THE BIOSTRATIGRAPHY AND PALAEOECOLOGY OF SOUTH AUSTRALIAN PRECAMBRIAN STROMATOLITES

by

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CONTENTS

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Date 2 February 1971. Signed

SUMMARY

Precambrian stromatolites in South Australia are almost entirely restricted to the folded rock sequence of the Adelaide Geosyncline, a large, deeply subsiding basin with predominantly shallow-water sediments. The history of research into the age and fossils of the Precambrian rocks is reviewed, and a possible time-framework is suggested on the basis of available radiometric data.

Stromatolites, laminated structures formed by trapping of detritus and precipitation of chemical sediment by algae and bacteria, have been studied by other workers from at least two points of view: most Western authors regard stromatolite morphology to be purely environmentally determined, while one Russian school maintains that it is largely controlled by the algae present, and that stromatolites evolve as a consequence of the evolution of the algae forming them. They concluded this from an empirical study of widespread stromatolites of different ages, which made possible the biostratigraphic subdivision and correlation of many Late Precambrian sections.

The Russian methods of study and taxonomy have now been applied to South Australian stromatolites for the first time. Of the eighteen forms of columnar stromatolites described, five are identical or nearly identical to Russian forms. Nine forms are new, but sufficiently similar to Russian forms to allow inclusion in the same groups as these. Groups and forms must be defined on the basis of numerous characters, which may be given different relative weighting for different taxa. The taxa so defined have restricted ranges in geological time.

Stromatolite correlation with the Russian sequence suggests that the Early Adelaidean (i.e. pre-tillite) beds are Middle Riphean; the Skillogalee Dolomite is youngest Middle Riphean, i.e. older than the Late Riphean Bitter Springs Formation of Central Australia. The Late Adelaidean Umberatana Group assemblage, correlated with the youngest Late Riphean, has seven groups in common with the Bitter Springs Formation, but unlike the latter, it overlies the lower tillite. A comparison with available radiometric data shows good agreement for the Umberatana Group, but some conflict with one recent age determination exists for the Early Adelaidean.

A study of the environments of growth of South Australian stromatolites shows that at least three forms, of widespread distribution, grew under a variety of conditions of energy, oxidation, type of sediment influx, and possibly salinity. The taxa defined are stable under these varying conditions, but there are minor modifications due to differences in environmental energy. Skillogalee Dolomite stromatolites grew under varying energy conditions on a very extensive and level carbonate depositing platform, frequently under hypersaline conditions. Umberatana Group stromatolites inhabited a marine environment, either in marginal littoral zones in the south-western and north-eastern Flinders Ranges, or on off-shore carbonate banks interpreted to be related to rising diapirs. In both cases, stromatolites formed during episodes of shallowing water depth.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University nor, to the best of my knowledge and belief, does it contain any material previously published or written by another person, except where due reference is made in the text.

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GENERAL INTRODUCTION

The geology of the Precambrian sedimentary rocks of South Australia has been a subject of continuing interest throughout this century. Like Precambrian sequences elsewhere in the world, the succession in the Adelaide Geosyncline has for a long time defied attempts at time-correlation and age determination by conventional means, due to the lack of index fossils in all but the Cambrian section. However, the excellent outcrop and continuity of the Precambrian beds of the Flinders Ranges enabled the pioneer geologists of South Australia to establish local sequences and sometimes to correlate between different areas with the aid of marker beds such as tillites.

Stromatolites, now known to be structures formed in sediments, mostly carbonates, by the trapping and precipitation of sediment by algae and bacteria, have been recognized in South Australia for many years. But despite the interest shown by Sir Douglas Mawson in the 1920's, they have never before received detailed attention. The results obtained by some Russian geologists in using stromatolites for Precambrian biostratigraphy seemed especially promising, and Prof. M. F. Glaessner, realizing their potential value, suggested this project to me.

With the systematic regional mapping of the Adelaide Geosyncline nearing completion, the opportunity existed to collect and study stromatolites over a wide area, from formations whose relative stratigraphic positions were well established. Many localities were suggested to me by members of the South Australian Mines Department, and others were discovered in the course of a routine field search.

The results of the study are presented in this thesis. Part I is an introduction to the stratigraphy of the Adelaide Geosyncline, from a historical viewpoint, in which it is shown how stratigraphic ideas have evolved, and been modified recently by radiometric age determinations. The study of Precambrian fossils and pseudofossils by other authors is briefly reviewed.

Part II deals with the theoretical aspects of stromatilite taxonomy and biostratigraphy and the application of the modern methods to a study of stromatolites collected from several stratigraphic levels throughout the Precambrian-Cambrian sequence of the Adelaide Geosyncline. On the basis of the stromatolites identified, correlations are suggested with the established Russian succession, and these are viewed in the context of the radiometric evidence available. The results are a contribution towards the establishment of a biostratigraphic Precambrian time-scale, which, hopefully, will one day be of world-wide applicability.

The question of stromatolite palaeoecology is examined in Part III where an interpretation is made of the environments of deposition and palaeogeographic settings of the two major stromatolite-bearing sequences, the Skillogalee Dolomite and the Umberatana Group. The palaeoecology of each of the stromatolite forms described is examined in relation to the postulated environments, in order to estimate the effect of environmental factors on the characters of stromatolite taxa. This approach attempts to reconcile some of the differences of opinion between the Russian and the Western stromatolite schools, i.e. respectively that stromatolite morphology is controlled by the algae forming them, and therefore evolves as the algae evolve, and that stromatolite morphology is purely environmentally controlled.

Part I

STRATIGRAPHIC REVIEW OF THE ADELAIDE GEOSYNCLINE

Chapter 1

INTRODUCTION

The area from which Precambrian fossils and associated sediments have been studied, the Flinders and northern Mt Lofty Ranges, is part of a Cainozoic uplift of a large Late Precambrian to Cambrian sedimentary basin, involved in Early Palaeozoic folding. This basin, which forms a roughly meridianal belt in south-eastern South Australia (Fig.1,1a) has been termed the "Adelaide Geosyncline" (Sprigg, 1952). All locality names referred to in this thesis are shown in Fig.1.

Geography

The greatest part of the Adelaide Geosyncline as presently exposed, has low relief, with gently undulating hills, rarely exceeding 2,000 ft above sea level. The highest peaks are restricted to the Flinders Ranges, and are almost always composed of quartzitic rocks, e.g. St Mary Peak at Wilpena Pound, 3,900 ft, consisting of the uppermost Precambrian Pound Quartzite. Although in these more mountainous regions the sandstones are spectacularly exposed, the carbonate rocks which have been the main subject of this study form lower hills with relatively more patchy outcrop. This has sometimes been a problem in deciding field relationships, especially in the more temperate Southern Flinders Ranges.

The whole area is relatively arid, the highest annual rainfall occurring in the Mt Lofty Ranges nearest to Adelaide, where outcrop conditions are correspondingly poor, due to extensive soil cover and deep weathering, under dissected uplifted Tertiary peneplains. Although rather similar conditions exist in the western part of the Southern Flinders Ranges, a striking contrast exists in the northern part of the Ranges. Here soil cover is thin and discontinuous, and beds may easily be traced in the field and on aerial photographs. Rocks are almost completely fresh at the surface, unless they occur below Tertiary weathering surfaces. The lack of cultivation of the land has led to a conservation of natural outcrop, often augmented by soil erosion due to overstocking of these arid pastures.

From the point of view of this study, the most significant flora is the lichen, which encrusts most carbonate rocks in the Southern and much of the Central Flinders Ranges, effectively concealing all their internal structures, and protecting them from the natural etching effects of weathering. This makes field photographs virtually useless, even if the lichen cover is removed, and greatly hinders the recognition and selection of representative specimens in situ. In contrast, carbonates from the arid Northern Flinders Ranges are free of lichen and quite fresh, with organic and sedimentary structures easily visible in outcrop.

Geological Setting

Fig.2 summarizes the geological setting of the Adelaide Geosyncline.

The western part of the State is a shield area, stable since Late Precambrian time, and comprises the Gawler Platform and Stuart Shelf.

The basement rocks of the Gawler Platform, consisting of granite gneisses, granulites and metasediments, have been variously subdivided and interpreted, but no detailed work has been carried out. Granulites from Pt Lincoln have been dated at 1780 ± 120 m.y. (Compston & Arriens, 1968). A folded arenaceous sequence, the Moonabie Formation, flanks the gneisses to the east of Whyalla and is itself succeeded unconformably by the Corunna Conglomerate and the penecontemporaneous Gawler Range Volcanics, both dated at about 1540 m.y. On the Stuart Shelf the basement rocks and the older, mildly deformed cover rocks are unconformably overlain by a nearly flat-lying dominantly arenaceous-argillaceous sequence, generally correlated with the upper parts of the succession in the fold belt.

To the east lies the so-called Adelaide Geosyncline, with its thick (a total of perhaps over 50,000 ft in its central portion) mildly to moderately folded sedimentary fill. Basement inliers occur only in the Mt Lofty Ranges, Mt Painter Province, Olary Province, and the Peake and Denison Ranges. The sequence bears evidence of shallow-water deposition almost throughout its thickness, which is an important distinction from most typical geosynclines. Volcanics are very rare, being restricted to near the base of the succession and locally to the Lower Cambrian. Dominant rock types are clean washed sandstones, red and green shales, and various carbonates which are very commonly stromatolitic. Two horizons of tillite and associated fluvioglacials have been recognized, the lower being almost ubiquitous, and the upper restricted to the south-east and north-west regions. The sequence has traditionally been assigned to the "Proterozoic", but until recently no age data have been available, except that it underlies fossiliferous Lower Cambrian. Sedimentation continued well into at least Middle Cambrian times, significant breaks occurring only at the base of the lower tillite and the base of the Cambrian. During the Cambrian, thick clastic sedimentation persisted south and east of Adelaide in the so-called Kanmantoo Trough, whose sediments have been interpreted as of flysch facies (Sprigg & Campana, 1953).

Structure and Metamorphism

Sedimentation was terminated by orogeny estimated to have occurred from Late Cambrian to Ordovician time. There is great variation in intensity of deformation. Fig.3 illustrates the dominating fold trends and metamorphic zones.

The least deformed area constitutes the southern part of the Northern, and most of the Central Flinders Ranges. Here folds are dominantly very open domes and basins (e.g. Blinman Dome and Wilpena Pound). Dips are gentle, usually less than 45°, except near the intrusive contacts of diapiric piercement structures (Dalgarno & Johnson, 1968), which characteristically occupy the cores of the domes. Slaty cleavages and penetrative deformation are absent. To the north and to the south-east, the degree of deformation increases: folds become tighter, more linear or arcuate, with rarer domes and basins. Slaty cleavage is more or less developed in most shales and many limestones. Limestones are often deformed, as seen by compressed stromatolite columns, presenting a further difficulty in their study. Sericite and chlorite are often developed in the slaty rocks. This scheme characterizes most of the Southern Flinders Ranges.

Towards the south and east, in the Olary Arc, folds become still tighter, slaty cleavage is well developed, and biotite grade of metamorphism is attained, extending south into the Northern Mt Lofty Ranges (Offler & Fleming, 1969). On the eastern side of the Mt Lofty Ranges, deformation is most intense, with the development of upper amphibolite facies metamorphism, migmatites and syntectonic granites dated at 490 ± 15 m.y. (White, Compston & Kleeman, 1967). This places a minimum age on the cessation of sedimentation in the Adelaide Geosyncline.

Concluding Remarks

The sedimentary environments of portions of the Adelaide Geosyncline sequence will be discussed in Chapters 10 and 11. It seems that mostly they resembled those of shallow intracratonic epeiric seas rather than of typical, geosynclines (at least the "Orthogeosynclines" of Kay, 1947). Moreover, the basin may have been in existence for a much longer time (up to 900 m.y.) than typical geosynclinal cycles. All that can be said is that its basement was sufficiently mobile to allow deep but slow subsidence, and subsequent folding of the sedimentary pile, thus differentiating it from the stable Stuart Shelf to the west. The term "Adelaide Geosyncline is convenient and will be retained here.

Chapter 2

A REVIEW OF STRATIGRAPHIC INVESTIGATIONS OF THE ADELAIDE GEOSYNCLINE

Early attempts during the latter part of the last century to date the various bed-rock formations in the vicinity of Adelaide were largely intuitive. Few areas had been examined in any detail, but by the turn of the century, much wider interest was already being shown, and since then, stratigraphic knowledge of the Adelaide Geosyncline has steadily increased. In recent years systematic mapping has been carried out by the South Australian Geological Survey. These maps have proved invaluable for the studies presented in this thesis.

The first significant contribution was by Selwyn (1860, quoted by Howchin, 1904) who made a reconnaissance tour from Cape Jervis to Mt Serle, and described the stratigraphy in terms of three stages, probably separated by unconformities. The "auriferous rocks of the watershed of the Onkaparinga River" he assigned to the oldest, the schists and gneisses, and slates and sandstones north of there, up to the Central Flinders Ranges, to the second, and the ridge forming quartzites, the purple and green shales and limestones of the Central and Northern Flinders Ranges to the youngest. He regarded these stages as possibly Cambrian and Silurian, perhaps reaching the Devonian. Selwyn's order of succession was partly correct, but he admitted that observed differences might only be due to metamorphism in the south.

Ulrich (1872, quoted by Howchin, 1904), in touring the Central and Northern Flinders Ranges, doubted if Selwyn's three stages were really unconformable, and regarded them all as deposited in one Lower Palaeozoic period, but locally metamorphosed by intrusions.

The first concrete evidence as to the age of the South Australian bedrock was the discovery by Tepper of Lower Palaeozoic fossils at Ardrossan, Yorke Peninsula. These fossils were at first regarded by Tate (1878) as Lower Silurian and the basement rocks under the fossiliferous limestone were therefore pre-Silurian. In 1883, H. Y. L. Brown, Government Geologist, published a geological map of the State, and in 1886, tabulated the stratigraphic succession for the map as follows (quoted by Howchin, 1904):

TABLE I

Tent Hill Formation (West of Port Augusta) - Devonian?

Slates, quartzites and limestones (Cape Jervis to Mt Babbage) - Lower Silurian

Metamorphics - schists, quartzites and crystalline limestones - Palaeozoic or Azoic

Metamorphics - granite, gneiss, mica-schists, crystalline limestones - Archaean

There were, however, arguments as to whether the metamorphics occur at the base or top of the sequence: Brown considered that they must be at the base, while Tate, regarding all rocks of the Mt Lofty Ranges as dipping southeastwards, in a vast monocline, required the metamorphics in the east to be the youngest. All Mt. Lofty Ranges rocks were assigned by him to the Archaean. In summarizing these conflicting views, Howchin (1904), supported Brown and Selwyn in that the main part of the Mt Lofty Ranges is of post-Archaean age.

The matter was settled by David and Howchin's discovery (Howchin, 1897) of Archaeocyatha, then already recognized as Cambrian fossils (Etheridge, 1890) in the limestones at Normanville; they followed these along their strike for 25 miles. This proved that at least a major part of the succession was actually Cambrian. The ensuing controversy as to the significance of the find, led Howchin to conduct a thorough investigation, after which he chose the Adelaide area as type section for his "Adelaide Series". His general stratigraphic section is still valid; moreover his discovery of beds of glacial origin enabled him and many subsequent stratigraphers to correlate remote sections with the Adelaide region.

Howchin at that time had believed that the whole of the "Adelaide Series" was of Cambrian age. Following the discovery of Archaeocyatha at Normanville, Howchin located the same horizon, much richer in fossils, at Sellick Hill. Here the beds dip steeply east, and Howchin, assuming that they were the right way up, grouped them lithologically into three units - the argillites the oldest, then the limestones, and quartzites the youngest. The limestones were further subdivided; the Archaeocyatha occurred in what he considered the lower members, just above the argillites. The occurrence of Cambrian fossils in what appeared to be a low position in the sequence, meant that either the sequence is all of Cambrian age, or that the fossiliferous beds are faulted against Precambrian rocks forming the bulk of the Mt Lofty Ranges. Howchin favoured the former alternative, and Tate the latter.

In two publications (1904, part I op.cit., and 1906, part II) Howchin gave the result of his investigations, the first comprehensive description of the whole succession, from the basement inliers to the top of the purple slates and quartzites. His scheme may be summarized as follows, together with some currently applied names:

TABLE II

Youngest: A. Purple slates, quartzites and limestones (Marinoan Series)

B. Siliceous, blue, pink (oolitic) and dolomitic limestones (Brighton Limestone)

C. Banded slates (Tapley Hill Formation)

D. Glacial till and grits (Sturt Tillite)

E. Siliceous and feldspathic quartzites and phyllites (Belair Subgroup, Mitcham Quartzite at base)

F. Thick slate (Glen Osmond Slate)

G. "Blue metal" limestone (Beaumont Dolomite)

H. Thick Quartzite (Stonyfell Quartzite)

I. Phyllites and Lower Limestone (Castambul and Montacute Dolomites)

J. Basal Grits and Conglomerates (Aldgate Sandstone)

Oldest: K. Precambrian Complex

A boulder of archaeocyathan limestone lying at the base of the cliffs of purple slates and quartzites at Hallett Cove (most probably this was a Permian erratic) caused Howchin to assign a Cambrian age to these slates; thus the lower units, which Howchin later termed "Adelaide Series", could be no younger than Cambrian. He continued to regard the whole succession as Cambrian, the basement complex exposed at Aldgate being Precambrian.

In 1907, he gave a general description of the sequence in the then known portions of the State (Howchin, 1907). He estimated the thickness to be 30,000 to 40,000 feet or more, conformable throughout, but with a major gradational lithological change above the Brighton Limestone - the incoming of redbeds. Reputed radiolaria from the Brighton Limestone (David & Howchin, 1896), and more especially the fossiliferous limestones at Ardrossan and Sellick Hill argued for a Cambrian age. The purple slates above the Brighton Limestone were conveniently termed Upper Cambrian, and the beds below, Lower Cambrian.

Meanwhile, Sir Douglas Mawson had become interested in the Adelaide Geosyncline, and especially the glacial beds. Working in the Barrier Ranges, N.S.W. and Olary District, S.A., Mawson (1912) was able to demonstrate that the Torrowangee Series (then supposed to be Cambrian) overlies the Precambrian Willyama Series of metamorphics with a marked unconformity. In this area, and also in the Mt Painter area, Mawson recognized extensive developments of the glacials.

Both Mawson and Howchin examined the Precambrian tillites and associated sequences from all over South Australia, more or less simultaneously for the next several years. The following is a brief summary of their work.

Howchin (1920) described South Australian examples of intraformational breccias and conglomerates from the Brighton Limestone and its equivalents at Brighton, Pekina Creek, Mt Remarkable, Depot Creek, and also Burra - he considered the dolomites at Burra to be Brighton Limestone (see Chs.3,7,10). At Depot Creek, he recognized a limestone breccia of oolitic fragments and associated wavy bedded limestone, resembling stromatopora; the latter are stromatolites, and will be discussed in Ch.7.

Howchin (1922), having traversed the Central Flinders Ranges near Blinman, recorded a section with flaggy siltstones (Tapley Hill Formation) at its base, passing up into calcareous grits and oolitic limestones (now termed Etina Formation), shales (now the Enorama, Brachina and Bunyeroo Formations), pink limestone (Wonoka Formation), thick quartzites (Pound Quartzite) and finishing with various limestones, including archaeocyathan limestones - near the top. He recognized essentially the same sequence east of Blinman, near Wirrealpa.

In 1924, Howchin described the tillite in the Willouran Ranges, and in the north-eastern part of the Flinders Ranges (near Umberatana, Mt Babbage and Mt Fitton), In each case he found flaggy shales or slates (Tapley Hill equivalents), above the tillites.

The Wooltana area was investigated by Mawson, who recognized the vesicular and altered basalts, here directly overlain by the tillite (Mawson, 1926) and argued that no great time interval could have elapsed between the effusion of the lavas and the deposition of the till. This view is no longer held (see later this chapter).

Now Mawson also visited the Willouran Ranges, in particular the north-eastern part near Marree, where he defined his "Mundowdna Series" of slates with fluvioglacial breccias at the base, overlying and containing slate pebbles of the "Willouran Series" (Mawson, 1927). He assumed the contact was unconformable.

In 1928, Howchin continued his studies further south on the western scarp of the Southern Flinders Ranges, where he described the units which are so similar to those of the Adelaide region. His sequence at Depot Creek was as follows:

TABLE III

Top:	Quartzite - e.g. west of Devil's Peak
	Purple slate series
	Brighton Limestone
	Wavy laminated limestone
	Impure limestones with large concentric lines (these were probably stromatolites)
	Tapley Hill Shales
	Buff limestone at base
Base:	Tillite

South of Depot Creek, he examined sections at Mundallio Creek and Spear Creek, recognizing parts of the same sequence. This paper made two important advances: firstly the recognition of chert in the tillite led Howchin to consider the possibility of an unconformity between the tillite and underlying cherty dolomites, and secondly, he interpreted the environment of deposition of the Brighton Limestone. He felt that the limestone breccias were intraformational - formed by induration and erosion of calcareous mud flats. At Telowie Gorge, Back Creek (Port Germein) Gorge, and Crystal Brook, he examined the quartzites and dolomites beneath the tillite. Segnit (1929) independently concluded that in the Worumba area, the tillite lies conformably on older rocks.

Differing from Howchin, who, even in 1929, writing his "Geology of South Australia", still favoured a Cambrian age for the whole sequence, Mawson believed that the absence of fossils in the lower part of the sequence (including the tillite), suggested rather a Late Precambrian age. This is correct, and it will be shown how the position of the boundary has since been refined (Ch.3). Mawson considered the thick Pound Quartzite of the Central Flinders Ranges as the basal unit of the Cambrian.

Sir T. W. Edgeworth David (David, 1932) proposed the first comprehensive scheme of correlation and subdivision of the Australian Precambrian. The areas from which he correlated sequences were the Kimberleys, W.A., the Nullagine area, W.A., South Australia and South Africa. The correlations were based on broad lithological similarities only and have been largely disproved by recent radiometric studies. David accepted either a Late Proterozoic or Early Cambrian age for the sequences in each of these four areas.

Mawson (1934) described a sequence in the Balcanoona area of the north-eastern Flinders Ranges, which he termed the "Munyallina Beds". He did not recognize the Paralana Fault, which passes through the area, repeating almost the whole section, including the tillite. This led him to believe that sedimentation extended longer than in the Adelaide region after deposition of the Sturt Tillite; he also demonstrated the existence of an unconformity below the tillite in this area.

The next contributor to South Australian geology was Hossfeld. In a comprehensive study of the northern Mt Lofty Ranges (Hossfeld, 1935) he broke away from the stratigraphic scheme which Howchin and Mawson had developed. However, Hossfeld was first to use a "series" subdivision for rocks in the Mt Lofty Ranges; his names therefore have priority to those proposed by Mawson & Sprigg (1950). The reason that they were not later accepted was probably because the later stratigraphic interpretation of the area by the Geological Survey, on the Gawler 1-mile sheet (Campana, 1953) differed radically from Hossfeld's. His stratigraphy was based on a three-fold division of the Precambrian rocks, but later classifications have cut right across this scheme:

Older: Barossa Series: The most metamorphosed. He considered it to consist mainly of metasediments, except for the augen gneisses at Humbug Scrub. (This difference between the two areas is not surprising, since the Humbug Scrub area comprises basement rocks, while the Barossa Ranges themselves are composed of Kanmantoo Group).

Younger: Adelaide Series: This he divided into two unconformable series, the Para Series and the Narcoota Series. The Para Series included sediments up to the base of the Mitcham Quartzite, and the Narcoota Series those above (partly); but what he included in one or the other series was not confirmed as distinguishable by later mapping. The inlier at Humbug Scrub was overlain by Para Series on the Western side, and Narcoota Series on the eastern side. Thus what is at present regarded as the Aldgate Sandstone equivalent was assigned to both series. Moreover, in the Barossa Ranges, he called part of the Kanmantoo Group Narcoota Series, and part the underlying Barossa Series. Tillites were only poorly developed in the Barossa Ranges area, but reappear further north. A marble above the tillite near Kapunda, he reasonably correlated with the Brighton Limestone, but he also included the probably Cambrian Angaston Marble. In view of the break between the two series, Hossfeld recommended a search for a similar break below the Mitcham Quartzite. This has never been substantiated.

In his centenary address of 1936, Mawson summarized the major work his predecessors had undertaken, and added his own interpretation of the age of the succession. Arguing that Howchin's "Lower Cambrian" occurred throughout the State, never associated with Cambrian fossils, and that in other parts of the world, Archaeocyatha occur low in the Cambrian, Mawson showed that most of Howchin's "Upper Cambrian" was in fact Lower, and his "Lower Cambrian" was Proterozoic. Mawson had already recognized Late Precambrian glaciations from other parts of the world, and this fact supported his conclusions. "Some non-committal term" (p.lx) as to age was adopted: the "Adelaide Series", originally proposed by Mawson himself. Yet Mawson's contention that the almost unfossiliferous rocks beneath Cambrian fossils, were in fact Precambrian, has been accepted by all subsequent workers. For example, Segnit (1939) mapped small areas at Pichi Richi Pass, Horrocks Pass, Ediacara, Copley, Appila, Mt Grainger, Burra, Mongolata, Kapunda, Moana, Myponga, Lake Torrens, assigning all beds below the fossiliferous limestones to the Precambrian.

