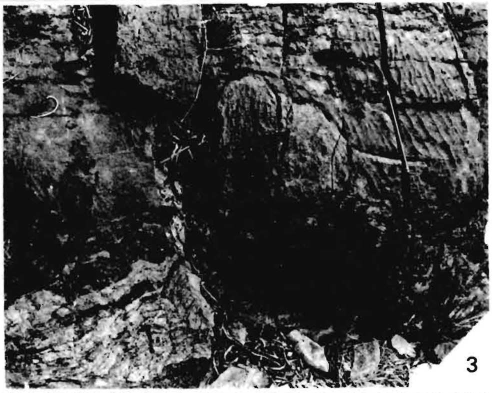

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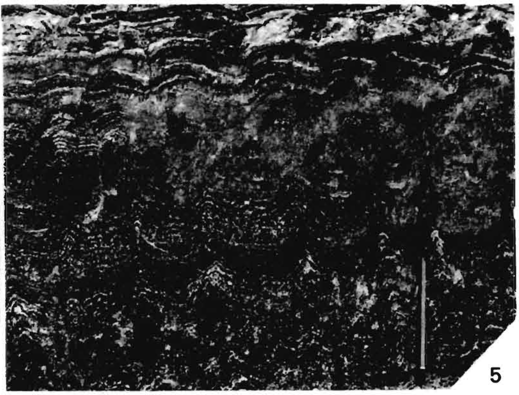

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WALTER, Stromatolite occurrence

EXPLANATION OF PLATE 33

Aerial photographs of two important stromatolite localities in the Bitter Springs Formation of the Amadeus Basin. Photographs reproduced with the permission of the Commonwealth Division of National Mapping, Australia.

Fig. 1. The section measured (text-figure 14) near Jay Creek is indicated, as is an easy access route. The whole late Precambrian sedimentary sequence is shown here, from the Heavitree Quartzite (dark ridges in the centre and upper part of the photo) to the Arumbera Sandstone (darkest ridge in the lower third of the photograph). 10 cm is equivalent to 4·1 km. Survey 846, Hermannsburg Run 13, Photo 5038.

Fig. 2. The Bitter Springs Formation on the ridge arrowed contains *Inzeria intia* and probable *Boxonia pertaknurra*. 10 cm is equivalent to 3·6 km. Survey 851, Alice Springs Run 9, Photo 5140.

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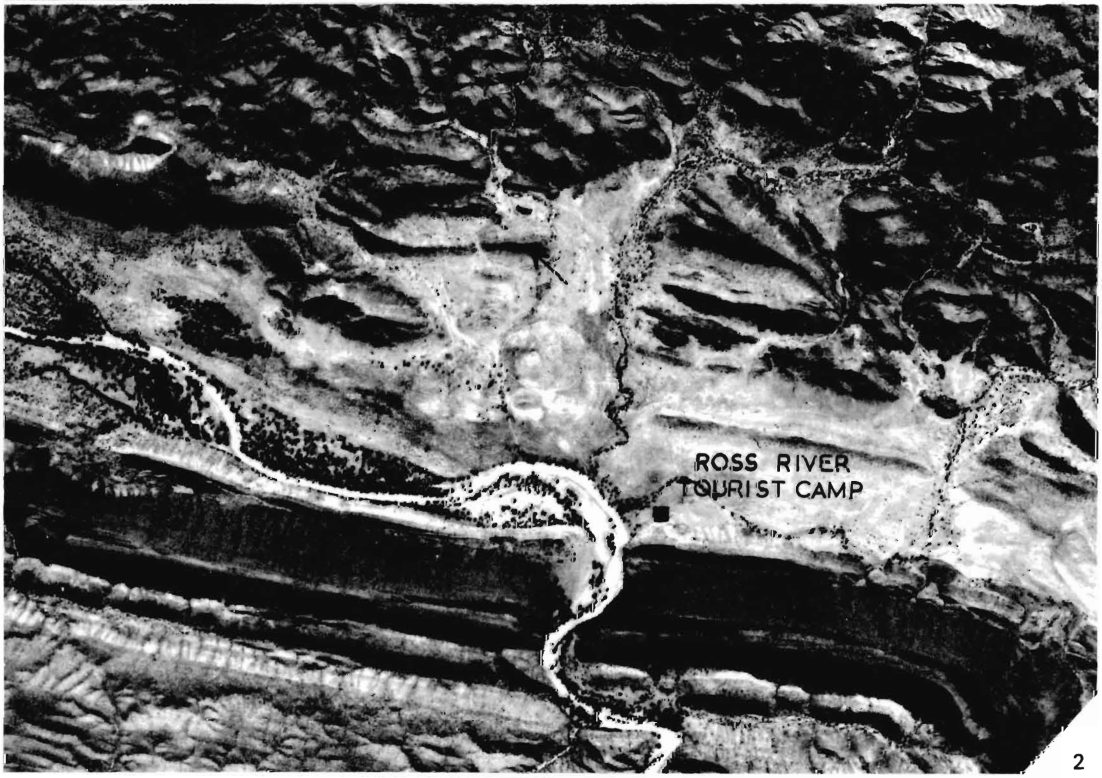

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WALTER, Stromatolite localities