Meanwhile, Mawson's researches in the Flinders Ranges continued. In 1938 he described the succession east of Oraparinna Homestead, including what is now known as the Umberatana Group (Dalgarno, 1965; Oraparinna 1-mile). In 1940, he summarized his views on the "Adelaide Series", recognizing that major thickness variations occur in some units. In 1941 he extended his studies to the Copley area and in 1947 to the South-western Flinders Ranges. In 1949 he interpreted the boulder beds at Elatina Hut to be tillites - "a third recurrence of glaciation", post-dating the earlier two recognized at Bibliando (Mawson, 1948). He suggested correlation of the Elatina beds with the arkosic grits near Hallett Cove. Then, also in 1949, Mawson and

Segnit speculated as to the origin of the purple slates, and suggested deposition under oxidizing conditions, perhaps as a loess, or in a very shallow-water terrestrial environment.

Until this time, little attention had been paid to strict stratigraphic nomenclature. Rock sequences had usually been referred to informally as "series" or "beds" or "groups". The need for more precise stratigraphic nomenclature was felt. Glaessner et al. (1948) proposed a Code of Stratigraphic Nomenclature, based on the American Code, in which Time, Time-Stratigraphic and Rock-Stratigraphic Units were distinguished. Thus the rock units which the early workers had referred to informally, could now be classified as Groups, Formations, Members etc., and Time-rock units as Systems, Series etc.; this practice has since been followed.

In an attempt to apply the new Code of Stratigraphic Nomenclature, Mawson & Sprigg (1950) gave a revised stratigraphic subdivision. They used the term "Adelaide Geosyncline" for the regional geological setting, and proposed the term "Adelaide System" in favour of "Adelaide Series", for the whole sequence to the base of the Cambrian, and including the redbeds which Howchin had considered as Cambrian. In the Flinders Ranges, the Pound Quartzite, below the Archaeocyathan limestones was taken as the basal unit of the Cambrian, following Sprigg's (1947) discovery of metazoan fossils in the Pound Quartzite. In their "Geology of the Commonwealth", David & Browne (1950) had subdivided the "Adelaide Series" into an upper and lower series. Mawson and Sprigg opposed this, and used a three-fold division of the "Adelaide System" in the Adelaide region into the Torrensian Series (Aldgate Sandstone to Glen Osmond Slates, inclusive), Sturtian Series

(Mitchan Quartzite to Brighton Limestone, inclusive) and Marinoan Series (purple slates to grey quartzites, inclusive). They added an account of type sections of the various formations in the Mt Lofty Ranges. Later, the Willouran Series of Mawson (1927) was added, below the Torrensian Series.

Wilson (1952) was the first to study the geology of the Mid-North in any detail. His stratigraphic subdivision of the Riverton-Clare region, his nomenclature and correlations are mainly still accepted. His work may be summarized in the following correlation table:

TABLE IV

Mid-North	Adelaide Region
Tillite	Sturt Tillite
Gilbert Range Quartzite	Belair Slates Mitcham Quartzite
Mintaro Slates	Glen Osmond Slates
Auburn Dolomite	Beaumont Dolomite
Undalya Quartzite	Stonyfell Quartzite
Woolshed Flat Shale	Lower Phyllites
Skillogalee Dolomite	Montacute and Castambul Dolomites
Rhynie Sandstone	Aldgate Sandstone
River Wakefield Group	(Absent)

Regional mapping by the Geological Survey subsequently traced many of Wilson's units throughout the Flinders Ranges, in particular the Skillogalee Dolomite and Rhynie Sandstone. The River Wakefield Group, conformable below the Rhynie Sandstone, was thought to be partly equivalent to Mawson's Willouran Series.

In a contribution to the Sir Douglas Mawson Anniversary Volume, Sprigg (1952) gave his impression of sedimentation in the Adelaide Geosyncline as "continental terrace outgrowths from the ancient West Australian continental shield". He interpreted the western shelf area as slightly unstable, with only temporary sedimentation. Across the submeridianal line of faulting postulated along the western side of Lake Torrens, lay the more consistently subsiding Adelaide Geosyncline. Shelf sediments were often eroded and reworked into the geosyncline. Eastern provenance from "Willyamia" was not considered important until Sturtian glacial times. During periods of instability, rapid terrace outbuilding in an unstable slope environment dominated Thus "brecciolic magnesites" were considered the products of turbidity current action on continental slopes. The Marinoan Series marked the onset of oxidized sediments (red coloured); it was regarded as the result of a climatic change rather than that of depositional environment. In the Cambrian, archaeocyathan bioherms formed at what was thought to be the shelf edge. Sprigg concluded that the Adelaide Miogeosyncline was a typical fossil continental terrace. The subject of geosynclines in Australia was pursued by Voisey (1959) who discussed the possible relations between the Adelaide Geosyncline and the Palaeozoic geosynclines of Eastern Australia.

During the early 1950's, systematic mapping of the State on a 1:63,360 scale was commenced by the Geological Survey. At first it concentrated on the sheets near Adelaide, then gradually extended northwards, generally firstly to areas of some economic interest - e.g. the Leigh Creek coalfield. During the 1950's, stratigraphic knowledge of the Flinders Ranges was still insufficient to allow correlation of all units encountered, and the stratigraphic columns remained more or less generalized.

Meanwhile individual workers, chiefly from the University of Adelaide, continued studies of specific projects. In two papers (1960, 1961) Forbes discussed the origin of sedimentary magnesite in the equivalents of the Montacute Dolomite (Skillogalee Dolomite). He postulated a process of deposition in paralic or lagoonal environments, polygonal cracking of carbonate muds, and reworking forming conglomerate beds. Repeated slight transgressions and regressions were called on to explain the alternations of dolomites and magnesites, and the reverse graded bedding observed in the magnesite conglomerates. This general interpretation differed radically from that of Sprigg (1952) of magnesite brecciolas deposited by turbidity currents on the continental slope. The implications of Forbes' interpretations will be discussed in Ch.10.

By this time, the Geological Survey had decided on a programme of 1:250,000 mapping to cover the State. The first of these, the Barker Sheet, was produced in 1962. It was recognized, here and in some previously published maps, that the boundary between the Sturtian and Marinoan Series was not easy to recognize away from the type section. As mapping proceeded in the Flinders Ranges, it was found that neither the Brighton Limestone nor the overlying redbeds persist very far eastward, and northward. On many of the early maps (e.g. Kapunda, Serle) the Sturtian Series was extended to the top of the upper glacial unit to overcome this problem.

The question of the distribution of the upper glacials was investigated by Horwitz (1962). He distinguished a western zone, in which lower Marinoan beds are purple and green shales with "hieroglyphic" and stromatolitic limestones and arkosic grits. Boulder tillites are very rare, (e.g. Elatina Hut). In a central or passage zone, grey laminated shales and siltstones persist above the Brighton Limestone. In the eastern zone (south-east part of Olary Arc and northernmost Flinders Ranges), boulder tillites occur. Horwitz considered that there were two separate facies with different provenances: the western had a westerly source, while the eastern was "orogenic" and had an easterly source.

Crawford (1963) re-investigated the Wooltana area, with the aim of interpreting the relationships of the Wooltana Volcanics to the established sequence. He noted differences across the Paralana Fault (which Mawson had not recognized in 1934). West of the fault, south of the basement inlier, metamorphosed volcanics are overlain unconformably by phyllites and the conglomeratic arkose near Arkaroola. These rocks all underlie the equivalent of the basal Torrensian quartzite, and were therefore correlated with the Willouran Series of the Witchelina area. East of the Paralana Fault, the sequence is much less metamorphosed. Here amygdaloidal Willouran lavas are overlain unconformably by tillite (the Torrensian was eroded off prior to deposition of tillite), but Crawford included the basal beds of the tillite in the Willouran, interpreting them as pyroclastics with porphyry bombs. The contact was reinterpreted by Mirams (1964a) as a glacial pavement: the "pyroclastics" are in fact laminated shales with erratics, including porphyries, which overlie the volcanic rocks.

By now, interest in the subdivision and nomenclature of the Adelaide System had intensified. It commenced when Daily (1963) objected to the use of the time-rock terms "system" and "series", in Precambrian rocks for which no valid time correlations can be made with regions outside the type area, in the absence of fossils. He proposed that "Adelaide

Supergroup", "Torrens Group", "Sturt Group" and "Marino Group" should replace "Adelaide System", "Torrensian Series", "Sturtian Series" and "Marinoan Series" respectively. The reasoning is sound in principle, but the task of recognizing these particular rock groups throughout the Adelaide Geosyncline is very difficult, due to certain facies changes in critical parts of the column. A totally new rock subdivision, proposed by the Geological Survey in 1964 (Thomson et al., 1964), and later slightly modified (Forbes, 1967; Thomson, 1966a) has been shown to be more easily applied throughout the basin, and is used on all subsequent maps.

The Geological Survey has also retained Mawson and Sprigg's time-rock classification to provide a time-framework. Although Daily's (1963) objections to time-correlation and time-rock subdivisions are valid in theory, nevertheless because of the special conditions in the Adelaide Geosyncline (the presence of tillites and the general continuity of outcrop) the approximate time-equivalence of some units may be established, and some lateral facies changes may be deduced. But whereas the Sturt Tillite is an excellent time marker throughout the basin, many of the units at and near both the Torrensian-Sturtian and Sturtian-Marinoan boundaries either cannot be recognized, or are plainly diachronous, over much of the Flinders Ranges. Perhaps the trouble lies not so much in having a time framework, but rather with the unfortunate choice of boundaries for the series subdivisions.

The concept of time subdivision of the Australian Precambrian was carried further by Dunn, Plumb & Roberts (1966), who proposed a four-fold time framework, based on then available radiometric ages. They argued that type sections could be defined, in which, ideally the time intervals of the systems are fully represented by sedimentation, and which are not too badly altered, and which have a clearly defined base with a dateable unit at or near it. Major unconformities and igneous activity provided the boundaries between the systems. The depositional sequences chosen and the time-rock units they represent may be shown as follows:

TABLE V

	Time-rock unit	Type Section
PROTEROZOIC (Divisible into time-rock units)	Adelaidean System Base: 1400 m.y.	Adelaide Geosyncline, S.A.
	Carpentarian System Base: 1800 m.y.	McArthur Group and Tawallah Group, Gulf of Carpentaria, N.T.
	Lower Proterozoic ("Nullaginian") System Base: 2300 m.y.	Mt Bruce Supergroup, Pilbara Region, W.A.
ARCHAEAN (Not yet divisible into time-rock units)	------	No formal type section

The authors compared the proposed subdivision with similar subdivisions in other countries based on the ages of plutonic events, and found some considerable similarities.

The new rock classification of the Geological Survey of South Australia was based largely on the upper and lower tillites, or their equivalents. As first defined, the Callanna Beds and River Wakefield Group are synonymous with the Willouran, and the Burra Group with Daily's Torrens Group. The Umberatana Group is Daily's Sturt Group plus the lower part of the Marino Group, and the Wilpena Group is the upper part of the Marino Group. The top of the Umberatana Group was taken as the top of the Elatina Formation (various lithologies from red diamictite to clean washed cross-bedded sandstones) or the equivalent upper glacial sequence (Grampus Quartzite, Pepuarta Tillite, Gumbowie Arkose in the south-east, and Yerelina Subgroup in the Northern Flinders Ranges). (See Table VI). The top of the Wilpena Group was placed at the Pound Quartzite-Parachilna Formation contact; the Parachilna Formation with vertical U-shaped burrows Diplocraterion in the Flinders Ranges (Dalgarno, 1964) and the fossiliferous Mt Terrible Formation with hyolithids in the Mt Lofty Ranges (Daily, 1963) were considered as basal Cambrian.

This scheme was adopted on the Burra and Parachilna 1:250,000 Sheets (Mirams, 1964b, and Dalgarno & Johnson, 1966). Forbes (1967), investigating the Burra Group - Umberatana Group contact west of Pekina (Orroroo 1:250,000 Sheet), recorded a slight angular unconformity below the Appila Tillite, but above the Mintaro Shale. Rather than have an unconformity within the Umberatana Group, Forbes suggested that the base of the Appila Tillite be taken as the base of the Umberatana Group. Following this concept, Coats (1967) regarded the Sturt Tillite of the Adelaide area as the basal unit of the Umberatana Group, probably unconformable over the Belair "Group" (later designated "Belair Subgroup") which was included in the Burra Group. Coats thus rejected Mawson and Sprigg's criterion of feldspar content as an indication of glacial sediments, in the Belair Subgroup.

The Umberatana - Wilpena Group boundary in the Adelaide area was also revised. Thomson (1966a) correlated three section at Hallett Cove, Willunga Scarp, and Kulpara respectively. Whereas Mawson had correlated the Marino Arkose with the Elatina Formation, Thomson correlated it with the gritty limestones of the Etina Formation, and with a gritty and stromatolitic limestone at Kulpara. The Elatina equivalents in the three sections were taken to be red gritty and pebbly siltstones (Reynella Siltstone) well above the Marino Arkose. The overlying purple and white quartzites (Seacliff Sandstone) were taken as the basal formation of the Wilpena Group; the contact of the Seacliff Sandstone with the Umberatana Group is sharp, while its upper boundary is gradational and intertonguing with the overlying chocolate coloured siltstones (Brachina Formation). A similar sandstone (Whyalla Sandstone Member) occurs at the base of the Wilpena Group on the Stuart Shelf (Woomera Bore, Thomson & Johnson, 1968). In these south-western areas, the Nuccaleena Formation of the Flinders Ranges (a cream dolomite, usually the basal formation of the Wilpena Group) is absent - it recurs near Eudunda, some seventy miles east of Kulpara.

The revised rock-subdivision was applied to the Orroroo 1:250,000 Sheet by Binks (1968). This excellent map is the first in which an attempt was made to decipher facies changes across the basin from west to east. Binks' mapping largely forms the basis of environmental interpretations presented in Ch.11 for the Umberatana Group. Here three important facies changes are noted: firstly, the Brighton Limestone equivalent thins and lenses out to the east; secondly, the overlying argillites change across the basin from purple, ripple-marked, mudcracked Lower Willochra Formation, to drab grey and green siltstones (Taroowie Siltstone and

Enorama Shale); thirdly, the Elatina Formation (sandstone) in the west passes into Pepuarta Tillite in the east.

Thomson (1966b) discussed the lower boundary of the Adelaide System. Having outlined the major tectonic units of South Australia, he described the areas in which Willouran sediments occur. In the Mt Painter area, the Willouran sequence contains near its base the Wooltana Volcanics; a dating on these would provide an approximate age of the base of the Adelaide System. In the Willouran Ranges, the Callanna Beds underlying the Burra Group pass down into a diapiric zone, including basic lavas, and basement is nowhere exposed. However, basement inliers occur in the Peake and Denison Ranges, but their relationship with the Callanna Beds and Burra Group is usually obscured by faulting or diapiric activity. At Depot Creek in the Southern Flinders Ranges, volcanics similar to those at Wooltana occur unconformably below the Emeroo Quartzite (Mawson, 1947; Brunnschweiler, 1956). This area was investigated as an Honours project (Preiss & Sweet, 1966).

The volcanic rocks at Wooltana, Depot Creek and in the Willouran Ranges were considered to be petrologically similar to the Roopena lava exposed on north-eastern Eyre Peninsula. Here mapping has shown these lavas to underlie the clastic Pandurra Formation, which Johns et al. (1964) had correlated (as "Pernatty Grit") with the upper glacial unit of the Umberatana Group, but which Thomson considers is pre-Sturtian, because of erratics of it in the Sturtian Tillite. The Tregolana Shale and Tent Hill Formation (Wilpena Group equivalents) overlie the Pandurra Formation disconformably, as shown by Thomson & Johnson (1968).

In summary, Thomson maintained that Willouran basic volcanism commenced soon after the onset of sedimentation both in the Adelaide Geosyncline and on the Stuart Shelf. The consequences of the correlation of all these volcanic rocks will be discussed later (p.30).

On the Mt Painter Province map (Coats et al., 1969) Coats has given the first detailed subdivision of the Umberatana Group in the Northern Flinders Ranges. He demonstrated the effect of penecontemporaneous faulting during the deposition of the glacial Yudnamutana Subgroup, the control by faulting of the distribution of certain limestones (Balcanoona Formation), and the lateral facies relationships between red and green shales, and between the arenaceous Elatina Formation and the tillitic Yerelina Subgroup. He also clarified the relations near the base of the sequence, demonstrating an unconformity within the Callanna Beds.

Finally, the Adelaide 1:250,000 Sheet was published (Thomson, 1969). This map is mainly a compilation of earlier work, and demonstrates how the new rock subdivision was extended to the Adelaide region.

Table VI summarizes the lithological correlations which I accept.

Radiometric Estimates of the Age of the Adelaide System

The first age determination to bear any relevance to this question was by Kleeman (1946), on a samarskite from the basement complex at Mt Painter. The age obtained, 400 ± 50 m.y. implied a Lower Palaeozoic metamorphic event. Campana (1954) reported age determinations of 580 ± 30 m.y. by Kulp on uraniferous basement granites near Crocker Well, but little account was taken of subsequent metamorphism. Greenhalgh & Jeffery (1959) obtained additional older ages for the uranium (1730 m.y.) and concluded that there were two periods of mineralization. Uraninite from the basement at Myponga gave an age of 520 m.y., again reflecting Lower Palaeozoic events. Wilson, Compston & Jeffery (1960) summarized all Precambrian age determinations then completed.

Compston, Crawford & Bofinger (1966) made the as yet only deliberate attempt to determine the duration of sedimentation. Their results were inconclusive, and left many unanswered questions. The aim was to date volcanics and sediments (by Rb/Sr total-rock isochron methods) from near the base of the Adelaide System. These were compared with the ages obtained from the Roopena lavas of Eyre Peninsula.

Igneous rocks below the sequence were also dated, and perhaps give the best indication of a maximum age. The dating of "shales" was quite unsatisfactory, largely owing to the unfortunate choice of samples mainly from metamorphosed sequences in the northern Mt Lofty Ranges.

The Wooltana Volcanics were extensively studied. Samples were obtained from the least altered, hard, amygdaloidal lavas. Rb/Sr measurements on amygdalar microcline gave a Lower Palaeozoic age - either the microcline was formed then or radiogenic Sr had escaped, making the age meaningless. Similar microcline at Roopena gives a Precambrian age, suggesting that at Wooltana also, it may not be Palaeozoic. The post-Adelaide System Arkaroola Creek Pegmatite fits well on an isochron at 460 m.y., thus dating the metamorphism. It was realized that the lavas were more altered than previously thought; when plotted on an isochron, the total-rock data showed considerable scatter, and there was a poor alignment of points near an isochron of 850 ± 50 m.y. The authors could not decide whether this dated extrusion or a subsequent metamorphism, but regarded it as a reliable minimum age. The fact that the initial $^{87}Sr/^{86}Sr$ ratio so calculated is high for basic igneous rocks suggested, not unequivocally, that it may represent a metamorphic age. The very similar Roopena lavas gave a much lower initial ratio; if this initial ratio were assumed for the Wooltana lavas, then an age exceeding 1000 m.y. would be indicated. The fact that the only Wooltana specimen with primary pyroxene still falls on the 850 m.y. isochron can be used to argue against the correlation of the two volcanic sequences. The possible interpretations of the datings must at present be considered quite ambiguous, and cannot be used to define accurately the base of the Adelaide System. The unaltered Roopena Volcanics were reliably dated at 1345 ± 30 m.y., but their correlation with the Wooltana Volcanics is neither supported, nor definitely contradicted by radiometric evidence.

The dating of "shales" from the Adelaide Geosyncline showed poor judgement in sampling, and can only help to cast suspicion upon the procedure of whole-rock dating of sedimentary rocks. The following were analyzed: metamorphosed shales from Truro, regarded from mapping as Lower Cambrian, metamorphosed Saddleworth Formation (Burra Group) near Riverton, and "Willouran" shales from Merinjina Well, near Wooltana.

The first set (Lower Cambrian) could be interpreted according to two models: (1) if only samples with the highest and the lowest $^{87}Rb/^{86}Sr$ are grouped, a convenient age of 530 m.y. results; (2) if the samples most obviously metamorphosed (to mica-schists) are grouped, a metamorphic age of 465 m.y. is obtained; grouping the remaining samples should give a maximum age (690 m.y.). It seems that unmetamorphosed Cambrian shales from the Central Flinders Ranges would have proved a better test of the method.

The Burra Group "Shales" from Riverton also recorded a metamorphic isochron at 465 m.y. By grouping various samples with an assumed initial $^{87}Sr/^{86}Sr$ ratio, minimum and maximum ages of 600 m.y. and 850 m.y. are obtained. Again, a better coice of location may have enabled the original sedimentary age to be determined.

The "Willouran" shales from Merinjina Well are the only ones that are not visibly affected by metamorphism. Nevertheless, an isochron of all points still gave a metamorphic age. Again, by various groupings and assumed initial ratios, ages of 1200 m.y. and 950 m.y. are obtained, and these are compared to the possible age range of Willouran lavas (850 m.y. to 1300-1400 m.y., the older limit resulting from correlation with the Roopena Volcanics). The only problem is that the shales are not Willouran, but the lowermost beds of the Sturtian Tillite, overlying the lavas unconformably (Mirams, 1964). I have visited the locality and agree with Mirams' interpretation; dropped pebbles in the shale demonstrate its glacial origin. This example serves to show that data represented by such scattered points cannot define a reliable age. What is required is a detailed sampling of shales throughout the sequence, from the areas least affected by the widespread low grade Palaeozoic metamorphism.

Dating of the Basement

Basement ages determined by Compston, Crawford and Bofinger appear to provide the only reliable maximum age for the base of the Adelaide System. The age data for basement and older, pre-Adelaidean cover rocks on Eyre Peninsula are consistent, and record a series of events at about 1600 to 1800 m.y., followed by the extrusion of the Gawler Range Volcanics at 1535 ± 25 m.y., the deposition of the penecontemporaneous Corunna Conglomerate, and the intrusion into the latter of the Cultana Granite, at least 1320 m.y. ago. These rocks are overlain by presumed Adelaide System equivalents, in particular the Roopena Volcanics.

Within the Adelaide Geosyncline Compston & Arriens (1968) quote ages for the Willyama Block between 1600 and 1700 m.y., a pooled estimate being 1640 ± 40 m.y., and 1560 ± 40 m.y. for the younger Mundi-Mundi Granite. In the Mt Painter Block, Compston, Crawford and Bofinger reported minimum ages between 1400 m.y. and 1650 m.y.

Clearly, the base of the Adelaide System must post-date 1500 to 1600 m.y. Beyond that, radiometric data are ambiguous; lithological correlation of two volcanic sequences argues for an age of about 1400 m.y. for its base, while the best fitted age determined from the altered Wooltana lavas suggests an age of approximately 900 m.y. The significance of the data of Cooper & Compston (1970, in press) is discussed below (p.35).

Dating of Tillites

Binns & Miller (1963) reported a 920 m.y. K-Ar age for muscovite from the matrix of the Torowangee tillite. They interpreted this as a metamorphic mica; then either 920 m.y. represents a minimum age for the deposition of the tillite, or reflects a gain of argon from other micas. So old an age for the tillite seems unlikely, for the following reasons.

In the Kimberley Region of Western Australia, two Late Precambrian tillites are known to overlie glaciated pavements over large areas. The lower tillite is more widespread than the upper (as in the Adelaide Geosyncline). The sequence of tillites and marine shales is overlain by the Antrim Plateau Basalts, which underlie rocks with Middle Cambrian fossils.

In the Amadeus Basin of Central Australia, again an extensive lower tillite (Areyonga Formation) and a local upper tillite occur. At least one glaciation is also present in the Georgina Basin, Northern Territory. In both areas, the tillites are not far below rocks with Cambrian fossils.

The general similarity of sequence over much of the Australian continent in these Late Precambrian times, with widespread lower and local upper tillites, suggests a correlation of the glacial beds. If this is accepted, the detailed radiometric work carried out in the Kimberley Region may be applied to other areas. Compston and Arriens quote the following age determinations:

Kimberley Region:

Lower tillite (Moonlight Valley Tillite)	740 ± 30 m.y.
Overlying marine shales	685 ± 70 m.y.
Marine shales overlying younger tillite	665 ± 45 m.y.

Amadeus Basin:

Shales above the lower tillite (in Pertatataka Formation) about	790 m.y.
Shales higher in the sequence about	600 m.y.

Georgina Basin:

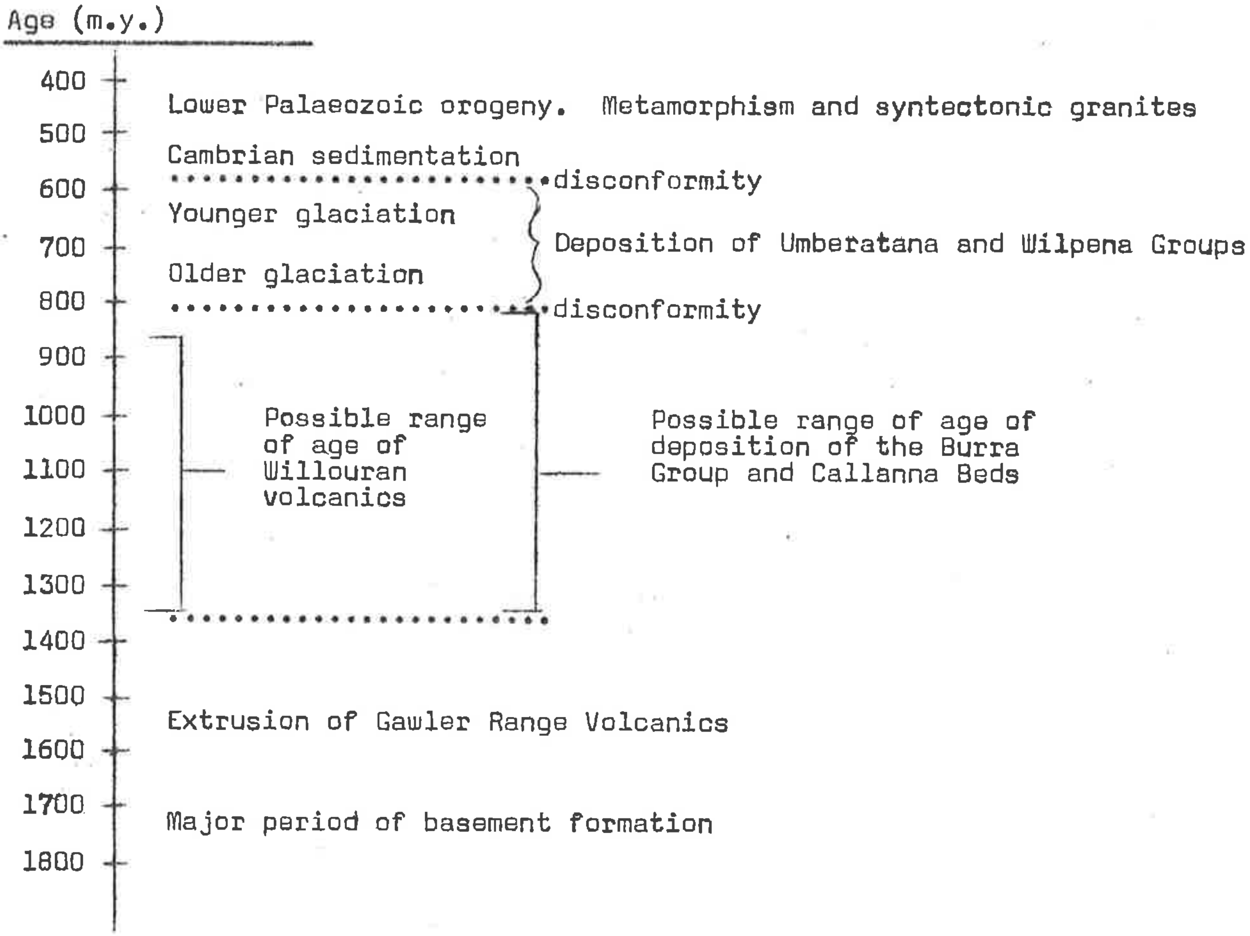
Shales from tillite (Field River Beds) about	790 m.y.
and about	600 m.y.

Dow & Gemuts (1969), in a discussion of the geology of the Kimberley Region, quote the following datings:

Moonlight Valley Tillite and Stein Formation		739 ± 30 m.y.
Johnny Cake Shale Member of the Ranford Formation (above Moonlight Valley Tillite)		685 ± 98 m.y.
McAlly and Timperley Shales	above the (younger) Egan Glacials	666 ± 56 m.y.
Elvire Formation		653 ± 48 m.y.

These data show that the age of the earlier one of the Late Precambrian glaciations probably does not exceed about 800 m.y. in northern Australia. If correlation of this with the Sturt Tillite is accepted, a radiometric framework for South Australia can be erected as follows:

TABLE VII



A possible contradiction to this scheme comes from the work of Cooper & Compston (1970, in press). They dated high grade metamorphic rocks from the basement Houghton Inlier by the Rb/Sr isochron method, and obtained the surprisingly young age of about 870 m.y. for the upper amphibolite facies metamorphism. If this dating is confirmed by later work, there will be two possible interpretations:

(1) The whole of the sedimentary sequence, including all the Callanna Beds, may be less than 870 m.y. old. In that case, the minimum age of 850 m.y. for the Wooltana Volcanics could be their true age.

(2) The unconformity within the Callanna Beds could reflect an extremely long time break; then the Upper Callanna Beds (River Wakefield Group) plus the Burra Group, would post-date the high grade metamorphism at Houghton 870 m.y. ago, but the Lower Callanna Beds (including the volcanics) could still be as old as 1300 m.y. Lower Callanna Beds are not known to occur within at least 100 miles of the Houghton Inlier, and perhaps the unconformity in the Northern Flinders Ranges between the Lower and Upper Callanna Beds cofresponds to the high grade metamorphism near Adelaide.

Concluding Remarks

It has been shown how the stratigraphic knowledge of South Australia has evolved since the last century, and how uncertainty as to the ages of the bed-rock formations has been reduced by stratigraphic, palaeontological and radiometric means. The sequence in the deeply subsiding Adelaide Geosyncline has been variously subdivided, but the scheme currently used seems to apply equally well throughout the basin. Some authors have attached a time significance to some subdivisions (e.g. Thomson et al., 1964) while others see no justification for the time connotations (e.g. Daily, 1963) and prefer to call the whole sequence "Adelaide Supergroup". More recently, the term "Adelaidean" has been used as a time term to describe the time interval from about 1300-1400 m.y. to the base of the Cambrian (570 m.y.). While "Adelaidean" is a useful term to describe the age of sequences deposited in this interval, the term "Adelaide Supergroup" is more correct to describe what is essentially only a sequence of rock units, just as "Supergroup" is used in other parts of Australia (e.g. the Mt Bruce Supergroup of Western Australia, of Lower Proterozoic age).

The age of the base of the sequence remains problematical. If Cooper and Compston's data are correct, the future status of the term "Adelaidean" is in doubt. It was partly in the hope of elucidating the problem that this project was undertaken, to attempt to date the sequence by palaeontological means.

Chapter 3

PRECAMBRIAN FOSSILS AND PSEUDOFOSSILS FROM THE ADELAIDE GEOSYNCLINE

Animal Fossils

David & Howchin's (1896) report of radiolaria from the Brighton Limestone was the first record in South Australia of Precambrian life. The authors were undecided as to the age of the Brighton Limestone - at first they considered it to be Precambrian, because of the differences between it and the known Lower Cambrian on Yorke Peninsula (the relatively greater degree of folding, and the absence of "pteropods" and other macroscopic marine fauna). They later modified this view, following their discovery of Archaeocyatha at Normanville, in a limestone which they correlated with the Brighton Limestone, and since then, continued to regard the Brighton Limestone as Cambrian.

The radiolarian casts were found in oolitic limestones, greenish siliceous limestones and laminated shales near Hallett Cove, and in black cherts at Crystal Brook (Skillogalee Dolomite, but correlated by David and Howchin with the Brighton Limestone). Both chalcedony and lime comprised the casts, which were partly filled with pyrite. As well as the spherical medullary shells, 0.1 to 0.22 mm in diameter, they found an outer denticulate ring and a black netted envelope. The casts are illustrated only by sketches which are difficult to interpret; one cannot rule out the possibility of their origin as diagenetically altered oolites or spherulites. Glaessner (1958b), critically reviewing the early finds of Precambrian fossils, dismissed the "radiolaria" from Crystal Brook as secondary segregations, but concluded that those from the Brighton Limestone could have been radiolaria, although this cannot be confirmed because the illustrated slide cannot be found.

In 1922, David found small ochreous fragments in the siliceous limestones below the Brighton Limestone, at Reynella. He interpreted these as parts of crustacean skeletons and extended his search throughout the Adelaide Hills. He reported his findings (David, 1922): fossil annelids and arthropods from the Brighton Limestone, the Tapley Hill Formation, the thin limestone (dolomite) immediately overlying the Sturtian Tillite, the "blue-metal" limestones (Beaumont Dolomite), the Upper Torrens Limestone (Montacute Dolomite), and a thin quartzite below the Montacute Dolomite (at Teatree Gully). The "fossils" took the form of ferruginous yellow streaks and patches in the carbonate and argillaceous rocks; occasionally they were apparently preserved as carbon. They were grouped into two faunas, the upper from the Tapley Hill Formation and Brighton Limestone, and the lower from the Montacute and Beaumont Dolomites, and the thin quartzite. The upper fauna supposedly comprised polychaete worms, a eurypterid *Reynella howchini*, a possible algal flora in the siliceous limestones, and annelid burrows. The lower fauna also contained eurypterids, annelids and arachnids. David augmented the collection in 1929, with further illustrations (David, 1929). Favouring a late Precambrian age, perhaps "Lipalian", David saw his discoveries as of great significance, and enthusiastically recommended a search of the Flinders Ranges for complete specimens. Chapman (1929) further examined David's specimens from the Beaumont Dolomite; he tentatively identified poorly preserved rust-stained patches in shale as the brachiopods *Lingulella* and *Obolella*.

David's researches culminated in a memoir (David & Tillyard, 1936), in which the Teatree Gully Fauna, the Beaumont Fauna and the Brighton Fauna were completely described and figured. The six pieces of evidence presented for the organic origin of the remains, (bilateral symmetry, segmentation, segmented appendages, sculpture, duplication of parts, and coordination), are unconvincing in the illustrations. The Teatree Gully Fauna was assigned to two species, Protoadelaidea howchini and P. browni, belonging to an especially created class, the Arthrocephala, of the arthropods. In his review, Glaessner (1958) stated reinterpretations of all these fragmentary remains, either as flattened clay pellets, or perhaps, as pyritized plant tissues.

What was to become one of the most significant Late Precambrian faunas in the world was discovered by Sprigg in 1947, in the Pound Quartzite at Ediacara. The Pound Quartzite was then considered to be basal Cambrian (Mawson, 1939), as it occurs well below the Archaeocyatha, then thought to be Upper Lower Cambrian. Sprigg (1947) recorded impressions of jellyfishes on partings in flaggy quartzites, and assigned them to the following species: Ediacaria flindersi, Ediacaria (?) sp., Beltanella gilesi, Cyclomedusa davidi, Dickinsonia costata, (?) Dickinsonia sp. and Papilionata eyrei. The environment of deposition was interpreted as intertidal flats or strandlines, and the fossils were thought to have been toughened due to dehydration, and therefore preserved if rapidly buried.

Further fossils were found at Ediacara, and also in an apparently equivalent horizon at Mt John, in the Kimberley District of Western Australia (Sprigg, 1949). The new specimens provided the basis for a better classification of the fossils. All were assigned to the Phylum

Coelenterata, Sub-phylum Cnidaria, characterized by radial symmetry. *Protonobia wadea*, (W.A.), *Protodipleurosoma wardi* (Ediacara) and *Beltanella gilesi* (Ediacara) were assigned to the Class Hydrozoa; *Ediacaria flindersi* (Ediacara), *Tateana inflata* (Ediacara), *Pseudorhizostomites howchini* (Ediacara) and *Pseudorhopilema chapmani* (Ediacara) were assigned to the Scyphozoa. Some medusoids could not be properly classified: *Medusina mawsoni*, *M. asteroides*, *M. filamentis*, *Cyclomedusa davidi*, *C. radiata*, *C. gigantea*, *Madigania annulata*, *Dickinsonia costata* and *D. minima*.

Glaessner (1958a) described a bilaterally symmetrical, segmented organism *Spriggina floundersi*, assigned to the polychaete annelids, and a shield-like fossil of unknown affinity, *Parvancorina minchami*, from the Ediacara fauna. It was suggested that the segmented *Dickinsonia* might also be an annelid rather than a coelenterate.

In his review of the oldest faunas of South Australia, Glaessner (1958b) considered the question of the position of the base of the Cambrian, whether above or below the Pound Quartzite, and concluded that since the Ediacara fauna is unlike any known Cambrian fauna, it is therefore probably Late Precambrian. The base of the Cambrian was placed at the top of the Pound Quartzite.

Later, representatives of the Octocorallia (Order Pennatulacea) were also found, and compared with *Charnia*, from the Charnwood Forest, England, and *Rangea* from the Kuibis Quartzite of the Nama System, South Africa (Glaessner, 1959).

Over a period of the next few years, a series of papers on Precambrian palaeontology appeared: a discussion of the regional geology, faunas, ecology, and biostratigraphy of the Ediacara Reserve (Glaessner & Daily, 1959); summaries of the then known Precambrian metazoan fossils from South Australia (Glaessner, 1960, 1961); discussions of the evolution of Precambrian life, and attempts to apply it to biostratigraphic zoning of the Precambrian (stromatolites, oncolites, catagraphia, microfossils, trace fossils and metazoan fossils) (Glaessner, 1962, 1965, 1966a and 1966b).

New genera and species from the Ediacara fauna were described by Glaessner & Wade (1966), and here the importance of mud laminae and lenses in preserving the fossils was recognized. During the deposition of mud, conditions were sufficiently quiescent to allow the soft bodies to accumulate and leave impressions. The following new species were described: *Cyclomedusa plana*, *Mawsonites spriggi*, *Conomedusites lobatus*, *Lorenzinites rarus*, *Rugoconites enigmaticus*, *Kimberia quadrata*, *Ovatoscutum concentricum* (all medusoids); *Rangea longa*, *R. grandis*, (Pennatulacea), and *Dickinsonia elongata*, *D. tenuis*, *Spriggina ovata* (annelids). *Precambridium sigillum*, and the previously described *Parvancorina minchami* and *Tribrachidium heraldicum* remained enigmatic, though a relation of *Tribrachidium* to the echinoderms was considered, in view of new observations of a possible mouth and bristle-like appendages.

The mode of preservation of the soft-bodied animals was investigated by Wade (1968), who distinguished the impressions of resistant forms which supported the encasing mud until diagenesis, and those less resistant, which collapsed before diagenesis. The former, mainly annelids and pennatulids, left concave impressions on the undersides of sandstone slabs (external moulds), while the latter, chiefly medusoids, left convex impressions.

Finally, Glaessner (1969) has reviewed animal tracks and trails from the Cambrian and Late Precambrian, and discussed the formation of certain worm burrow-like pseudofossils by syneresis shrinkage and cracking of mud.

Plant Fossils

Howchin (1914) described a fossil from a limestone (Bitter Springs Formation) in Central Australia, collected by Chewings, which he compared with Cryptozoon Hall. Its general growth form, of superposed concentric laminae, was considered to resemble the Stromatoporoidea, but lacked their distinctive microstructure. Howchin nevertheless favoured an ancestral stromatoporoidal origin for Cryptozoon, but recognized the possibility of its being a calcareous alga. He rejected Dawson's analogy with the rhizopod protozoans. The algal origin of Cryptozoon and other stromatolites was established later (Walcott, 1914), and confirmed by studies of Recent forms (Black, 1933). Howchin defined two species, Cryptozoon australicum and C. tesselatum, which Walter (1970) has recently redescribed as Acaciella australica.

Following Walcott's (1914) description of Precambrian algal limestones, David suggested to Mawson (1925) that many of South Australia's ancient limestones could be of algal origin also. Mawson examined the Lower Cambrian beds in Italowie Gorge, and found "massed fossil heads of a Cryptozoon-like alga", which he regarded as the same specimen as Howchin's Cryptozoon australicum. In a limestone apparently above the Sturtian Tillite, nine miles west of Wooltana, he found markings resembling "packed fan-shaped segments of Halimeda", and tentatively correlated the horizon with the Brighton Limestone.

In the same paper, Mawson described nodules from limestones near the Edelweiss Mine (in the vicinity of Burra). These were of oval cross-section, approximately 4 to 5 cm in diameter, with dark coloured outer rims; similar forms were also found in the Burra Creek. Mawson considered sponge, coelenterate, or calcareous algal origins for these structures. I have not visited these two locations, but have found similar structures in biostromes of the columnar stromatolite Baicalia burra (Plate 6a), near Dutton's Trough H.S.*, several miles to the north, where they are seen to be transverse sections of silicified subcylindrical columns. Howchin (1921) visited the Utica Mine area (approximately half a mile north of my locality), and decided that the contorted and sometimes concentric lamination seen here is due to deformation and infiltrations of silica. As cherty, laminated, contorted dolomite does occur in this area, this explanation cannot be discounted for the structures he saw.

Mawson also considered that calcareous algae contributed lime mud to the fine grained mottled limestones associated with the Cambrian archaeocyathan limestones at Sellick Hill.

Chapman (1927) examined a specimen of Mawson's Halimeda-like alga from west of Wooltana, which he named Mawsonella wooltanaensis. The "alga" consisted of a white, calcareous segmented "thallus", average size 3 mm by $1\frac{1}{2}$ mm, set in a darker lime matrix; an algal microstructure was described, but not well illustrated. Mawsonella probably represents a variation of

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* The abbreviations H.S. and O.S. refer to "Head Station" and "Out Station" respectively.

the magnesite conglomerate so widespread in the Skillogalee Dolomite throughout the Flinders Ranges. The carbonate unit from which Mawsonella comes is certainly Skillogalee, not Brighton equivalent. Magnesites which I have seen from this general area are conglomerates or breccias, of grain size comparable to Chapman's description: their rather angular, closely packed structure suggests that the magnesite bed may have been brecciated (by desiccation?) in place, without subsequent reworking. An origin of magnesite conglomerates by desiccation and reworking has been suggested for many other areas (Forbes, 1961).

Subsequent to the early interest in stromatolites and fossil algae shown by Howchin and Mawson, little is recorded of them in the South Australian literature.

Edgell (1964), in a superficial attempt to classify stromatolites and apply them to Precambrian correlations in Australia, recognized the following assemblages from various horizons: (1) Girvanella (Lower Cambrian), (2) Conophyton inclinatum and Collenia frequens (Upper Proterozoic), (3) Collenia australica, C. undosa and Newlandia lamellosa (Middle Proterozoic), (4) Collenia cf. kona and C. brockmani (younger Lower Proterozoic) and Collenia sp. aff. multiflabella (older Lower Proterozoic). In Table 2, p. 255, op.cit., Edgell shows assemblage (2) in the "multicoloured slates and shales" and in the Brighton Limestone of South Australia, but does not elaborate upon this in the text, so that no evaluation can be made.

Nixon (1965), in describing a copper occurrence at Paratoo, recognized a dolomitic "algal bioherm". The regional setting is a domed anticline, with a diapiric core; on the flanks of the anticline, the Auburn Dolomite equivalent is overlain by the Sturtian Tillite. Nixon considered that the stromatolitic unit occurs within the Auburn Dolomite, and differentiated it from the recrystallized and contorted carbonate of the diapir.

My field observations suggest that the stromatolitic unit forms an isolated outcrop surrounded by diapiric breccia, and is of different lithology from the Auburn Dolomite in sequence nearby. It is probably a large raft of dolomite, older than the upper Burra Group sediments into which the diapir intrudes. No similar occurrence has been found, either in situ or in diapirs, anywhere else in the Adelaide Geosyncline. For a description of the stromatolite, Conophyton garganicum garganicum, see p.117.

Dalgarno (1966) briefly described two types of dome-shaped structures, the one, from the Burra Group at Depot Creek, being stromatolitic, while the other, in the Trezona Formation, in Enorama Creek, was interpreted as of mechanical origin, by doming and piercing of the overlying lime mud. Dalgarno's criterion for stromatolites, of irregularity, small-scale arching and bifurcation of laminae, reported as absent in these structures, cannot be accepted; many stromatolites, both ancient and modern, have extremely regular lamination. Besides, these structures frequently have cuspate laminae (see p.214). The Trezona Formation structures are almost certainly stromatolites of the laterally linked hemispheroid and pseudocolumnar types, (see Glossary, p. i). Pseudocolumns occasionally project above the surrounding sediment surface (Dalgarno interpreted these as piercement structures).

Stromatolite occurrences have been noted on many Mines Department maps, (e.g. Arrowie, Mt Painter, Parachilna, Orroroo, Burra). Thomson (1966a) recorded a stromatolitic dolomite below the Reynella Siltstone (upper glacial equivalent) at Kulpara, Northern Yorke Peninsula (see *Kulparia kulparensis*, p.169).

In a preliminary note on the present Australian stromatolite research, Glaessner, Preiss & Walter (1969) recorded a succession of stromatolite assemblages similar to those found in the USSR. The assemblages and conclusions drawn from them have now been amplified by Walter (1970) and in the present thesis (Ch.8).

Finally, Schopf & Barghoorn (1969) studied specimens of silicified dolomites and black cherts collected from the Skillogalee Dolomite near Port Augusta by C. R. Dalgarno. They discovered in these cherts a filamentous blue-green alga, *Archaeonema longicellularis* Schopf, a spheroidal unicellular blue-green alga *Myxococcoides muricata*, and a fusiform microfossil of "uncertain systematic position", but apparently similar to the ascus of ascomycetous fungi. The fact that *A. longicellularis* was found also in the Bitter Springs Formation, Central Australia, (Schopf, 1968) was not considered to prove the widely accepted correlation of the Bitter Springs Formation and the Skillogalee Dolomite, since the evolutionary conservatism of blue-green algae reduces their value as index fossils. Glaessner et al. (1969, op.cit.), have shown that the stromatolite evidence disfavours the correlation of the two units (see Ch.8).

Concluding Remarks

The Precambrian fossils discussed above may be divided into four groups: trace fossils, microfossils, metazoa and stromatolites. Of these, the metazoa have been found in the uppermost Precambrian of most continents, but their restriction to these horizons limits their usefulness for subdividing and correlating the common, very thick sequences of little altered Precambrian sediments. Similarly, trace fossils of verifiable organic origin also appear to be restricted to the uppermost part of the Precambrian. Microfossils occur throughout the Precambrian sedimentary record, where this is preserved; procaryotic cells have been described from some of the oldest sedimentary rocks on Earth - the Fig Tree Series (Barghoon & Schopf, 1966) and the Onverwacht Series (Engel et al., 1968), of South Africa. But the general morphological conservatism of bacteria and blue-green algae (in particular the similarity of many Precambrian forms to modern ones) has not yet allowed them to be used for biostratigraphic zonation. The considerable success claimed for stromatolite zoning by Russian authors (Ch.4), has provided incentive to try to apply their empirical methods of study here; this thesis is therefore concerned chiefly with the systematics, biostratigraphy and ecology of South Australian stromatolites.

Part II

STROMATOLITES AND BIOSTRATIGRAPHY

Chapter 4

A REVIEW OF THE STUDY OF ANCIENT STROMATOLITES

Introduction

Stromatolites, long regarded as problematical fossils, have been the subject of discussion and varying viewpoints ever since their original discovery. The history of their early study has been comprehensively reviewed by Maslov (1960), who recognized two periods in their understanding. Prior to 1914, attention was paid to establishing the organic origin of stromatolites, while in the following period, the role of algae in their formation was recognized. Maslov excluded the early recognized genera Archaeozoon, Rivularites, Stromatactis, Camasia etc. from stromatolites, although Archaeozoon is in fact one (Hofmann, 1970, pers. comm.). Stromatactis has since been extensively reviewed in the literature of carbonate petrology (e.g. Wolf, 1965). The early workers, who frequently sought an animal origin, included Hall (1883) who erected the genus Cryptozoon, Gürich (1906, Spongiostroma), Matthew (1907, Archaeozoon) and Steinmann (1911) who considered his Gymnosolen to be a coelenterate.

As mentioned in Ch.3, Howchin had considered an algal origin for Cryptozoon. Other workers also favoured a plant origin. Kalkowsky (1908) introduced the term stromatolith for limestones composed of stromatoids, which he ascribed to a possible origin by mosses or Myxomycetes. Limestone pebbles formed in Recent lakes by algae were recognized by Murray (1895) and other authors. Walcott's (1914) discovery of filamentous microfossils in Precambrian stromatolites (his genus Collenia) from the Belt Series (since confirmed by Gutstadt & Schopf, 1969), paved the way for an understanding of stromatolite formation by algae.

Later workers clarified the role played by the algae. In particular, Black (1933) established the function of polyspecific algal mats whose mucilaginous filaments trap detrital grains. Pia (1926) recognized the rock-building properties of modern blue-green algae, and compared the structures so formed to the genera Collenia and Cryptozoon, which he considered may have been built by several species. Bradley (1929) described stromatolites from the Eocene Green River Formation, USA, which contained preserved algal filaments. Mawson's (1925) interest in Australian stromatolites has already been mentioned (p.42).

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

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

Modern Studies

At least three major schools of thought have evolved since the controversy originated. Firstly, a small group of Russians (e.g. Vologdin, 1962) considers any stromatolite nomenclature to be invalid unless the actual algal remains are named. But algae are very rarely preserved, especially in Precambrian stromatolites, and many of the structures referred by them to fossil algae are very doubtfully of organic origin.

The second group rejects the concept of biological control over stromatolite morphology, and uses purely descriptive classifications to aid environmental interpretations. Two outstanding examples of this classification are those of Maslov (1960) and Logan, Rezak & Ginsburg (1964). Maslov used the generic names _Collenia_, _Conophyton_, _Conocollenia_, _Glebulella_, _Fossella_, _Crustella_, _Macronubecularites_, _Tubistroma_ and _Saccus_, modified by a series of descriptive Latin adjectives. Logan, Rezak and Ginsburg applied a similar approach, but used symbols instead of Latin names, and also classified different features from those chosen by Maslov. The variable descriptive formulae which result from a combination of the symbols are often cumbersome and, like Maslov's multinomial nomenclature, cannot in themselves describe all the useful characters of stromatolites. Some of the simpler formulae are, however, very useful in routine field descriptions.

The third school is represented by a group of Russians who have developed a new, comprehensive method of studying and classifying stromatolites, chiefly the distinctive, columnar forms, since the mid 1950's. Their results culminated in a detailed and apparently workable biostratigraphic zonation of the Late Precambrian of the USSR based on stromatolite time ranges, which was first reported by Keller et al. (1960). Differences of emphasis now exist between different workers, but all agree on the use of a binomial classification, with the form taxa "group" (analogous to genus) and "form" (analogous to species). All have abandoned the simple naming of specimens on the basis of field examination or a study of single longitudinal sections, which had been carried out in the 1930's to early 1950's. The generic terms Cryptozoon and eventually Collenia fell into disuse for columnar branching stromatolites. Korolyuk (1960) studied stromatolites mainly on the basis of cut slabs and thin sections, and classified them into the four categories type, subtype, group and form. Thus there are the continuously layered, nodular and columnar types, with subdivisions based on wall structure, lamina shape and microstructure.

Other workers attach more significance to the gross morphology of columns. Thus Krylov (1959, 1963) developed the technique of "graphical reconstruction", whereby details of column shape, branching, and margin structure are determined by serial sectioning. Krylov's taxonomy places much emphasis on these gross features of columns; he does not allow small variations of these features without erecting new forms, even to the extent that the central and marginal portions of single bioherms must be differently named, e.g. Linella ukka in the bioherm centre, Tungussia bassa at the margin (Krylov, 1967). Krylov recognizes the dangers involved in basing taxonomy on microstructural features, since these are easily modified by diagenetic processes.

Other workers of the Russian school use the same approach as Krylov, but attach less significance to minor variations of gross morphology and more to microstructural differences. Thus Semikhatov (1962) discussed which characters are connected with algal evolution and should therefore be used for classification. He decided that this can be settled only by finding out which characters are useful in defining temporally restricted taxa, and lists the following: general shape of the structure, type of branching, nature of the lateral margin of columns (presence or absence of a wall), type of lateral surface (with cornices or peaks, or smooth) and the microstructure of laminae. Groups are defined on a complex of characters, while chiefly microstructure is used for the division of groups into forms.

Komar (1966) and Nuzhnov (1967) applied a similar approach to Semikhatov, attaching more significance to microstructure than to small variations of gross morphology for the differentiation of forms.

The views of Raaben (1964, 1969a) require special comment. She differs from most of the other Russians in recognizing formal categories higher than groups, although the dangers of this were pointed out by Semikhatov (1962, p.197). In addition, she places extreme importance on microstructure, and considerably changes the content of many of the earlier defined groups. Raaben's classification may be summarized as follows: (1) Conophytonida: unbranched columnar stromatolites, (2) Kussiellida: "passive" (i.e. alpha-parallel) branching columnar stromatolites, (3) Gymnosolenida: "active" parallel branching stromatolites (i.e. beta- and gamma-parallel branching) and (4) Tungussida: "active" non-parallel branching stromatolites (i.e. divergent branching). (See Glossary, Appendix I). Other Russian stromatolite taxonomists have now discarded the terms "active" and "passive" branching (e.g. Krylov, 1967).

Raaben's book (1969a) is concerned primarily with the Gymnosolenida, in which she recognized the groups _Gymnosolen_ Steinmann, _Inzeria_ Krylov, _Katavia_ Krylov and _Boxonia_ Korolyuk. She discarded the group _Minjaria_, which Krylov (1963) had distinguished on the basis of branching and column shape, and redistributed its contents in the groups _Inzeria_ and _Gymnosolen_.

Raaben gave a detailed account of the taxonomic significance of each character of stromatolites. She argued that branching and geometrical form depend on the mode of growth of the stromatolitic layers, which in turn reflects the nature of the algae. Characters which do not reflect this growth are given lower taxonomic rank. Perhaps unduly harshly, Raaben criticized current Russian usage of terms such as "complex" branching, "bushy" or "dendritic" branching, "churn-staff" branching as inexact and subjective, and enumerated misuses of the concepts of frequency of branching and dichotomous branching by previous authors. Some of her objections may be valid, but her own approach in describing and differentiating stromatolite forms does not facilitate comparisons despite her criticisms.

A similar criticism of the subjectivity of Russian stromatolite studies was made by Hofmann (1969b), who considered all the important attributes of stromatolites, gave a very comprehensive review of stromatolite classifications and raised some very searching questions. Hofmann regarded lamina shape as the most important feature of a stromatolite, since it reflects what the structure was like at the surface during growth, and devised means of representing shape parameters quantitatively. Many of his terms are useful in description, but he has not himself attempted to use them for a new classification. To the contrary, he has systematically rejected each of the characters commonly used by the Russian stromatolite taxonomists. Although many of the theoretical criticisms made by Hofmann are valid, and much subjectivity exists in the modern Russian descriptions, nevertheless their practical results are evident.

Stromatolite Biostratigraphy in the USSR

Allowing for minor personal differences of viewpoint among the Russians, their stromatolite school in the past 15 years brought forward a consistent biostratigraphy of the Late Precambrian (Riphean) sediments of the USSR. Different authors have worked in different areas and tectonic settings, yet all agree on the subdivision of the Riphean on the basis of stromatolites, and correlation of sections across most of the Eurasian continent. The correlations and the ages of the subdivisions have been independently checked by radiometric dating, as summarized by Kazakov & Tugarinov (1963), Garris, Kazakov & Keller (1964) and Garris & Postnikov (1967)

The Riphean cover rocks of the Russian and Siberian Platforms and the Ural Mountains date back to 1600 ± 50 m.y. Originally the sequence was subdivided into Lower, Middle and Upper Riphean, but subsequently the Vendian or Terminal Riphean was added. At present the following ages are accepted for the Late Precambrian subdivisions:

Vendian - Cambrian boundary	: 570 ± 10 m.y.
Riphean - Vendian boundary	: 680 ± 20 m.y.
Middle Riphean - Upper Riphean boundary	: 950 ± 50 m.y.
Lower Riphean - Middle Riphean boundary	: 1350 ± 50 m.y.
Base of the Lower Riphean	: 1600 ± 50 m.y.

The ages are based mainly on numerous K-Ar dates on glauconites, supported by Rb-Sr, K-Ar and U-Th-Pb dates on intrusives, e.g. the pre-Middle Riphean intrusives dated at 1300-1350 m.y., the Middle Riphean intrusives dated at about 1100 m.y. and the post-Upper Riphean intrusives of 650-700 m.y. age, which unconformably underlie the Vendian (Keller & Semikhatov, 1967). Basement granites range in age from about 1800 to 1600 m.y. Thus the time scale of the Riphean is reasonably well established.

The subdivisions of the Riphean are each characterized by assemblages of stromatolites rather than single forms. Thus the Early Riphean sequences are characterized by assemblages of *Kussiella* Krylov, *Omachtenia* Nuzhnov, and some forms of *Conophyton* Maslov and *Colonnella* Komar, while the Middle Riphean has *Anabaria* Komar, most forms of *Baicalia* Krylov and some forms of *Conophyton* Maslov and *Colonnella* Komar. A wide variety of groups occurs for the first time in the Late Riphean rocks: *Minjaria* Krylov, *Inzeria* Krylov, *Gymnosolen* Steinmann, *Katavia* Krylov, *Boxonia* Korolyuk, *Jurusania* Krylov. The Vendian is characterized by *Linella* Krylov, *Patomia* Krylov, and some forms of *Boxonia* and *Jurusania*.

The principal modern taxonomic works on these stromatolites and their areas of study are Semikhatov (1962), Yenisei Mountains; Krylov (1963), Southern Urals; Komar (1966), Northern Siberian Platform; Nuzhnov (1967), South-Eastern Siberian Platform; Krylov (1967), Tien Shan and Karatau; Raaben (1969a), the Upper Riphean and Semikhatov, Komar & Serebryakov (1970), the Yudoma Complex (now regarded as of Vendian age). The differences of viewpoint of the authors have already been mentioned, but these should not mask their common conclusions.

Glaessner et al. (1969) published the preliminary results of the extension of the Russian methods to Australian stromatolites. This work is now fully reported in the present thesis and that of Walter (1970).

Cloud & Semikhatov (1969) extended the Russian methods to specimens collected by Cloud from southern Africa, northern Australia, and parts of the USA.

Oncolites and Catagraphia

Another Russian branch of study deserves comment. Zhuravleva (1964) has given a detailed account of oncolites and catagraphia (now both termed Microphytoliths by most Russian authors), and their stratigraphic distribution. A comprehensive study of these structures is beyond the scope of this thesis, but a reinterpretation of some of the forms may be necessary. Oncolites are "unattached carbonate concretions of various sizes, round, oval, sometimes irregular shape, with well defined concentric lamination or radial structure" resulting "from the life-activity of blue-green algae, often encrusting fragments on the shallow sea floor". Catagraphia are "unlaminated carbonate bodies of various sizes and structures, and of irregular shape .... mainly resulting from the life-activity of blue-green algae" (Zhuravleva, 1964, p.5). That all the structures she figures are of blue-green algal origin may be disputed. She distinguishes oolites from oncolites by their spherical shape and extremely regular lamination, while oncolites are of less regular shape and have wavy lamination of varying thickness. In view of this definition, it is not clear why she considers _Osagia tenuilamellata_ (Zhuravleva, 1964, Pl.I), _O. libidinosa_, (Pl.III), _O. composita_ (Pl.IV), _O. aculeata_ (Pl.IV), _O. minuta_ (Pl.V) and *O. grandis* (Pl.V and VI) not to be ooids. Compound ooids such as in Pls. I(1), IV(1) and V(1) and those encrusting detrital grains (as in Pls. III(2), V(2) and VI(1) have an analogy in the botryoidal lumps in the Recent sediments of the Bahamas (Illing, 1954). Quiet-water ooids of non-spherical shape were described by Davis (1966). Many of Zhuravleva's "oncolites" have irregular nuclei, which may account for the relatively irregular shape of the whole structure. Moreover the outer laminae frequently appear to have smoothed out these irregularities; this is not typical of the behaviour of algal mats, which commonly exaggerate substrate irregularities (Logan, 1961; Carozzi, 1962; Aitken, 1967). Eardley (1938) figured examples of modern ooids with radial structure which he showed to be due to secondary recrystallization (p.1380); many of these resemble forms such as Zhuravleva's *Osagia aculeata*, the group *Asterospheroides*, *Radiosus limpidus*, *R. aculeatus*, *R. tenebricus*, *R. praerimosus*, *R. crustosus*, *R. stirpitus* and *R. ravidus*. Only the forms *Osagia undosa* and *O. columnata*, with their wavy, pinching and swelling laminae, may in my opinion be regarded as atypical of ooids, and therefore possibly of algal origin. *Radiosus badius* has a dark, cryptocrystalline rim, which could be interpreted as an example of micritization by algal boring (Bathurst, 1966).

Among the catagraphia, most resemble intraclasts, some of which may in fact be fragments of algal mats (e.g. *Vermiculites tortuosus*, *Hieroglyphites mirabilis*). The extreme angularity of *Vesicularites flexuosus*, *V. compositus* and *V. bothrydioformis* is unusual for normal intraclasts, and these show some resemblance to the "algal lapilli" described by Rothe (1970) as desiccated fragments of crenulated algal mat. Other catagraphia are simply structureless pellets of obscure origin (e.g. *Nubecularites*, *Glebosites*).

Narozhnykh (1967) described a new oncolite, Volvatella, which has a sparry core; it is not clear how this differs from an ooid with its nucleus dissolved out and replaced by sparry calcite.

Zabrodin (1968) was more cautious in his use of oncolites and catagraphia in biostratigraphy, while Karaulov (1967) found typical Riphean and Early Cambrian oncolites and catagraphia in the Devonian and Carboniferous.

Extreme caution is therefore urged in using microphytoliths for biostratigraphy; many of them may not be of organic origin at all.

Chapter 5

THE CHARACTERS OF STROMATOLITES AND THEIR METHODS OF STUDY

The Russian work of recent years has demonstrated the value of columnar stromatolites in Precambrian biostratigraphy. Only Komar (1966) has given a detailed account of laterally linked and cumulate stromatolites, but their usefulness has not been confirmed to the extent that that of columnar forms has. In this thesis, only columnar forms (including those with very numerous bridges) are described in detail; other occurrences are mentioned only briefly in the text or in Appendix II.

As has been stated, the various Russian authors place slightly different emphasis on different characters. The following is a dicsussion of the characters that are described and their possible significance. The terminology is based very largely on translated equivalents of Russian terms, with minor alterations. Most of the new terms introduced by Hofmann (1969b) are not necessary from the point of view of this study. Glaessner et al. (1969, Fig.1) have illustrated diagnostic terminology, which has been retained and added to herein (Fig.4).

Mode of Occurrence

Generally speaking, stromatolites form beds or sequences of beds of limited lateral extent. They always pass laterally into other lithologies at some point. A useful distinction may be made between bioherms, which are discrete bodies surrounded by other rocks, and biostromes which are extensive, stratiform bodies; the definitions used by Nelson, Brown & Brineman (1962) for these terms are accepted here. At least in stromatolites, the two intergrade, and an arbitrary limit must be set. A bioherm is defined as a body whose minimum width is less than 100 times its maximum thickness, while a biostrome has a minimum width more than 100 times its maximum thickness. Since the three dimensions of beds are rarely exposed, in practice, the distinction must be based on the visible width and thickness. Where outcrop is inadequate to determine whether stromatolites form a bioherm or biostrome, the informal term "bed" is used.

If a bioherm actually stood in relief above the surrounding sediment floor, it may be described as domed, ellipsoidal, hemispherical or spherical, depending on its shape. But bioherms may also form by mats growing at the surface, with little or no growth relief. Then sedimentation adjacent to the bioherm may keep pace with vertical growth of the stromatolites; the resulting bioherms interfinger at their margins with the surrounding sediment, and are termed "tonguing bioherms". Their shape may in turn be described as tabular, or lenticular.

Biostromes may be tabular, if their upper and lower surfaces are flat and parallel, or domed, if their upper surfaces bear contiguous domes. The latter case is especially common in biostromes consisting of contiguous smaller bioherms.

The mode of occurrence is probably closely related to environmental factors, especially depth of water and dominant currents but the role of the algal mats themselves is not clear.

Vertical changes within a bioherm or biostrome from flat or wavy continuously laminated stromatolites into columns, and then back to continuous laminae, are extremely common in many diverse forms of stromatolites. In addition, columns and continuous laminae may alternate. From a utilitarian viewpoint, names must be given on the basis of the columnar portions of bioherms and biostromes, not because these were necessarily formed by different algae from the continuously laminated forms, but because they are the most distinctive portions, which display evolutionary changes in the course of geological time. For example, similar flat or wavy continuously laminated stromatolites may form the basal portions of many different forms which can nevertheless be distinguished by their columnar portions. Microstructural features are most commonly uniform in such a vertical gradation of gross morphology, unless there has been differential diagenetic modification.

Various terms are used for non-columnar stromatolites. Any stromatolite which forms discrete round or elliptical mounds rising above the surrounding sediment surface, but lacking columns, is termed "cumulate". Frequently, a basal cumulus gives rise to branching columns. Laterally linked stromatolites in which successive crests are superimposed may be described as pseudocolumnar (e.g. *Stratifera flexurata* Komar) while columnar forms in which continuous, bridging laminae alternate consistently with very short columnar portions, are referred to as columnar-layered (e.g. *Omachtenia* Nuzhnov).

Any group of stromatolite columns which branch from a single basal column, or a discrete non-columnar stromatolite within which laminae are continuous, is conveniently referred to as an individual.

Column Arrangement and Shape

These features are frequently dependent on position in the bioherm. Columns which are vertical in the centre of a bioherm may be inclined or radially arranged at its margin; in addition they may be of more irregular shape.

The shape of columns (e.g. subcylindrical, tuberous, irregular) depends on the way in which successive laminae are stacked one on another, and on the modifying effects of currents. Insofar as the stacking of laminae depends on the nature and morphology of the laminae, which is at least in part biologically controlled (Eardley, 1938; Monty, 1967) so the gross shape will be affected by the nature of the algae present. This is not to deny the very important influence of current activity in producing elongated structures (e.g. Logan, 1961), unidirectional asymmetry of structures (e.g. Hoffman, 1967) and contemporaneous erosion (p.266, this thesis). Thus although column shape has been found to be an empirically useful character by the Russian workers, it is difficult to interpret. In particular, which column features are biologically determined and therefore taxonomically significant?

Branching

Branching is considered to be of great importance by Russian taxonomists, but there is general disagreement as regards terminology for branching. The terminology proposed by Glaessner et al. (1969) is retained here: branching is termed parallel if the axes of the daughter columns are parallel (usually they are also parallel to the axis of the parent column). Parallel branching is further subdivided into alpha-, beta- and gamma-parallel types, in which respectively there is no change, a gradual increase and an abrupt increase in overall width of the individual before branching (see Appendix I). An arbitrary division is made between slightly and markedly divergent branching, where the axis of the daughter columns diverge at 45°.

Branching may be dichotomous, trichotomous or multiple, depending on how many columns branch from one point.

The possible biological significance of branching lies in its relation to lamina shape. Walter (1970) has shown that in some cases of complex divergent branching, laminae are complexly wavy, while parallel branching forms usually have smooth laminae. There are, however, numerous exceptions, and these conclusions are not generally supported by a study of the South Australian forms (compare the wavy and wrinkled laminae of _Katavia costata_ with the smooth laminae of _Tungussia wilkatanna_). The complexity of branching in some forms may be partly controlled by environmental energy (see p.266). The view of Hofmann (1969b, p.17) that branching results from a local constraint of growth on the surface of a lamina can be refuted, since laminae almost always gradually become doubly-crested some distance below the branch. The lamina shape changes, then the laminae become discontinuous across the interspaces, and at that point the column is said to have branched.

Margin Structure

Margin structure is another consequence of lamina shape, frequently used in the Russian taxonomy. If laminae bend downwards at the column margins so that they coat its surface, this marginal zone is termed a "wall".

Hofmann (1969b) attributed the presence or absence of a wall to the relation between rates of sediment influx and growth of the column. Thus he argued that low sedimentation rates would result in walled and "tuberculate" (i.e. bumpy) columns, while high rates would result in "fimbriate" and "rugate" margins (i.e. with peaks and cornices). Moreover, he states (p.19) that "fringed or veiled stromatolite forms do not represent streamlined conditions; moving water would soon tear off the fringes". These conclusions are clearly not applicable in the case of the modern stromatolites at Shark Bay, where columns with a metre or so of growth relief stand in highly agitated water, and their "fringes" are not torn off. Moreover despite the high growth relief, the Shark Bay stromatolites are not usually walled. Similarly, my studies show that many unwalled forms had substantial growth relief, while in others sediment accumulation in the interspaces kept pace with column growth.

Laminae in unwalled columns may overhang the margin in various ways. Pointed overhangs are termed "peaks" (Hofmann's "fimbriate" columns) and peripheral overhangs are "cornices" ("rugate" columns). Translations of the Russian terms are used here.

Where laminae are continuous between two adjacent columns, the resulting structure is termed a "bridge". Bridges may be delicate, if only one or two laminae are involved, or massive, comprising many laminae.

Column margins may be described as smooth, bumpy or ribbed, bumps being low equidimensional protuberances while ribs are transversely elongated. Other surface features of diagnostic value are rounded or pointed projections (in which laminae are still convex upwards) and niches, which are deep indentations into column margins.

Some stromatolites (either walled or unwalled) bear an unlaminated "selvage" (Cloud & Semikhatov, 1969) of cryptocrystalline carbonate on their lateral surfaces. There are at least three possible interpretations of the selvage: (1) micritization by algal boring (Bathurst, 1966), (2) inorganic precipitation of lime on the column margin after growth, or (3) a thin algal film on the column margin, formed after column growth. In some South Australian walled stromatolites, a selvage may have its origin in differential recrystallization of the inner part of the wall zone, while preserving the very fine grained outer laminae intact.

Lamina Shape

Although this is in a sense the most fundamental gross feature of a stromatolite, since the lamina is its fundamental unit (Hofmann, 1969b), lamina shape is frequently as variable within one form as between different forms. It is therefore of limited diagnostic value, but may be used in conjunction with other characters, to distinguish taxa. The convexity of laminae is measured by the ratio of "h" (height of a single lamina) to "d" (its width). Gently convex laminae have h/d less than 0.5, while those over 0.5 are termed steeply convex. Since this parameter is so variable even in single specimens, the data is best treated statistically by plotting numerous measurements on a histogram.

In addition, the lamina shape is described by the terms hemispherical, parabolic, conical, sub-conical, rhombic or rectangular (see Fig.4). The finer-scale structure which may be smooth, wavy or wrinkled (wrinkles have a wavelength of less than 2 mm), is often of more diagnostic value than the convexity.

The extent to which a lamina maintains the shape of its predecessor is referred to as the degree of inheritance, and varies for different stromatolites. Thus stromatolites with frequent, sharp changes in lamina shape have a low degree of inheritance.

The laminae of Conophyton constitute a special case. They are predominantly conical, and are characterized by being thickened and often contorted in their crests. The three types of crestal zones of Conophyton recognized by Komar, Raaben & Semikhatov (1965) are illustrated in Fig.4. Walter (1970, p.23) has rejected the use of their parameter, the inscribed angle "alpha". But the statistical distributions of lamina thicknesses, ratios of thickness of adjacent light and dark and the coefficient of thickening of a lamina in the crestal zone, are significant parameters for conophytons, which as a group, are characterized by very distinct and consistent lamination. The definition of the width of the crestal zone given by Walter (p.24), i.e. "the width of the thickened or contorted part of each lamina measured perpendicular to the crestal zone" is accepted here.

Microstructure

Microstructure is a particularly difficult character to describe objectively. Various Russian authors have used terms such as "ribboned", "lumpy", "platy" or "striated", often somewhat loosely, to describe the nature and continuity of laminae. Hofmann (1969b, Fig.13) has also proposed some of these terms.

It is felt that single terms cannot replace detailed descriptions of microstructures in view of the almost infinite variations and combinations possible. The descriptive terms used here are, however, considered useful for diagnoses, and were decided on in conjunction with Dr M. R. Walter.

Hofmann proposed "ribboned" for a microstructure consisting of continuous light and dark laminae which do not intergrade and have more or less parallel boundaries. "Banded" is here considered to be a better, more descriptive translation of the Russian term.

Hofmann's term "striated" is a translation of a term used by the Russians to describe the microstructure of *Conophyton garganicum*, in which there are both continuous (banded) laminae, and laminae consisting of chains of lenses (striated).

An intermediate microstructure consisting of more or less continuous dark laminae, not of constant thickness, which grade vertically and sometimes laterally into light laminae, is termed "streaky". Any of the above terms may be modified as to whether the laminae are thick or thin, diffuse or distinct, regular or irregular etc.

In addition, detrital elements may be found in laminae, which may then be described as "oolitic", "pelletal", "sandy" or "silty". In this thesis, laminae which contain pellets (structureless microcrystalline carbonate particles of silt or sand size) are termed pelletal, irrespective of the mode of origin, but grumous textures, due to the partial secondary recrystallization of micrite, are excluded.

The microstructure of *Madiganites mawsoni* Walter and *Ilicta composita* Sidorov, both of Cambrian age, consists of narrow, sinuous sparry patches surrounded by dark, very fine grained carbonate, and is termed "vermiform". In South Australia, a vermiform microstructure is poorly developed in the

Cambrian stromatolite Acaciella angepena Preiss, and is here interpreted as possibly due to algal boring.

Many stromatolites contain distinctive broad laminae composed of sets of the normal fine laminae; these are termed macrolaminae. In some cases macrolaminae are accentuated by secondary recrystallization.

Methods of Study

Stromatolites must be studied both in the field and in the laboratory to determine all features necessary for taxonomy and environmental interpretation.

Field observations are frequently hampered in the wetter areas by extensive lichen cover and discontinuous outcrops, and in these cases, relationships had to be inferred from a laboratory study. However, in well exposed terrains, the mode of occurrence, column shape, arrangement and branching could be determined, so that an impression was gained of the total variability. In addition, the lithologies and sedimentary structures of the associated sediments were determined to aid environmental interpretations.

Because of the variable nature of stromatolites, sufficient material must be sampled to allow generalizations to be made about the modal forms present: the most frequently occurring variety of a particular feature, which then characterizes that stromatolite. Large specimens weighing from 10 to 150 lbs are necessary, depending on the size of the columns, and the relative position and orientation of these must be noted. Ideally, specimens should be collected from both the bioherm centre and its margin.

Almost all the diagnostic gross features of stromatolites can be determined only from a three-dimensional view of the structure. It is conceivable that in very rare cases columns could be completely silicified while the interspaces remain calcareous, allowing the structure to be freed by solution in acid. But no such occurrence is known to me, and the method of "graphical reconstruction", as described by Krylov (1963) and Walter (1970) must be used. Serial longitudinal sections, spaced at 2 to 6 mm, depending on the size of columns, were cut on an oil-cooled 24-inch diamond saw with a saw cut 2 mm wide. Each cut then provides two sections. The columns were outlined in pencil to make them visible, and traced on to a block diagram framework on tracing paper, each longitudinal section being parallel to the front face of the block (Walter, 1970, Fig.7). The reconstruction was retraced with shading to show the surface morphology, and finally redrafted by stippling.

Lamina shape, margin structure and microstructure were studied in large longitudinal thin sections, up to 20 cm long. Their thickness must vary with the nature of the rock, but in general, they must be thicker than petrological sections to preserve the distinctness of the structures. Carbonates were mostly identified by staining with Alizarin Red S, but were frequently checked by X-ray diffraction powder photographs. Thin sections were either photographed with Ilford Pan F film using a Zeiss Contarex camera on a cartographic light table, or where natural scale reproduction was required, a contact-printing process was highly successful.

Depositories

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

Chapter 6

THE PRINCIPLES OF STROMATOLITE TAXONOMY

In the previous two chapters the history of stromatolite taxonomy was reviewed and the useful characters of stromatolites were defined. The following is a summary of the principles I have adopted in classifying the South Australian forms.

In general the methods of classification adopted here are those used by that Russian school which studies both the gross and microscopic morphology of stromatolites. The characters outlined in the previous chapter were studied for all stromatolites but the relative significance attached to a particular feature may vary slightly from taxon to taxon, depending on its diagnostic value. Walter (1970) has illustrated this approach in his distinction between various taxa; thus while his *Acaciella australica*, *Boxonia pertaknurra* and *Inzeria intia* all have a similar microstructure, they are distinguished by various gross features. *B. pertaknurra* is distinguished from *A. australica* chiefly by the presence of a wall, but this same character cannot distinguish *I. intia*, which partly has a wall and partly lacks it. *I. intia* is characterized by its ribbed columns and niche-projections.

South Australian stromatolites have no representatives with both discrete walled and unwalled portions, so that this problem does not arise. Different forms may be walled (e.g. *Boxonia melrosa*), unwalled (e.g. *Inzeria multiplex*), or patchily walled (e.g. *Tungussia etina*), and in each case that distinction is diagnostic.

In this study, it was considered unnecessary to use categories higher than "group", as Raaben (1964) has done. There are several other ways in which groups could have been placed into higher taxa, but all are equally questionable. On the other hand, the "variety", a subdivision of "form" is useful in cases where finer distinctions can be made, and is therefore retained for *Conophyton garganicum*, which is subdivided into *C. g. garganicum*, *C. g. nordicum* (Komar, Raaben & Semikhatov, 1965) and *C. g. australe* (Walter, 1970).

It could be argued that a single name would be sufficient to characterize a particular stromatolite, but the value of a binomial nomenclature is that it indicates real similarities and differences between various forms. Thus groups consist of forms which all share a number of characters considered diagnostic for that group, but the content of a group should not be broadened beyond those limits unnecessarily. New forms are erected within a group whenever there are sufficient gross or microstructural differences; e.g. *Boxonia melrosa* lacks the pelletal microstructure of Russian *Boxonia*, and *Katavia costata* has transverse ribs as well as the bumps of *K. karatavica* Krylov. In both cases, the stromatolites are still very close to the other representatives of the groups, and this essential comparison would be lost without a binomial nomenclature.

In some cases, differences in details of gross structure between superficially similar forms are sufficient to classify them in different groups. Thus *Acaciella augusta* and *Inzeria conjuncta* have similar microstructures and occur in the same lithological context. Yet they may be distinguished on the basis of their gross morphology, as determined from three-dimensional reconstructions. Similarly, *Tungussia wilkatanna* is distinguished from *Baicalia burra* by its wall and its consistently markedly divergent, multiple branching.

These forms have not been observed to intergrade, and hence their separation into different taxa is justifiable.

However, there are stromatolites which show a considerable range of variation in gross morphology, and these variations may be observed to intergrade. The microstructures are as constant as can be expected with varying degrees of preservation. The best example of this is *Tungussia etina*, for which a complete series of intergradations can be observed, sometimes within a single bioherm. The typical morphology, developed at Mt Chambers Gorge, has markedly divergent branching, vertical to horizontal tuberous columns, and a patchy wall. But these grade laterally and vertically into bulbous or irregularly cumulate stromatolites similar to those found at Blinman or Enorama Creek. At Teatree O.S. *Tungussia etina* has parallel branching patches as well as the usual markedly divergent branching; although this is aberrant for *Tungussia*, no separation can be made between the two types, and both must be included in the one form, *T. etina*.

Similarly, *Linella munyallina* shows gradational variation in branching, lamina shape, and continuity of the wall, within single bioherms as well as in different areas. These variations are again included in the one form. The differentiation by Krylov (1967) of *Tungussia bassa* from the margins of *Linella ukka* bioherms cannot be accepted as a reasonable or natural classification; in the South Australian occurrence of *L. ukka*, marginal columns are also inclined or sub-horizontal, but do not warrant separation into a different taxon.

On this basis, Walter's (1970) assignment of smooth, parallel, rarely branching columns within a Linella avis bed, to a separate group and form, Minjaria pontifera, could be questioned. But Walter states (p.31), that it is not known if the two intergrade, and the differences are sufficient to classify them as different groups even if they do. Such a position would be difficult to maintain for the stromatolites studied in this thesis: e.g. Linella munyallina contains both tuberous, bumpy, divergent branching columns and smooth, subcylindrical parallel branching columns, sometimes even within single specimens (compare Figs.16k,l,m,n with 16p,q and 17f with 17g). These definitely intergrade and the range of variation of L. munyallina must be extended to include all variants observed. In the case of M. pontifera, however, it is possible that these do form a discrete unit, not related to the surrounding L. avis, and in that case the separation into another group and form would be quite justified.

In any study of different groups it will be seen that many characters overlap, and distinctions must be made on the most commonly occurring form, i.e. the modal form, of each character. This is especially true of branching: Boxonia is characterized by alpha-parallel and some beta-parallel branching, while gamma-parallel is rare. In Gymnosolen, gamma-parallel predominates, but not to the total exclusion of the other types. Similarly there is overlap between the branching styles of Baicalia (whose forms show a tremendous variation of branching, as shown by Krylov, 1967) and that of Tungussia. But while Baicalia has predominantly slightly to moderately divergent branching, in Tungussia, multiple, markedly divergent branching predominates.

Walter (1970, p.22) states that bridges are of little diagnostic significance, but distinguishes the group Kulparia on the basis of frequent bridges, combined with other features (e.g. frequent coalescing, a thin wall, and bumpy columns). On the other hand, he includes Omachtenia Nuzhnov in the group Kussiella Krylov. But Nuzhnov (1967, p.132) differentiates Omachtenia from Kussiella on features other than the presence of numerous bridges - its columns are sometimes curved or radially arranged, and may expand in width upwards, while some have small outgrowths. In South Australia, O. utschurica fits all these characteristics of the group Omachtenia, but could not under any circumstances be identified as Kussiella. The distinction between these two groups is therefore maintained in this thesis.

Although it is usually easy to recognize groups even from limited reconstructions and longitudinal sections, the identification of forms can be a difficult and sometimes subjective choice. Forms are frequently distinguished on minor features of column morphology (e.g. Linella ukka Krylov has broad bumps while L. simica Krylov has ribs), lamina shape (e.g. Omachtenia givunensis Nuzhnov has more steeply convex laminae than O. utschurica Nuzhnov) or microstructure. But microstructure is a difficult character to use, except in the case of Conophyton, all of whose forms have very distinctive and consistent microstructures which are amenable to statistical study (Komar, Raaben & Semikhatov, 1965). Similar studies have been attempted by Raaben (1969a) on Inzeria (measuring the size distribution of "cryptocrystalline components") and by Semikhatov, Komar & Serebryakov

(1970) on the sizes of clots and pellets in forms of *Boxonia*. At present, the real significance of the textures of Russian *Boxonia* are in doubt, and in any case they have not been found to occur in the South Australian form. The laminae of most South Australian columnar branching stromatolites are too diffuse and lenticular to allow a detailed statistical study as was carried out for *Conophyton garganicum garganicum* (p.122). However, it is possible that the well preserved representatives of the banded microstructure of *Baicalia burra* could be studied in this way.

The conclusion of Walter (1970) that the taxonomic significance of characters varies from taxon to taxon, must be accepted, and stromatolites can be classified only on the basis of combinations of characters. The classification has been found empirically to be useful in that the resulting taxa are temporally restricted. The question arises as to the fundamental meaning of these taxa, and why they are so restricted.

Several possibilities exist:

(1) Each form is built by a particular association of algal species.

(2) Each form is built by a dominant algal species, in association with other species that have little effect on stromatolite morphology.

(3) The environment, and not the algal composition, entirely controls the stromatolite morphology.

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

If (1) were true, we could expect the overall algal composition to change gradually as one species replaces another in the association. On the other hand, if one species controls the morphology, a rapid change would be expected. At present it is not possible to tell which of (1) and (2) is correct - possibly both apply.

Hofmann (1969b) regarded Conophyton as apart from other stromatolites, and that the only real distinction that can be made is between conically- and domed-layered stromatolites. But recent Russian work shows that conophytons and columnar branching stromatolites possibly intergrade: Shapovalova (1968) described Baicalia overlain by Jacutophyton (i.e. a group with a conophyton-like trunk and lateral branches) and then by Conophyton, but the nature of the contacts is not described. Shapovalova noted a corresponding increase in the size of intraclasts in the interspaces from the base to the top, and interpreted this to reflect a shallowing of the basin floor. Bertrand (1968) described Conophyton grading into a branched form that fits the definition of Jacutophyton, and noted that the limestone around the Jacutophyton columns contains more detritus than the Conophyton interspaces. Raaben (1969a) noted that narrow branching columns sometimes occur on the periphery of C. miloradovici. The taxonomic significance of these changing morphologies and their relationship to environmental factors has not been fully determined, but what is clear is that Conophyton is not fundamentally different from other stromatolites.

The comments made by Raaben (1969a) on taxonomy need to be mentioned here. She was especially concerned with the association of different morphologies in different parts of bioherms, and criticized Krylov (1967) for his naming different parts of bioherms separately. While a regular vertical sequence from basal laterally linked stromatolites to columns to more laterally linked forms is common in many occurrences, she pointed out that not all of these three zones are necessarily developed at once. While Krylov had recognized Tungussia from the marginal portions of Gymnosolen bioherms, Raaben was doubtful that these were really Tungussia, and noted occurrences of bioherms composed entirely of Tungussia. On the other hand, she regarded her divergent branching Tungussida to be more prone to lateral changes of column inclination than the parallel branching forms.

Raaben concludes, p.53, "If it could be shown that Conophyton can grade upwards into Baicalia or Inzeria, and these into laterally linked and columnar-layered forms, without change of algal composition, then it would be obvious that the morphological characters of stromatolites are only a function of a series of external factors, which would be difficult to account for. This would also completely destroy the prospect of studying the evolution of stromatolites in time, leaving to the investigator who aspires to use stromatolites in stratigraphy the possibility of describing and comparing stromatolites from various horizons, maintaining that despite the theoretical arguments, similar stromatolites are found in similar stratigraphic levels.

"Since, as we know, this does take place, the theoretical arguments are wrong, and the morphological characters of stromatolites are a reflection, however indirect, of the algal composition".

This is probably an oversimplification of a complex problem, and more research is now required from stromatolites of all ages, to determine precisely which characters are environmentally controlled.

Conclusions

Walter's conclusion (1970, p.34) that the taxonomic significance given to characters must vary from taxon to taxon in order to maintain a useful and workable classification is confirmed by the present study. Groups are distinguished on the basis of column shape and arrangement, branching, margin structure, and sometimes lamina shape (e.g. Conophyton) or microstructure (e.g. Baicalia). Forms are distinguished chiefly by differences of lamina shape and microstructure, as well as minor variations of gross morphology. The definition of all taxa depends on combinations of characters, not single characters in isolation.

Special problems arise in the taxonomy of stromatolites in which different morphologies occur together in a single bioherm. The view is taken here that different morphologies which visibly intergrade in a single bioherm must be considered as ecological variants of one form. Where the change between two forms is abrupt (either laterally or vertically), and especially where the lamina shape and microstructure change correspondingly, differentiation into separate taxa is necessary, but such situations have not been observed in South Australia. As Walter (p.30) points out, inclusion of marginal variants of Baicalia, Linella or Minjaria in those groups rather than naming them Tungussia could usefully reduce the stratigraphic range of forms of this group. The two forms of Tungussia described here are not lateral variants of other stromatolites.

Chapter 7

SYSTEMATIC DESCRIPTIONS OF SOUTH AUSTRALIAN STROMATOLITES

In this chapter, systematic descriptions are given of the 17 forms of stromatolites identified from the Adelaide Geosyncline, while some less well known occurrences are commented on.

For each group from which forms are described, a diagnosis, a list of the known constituent forms and the stratigraphic and geographic distributions are presented. Forms are diagnosed only if they are described here for the first time. Descriptions then follow, under the headings "mode of occurrence", "column shape and arrangement", "branching", "margin structure", "lamina shape" and "microstructure". In addition, the interspace sediment and the nature of secondary alteration provide important clues to the depositional environment and the diagenetic history.

In the sections "comparisons", the reasons for the identifications and differentiation from other similar forms are outlined.

The distribution of forms refers both to their geographic distributions and to the rock-stratigraphic units in which they occur.

From the point of view of regional sedimentation and of stromatolites, the duration of sedimentation in the Adelaidean sequence is very conveniently divided into two time units: the Early Adelaidean, including all sediments up to the pre-tillite unconformity, and the Late Adelaidean, from the base of the lower tillite to the base of the Cambrian. Therefore the age of stromatolite forms will be referred to as either Early or Late Adelaidean, but the probable correlations with the sub-divisions of the Riphean will be noted in each case.

GROUP *ACACIELLA* Walter

Type Form: *Acaciella australica*, Bitter Springs Formation, Central Australia (Walter, 1970, p.123).

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

Content: *Acaciella australica* Walter, *Acaciella augusta* Preiss, and *Acaciella angepena* Preiss.

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

Acaciella augusta f. nov.

Pls. 1, 2, 3a; Fig. 5a to 5j

Material: Thirteen specimens from two localities.

Holotype: S401 (Pl.2a,c; Fig.5c,e).

Name: After the city of Port Augusta, 20 miles south of the type occurrence.

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

Description:

Mode of Occurrence

The stromatolites form lenticular and tonguing bioherms (Pl.1a) varying in thickness from 3 m to 50 m, and extending laterally for up to nearly 2 km. All are intercalated at varying stratigraphic levels in the oolitic-intraclastic limestone facies of the Brighton Limestone equivalent, observed at Mundallio Creek and Depot Creek. Most commonly growth commences on a substrate of oolitic-intraclastic limestone, as laterally linked stromatolites, up to 3 m thick; these gradually develop interspaces to form broad, bridging and coalescing columns (Pl.1b,e). At various levels, these columns branch into narrower columns 1 to 3 cm wide, frequently with parallel basal and slightly divergent upper branches (Pl.1b,e). Occasionally, narrow columns arise directly from an undulatory or flat-laminated base (Pl.1c). Columns repeatedly alternate with continuous undulatory or flat-laminated stromatolites (Pl.1d), which commonly intertongue with the adjacent sediment; they apparently mark periods of reduced sediment influx.

At bioherm margins, columns become slightly inclined. Rarely, there are hemispherical bioherms with columns strongly inclined at their margins.

Column Shape and Arrangement

Basal columns are up to 20 cm wide, of irregular shape, with frequent coalescing and bridging. Their margins are frequently inclined, although laminae remain subhorizontal (Pl.1e).

Narrow columns are 1 to 3 cm wide, and up to 10 cm long between branches (Fig. 5a to 5j). Transverse sections are round, rounded polygonal, elongated, or complexly lobate. At least some of the elongation is of tectonic origin. Columns are straight or gently curved, with slight swellings and constrictions (Fig. 5e,g). A few columns are short and narrow, and terminate their growth after a few centimetres (Fig. 5a,b,e).

Coalescing is so frequent that almost all columns are interconnected; one specimen contains numerous irregular, frequently bridged and coalescing columns (Pl.3a).

Branching

Branching is frequent at all levels, and generally multiple (Fig. 5d,e,g). Broad basal columns divide by alpha-parallel branching into narrower columns, which frequently branch again at intervals of less than 10 cm (Fig.5h); this branching is usually alpha- or beta-parallel, occasionally gamma-parallel, or slightly divergent (Pl.2b,c). Near points of coalescing, branching tends to be more irregular; gamma-parallel or divergently branched columns approach each other and coalesce (Fig. 5d,g).

Margin Structure

The lateral surfaces of all columns bear relatively low bumps, short discontinuous ribs, and a few short peaks and cornices (Fig. 5c,e,f). In places, bridges, varying from delicate bridges only one or two laminae thick to massive, thick bridges (Pl.2a), are very frequent; in other places, columns remain relatively unaffected by bridging throughout most of their length.

Nowhere do columns have a wall; depending on the degree of convexity, laminae approach the margin at various angles; between bridges and cornices, the lateral surface is relatively smooth, unwalled (Pl. 2a,c).

Lamina Shape

Lamina shape varies according to column diameter; narrow columns have moderately convex, or sometimes steeply convex laminae, $^h/_d$ greater than 0.6 being rare. Broad columns have very gently convex to rectangular laminae (Fig.21a). Of all laminae measured, 70% have $^h/_d$ between 0.2 and 0.6 (Fig.22a).

Laminae are most frequently smooth, but sometimes broadly wavy, especially before branching (Pl.2c). Laminae frequently become doubly-crested before branching (Pl.2b), but the interspace so formed may be bridged over, in which case the column resumes its former growth pattern (Pl.2c).

Microstructure

In the best preserved specimens, distinct, regular light and dark (green) laminae, and in places macrolaminae up to 4 mm thick, alternate, forming a regular streaky microstructure (Pl.2a).

Dark laminae, varying in thickness from 0.05 mm to 2 mm, are smooth to gently wavy, occasionally wrinkled, and have parallel upper and lower boundaries. Single laminae have relatively constant thickness across the column width, but frequently lens out. They consist chiefly of hypidiotopic to idiotopic dolomite, of grain size ranging from 0.005 to 0.02 mm. The crystals are equidimensional, commonly euhedral, and stained pale green, which gives the laminae their colour. Dolomite crystals are densely packed in the dark laminae, leaving only occasional irregular undolomitized patches, consisting of xenotopic calcite, ranging in grain size from 0.003 to 0.01 mm.

Light laminae vary in thickness from 0.07 to 2 mm, single laminae having constant thickness. They are sparsely dolomitized, consisting of xenotopic to hypidiotopic calcite, varying from 0.01 to 0.02 mm in grain size, with scattered euhedral dolomite rhombs, 0.005 to 0.04 mm long.

Laminae are frequently grouped into broad macrolaminae, up to 4 mm thick, in which very thin, lenticular, either light or dark laminae predominate.

In places, laminae are slightly wrinkled, or draped over underlying irregularities; in one case a lamina is domed over a sparry calcite nodule, which may be an open space filling (Pl.2e).

Occasional euhedral to subhedral reddish brown limonite grains of 0.01 to 0.02 mm diameter (possible pseudomorphs after pyrite) occur in both lamina types.

In a few places small scour structures up to 2 mm deep are cut into the tops of dark laminae.

Interspaces

The distance between columns varies from 1 to 10 mm. Interspaces are filled with banded limestone; layers of micrite 1 to 6 mm thick alternate with thicker intervals of partially dolomitized intraclast limestone. Laminae in the interspace commonly abut against the column margins, having accumulated after the growth of that part of the column (Pl. 2a,c). The micrite laminae, consisting of xenotopic calcite of grain size varying from 0.003 to 0.01 mm, are frequently silty, and slightly graded, generally with sharp upper boundaries, and are overlain by matrix-supported intraclastic and partly oolitic limestone. This sediment was apparently more porous, and is extensively dolomitized; dolomite is of similar texture to that in columns. All remnant calcite is recrystallized to a hypidiotopic sparry mosaic; no micrite matrix remains. Alternatively, this calcite may represent infilling of voids left by dolomitization. Intraclasts, which may be preserved as undolomitized micrite, or entirely idiotopic dolomite, are from 1 to 10 mm long, and up to 1 mm thick, and may represent eroded fragments of algal mat. Strongly recrystallized dolomitized oolites are occasionally present. Intraclasts, which commonly lie at a high angle to the bedding, may have fine grained laminae draped over them. Coarse sediment influx was periodic; columns may have had up to 2 cm of relief over the interspace sediment or a bridge, then the interspaces were filled rapidly with intraclasts and finer calcareous sediment; during periods of relative quiescence, lime mud accumulated to form thin layers. In some specimens, bridging is very frequent, so that there never was more than about a centimetre of relief.

Secondary Alteration

Little is preserved of the primary difference between the light and the dark (green) laminae, which now differ in the extent of dolomitization. The dolomite is equigranular, idiotopic, and probably secondary, although an alternative explanation could be that it is detrital; Logan (1970, pers. comm.) has reported Recent idiotopic dolomite which is detrital. If the dolomite originated by replacement of calcite, the preferential dolomitization of dark laminae may indicate that they were originally more porous.

Small irregular patches of coarsely crystalline sparry calcite within both columns and interspaces post-date dolomitization, and are associated with fine calcite veins. Stylolites are very rare, being restricted to a few which are concordant with the lamination or column margins.

The green staining of dolomite crystals oxidizes under subaerial weathering to form finely disseminated limonite, which may be concentrated along column margins or stylolites.

Columns are commonly slightly flattened parallel to an axial plane cleavage, which is better developed south of Depot Creek and at Mundallio Creek. The cleavage is an irregular fracture which passes around, not through stromatolite columns and is commonly expressed as stylolites in the carbonate rocks.

A specimen from Mundallio Creek contains light laminae with prominent radiating structures; these consist of dolomite crystals aligned in rows almost perpendicular to the lamination (Pl.2d), and may represent a dolomitized, earlier acicular texture.

Comparisons:

The predominantly parallel branching (alpha-parallel at base, then beta- or rarely gamma-parallel) and almost total absence of a wall, identify the stromatolites as Acaciella. They are readily distinguished from Inzeria conjuncta, which occurs at the same stratigraphic level, by their repeated alternation of flat laminae, broad columns and narrow branching columns, lack of pronounced ribs, and the absence of niche-projections.

Acaciella augusta is distinguished from A. australica by the rarity of discrete broad basal columns, by its mode of occurrence (lenticular and tonguing bioherms instead of tabular and domed biostromes), by its extremely frequent coalescing and bridging, and by its very distinct microstructure. A. augusta has many wavy, sometimes lenticular laminae, and prominent macrolaminae. Dark laminae are preferentially dolomitized.

A. augusta is very similar to Eucapsiphora paradisa Cloud & Semikhatov, from the Paradise Creek Formation near Mt Isa, N.W. Queensland. E. paradisa is difficult to distinguish on the basis of the published description, but apparently has a patchy wall.

Distribution: Brighton Limestone, Depot Creek and Mundallio Creek, Southern Flinders Ranges (Figs.24 & 28).

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

Acaciella form unidentified

Pl. 3c,d; Fig. 5k to n

Material: Two specimens from one locality.

Description:

Mode of Occurrence

Both stromatolite specimens are erratic boulders in the lower (Sturtian) tillite; their provenance is unknown.

Column Shape and Arrangement

One specimen (S509), consists of pseudocolumns and frequently bridged columns, oriented subparallel to slightly radiating, and passing laterally into flat-laminated stromatolites (Fig.5n; pl.3c).

The other specimen (S539) consists of rather smooth, erect, parallel, cylindrical, discrete columns, 1 to 5 cm wide. Transverse sections are round or rounded polygonal (Fig. 5l,m).

Branching

Branching is commonly alpha- or beta-parallel; columns either retain their width or widen gradually before branching. Axes of branching columns may be very slightly divergent (Fig.5l). Specimen S539 shows only dichotomous branching, but S509 has some multiple, alpha-parallel.

Margin Structure

S539 has a rather smooth margin structure, with low bumps and a few very short peaks and overhanging laminae (Fig. 5k,l,m). There is no wall;

laminae simply terminate, without appreciable thinning, at the column margins (Pl.3d). Bridges are extremely frequent in S509, but otherwise column margins are similar to S539.

Few columns in S509 are entirely discrete.

Lamina Shape

All laminae are gently convex (Fig.21b), $^h/_d$ never exceeding 0.5. 84% of laminae measured have $^h/_d$ between 0.2 and 0.4 (Fig.22b). Laminae are smoothly curved, rarely rectangular, and without wrinkles or sharp flexures. Occasionally laminae are slightly wavy, and before branching always develop multiple crests (Pl.3c,d). Laminae are not normally deflexed at the column margins.

Microstructure

Microstructure consists of very smooth or broadly wavy light and dark dolomitic striated to banded laminae. There is little contrast between laminae.

Dark laminae are 0.05 to 0.5 mm thick, and commonly pinch and swell slightly across the column; in places they are lenticular. Otherwise, the laminae have smooth, parallel boundaries. They consist of pale grey stained hypidiotopic to idiotopic dolomite of grain size varying from 0.003 to 0.015 mm.

Light laminae vary in thickness from 0.05 to 1.0 mm, generally with little change across a column, thinning only slightly towards column margins. They consist of hypidiotopic to idiotopic transparent, unstained dolomite of grain size varying from 0.015 to 0.06 mm.

Very characteristic of S539 is the presence of very fine, limonite-rich solution surfaces, concordant with the laminae. Some at least are stylolites; especially common are surfaces with little or no wrinkling, which follow the fine-scale structure of laminae exactly (Pl.3d). In places these are only about 0.5 mm apart, and light laminae may be separated by them, without intervening dark laminae.

Interspaces

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

Secondary Alteration

Dolomitization of the stromatolites and interspaces is clearly secondary, as indicated by the general idiotopic, equigranular texture, and poor preservation of the finest structures.

Stylolites are of at least two generations. The earliest stylolites are almost perfectly concordant, without lobes or wrinkles; these possibly predate the dolomite euhedra, which in places cut into them, and certainly predate a relatively coarse grained dolomite vein (grain size up to 0.1 mm). The vein is itself cut by more pronounced, slightly discordant stylolites. Occasional cross-cutting stylolites cut interspaces and columns, some following column margins.

Dolomitization almost certainly predates the erosion and deposition of the clasts into the tillite.

Comparisons:

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

Distribution: As clasts in the lower (Sturtian) tillite, on the flanks of Enorama Diapir, 4 miles North of Oraparinna H.S., Central Flinders Ranges (Fig.27).
Age: Probably Adelaidean, but not younger than the Sturtian tillite.

Acaciella angepena f. nov.

Pls. 3b, 3e to 3g, 4, 5a to 5c; Fig. 6

Material: Forty-seven specimens from nine localities.

Holotype: S460 (Pl.4e; Fig.6a).

Name: After the Angepena H.S., 2 miles south of which the stromatolites have been studied.

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

Description:

Mode of Occurrence

Outcrops of Cambrian stromatolites have been studied only in the Angepena area. Here lenticular stromatolite beds consist of closely spaced ellipsoidal and domed bioherms 3 to 50 m wide. Bioherms commonly overlie flaggy, laminated, dark grey limestone with irregular erosional contact. Stromatolitic laminae commence growth upon the erosional highs, forming cumulate or pseudocolumnar individuals, which pass up into radially arranged or parallel short columns with very numerous bridging layers. At bioherm margins, columns and pseudocolumns become horizontal, and laminae are deflexed parallel to the overhanging sides of the bioherm, so that here growth actually proceeded downwards. (Pl. 4d,f & g, showing longitudinal sections of a bioherm margin). Where adjacent bioherms become contiguous, they are overlain by a domed biostromal layer of columnar, pseudocolumnar and columnar-layered stromatolites, similar to those of the bioherm. At the edge of a stromatolite bed, the terminal bioherm has an abrupt vertical margin (Pl.4b & e); columns and pseudocolumns remain sub-vertical and the laminae bend downwards only slightly. The surrounding sediment of dark lime mud accumulated synchronously with stromatolite growth, and occasional algal laminae are intercalated in it; the bioherm probably never had more than 10 cm of relief over the surrounding sediment surface. Also, there is evidence of contemporaneous compaction of the lime mud the bioherm rests upon (Pl.4e); the lower layers of the surrounding muds are depressed, while the upper ones simply abut against and cover the bioherm.

Column Shape and Arrangement

Column shape is highly variable in single bioherms, mainly due to different degrees of coalescing and bridging. The structures vary from laterally linked pseudocolumns with some discrete small cumuli (Pls.3f;4a), to frequently bridged and coalescing columns (Pl.3e), to discrete, parallel subcylindrical columns (Pls.3g; 5a,c). The latter chiefly make up Mawson's collection from Italowie Gorge. In all specimens where columns are reasonably discrete, they are smooth to slightly bumpy, and sometimes with pointed terminations (Fig. 6b,h,j). Columns are commonly less than 1 cm in diameter, but broad, cumulate columns up to 10 cm in diameter have been observed (Pl.4a). Transverse sections of columns are round, rounded polygonal or lobate (Fig. 6a,d,f).

Columns may be vertical or radially arranged, especially on the margins of contiguous bioherms.

Some specimens contain minute columns, 1 to 3 mm wide, arising from the subcylindrical 1 cm columns; in many cases the dolomitization of interspaces obscures the original margins and so their shape cannot be accurately determined.

Branching

Branching is most commonly alpha- or beta-parallel, occasionally gamma-parallel. Columns frequently branch into narrower columns which do not regain the former diameter. Some branches are in the form of thin pointed projections (Fig.6j).

At bioherm margins, branching may remain parallel (Pl.4e) or become radial (Pl.4f,g), but here the stromatolites are chiefly pseudocolumnar. In a specimen from Old Wirrealpa, narrow columns branch upwards from broad cumuli, up to 5 cm in diameter.

Margin Structure

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

Bridging is extremely common in all specimens except those from Mawson's collection from Italowie Gorge, in which the columns are mostly discrete. These also have the smoothest margins, with only slight, occasional bumps and ribs.

Columns are always unwalled; laminae thin slightly and terminate at the column margin without coating the surface. Laminae may slightly overhang the margin, but long peaks and cornices are absent.

Lamina Shape

Fig.21c illustrates common lamina shapes; most are gently convex. Of 101 laminae measured, 69% have ratios of $^{h}/_{d}$ between 0.2 and 0.4; only 7% have ratios greater than 0.6 (Fig.22c).

Laminae are smoothly domed, without sharp changes in shape from lamina to lamina. A few of Mawson's specimens from Italowie have wavy laminae, of wavelength 3 to 10 mm, amplitude 1 to 3 mm (Pl.5a).

Microstructure

Microstructure in all specimens is regularly, thinly banded, with continuous laminae of uniform thickness across a column width. In most specimens there is little contrast between dark and light laminae, except in the amount of organic pigment. In the specimen from Old Wirrealpa, dark laminae are outlined by extremely finely disseminated haematite (Pl.3b). Some specimens, especially from Angepena, have irregularly sinuous, vermiform sparry patches crossing laminae, generally at a high angle (Pl.5b).

Dark laminae consist of xenotopic calcite of grain size varying from 0.003 to 0.01 mm, stained with grey organic pigment, but in some specimens, subhedral dolomite rhombs of grain size of 0.01 to 0.02 mm are interspersed. Minor subangular quartz silt may be present. Dark laminae vary in thickness from 0.03 to 0.07 but the ferruginous Old Wirrealpa specimen has some even finer laminae (0.01 mm thick) preserved. Individual laminae are very continuous, and of constant thickness across the column width, but may be markedly wavy.

In specimens with vermiform microstructure, dark laminae are generally thicker, up to 0.3 mm, but remnants of finer lamination are often preserved. The structure consists of 0.05 to 0.1 mm thick, up to 0.6 mm long, subparallel, sinuous, anastomosing tubular voids in micritic dark laminae, filled with sparry, hypidiotopic to xenotopic inequigranular mosaic calcite (Pl.5b). Their boundaries are often irregular and their orientation varies from perpendicular to gently inclined to the lamination, but is commonly at a high angle to it. The vermiform microstructure may be consistently developed preferentially on one side of columns (Pl.5b). Transverse sections of the tubules are round to elongated, irregularly oriented and anastomosing. The tubules may be interpreted as algal borings in the fine, lime mud laminae, but not the whole sediment was affected, since homogeneous and bored laminae occur side by side. This fact also makes it unlikely that they are casts of actual algal filaments. The distribution of borings on one side of columns may be environmentally determined. Bathurst (1966, p.20) illustrated a sequence of events involved in boring by algae; if the process were stopped at stage (2), and the borings infilled with sparry calcite, a structure similar to the vermiform microstructure of _A_. _angepena_ would result.

In the ferruginous specimen, dark, haematitic laminae commonly give rise to small dendritic distributions of haematite within the overlying light lamina. These dendrites are always oriented exactly perpendicular to the lamination, which distinguishes them from the tubules of the vermiform structures; they are interpreted to be of secondary inorganic origin, due to the redistribution of haematite during diagenesis.

Light laminae are 0.03 to 0.1 mm thick, frequently indistinct, but continuous across a column width. They are especially poorly differentiated in specimens with vermiform microstructure, where the tubules may pass across the light-dark lamina boundaries (Pl.5b). Light laminae consist of xenotopic calcite, often with interlocking crystals 0.015 to

0.03 mm in diameter. Subhedral to euhedral 0.01 mm dolomite rhombs are scattered throughout the light laminae in some specimens.

Interspaces

Interspaces are filled either with altered micrite or fine sandy and silty micrite. Specimens from Italowie (Mawson's collection) have very narrow interspaces filled with sparse, angular quartz silt, supported by a micrite matrix (Pls.3g; 5a & c), sometimes extensively dolomitized, with inequigranular hypidiotopic dolomite ranging in grain size from 0.005 to 0.1 mm. Extremely finely disseminated haematite may be present in interspaces.

Angepena stromatolites also have sandy interspaces, but these are more frequently interrupted by bridging laminae. Subangular to subrounded quartz grains vary in diameter from 0.08 to 0.5 mm, and may be partially or wholly replaced by calcite. Ooids and small intraclasts occur very rarely.

Only in the Old Wirrealpa specimen are interspaces filled with biomicrite, largely recrystallized. There are small curved shells, generally 0.05 to 0.1 mm thick and up to 2 cm long, both calcareous and phosphatic; hyolithids, sponge spicules, and archaeocyathan and brachiopod fragments may be recognized. The surrounding micrite matrix varies in grain size from 0.003 to 0.01 mm, but may be recrystallized to microspar.

Secondary Alteration

Dolomitization is common in all specimens, and is probably of late diagenetic origin. Within columns, rhombs 0.05 to 0.1 mm in size, post-dating the vermiform microstructures, are closely associated with minute stylolites. Dolomite rhombs have also formed in the micrite of interspaces, and in places, interspaces may be totally dolomitized. Here sparry calcite occurs as irregular patches between dolomite rhombs, perhaps filling a secondary porosity. Grain size and density of dolomite rhombs decreases markedly across the column margins; perhaps interspaces were originally more porous, to cause the preferential dolomitization (in Pl.4e, note the dark calcitic columns and the white, dolomitic interspaces).

Large patches of coarsely sparry calcite are bounded by markedly lobate fine stylolites, suggesting their origin as solution cavities.

Stylolites may follow column margins, or may be grossly cross-cutting.

Minute irregular calcite veins cut the whole rock, apparently predating the major dolomitization.

Haematite dispersed through carbonate is probably secondary. In Italowie specimens, it is concentrated in interspaces which pass into fine stylolites. The dendritic patterns of haematite in the Old Wirrealpa specimen superficially resemble the alga Epiphyton Bornemann, but lack its regular, branching tubular structure, and grade into homogeneous haematite laminae; they are considered to be inorganic dendrites.

Comparisons:

In gross form (mode of occurrence, column shape, branching and margin structure) the stromatolites from Italowie are similar to Acaciella Walter; in particular, some specimens very closely resemble Acaciella f. indet. from the boulders in the Sturtian Tillite (p.88). Columns are less discrete in other areas, due to frequent bridging and coalescing, but their columnar portions are similar to those of Italowie specimens. Microstructures are uniform, except for the local vermiform structure interpreted as algal boring.

Madiganites mawsoni Walter, from the Middle Cambrian Jay Creek Limestone of the Amadeus Basin, also has vermiform microstructure, but here the tubules are more consistently developed, and are complexly intertwined, the intervening micritic areas being reduced to clots. The gross form of *Madiganites mawsoni* is similar to some *Acaciella angepena* in having numerous irregular frequently bridged columns and pseudocolumns; however, it lacks the subcylindrical parallel branching discrete columns found at Italowie.

Acaciella angepena resembles *Vetella uschbasica* Krylov in having evenly banded lamination and wide columns branching into narrow columns, but has ragged column margins and lacks the wall of *V. uschbasica*. The Old Wirrealpa specimen is otherwise strikingly similar. *Ilicta composita* Sidorov is similar in also possessing vermiform microstructure, but is distinguished by its very smooth, walled columns.

At this stage it is difficult to be certain of the content of the form *Acaciella angepena*. Despite some variation of column shape (specimens from Italowie have predominantly subcylindrical, discrete columns, while those from Angepena have numerous bridges and less regular column margins), all the specimens studied are included in the one form, since these column morphologies intergrade and the microstructures remain constant.

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

Distribution: Widespread in the dark limestones of the Lower Cambrian at Angepena, Old Wirrealpa, near Point Well, at Mern Merna, Beltana Hill, Chace Range, near Narina H.S., Moro Springs south of Balcanoona, and 3 miles west of Italowie Gorge; Flinders Ranges, South Australia (Figs.25,27,29c).

Age: Lower Cambrian.

GROUP BAICALIA Krylov

Collenia baicalica Maslov (1937, p.287)
Baicalia Krylov (1963, p.64)
Baicalia (Semikhatov, 1962, p.198)
Baicalia (Komar, 1966, p.82)
Baicalia (Krylov, 1967, p.25)
Baicalia (Nuzhnov, 1967, p.135)
Baicalia (Cloud & Semikhatov, 1969, p.1035)
Baicalia (Walter, 1970, p.141)

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

Diagnosis: Tuberous, bumpy, swelling and constricting, parallel to markedly divergent branching columns, generally without wall, with frequent overhanging laminae. Lamination is distinctly banded.

Content: *B. baicalica* (Maslov) Krylov, *B. kirgisica* Krylov, *B. rara* Semikhatov, *B. unca* Semikhatov, *B. prima* Sekikhatov, *B. ampla* Semikhatov, *B. ingilensis* Nuzhnov, *B. aimica* Nuzhnov, *B. maica* Nuzhnov, *B. minuta* Komar, *B. capricornia* Walter, and *B. burra* Preiss (new form).

Age: Middle Riphean to early Late Riphean.

Baicalia burra f. nov.

Pls. 5d,e,f; 6; 7; 8 & 9a,b,c; Figs. 7,8,9

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

Material: Thirty-three specimens from ten localities.

Holotype: S222 (Pls. 5d,8e; Fig. 7a,c).

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

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

Description:

Mode of Occurrence

Two modes of occurrence have been noted: biostromal and biohermal, the latter occurring only at one locality (Yatina). Biostromes vary in thickness from 0.3 to 2 m, the stromatolites being evenly distributed throughout their extent; they have been followed for 100 m or more, without lensing, before outcrop disappears under soil cover. Biostromes are frequently interbedded in green shales (e.g. Myrtle Springs, Willouran Ranges), platy dolomites (e.g. Arkaroola, Worumba) or massive dolomites (e.g. Burra, Pl.6b). The bioherms at Yatina are restricted to two thin beds; they are small lenticular stromatolitic mounds, approximately 20 to 30 cm thick, up to 1 m wide (Pl.5d), interbedded with and surrounded laterally by platy and shaly dark grey dolomites. The overlying sediment is draped over the mounds, showing that the stromatolites had at least 10 cm relief over the surrounding surface.

Columns arise from substrates in several ways: (1) Flat-laminated stromatolite passes gradually up into undulatory and pseudocolumnar stromatolites, then into discrete, vertical to inclined columns, often with steeply domed laminae, e.g. Burra, West Mount Hut (Pl.6d,e); (2) Columns arise directly from eroded surfaces of laminated or intraclastic dolomites (e.g. Yatina, Fig.7a); (3) Columns arise from flat-laminated stromatolite *via* broad cumuli, e.g. West Mount Hut (Pl.5f).

The degree of discreteness of columns varies greatly; in some beds, columns are almost immediately bridged over by laterally linked stromatolites (Pl.5e), but usually columns remain discrete for 20 to 30 cm. In some areas new sets of columns may arise from pseudocolumns. The upper surfaces of biostromes vary from flat (e.g. in the Willouran Ranges, Burra; Pl.6b) to broadly undulating (e.g. Worumba).

Column Shape and Arrangement

Columns are tuberous, varying from subcylindrical to irregular, with round, oval and irregular cross sections (Pl.6a). Elongated or flattened columns are variously oriented. The diameter of columns varies from 1 cm to 10 cm, most commonly 3 to 5 cm, with rapid swellings and constrictions. Columns are 2 to 15 cm high between branches (Pls.6c,f,g; 7a-f; 8a-g; 9b,c and Figs.7,8,9). Some but not all columns are constricted at the point of branching (Pl.7c,e; Figs.7e,f; 8c,d). The orientation of columns varies greatly from vertical to inclined, and is sometimes sub-horizontal for short distances (Pl.7c; Figs.8j,9e). Column axes vary from straight to strongly curved. In some specimens, the uppermost columns swell markedly upwards and become bridged over by laterally linked stromatolites. Adjoining columns coalesce very frequently, even in the discrete portions, but specimens from Burra show the least coalescing and bridging. In the Willouran Ranges, column growth is frequently interrupted by penecontemporaneous erosion; columns may grow over broken-off fragments of earlier columns (Pl.9b), contributing to the irregularity of the structure.

Branching

The most common form of branching is moderately divergent (Pl.7d) though some subparallel branching (Fig.8i) and some very markedly divergent branching occurs (Figs.8j,9e). In some specimens several branches arise from nearly one point (Fig.7i,m). Branching is moderately frequent, the length of column between branches commonly being only a few centimetres; but at any one point of branching it is usually dichotomous or less often trichotomous. In some specimens branches arise at a high angle to the main columns, and then turn sharply upwards. Some columns arise from the side of a main column (Pl.7e). Great variation is seen even in single outcrops.

Margin Structure

The lateral surface varies from smooth to very irregular; some specimens have very patchy walls, while the intervening unwalled areas are smooth or only slightly fringed with small peaks and cornices, for example those from Burra (Pl.7d), Yatina (Pl.8e,f), River Broughton (Fig.7m), Arkaroola (Pl.8g). Willouran Ranges specimens contain both smooth and highly irregular edges, with large overhanging peaks and sets of laminae (Fig.8n). Laminae approach the margin at various angles. Frequently large swellings are composed of numerous laminae overhanging over a constricted portion of a column (Fig.9d). Bridges between columns are especially common near the tops and bottoms of biostromes (Figs.7d,9e).

Lamina Shape

The lamina shape is most commonly gently convex, but varies in single specimens from very gently convex to nearly conical; many laminae are steeply convex. Micro-unconformities are especially prominent in specimens from the Willouran Ranges, but occur to some extent in all areas. In places, branching commences upon a partly eroded column surface (Pl.9b). Fig.21d illustrates the more commonly occurring lamina shapes; 92% of lamina have $^h/_d$ between 0.1 and 0.6, the mode being $^h/_d$ between 0.3 and 0.4 (28%) (Fig.22d). Generally, the widest columns have the most gently convex laminae, while strongly elongated columns have laminae gently convex in the section parallel to the long axis, and steeply convex at right angles to it. Rarely do laminae turn over sharply and thin at the column margins, to form a wall. Generally, where a patchy wall is present, it is formed by the edges of steeply convex or parabolic laminae (Pl.8b,h). Frequently, laminae develop two crests, anticipating branching immediately above (Fig.7a,m).

On a smaller scale, lamina shape varies from smooth and regularly curved to slightly wavy, with discontinuous curvature and sharp crests. Both types occur in single specimens (Pl.8a,d).

Microstructure

The microstructures and textures observed in the different areas vary considerably depending on the degree of recrystallization. In the best preserved specimens, the layering is seen to comprise alternating relatively thick, continuous light and dark laminae, giving a banded appearance. Some are single homogeneous thick layers, while others are macrolaminae consisting of several very thin light-dark lamination pairs (Pl.8h). Laminae are very distinct and continuous; most commonly single laminae traverse the while column width, except where cut by micro-unconformities. Ooids or other detrital grains are sometimes included in the laminae. Upper and lower boundaries of laminae are usually smooth and even, sometimes wavy or broadly wrinkled, but always more or less parallel. Exceptions occur only where erosional scour has taken place during growth. Rarely, lenticular swellings occur.

Light laminae vary in thickness from 0.02 to 0.5 mm, very rarely to 1.0 mm. Most light laminae thin towards the column edges, but rarely lens out.

In the best preserved specimens the sparry dolomite forming light layers is inequigranular, xenotopic, and of grain size ranging from 0.005 to 0.06 mm. With greater recrystallization an equigranular mosaic of 0.05 to 0.2 mm grain size results (e.g. Burra). The light laminae usually have sharp and smooth upper boundaries, but sometimes grade down into grumous textured laminae, consisting of irregular and interconnected micritic patches up to 0.1 mm diameter set in xenotopic equidimensional sparry dolomite with a grain size of about 0.01 to 0.03 mm, i.e. partially recrystallized dark laminae. In some specimens, e.g. Yatina, West Mount Hut, Worumba, the light laminae contain detrital granules, including small flat intraclasts, up to 0.5 mm long, and rare ooids up to 0.3 mm in diameter. Overlying laminae are draped over the larger detrital grains. Laminae in the Copley specimen may be pelletal (Pl.8d).

Dark laminae occur either singly, alternating with light laminae, or in dark macrolaminae. Thin dark laminae are commonly 0.04 to 0.3 mm thick, but macrolaminae range up to 2.5 mm in thickness, generally constant across the column, or thinning slightly towards the margins. They are either continuous, or consist of a series of aligned lenses, each up to 0.2 mm long. In well preserved specimens the dark laminae have smooth, sharp, parallel boundaries; rarely, single laminae may be wrinkled, suggesting intraformational crumpling during growth. Dark laminae are variously altered to grumous textured dolomite, lateral and vertical gradations from unaltered to grumous textures being common.

Well preserved dark laminae consist of dense, brownish-pigmented xenotopic dolomite, of equidimensional grains 0.003 to 0.01 mm in diameter. Where dark laminae are grouped into macrolaminae, they alternate with very thin, discontinuous light laminae, and frequently fuse to form solid, thick dark laminae.

Interspaces

A few specimens have interspaces filled predominantly with bedded dolomite mud (e.g. Burra), but generally the sediment is unbedded intrasparite or oosparite, less commonly intramicrite. Frequently, intraclasts are derived from the erosion of stromatolitic columns; in places, a large fragment torn from a column has acted as a base for new growth.

Intraclasts are flat to gently curved tabular dolomite pebbles up to 3 cm long, 1 to 2 mm thick, and only slightly rounded. Many are fragile and could have survived very little transport. They contain the typical internal laminations of the associated stromatolites, and are probably derived directly from them. Occasional flat pebbles stand vertically, but generally they lie flat or imbricated.

Ooids vary in shape from round to oval, have a diameter of 0.2 to 1.0 mm, and consist of one dark-rimmed sparry layer coating a micritic core, or less commonly, several sparry layers.

Most commonly, allochems are closely packed and cemented by a clear, sparry dolomite cement. Some specimens contain significant amounts of dolomitic mud, variously recrystallized, forming a matrix between allochems; in these cases the sediment is poorly laminated.

Secondary Alteration

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

(1) Penecontemporaneous

The fact that dolomite consistently constitutes the whole rock to the exclusion of calcite, while still preserving fine structures, suggests very early dolomitization, during the growth of the stromatolites. It is also possible that penecontemporaneously dolomitized lime muds were reworked and trapped in the algal mats. During growth, erosion by strong currents scoured the living surfaces of columns, creating microconformities. In some specimens, e.g. West Mount Hut, laminae are sometimes separated by lenticular vughs, later filled with sparry dolomite (Pl.8a,b & h). These voids were probably formed by arching up of laminae, perhaps due to lateral expansion in growth of the algal mats building the stromatolites.

(2) Early Diagenetic

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

(3) Late Diagenetic

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

(4) Tectonic

The only specimens affected by tectonic deformation are from the Burra region. Here columns are slightly flattened (Fig.7g), and laminae are crenulated along a slight tectonic foliation. These are also the most highly metamorphosed, and display the greatest degree of recrystallization. Tensional joints filled with coarsely crystalline dolomite are common in most areas.

Comparisons:

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

Distribution:

Widespread in the Skillogalee Dolomite, Burra Group; Dutton's Trough H.S., 10 miles south of Burra; Scrubby Range, 17 miles south of Burra; 2 miles west of Yatina; River Broughton, 5 miles west of Spalding; 7 miles south-west of Worumba; 7 miles south of Arkaroola; 2 miles west of Copley; 2 miles east of Myrtle Springs H.S. near Leigh Creek; West Mount Hut, 17 miles west of Witchelina H.S. and Chintapanna Well, about 10 miles west of Witchelina H.S. Possible *B. burra* occurs also in the Skillogalee Dolomite, Depot Creek (Pl.6c) but these have not been studied in detail. Specimens from the River Wakefield Group, Carrieton (Pl.9a) are inadequate for identification, but are possibly to be included. Locations are shown in Figs. 25, 26, 27, 28, 29d & h.

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

GROUP *BOXONIA* Korolyuk

Boxonia Korolyuk, 1960 (p.139)

Boxonia (Komar, 1966, p.79)

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

Boxonia (Walter, 1970, p.156)

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

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

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

Content: *B. gracilis* Korolyuk, *B. lissa* Komar, *B. krasivica* Golovanov, *B. allahjunica* Komar & Semikhatov, *B. ingilica* Komar & Semikhatov, *B. bianca* Raaben and *B. pertaknurra* Walter. Raaben (1969a) places *B. grumulosa* Komar into partial synonymy with *B. gracilis* Korolyuk. *B. divertata* Sidorov has only a patchy wall and may therefore be excluded. The South Australian form is *Boxonia melrosa*.

Age: Late Riphean and Vendian.

Boxonia melrosa f. nov.

Pls. 9,10; Fig. 10a to h

Material: Four specimens from one locality.

Holotype: S503 (Pl.10c; Fig.10b,c,d).

Name: After the township of Melrose near which the stromatolites occur.

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

Description:

Mode of Occurrence

The stromatolites are relatively poorly exposed in a faulted area, so that relationships are not clear. At least two bioherms occur, preserved as grey or pale buff dolomite. The beds are overturned, dipping south at about 40°. The narrow, parallel columns arise directly from laterally linked stromatolites, partly pseudocolumnar, the base of which is not exposed. The overlying columnar portion is approximately 6 metres thick and consists of vertical columns near the centre of the bioherm, and inclined columns at the margins, where they pass laterally into pseudocolumnar stromatolites. Columns are overlain by wavy laminated stromatolitic dolomite, which covers the whole bioherm. Bioherms are of cumulate shape, broadly domed, up to 60 metres long, and are surrounded by flat-bedded dolomite.

Column Shape and Arrangement

Columns are straight, erect, subcylindrical, with circular or slightly lobate, rounded polygonal cross-sections, of diameter 1 to 5 cm (Pl.9d). The diameter of a single column generally remains constant throughout its length. Columns may reach a length of up to 20 cm between branches. Some columns are only a few centimetres high, occasionally in the form of rounded projections.

The columns are smooth to gently bumpy, lacking large constrictions or irregularities. Bumps are up to several centimetres wide, with a relief of 1 to 5 mm (Pl.10a,b,c; Fig.10a to h).

Branching

Branching varies from alpha- to beta-parallel; gamma-parallel branching is rare (Fig.10h). Commonly a 3 to 5 cm column divides into two or three narrower, parallel, very closely spaced columns, 1 to 2 cm in diameter (Fig.10f). Occasionally, two narrow columns may coalesce (Fig.10c). Not all branches develop into long columns; some terminate their growth only a few centimetres above branching (Fig.10d,h).

Margin Structure

The lateral surface is even, smooth or with low, broad bumps. Peaks and cornices are entirely absent, but very rarely bridges up to 1 cm thick occur between adjacent columns.

A multilaminate wall is almost ubiquitous. At the margins of columns laminae are poorly preserved, but in places up to 10 laminae may be seen to comprise the wall. Single laminae generally extend for a distance of 1 to 2 cm down the column margin (Pls.9f,10a).

Lamina Shape

Laminae are most commonly moderately convex, hemispherical, in places approaching rectangular (Fig.21e). Frequently they are slightly asymmetrical, especially in inclined columns. Before branching, laminae usually develop two crests. The degree of convexity, $^{h}/_{d}$, is moderately constant, even in columns of differing widths. 91% of laminae measured have $^{h}/_{d}$ between 0.3 and 0.7; the mode (39%) being between 0.5 and 0.6 (Fig.22e). The shape of crests varies from tightly arcuate to gently rounded (Fig.21e).

At column margins, laminae thin and turn downwards, subparallel to the margin, forming the wall. Most laminae are broadly wavy (wavelength up to 8 mm, amplitude 1 to 2 mm) but not wrinkled.

Microstructure

Microstructure is poorly preserved in both pale and dark specimens; laminae are broadly continuous, but may be broken into a series of clots and lenses by recrystallization, and even where their continuity is preserved, they are extensively embayed by recrystallized carbonate. Microstructure is indistinctly banded with alternating darker and lighter laminae.

Light laminae very in thickness from 0.08 to 0.4 mm, but usually thin towards column margins. Continuity is usually retained across a column, although the finest laminae frequently lose their identity by recrystallization. The upper and lower boundaries are smooth and parallel. The laminae consist of transparent, slightly inequigranular (of grain size 0.01 to 0.04 mm) equidimensional dolomite of polygonal, hypidiotopic texture. Within this occur irregular 0.05 to 0.1 mm segregations of darker, greyish pigment, with no relation to grain boundaries. These are apparently remnants of pigment left by partial recrystallization, as they may grade into more or less continuous laminae. Distinct round to oval pellets (as in Russian Boxonia) are absent.

Dark laminae are less continuous, and often diffuse. Their thickness varies from 0.08 to 0.3 mm; towards the margins they frequently thin or lens out completely, and do not take part in the formation of the wall. (The layering in the wall is extremely indistinct). In places, they lens out also within the central part of a column. Dark laminae are composed of equidimensional xenotopic, equigranular dolomite (of grain size ranging from 0.003 to 0.01 mm), and in places, are disrupted into a series of irregular clots and lenses separated by sparry dolomite.

Interspaces

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

Secondary Alteration

Stromatolite columns and interspaces consist of dolomite, considered to result from the replacement of original calcium carbonate. Most fine structure has been lost; dark laminae are outlined mainly by segregations of dark pigmented dolomite, but recrystallization has partly embayed and partly obliterated the fine dark laminae. The irregular distribution of pigment is due to recrystallization. In places, coarser, sparry laminae of grain size up to 0.08 mm occur, and may contain dismembered remnants of dark laminae.

Stylolites are moderately frequent, and usually discordant to the lamination. In places they follow column margins for short distances, removing the wall. Occasional thin dolomite veins follow the path of stylolites. Some stylolites are parallel to overall bedding, and displace column axes slightly (Fig.10e).

Comparisons:

The stromatolites are assigned to the group Boxonia on the basis of their long, smooth, walled columns with moderately frequent alpha- and beta-parallel branching. Katavia Krylov and Acaciella Walter have similar gross structure; Katavia is distinguished by its very prominent bumps, while Acaciella generally lacks a wall. Minjaria Krylov also has parallel straight columns but is distinguished by its less frequent branching.

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

Distribution: Brighton Limestone equivalent, one mile west of Melrose (Fig.28).

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

GROUP *CONOPHYTON* Maslov

Conophyton Maslov (1937, p.334)
Conophyton (Korolyuk, 1963, Pl.5, Fig.3)
Conophyton (Komar, Raaben & Semikhatov, 1965, p.27)
Conophyton (Komar, 1966, p.72)
Conophyton (Cloud & Semikhatov, 1969, p.1037)
Conophyton (Walter, 1970, p.96)

Type Form: *Conophyton lituum* Maslov.

Diagnosis: Extremely rarely branching columnar stromatolites with conical laminae, usually thickened and/or contorted 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* Menchikoff; *C. cadilnicus* Korolyuk and *C. confertum* Semikhatov.

Conophyton garganicum garganicum Korolyuk (emend.)

Pls. 10d,e,f, 11 & 12; Fig. 10i

Conophyton cf. *garganicus* (partim), Glaessner, Preiss & Walter, 1969 (p.1056)

Material: Eleven specimens from one locality.

Description:

Mode of Occurrence

The basal portion consists of flat-laminated stromatolite, passing up into large domal structures up to one metre diameter (Pl.10d). The domes are usually laterally linked, but occasionally separated by small interspaces, and then divided into discrete columns, 15 to 40 cm in diameter, with conical laminae. Transverse sections of columns are round to oval or lanceolate (Pl.10e,f). Columns are 1 to 4 cm apart, with some massive bridges, and often slightly bent, non-parallel, diverging at up to 30° (Pl.11d). Some of this may be due to tectonic disturbance. The original mode of occurrence is not clear because of the discontinuous outcrop; it may have been a bioherm or thick biostrome, perhaps 30 m thick. The only evidence as to the way up of the bed is the upward passage from flat-laminated to conical stromatolites, with apices growing upwards.

Column Shape

Field occurrence shows that columns are somewhat irregular cylinders, with ragged edges, massive bridges and overhanging laminae. Only one specimen was suitable for reconstruction (Fig.10i). Laminae are always conical with a pronounced, thickened crestal zone. Columns of round transverse section have a linear crestal zone, while those of elliptical and lanceolate sections have crestal planes, in the long axis of the ellipse. Specimens studied in the laboratory also show both types.

The margin structure is very irregular, with numerous large bumps, overhanging peaks and short cornices (Pl.11e). Bridges vary in thickness from one or two to several tens of laminae, apparently linking adjacent columns.

Branching

No true branching was seen, apart from the actual separation of columns from the domed and flat-laminated base. Rarely a small projection occurs on the margin of a column (Pl.11c). These projections have convex, non-conical laminae, lacking a crestal zone and are probably exaggerated bumps rather than branches.

Lamina Shape

In longitudinal axial sections laminae are steeply conical, the apical angle generally being acute (50-90°) but obtuse angles occur near the base of the columns where they arise from the basal domes. Away from the crestal zone, laminae are usually straight and parallel in longitudinal section, but in places they bend downwards near the column margins, producing a shape resembling gothic arches (Pl.11a).

Crestal Zone

All laminae are more or less thickened in the crestal zone. Some light laminae are greatly thickened. Dark laminae are arched up and contorted, often leaving irregular voids filled with sparry dolomite, within the thickened light laminae. The crestal line, joining the apices of successive conical laminae, is very wavy, with frequent sharp displacements of the crests (Fig.23a). The overall shape of the crestal zone is however straight (Pl.11a,b). The crestal zone corresponds mostly to Type III

(Fig.21f, after Komar, Raaben & Semikhatov, p.23, Fig.5) with its uneven thickenings and sharp lateral displacements, but some examples of Type II (without lateral displacements) do occur. In places, laminae are deflexed immediately outside the crestal zone (Pl.11a,b; Fig.21f).

The diameter of the crestal zone is taken as the width between the limits of thickening of laminae. Out of 33 measurements, 63% lie between 7 and 9 mm, 24% between 5 and 7 mm, and 12% between 9 and 12 mm (Pl.12a).

Microscopic and Statistical Study:

Lamination

Lamination is very distinctly banded and striated in the better preserved specimens. It consists of straight, parallel, smooth very thin laminae, either very continuous, or formed by chains of elongated lenses, aligned in definite layers.

Two types of primary layers occur: light (L_1) and dark (L_2). In some specimens L_2 layers are grouped into fairly distinct macrolaminae, in which light laminae are thin and subordinate, separated by layers of predominantly L_1 type (Pl.12a,b). The appearance of macrolaminae has been exaggerated by the preferential recrystallization of light laminae.

L_1 Laminae

These are relatively pure and transparent. The majority of the light laminae are between 0.08 and 0.1 mm thick, generally of very constant thickness from the edge of the crestal zone to the column margin, and never lens out. They are internally homogeneous, composed of xenotopic, almost equigranular dolomite, of grain size varying from 0.01 to 0.03 mm. Many grains are slightly inequidimensional (Pl.12c). Occasional lenticular spar-filled cavities occur, with dark laminae draped around them (Pl.12f).

L_2 Laminae

Dark laminae are much less transparent and somewhat finer grained, the fine crystals being stained by a pale brownish, possibly organic, colouration (Pl.12d,e). The majority of dark laminae vary from 0.02 to 0.10 mm in thickness, and are not as continuous as L_1 laminae, frequently splitting into a series of lenses, 0.2 to 1.0 mm long, and 0.1 to 1.0 mm apart, aligned parallel and separated by pale laminae. Some dark laminae are continuous for several centimetres. Occasionally, slight rounded, lenticular swellings occur in the dark laminae. These, as well as the lenses, may be blunt ended, rounded, or pointed. Rarely, significant swellings occur, the underlying and overlying laminae being draped around them. Relatively large (0.5 to 2.0 mm) nodules, within a pale lamina (Pl.12b) are probably detrital carbonate grains. L_2 laminae are composed of equidimensional, equigranular, xenotopic dolomite, of grain size ranging from 0.006 to 0.015 mm.

The boundaries of L_1 and L_2 laminae are distinct and smooth, but slight recrystallization has made them a little diffuse.

Macrolaminae consisting of sets of L_1 laminae are very prominent in some specimens. They are 0.4 to 1.0 mm thick, composed of 5 to 10 L_1-L_2 lamination pairs. They are bounded by predominantly light macrolaminae 0.2 to 0.5 mm thick; the light macrolaminae are often sparry and recrystallized, emphasizing the distinctness of the macrolaminae in some specimens (Pl.12b,c).

Statistical Study

Numerous measurements were made on six large thin sections, of the following parameters: (1) thickness of light laminae L_1; (2) thickness of dark laminae L_2; (3) ratio of thicknesses of adjacent dark and light laminae $\frac{L_2}{L_1}$ and (4) the coefficient of thickening, i.e. the thickness of a lamina in the crestal zone, divided by the thickness of the same lamina outside the crestal zone.

Thickness of the Lamina

The distribution of thicknesses of laminae L_1 and L_2 were plotted graphically for thickness intervals of 0.02 mm; the frequencies of the intervals were plotted against the mid-point of each interval, for the six specimens (Fig.23b to g). A comparison of the six graphs for each lamination type shows some variation between specimens, especially for L_2 laminae.

The result is interpreted as being due to the difficulty of distinguishing single dark laminae and the thinner macrolaminae in some specimens. This difficulty is increased with greater recrystallization. On this basis, one would expect the more recrystallized specimens to have proportionately more numerous thicker laminae (actually thin macrolaminae), i.e. the mean thickness should be higher than for less recrystallized ones. The following table compares mean thickness (in mm) of L_1 and L_2 with degree of recrystallization observed.

It is seen that L_2 means have much greater spread about the total mean than L_1, and that the highest means of L_2 correspond to the most recrystallized specimens.

TABLE VIII

Specimen Number	L_1 mean	L_2 mean	Degree of Recrystallization
S214	0.128	0.073	Well preserved
S213	0.107	0.066	Slightly recrystallized
S278	0.145	0.065	Slightly recrystallized
S277	0.111	0.084	Slightly recrystallized
S532	0.115	0.089	Strongly recrystallized
S531	0.087	0.134	Strongly recrystallized
Total	0.123	0.086	

The data for the six specimens were combined, replotted, and compared with the distribution curve of the Russian Conophyton garganicum garganicum (Fig.23h and the overlay 23h(1)). This shows that the L_2 curves are very similar, while L_1 has a higher mode in the South Australian form (0.08 to 0.10 mm), with a secondary peak in the interval 0.04 to 0.06 mm, which characterizes the Russian form. To some extent, the bimodality is due to errors of measurement arising from the judgement of lamina thickness relative to the scale of the graduated eyepiece, and to the presence of thinner macrolaminae as discussed above.

Ratio L_2/L_1 for Adjacent Laminae

Results from all six specimens were pooled and plotted in intervals of 0.25. The graph compares very closely with that of the Russian form (Fig.23i and the overlay 23i(1)).

The data may also be represented in the form of a contoured frequency diagram of L_2 against L_1. The shape and position of the maximum are compared with those of contoured Russian plots; they differ only in that the South Australian form has a displaced secondary peak at L_1 = 0.08 to 0.10 mm, L_2 = 0.08 to 0.10 mm (Fig.23k and overlay 23k(1)).

Coefficient of Thickening

Randomly selected light and dark laminae, and macrolaminae, were measured outside the crestal zone (h), then traced into the crestal zone and remeasured (H). H/h was plotted at 0.5 unit intervals. In a total of 52 measurements, the modal value of H/h is the interval 2.0 to 2.5 (26.9%) while only 15.5% exceed 3.5, and none less than 1.0 occur (Fig.23j and the overlay 23j(1)).

Interspaces

The interspace fillings between columns are strongly altered, consisting of homogeneous recrystallized dolomite. Some is of grumous texture, composed of xenotopic equidimensional grains varying in size from 0.005 to 0.01 mm, forming patches 0.05 to 0.10 mm in diameter, set in a sparry matrix of grain size 0.1 to 0.3 mm. The only observed remnantsof primary internal structure are possible small intraclasts in one specimen.

Secondary Alteration

Fracturing of laminae is restricted almost entirely to the crestal zones of some specimens and marginal zones of others. Portions of the crestal zone are more or less brecciated and recemented in place. Contortion frequently occurs within the crestal zone, while laminae are deflexed immediately outside it. These effects are probably due to compaction during burial. The brecciation of macrolaminae into cleanly broken fragments several millimetres long suggests that the carbonate was already lithified during the deformation (Pl.12g).

In places, on the column margins, laminae may truncate underlying laminae. Whether this is due to penecontemporaneous erosion or to sliding of the overlying laminae during compaction could not be determined, but associated brecciation around the column margin suggests the latter possibility.

No overfolds or diapiric structures as in Conophyton garganicum australe Walter were observed (Walter, 1970), supporting the idea that columns were lithified soon after growth.

Columns and interspaces consist entirely of dolomite. The preservation of very fine lamination suggests that dolomitization was probably penecontemporaneous. All laminae are more or less recrystallized; the dark laminae are coarser and more transparent than in the Russian or Western Australian forms. Recrystallization may be due to the low grade regional metamorphism which has affected the Mt Lofty-Olary Arc.

Pale laminae between dark macrolaminae are preferentially recrystallized, emphasizing the distinctness of the macrolaminae. These recrystallized laminae consist of sparry, hypidiotopic to xenotopic inequigranular dolomite, of grain size 0.02 to 0.10 mm. The most recrystallized specimen is a fine marble, in which dark macrolaminae, approximately 1 mm thick, contain no preserved internal laminae, and consist of xenotopic equidimensional carbonate with interlobate crystal boundaries, of grain size 0.02 to 0.05 mm. The grain size of the light laminae is 0.05 to 0.10 mm, and in places much coarser.

One specimen is extensively silicified. Silicification post-dates the growth of the whole column, and may be related to tectonics and diapiric emplacement rather than to sedimentation. Silica consists of xenotopic quartz aggregates, of grain size 0.05 to 0.10 mm, in places containing small dolomite rhombs. Portions are completely redolomitized.

Comparisons:

The conical lamination with a thickened crestal zone distinguishes this stromatolite from all groups except *Conophyton*. It differs from most conophytons in that the columns are not always parallel, but their original growth orientation is not clear, due to structural disturbance.

On microstructural features, it falls into the *Conophyton garganicum* subgroup, (*Conophyton garganicum*, *C. miloradovici*, *G. gaubitza*, and perhaps *C. basalticum* Walter) and exactly matches *Conophyton garganicum*. The closely allied *C. miloradovici* has more irregular and lenticular laminae. *C. basalticum* Walter also has very thin smooth continuous laminae, but lacks the distinctive Types II & III crestal zone. The absence of numerous knotted lenses and sharp swellings distinguishes it from the variety *C. garganicum nordicum*.

The statistical study confirms the identification as *C. garganicum* garganicum, and distinguishes it clearly from *C. garganicum australe* Walter.

The modes of thicknesses L_1 and L_2 most closely resemble *C. garganicum*

garganicum, especially L_2 (mode at 0.04to 0.06 mm), while most other conophytons have modes at much higher values. C. garganicum nordicum has a modal value of L_2 at 0.10 mm, and C. garganicum australe Walter at about 0.08 mm.

The ratio L_2/L_1 is the most distinctive character for Conophyton garganicum garganicum. The modal value is the interval 0.50 to 0.75, which falls within the broader peak of the Russian form (0.50 to 1.00), but distinguishes it from C. garganicum nordicum Komar, Raaben and Semikhatov (mode 2.00) and from C. garganicum australe Walter (1.0 to 1.5).

The coefficient of thickening is less distinctive: the mode at 2.0 to 2.5 does not distinguish C. garganicum garganicum, C. miloradovici and C. cylindricum but excludes C. garganicum nordicum, and probably C. g. australe.

The minor differences in parameters between the South Australian form and C. garganicum garganicum are insufficient to allow a distinction to be made.

Distribution: Lower Subsuite of the Yusmastakh Suite of the west and east slopes of the Anabar Massif; the Kyutingdin, Arymas and Debengdin Suites of the Olenek Uplift; the Gonam Suite of the Uchur-Maya Region, Ust'-sakharin Suite of the Western Priverkhoyan'ye, Mongoshin Suite of the south-east part of the Eastern Sayan, Bul'bukhtin Suite of the Baikalo-Patom Mountains, Satkin Suite of the Southern Urals; in pre-Late Burra Group sediments, Paratoo Diapir, South Australia (Fig.29f).

Age: Early and Middle Riphean; in South Australia, it is early Adelaidean.

GROUP GYMNOSOLEN Steinmann

Gymnosolen Steinmann (1911, p.18)

Gymnosolen (Semikhatov, 1962, p.219)

Gymnosolen (Krylov, 1963, p.84)

Gymnosolen (Komar, 1966, p.88)

Gymnosolen (Krylov, 1967, p.36)

Gymnosolen (Raaben, 1969, p.73, partim)

Gymnosolen (Glaessner, Preiss & Walter, 1969, p.1057)

Type Form: Gymnosolen ramsayi Steinmann, from the Dolomitic Suite of the Kanin Peninsula; also widespread in the Southern Urals, the Polyudov Mountains, Kil'din Island, and the Tien-Shan, USSR.

Diagnosis: Smooth to gently bumpy, swelling and constricting, walled columns with frequent, gamma-parallel, often multiple branching, less frequently slightly divergent branching.

Content: Gymnosolen ramsayi Steinmann; G. levis Krylov; G. furcatus Komar; G. altus Semikhatov; "G. confragosus" (in part) Semikhatov and G. asymmetricus Raaben. Raaben (1969a) has included part of the group Minjaria Krylov in Gymnosolen, chiefly on the basis of microstructural similarity, but Krylov (1963) has clearly distinguished Minjaria from Gymnosolen by its regular, subcylindrical shape of columns, of constant diameter, and relatively rare and simple branching.

Age: Late Riphean.

Gymnosolen ramsayi Steinmann

Pls. 13, 14a & c; Figs. 10j to o, 11

Gymnosolen sp. Glaessner, Preiss and Walter, 1969 (p.1057)

Material: Five specimens from one locality.

Description:

Mode of Occurrence

All specimens are boulders from conglomerate and breccia beds within the Tapley Hill Formation (Pl.13b), on the flank of a small diapir. Only one specimen shows completely separate, discrete, vertical columns, and is interpreted to have been derived from the central portion of a bioherm (Pl.13a). Of two specimens showing much coalescing and bridging, one also has markedly inclined columns (Fig.11b,d; Pl.13d). These are considered to represent the marginal portions of bioherms. The provenance of the boulders has not been determined.

Column Shape and Arrangement

Columns vary from straight to gently curved, erect, 1 to 5 cm in diameter, with gentle swellings and constrictions (Fig.10k,l,m,n,o). Transverse sections of columns are generally circular to oval, but at points of branching, lobate and rounded polygonal sections occur (Fig.11a). The length of columns between branches varies from 5 to 20 cm. Some columns are short (only 2 to 5 cm long), with rounded or pointed terminations (Fig.10k,l).

Columns presumed to represent the marginal portions of bioherms are inclined (as estimated from the asymmetry of laminae and the occasional presence of interspace lamination). The gross morphology of these columns differs only in their frequent coalescing and bridging, and narrow interspaces (Fig.11b). One specimen with apparently erect columns is markedly bumpy (Fig.10j).

Branching

Branching varies from slightly divergent to beta- or gamma-parallel; gamma-parallel is most common. The column expands rapidly, then branches into two, three or four columns within a very short distance. Some branches terminate their growth as pointed projections, Even in the discrete specimens, adjacent columns may occasionally coalesce. The inclined-column specimens branch in generally the same way, but widening of a column before branching is more marked. In these specimens adjacent branches either are frequently linked by massive bridges, or coalesce.

Margin Structure

The surface of columns bears low, rounded bumps, 1 to 2 cm wide, with a relief of a few millimetres. Short, transverse or inclined ribs are exceptional.

Most of the lateral surface is covered by a wall, up to 3 mm thick, composed of from one or two to ten laminae (Pl.13c,e). Generally, the marginal zone of columns is recrystallized, but in places, laminae may be seen to bend down near the column margin and extend parallel to it for up to 2 cm. Even if the wall is recrystallized, the outer laminae is generally sharp and well preserved (Pl.13c). In places, an unlaminated selvage, up to 0.5 mm thick, lines the column surface. This post-dates the wall formation, and pre-dates the interspace sediment.

In the discrete column specimen, bridges are rare; occasionally where two columns come very close together, a few laminae may bridge across. In places, overhanging peaks occur; otherwise the wall may be interrupted by a group of laminae draping out over interspace sediment, especially over flat intraclasts. In places, columns arise from laminae grown on intraclasts. Peaks may be formed by the wall of a column draping over an adjacent erect intraclast.

Columns in the inferred marginal specimens are partly unwalled; the laminae then thin and wedge out, forming a smooth margin, but do not extend over it.

Lamina Shape

Lamina shape varies within broad limits. Gently convex laminae are most frequent, varying from rectangular to hemispherical. Frequently, prior to branching laminae develop two or more crests; but in some cases, incipient branches are immediately bridged over, and growth of the original column resumes (e.g. the column on the right of the photograph, Pl.13e). Different lamina shapes occur close together in a column, i.e. the degree of inheritance of shape is low. Fig.21g illustrates the commonly occurring shapes. Of laminae measured, 69% have $^{h}/_{d}$ ratio between 0.2 and 0.6, the mode (26%) being the interval between 0.2 and 0.3 (Fig.22g). (In determining lamina shape, the poorly visible, downturned marginal portions of laminae in the wall were excluded).

Laminae are mostly slightly wavy, with a wavelength of 2 or 3 mm, and amplitude of 0.2 to 0.5 mm.

Microstructure

Microstructure is extensively altered. Where alteration is minimal, alternating light and dark laminae of greatly varying thickness are seen, forming a distinct streaky microstructure (Pl.13e,14a).

Light laminae vary in thickness from 0.1 to 0.5 mm. In places, thick light laminae (up to 1 mm) occur, but these may actually be recrystallized macrolaminae. Light laminae are continuous across the column, but thin in the wall zone. Vary rarely, they are truncated by micro-unconformities. They are wrinkled and wavy, corresponding to irregularities in the dark laminae. Light laminae consist of sparry, equidimensional, xenotopic to hypidiotopic calcite, of grain size ranging from 0.01 to 0.05 mm. Irregular patches, approximately 0.05 mm in diameter, are stained with a pale brownish (organic?) pigment.

Dark laminae vary in thickness from 0.05 to 0.30 mm, but pinch and swell rapidly along their length. In many places, they are lenticular, consisting of adjoining lenses or nodules 0.1 to 0.5 mm long. Usually dark laminae persist across the column margin, but occasionally they lens out completely, so that the adjacent light laminae merge. Laminae are thickest in their crests. The dark laminae consist of brown pigmented xenotopic, equidimensional calcite, of grain size ranging from 0.005 to 0.015 mm. In places, dark laminae are limonitic. In areas of more pervasive recrystallization, grumous textures are developed in which clotty remnants of dark laminae are set in a matrix of sparry hypidiotopic calcite.

Pl.14c illustrates some strongly recrystallized columns.

Poorly differentiated macrolaminae, 0.5 to 2.0 mm thick, consisting of up to 8 light-dark lamination pairs, occur in many parts of columns. The internal structure of these is often not preserved, and more or less homogeneous thick dark laminae with wavy, sharp, upper surfaces result.

Interspaces

Interspaces between columns vary in width from 2 mm to 5 cm; where columns are more widely spaced, interspaces are filled with silty intramicrite. Intraclasts are flat pebbles 0.5 to 3 cm long (Pl.13e), subrounded, variously oriented, and loosely packed (matrix supported). Many stand vertically in the interspace. Some intraclasts are curved, suggestive of a mud-cracked origin. The matrix consists of broadly laminated silty, recrystallized lime mud; fine laminae, 2 to 5 mm thick, consist of xenotopic calcite ranging in grain size from 0.003 to 0.01 mm, while coarse laminae, of about the same thickness, consist of hypidiotopic 0.03 to 0.05 mm grain size calcite, with much subangular quartz silt. Laminations of the interspace sediment abut against the column walls, having accumulated after the development of significant relief of columns.

Secondary Alteration

Laminae are extensively altered especially in the marginal wall zone. In places the lamination is completely disrupted around centres of recrystallization, but commonly faint lamination or rows of dark clots are preserved, to indicate the presence of originally continuous dark laminae in the wall zone. The outer few millimetres of columns are commonly recrystallized to coarse, twinned hypidiotopic calcite, of grain size up to 0.3 mm with inclusions of dark lamination relics. In places, acicular texture is developed in the wall zone, perpendicular to the column margin.

The central parts of columns are less affected, but even here, laminae are commonly reduced to dark clots in a sparry calcite matrix.

Dolomitization of both interspace and columns occurs in some specimens. Here anhedral to subhedral rhombs of dolomite, of 0.02 to 0.06 mm grain size, are scattered more or less uniformly throughout a recrystallized sparry calcite mosaic.

Frequently, lenses of coarsely crystalline, clear calcite occur within the lamination. Coarsely sparry patches, cutting across all earlier structures, are probably infillings of solution cavities, since they are closely associated with discordant stylolites.

Stylolites are rather rare, and of two generations. The first are concordant with laminae, and contain concentrations of limonite. These are cut by major calcite veins, which, in turn are off-set by the discordant stylolites mentioned above.

Comparisons:

The stromatolites are assigned to the group Gymnosolen on the basis of their column shape, frequent gamma-parallel and slightly divergent branching, and wall.

In overall column shape and type of branching, presence of pointed projections, shape of laminae and microstructure, the South Australian form closely resembles Russian *G. ramsayi*. Slight differences include unwalled patches of columns, occasional peaks and bridges, and in places a slightly bumpier margin structure. *G. ramsayi* is distinguished from *G. furcatus* by the absence of markedly gamma-parallel, multiple branching and the presence of pointed projections, and from *G. levis* by its more widely spaced, less markedly bumpy columns. *G. altus* Semikhatov has apparently been affected by a strong cleavage, and its columns are slightly deformed, making comparisons difficult, but it appears to have a more continuous, banded lamination. *G. asymmetricus* Raaben has thinner, smoother laminae than *G. ramsayi*. *G. confragosus* Semikhatov has in part (specimens from the Shorikhin Suite) been reassigned by Raaben (1969) to *Inzeria* (*I. confragosa*); these specimens are distinguished from *G. ramsayi* by their irregular columns, interrupted wall and more frequent peaks and cornices. Semikhatov's specimens from the Dashkin Suite, now considered as Vendian (Krylov in Rozanov et al., 1969, p.215), have much smaller, bumpier columns than *G. ramsayi*.

Distribution: Sub-Inzer Beds of the Katav Suite and Minjar Suite of the Karatav Series of the Southern Urals; Niz'ven Suite of the Polyudov Mountains; Carbonate Beds of the Metamorphic Series of the Kanin Peninsula; Kil'din Series of Kil'din Island; possibly the Sparagmites of Norway; Bystrin Suite of Southern Timan; Chatkaragay Suite of Tien-Shan; as clasts in Tapley Hill Formation, 5 miles E of Wilson, Southern Flinders Ranges, South Australia (Fig.27).

Age: Late Riphean; in South Australia, not younger than the Tapley Hill Formation.

GROUP INZERIA Krylov

Inzeria Krylov, 1963 (p.71)
Inzeria (partim, Raaben, 1964, p.98)
Inzeria (Krylov, 1967, p.29)
Inzeria (Cloud and Semikhatov, 1969, p.1042)
Inzeria (Raaben, 1969a, p.77)
Inzeria (Glaessner, Preiss & Walter, 1969, p.1057)
Inzeria (Walter, 1979, p.163)

Type Form: Inzeria tjomusi Krylov, from the Katav Suite of the Southern Urals, and the Demin Suite of the Polyudov Mountains, USSR.

Diagnosis: Subparallel, usually unwalled, subcylindrical, ribbed columns, frequently with niches containing projections. Branching is mostly alpha- to beta-parallel to slightly divergent, rarely gamma-parallel or markedly divergent.

Content: I. tjomusi Krylov, I. toctogulii Krylov, I. intia Walter, and probably I. djejimi Raaben and I. nyfryslandica Raaben. I. (Minjaria) nimbifera Semikhatov may be included, but Raaben (1969a) has placed it in synonymy with I. tjomusi, and has partly reassigned Gymnosolen confragosus (Semikhatov) to Inzeria (I. confragosa). Raaben has, however, considerably broadened the concept of Inzeria, placing little importance on Krylov's (1963) criteria of ribbed columns with niche-projections. On this basis, Aldania Krylov (in Rozanov et al., 1969) could perhaps be better included in Inzeria.

Descriptions of I. macula, I. variusata, I. sovinica and I. chunnbergica

Golovanov were unavailable, but Raaben's (1969a, Fig.21) illustration of _Inzeria macula_ does not resemble any known _Inzeria_. The new South Australian forms are _I. multiplex_ and _I. conjuncta_.

Age and Distribution: Late Riphean, widespread in the USSR; Bitter Springs Formation, Central Australia; Brighton Limestone and Wundowie Limestone, South Australia; Hinde Dolomite, and doubtfully, Dook Creek Formation, Northern Territory.

Inzeria cf. _tjomusi_ Krylov

Pls.14b,d,e, 15a,c,e; Figs. 11f,g, 12a to g

Material: Three specimens from one locality.

Description:

Mode of Occurrence

The stromatolites form a lenticular bed, interbedded with green shales, within the Wundowie Limestone. The bed consists of four or five contiguous gently domed bioherms (Pl.14e), 2 to 4 m in diameter, with a maximum thickness of about ½ m. Towards the west, the bed thins and lenses out gradually; in the easterly extension, columnar stromatolites give way to flat-laminated limestone. The lower portion of a domed bioherm consists of flat-laminated stromatolitic limestone, or contiguous, very broad cumuli (parts of which are seen in Pl.14b,d), up to 20 cm thick; overlying this (but never seen in sedimentary contact with it), is a zone, up to 20 cm thick, of discrete, vertical, subcylindrical columns, 2 to 10 cm wide. The base of these columns is always an intensely stylolitic zone, in which a thickness of up to several centimetres has been removed

(Pl.14b,d). At the margins of bioherms, the columns become irregular and slightly inclined from vertical. Columns are bridged over by a thin, poorly exposed zone of flat-laminated stromatolites.

Column Shape and Arrangement

Columns are short, subcylindrical, with some swellings and constrictions, and vary in diameter from 2 to 10 cm (Figs.11f,g; 12a to g). The height of columns is 10 to 20 cm (the whole thickness of the columnar zone). Transverse sections of columns are round, rounded polygonal or slightly lobate. Columns have vertical, straight axes in the central parts of bioherms, but become irregular at the edges.

Branching

Branching into discrete new columns is rare; this may be due to the small thickness of the bed. Niche-projections are, however, very frequent; they are short, narrow, usually rounded projections, sometimes slightly elongated, set into niches in the side of the main columns, which, most commonly, resumes its former diameter at the top of the niche (Pl.15a,c,e; Figs.12a,c,d,g).

Occasionally adjacent columns coalesce.

Margin Structure

Due to strong recrystallization of columns the margin structure is obscure. Laminae approach the margin at a high angle, and are not deflexed at their edges; columns are always unwalled. The lateral surface of columns bears numerous short transverse ribs, up to 2 cm long, and occasional overhanging laminae and peaks. In places, adjacent columns are linked by bridges up to $\frac{1}{2}$ cm thick.

Lamina Shape

Laminae are always gently convex, varying in shape from continuously curved domes to very low, obtuse cones, as illustrated in Fig.21h. Lamina shape is inherited from underlying laminae, without rapid changes in convexity. Ratios of $^h/_d$ are usually low: 91% of laminae measured have $^h/_d$ between 0.2 and 0.4 (Fig.22h). The fine-scale structure of laminae is smooth to gently wrinkled. At column margins, laminae are not deflexed, but end abruptly; part of this outer zone may have been removed by secondary alteration.

Microstructure

Microstructure is strongly recrystallized throughout the columns, but in places the gross indistinctly banded structure of laminae is moderately well preserved (Pl.15a,e). Relatively thicker light laminae alternate with thinner dark laminae, but recrystallization has in places obliterated the distinction. All laminae have diffuse boundaries.

Light laminae vary in thickness from 0.2 to 2.5 mm, commonly being significantly thicker at their crests than their edges, especially in the obtusely-conical laminae. They consist of a sparry, equigranular, hypidiotopic mosaic of calcite, of grain size ranging from 0.015 to 0.02 mm. Included are small, irregular patches of darker pigmentation.

Dark laminae are either very finely wrinkled or smooth. The wrinkling is largely due to embayment by recrystallized adjacent light laminae. Dark laminae vary in thickness from 0.2 to 1.0 mm, and are generally thinner than adjacent light laminae. Occasionally thinner dark laminae are lenticular, but whether this feature is primary or due to recrystallization is unresolved. Like the light laminae, they are slightly thickened in their crests. Dark laminae consist of xenotopic, slightly inequigranular calcite, of grain size ranging from 0.005 to 0.03 mm, stained with a pale brownish pigment.

Interspaces

Interspaces are filled with homogeneous recrystallized silty lime mud, with occasional intraclasts. The calcite is xenotopic to hypidiotopic, of grain size 0.01 to 0.03 mm. Included angular quartz silt forms approximately 5% of the sediment. Quartz grains are corroded by the recrystallized calcite. Occasional flat intraclasts up to 1 cm long, which occur in parts of the interspaces, are badly recrystallized and have diffuse boundaries. They now consist of sparry mosaic calcite, generally hypidiotopic, with a grain size of 0.02 to 0.03 mm.

Secondary Alteration

The whole rock is pervasively altered. While columns are pale grey, transparent in thin section (Pl.15a), the dark laminae perhaps being tinted with organic matter, interspaces are pale buff coloured, probably due to the presence of small amounts of limonite. Neither columns nor interspaces are dolomitized. The boundary between the interspace and the column is always diffuse, obliterated by recrystallization in both. This reduces the reliability of the reconstructions.

Highly irregular stylolites with large lobes separate the basal laminated sediment from the discrete columns, which are separated from it by a zone up to 5 cm thick of intense brecciation and late-stage infilling of fractures by coarsely crystalline calcite. Possible remnants of the lower portions of columns, highly enriched in limonite, are sometimes preserved between cross-cutting stylolites (Pl.15a).

Large subspherical nodules, up to 5 cm in diameter, of coarsely crystalline calcite are very common in the limestones at this locality. Most frequently, these are located within columns. The twinned calcite crystals, which are highly elongated, 1 to 3 mm wide, up to 3 cm long, are vertical or radially arranged. Most crystals are terminated upwards; their acute terminations project into the laminated limestone of columns.

Over large areas, columns are completely recrystallized so that lamination is partly or totally obliterated. Such areas consist of xenotopic, to hypidiotopic mosaic calcite, of grain size up to 0.5 mm. Where recrystallization is incomplete, irregular fragments of disrupted dark laminae are surrounded by sparry, recrystallized mosaic calcite.

The major cross-cutting stylolites post-date the coarsely crystalline nodules.

Comparisons:

The presence of ribbed columns with numerous niche-projections places the stromatolites in the group Inzeria. They are differentiated from all other Australian forms of Inzeria, I. toctogulii Krylov and I. djejimi Raaben by their very infrequent branching, consistently gently convex laminae (grading to low-conical rather than rectangular), and their short length of columns. In having subcylindrical, erect, ribbed columns with numerous niche-projections, they closely resemble Russian specimens of *I. tjomusi* Krylov, but differ in the thinness of the columnar bed; the absence of branching may simply be a consequence of the short lengths of columns. Unlike *I. tjomusi* from the Southern Urals, steeply convex laminae are absent. The broadly banded microstructure with pinching and swelling or wrinkled dark laminae is similar, but the prominent concentrations of iron oxides along concordant solution surfaces are absent.

Until bioherms are found in which the columns had the opportunity to grow higher, so that the mode and frequency of branching can be determined, and which are less recrystallized, so as to preserve the margin structure, no reliable identification is possible. The stromatolites are assigned to *Inzeria* cf. *tjomusi*.

Distribution: Middle member of the Wundowie Limestone, Umberatana Group; Burr Well, Northern Flinders Ranges, South Australia (Fig.25).

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

Inzeria conjuncta f. nov.

Pls. 15b,d,f, 16a,c; Fig. 12h to m

Material: Three specimens from one locality.

Holotype: S402 (Pl.16a,c; Fig.12h,i,j).

Name: Latin *conjuncta*, meaning joined, refers to the frequent coalescing and bridging of columns.

Diagnosis: *Inzeria* with broad, unwalled, rarely branching, frequently bridged and coalescing basal columns, which divide by alpha-parallel branching into narrower, unwalled upper columns with occasional alpha- and beta-parallel branches. Niche-projections are moderately frequent. Laminae vary from nearly flat to rectangular or gently convex, and are wavy or wrinkled, with a distinct streaky microstructure.

Description:

Mode of Occurrence

Field examination of bioherms is hampered by the very extensive lichen cover on rock faces (Pl.15b), and by the discontinuous outcrop. Three domed bioherms, up to 50 m long, 3 m thick, occur interbedded in massive oolitic-intraclastic limestone. The basal, central portion of bioherms consists of flat-laminated stromatolitic limestone, which passes up gradationally into broad columns, 5 to 20 cm wide, with frequent coalescing and massive bridges. Flat-laminated intervals may intervene. At slightly different levels, the broad columns divide by alpha-parallel branching into 1 to 5 cm wide columns. At bioherm margins, columns are strongly elongated, closely spaced, and uniformly inclined at about 45° (Pl.15f; Fig.12k).

Column Shape and Arrangement

Broad columns in the lower part of bioherms are subcylindrical, up to 30 cm long in their discrete portions, commonly with rounded polygonal transverse sections. Where adjacent columns coalesce, or a wider column branches, transverse sections may be complexly lobate. Columns gradually become more discrete upwards. The overlying narrow columns are slightly elongated, varying from 1 x 2 cm to 3 x 5 cm in transverse section, and are up to 15 cm long between branches. Columns within the central part of the bioherm are straight, erect (Fig.12h,i,j), while at the margins, they become inclined at 45^0, and slightly curved (Fig.12k). Some columns bear gentle swellings and constrictions. Short projections set in niches are moderately frequent (Fig.12h,i,j,l,m).

Marginal columns are strongly elongated, with long axes up to five times the short (Fig.12k), with marked swellings and constrictions.

Branching

Basal flat laminae pass up directly into broad columns with niche-projections. Niche-projections are formed by unequal, alpha-parallel branching, or, less commonly, divergent branching; the narrower column is set into the niche in the main wide column, which generally resumes its former diameter after the termination of the projection. Where projections branch divergently, they protrude beyond the margin of the main column. Projections vary in length from 0.5 to 4 cm.

Within the broad column level, branching (other than by niche-projections) is rare. Broad columns then divide by alpha-parallel, rarely beta-parallel branching, into narrower, 1 to 5 cm wide columns, which branch again, less frequently, by alpha- or beta-parallel branching.

In the marginal zone of the bioherm, branching is beta- to gamma-parallel, often with constriction at branching. Niches are still common, but are elongated parallel to the long axes of the platy columns (Fig.12k).

Margin Structure

The lateral surface of columns is uneven, with very frequent transverse ribs, some small projections, bumps, bridges, and occasional small peaks. Ribs, 0.5 to 1 cm wide, may be followed around column margins for a few centimetres. Both massive and delicate bridges occur between adjacent columns, and, sometimes, between columns and projections. Niches in the column margins vary in depth from ½ to several centimetres; some niches are partly closed at one end (Fig.12h). Occasional niches are elongated transversely, grading into prominent ribs (Fig.12h,j).

There is no wall; at the column margins, laminae thin only slightly, and either end abruptly or turn down and wedge out; they do not cover the lateral surface of the column (Pl.16c).

Lamina Shape

Lamina shape varies greatly from the broad columns to the upper narrow columns. In broad columns most laminae are flat, gently convex, or rectangular (Fig.21i). In places laminae develop two or more crests, then either the column branches (if near the branching level) or the interspace is bridged over, and the column resumes its normal growth (Pl.16a). In the broad columns, values of $^h/_d$ are low; all those measured are below 0.25.

In the narrow, upper columns, laminae are consistently more steeply convex. Of those measured, 81% lie between 0.3 and 0.6. Columns in the marginal zone of bioherms have laminae strongly asymmetrical towards the exterior of the bioherm. Here the laminae are commonly as steeply convex as in the upper narrow columns from the bioherm centre (60% of $^h/_d$ between 0.3 and 0.4). Fig.22i illustrates the distribution of lamina convexities.

All laminae are wavy, with a wavelength of 2 to 4 mm, and in some places, wrinkled.

Microstructure

Microstructure is distinctly streaky with both lenticular and continuous, wavy, swelling and constricting laminae.

Dark laminae vary in thickness from 0.05 to 0.3 mm. They are wrinkled and wavy, and their upper and lower boundaries are not parallel. The amplitude of waves and wrinkles varies from 0.2 to 0.5 mm; in addition, the thickness of laminae changes rapidly within a few millimetres. In places, dark laminae grade into aligned lenses and clots.

Dark laminae consist of equigranular hypidiotopic to idiotopic dolomite, ranging in grain size from 0.005 to 0.01 mm. The crystals are equidimensional and stained a pale green tint. This is responsible for the green colour of the laminae. No individual grains of pigment could be resolved even at 1200 x magnification.

Light laminae consist of white to pale grey partly dolomitized limestone. At the column margins, these laminae tend to lens out, so that the adjacent dark laminae merge. The calcite is sparry, devoid of pigment, and of xenotopic to hypidiotopic texture, with a grain size of between 0.005 and 0.035 mm. Light laminae also contain some coarser detritus, including fine sand-sized, well rounded quartz and feldspar. Small dolomite rhombs similar to those of the dark laminae but less pigmented are dispersed throughout these laminae.

Over most of the area of sections, dark laminae tend to be grouped into macrolaminae 1 to 5 mm thick, which, like individual laminae, pinch and swell markedly. There is evidence of minor contemporaneous erosion of thickenings and wave-crests of macrolaminae.

Interspaces

Both the lower broad and the upper narrow columns are separated by narrow interspaces, varying in width from 1 to 20 mm, but columns from the bioherm margins are almost in contact. The infilling sediment is layered, either by sandy laminae, or by single stromatolitic laminae bridging between columns. Interspace laminae are depressed, concave upwards (Pl.16a). The carbonate of the interspaces is dolomitized limestone: slightly inequigranular hypidiotopic calcite (partly recrystallized lime mud), of grain size 0.005 to 0.02 mm, contains subhedral rhombs of dolomite, between 0.005 and 0.05 mm in diameter. In places, quartz sand occurs in laminae up to a few millimetres thick, which abut against the column margins, suggesting that they post-date the growth of that portion of the adjacent column. No carbonate allochems were observed.

At times of bridging, the structures had a relief of less than one centimetre, and bridging laminae may be only one or two centimetres apart.

Secondary Alteration

Quartz and feldspar grains, both in columns and interspace sediment, have corroded boundaries; in places their margins are completely replaced by carbonate.

While the dark laminae are almost completely dolomitized, the lime mud comprising the light laminae and the interspace filling is patchily dolomitized and also contains hypidiotopic, coarser calcite due to partial recrystallization. The dolomitization is probably secondary.

Stylolites are rare except in the bioherm margins, where they separate columns. Concordant stylolites are also rare.

Small vughs, up to 3 mm in diameter, filled with coarse, twinned sparry calcite occasionally cut across the lamination.

The origin of the green colouration of dark laminae is not clear, since no particles of pigment could be resolved; the dolomite crystals themselves are tinted. Surface oxidation during weathering either partly removes the colour, or deposits yellow-brown limonite in interspaces or along stylolites.

Comparisons:

The stromatolites are assigned to Inzeria on the following characters: ribbed lateral surface, absence of wall, dominance of parallel branching, and niche-projections. The upper narrow columns resemble Katavia and Kulparia but are distinguished by the presence of long transverse ribs, the absence of a wall, and by microstructure; unlike Katavia and Kulparia, their projections are usually rounded, and set in niches.

I. conjuncta differs from I. tjomusi Krylov and I. intia Walter in having frequently coalescing columns, and consistently gently convex, wavy and wrinkled laminae; it lacks the consistently elongated niche-projections and the complex bioherms of *I. intia*. Unlike *I. djejimi* Raaben, its columns are straight, with frequent niche-projections, and rarer branching. *I. conjuncta* is distinguished from *I. toctogulii* Krylov by its less frequent, dominantly alpha-parallel branching, and by its coalescing and bridging. *I. conjuncta* is especially similar to *Aldania sibirica* in margin structure and microstructure, but has more irregular and coalescing columns. As pointed out above, *Aldania* would be better included in *Inzeria*.

Distribution: Brighton Limestone equivalent, two miles north of Depot Flat H.S., Southern Flinders Ranges, S.A. (Fig.24).

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

Inzeria multiplex

Pls. 16b & d, 17a to d; Fig. 13

Inzeria sp. nov.II, Glaessner, Preiss & Walter, 1969, p.1057

Material: Six specimens from two localities.

Holotype: S385.

Name: Latin *multiplex*, meaning complex, manifold or with many parts.

Diagnosis: Inzeria with frequent, dichotomous to multiple, alpha- and beta-parallel to slightly divergent branching, and rarer branches arising from niches. Columns have irregular transverse sections. Margin bears ribs, bumps and short projections. Laminae are gently convex, smooth to wrinkled, and of regularly streaky microstructure.

Description:

Mode of Occurrence

Due to poor outcrop, the exact mode of occurrence at Mt Remarkable is not known; a large bioherm is inferred, since, when followed along strike, the stromatolitic bed passes into massive intraclastic limestone, but the contact is not exposed. At Yednalue, the stromatolites form an extensive, very thick bed, which has not been traced. Moreover, the limestone at this locality is cleaved, and columns are often difficult to discern.

At Mt Remarkable, the basal part of the Brighton Limestone consists of laterally linked, usually elongated, stromatolites. Wide columns are also present (Pl.16b) but their relationships are not exposed. The outcrops of Inzeria resemble laterally linked stromatolites; columns become discernible only when the rock surface is cleaned or cut.

Column Shape and Arrangement

Columns vary from tuberous to sybcylindrical, erect to inclined (Pls.16d; 17b,c), with straight or gently curved axes; occasional columns are sharply bent, especially when associated with coalescing. The height of columns between branching varies from 4 to 20 cm. Transverse sections of columns vary from round to rounded polygonal or irregular and lobate, at points of branching or coalescing. Columns may be variously elongated. The diameter of columns varies from 1 to 5 cm. At the top of the bed, columns are frequently bridged by continuous, laterally linked layers.

Branching

Branching is very frequent and complex, either arising from niches in the parent column (Pl.16d; Fig.13i), or by equal division (Fig.13a,b,c); the latter being most common. This mode of branching is usually beta-parallel, rarely alpha- or gamma-parallel, or slightly divergent; it may be either dichotomous or multiple. Branching from niches may give rise to either new columns or short projections (Pls.16d,17a); the two intergrade. Adjacent columns frequently coalesce, especially in the upper part of the bed.

Margin Structure

Column margins are irregular, with numerous, short transverse ribs, low bumps and some slightly overhanging laminae. Bumps and ribs grade into very short, outgrowing projections, less than 1 cm long. These are more common than projections set in niches, especially in the Mt Remarkable specimens (Pl.17c).

There is no wall; commonly gently convex laminae terminate at the column margin, without bending over, at slightly differing distances from the column axis, forming ribs, and sometimes minute peaks and cornices. Small portions of column margins are relatively smooth. Bridges involving any number of laminae are common, especially near the top of the bed.

Lamina Shape

Laminae are almost always gently convex (Fig.21j); even in the narrowest columns $^h/_d$ does not exceed 0.5. Of laminae measured, 93% have $^h/_d$ between 0.1 and 0.4, the mode (40%) being in the range between 0.2 and 0.3 (Fig.22j). In most of the broader and narrower columns laminae do not bend over at the column margin, but simply terminate abruptly;

occasional patches of columns have more steeply convex laminae and a smoother margin. Laminae may be doubly-crested, prior to branching. On a small scale, laminae are broadly wavy, and in places slightly wrinkled.

Microstructure

The layering consists of an alternation of light, sparry laminae and dark, iron-stained laminae, with indistinct boundaries and varying continuity. In places, such laminae are grouped into macrolaminae 1 or 2 mm thick. The boundaries between laminae are frequently wrinkled.

Light laminae vary in thickness from 0.1 to 1.5 mm, usually constant across the column width; they may be smooth, wrinkled or wavy (Pl.17d), their upper and lower boundaries being parallel. Varying abundances of fine quartz sand and silt are incorporated in the light laminae, which consist of hypidiotopic to idiotopic carbonate, of grain size 0.01 to 0.03 mm. Grains are equidimensional, sometimes euhedral rhombs.

Dark laminae are thinner, generally between 0.1 and 0.5 mm, but pinch and swell across the column width. The crests of the laminae are commonly thickest. Dark laminae grade from smooth to wrinkled, and frequently become discontinuous, forming chains of clots and lenses up to 1 mm long, separated by sparry carbonate (Pl.17d). Dark laminae, clots and lenses are composed of reddish-brown stained, xenotopic carbonate, of grain size 0.003 to 0.01 mm.

Interspaces

The columns are generally closely spaced, but interspace width varies from 1 mm to 3 cm. The sediment is different in the two areas of occurrence.

(1) Mt Remarkable. Here the sediment is broadly laminated reddish coloured dolomite mud; laminae are 1 to 4 mm thick, and generally flat or slightly concave upwards. The darker laminae are generally thinner (up to 1 mm), and consist of xenotopic dolomite of grain size varying from 0.003 to 0.005 mm; they alternate with thicker, paler, silty laminae, up to 4 mm thick, of xenotopic dolomite of 0.005 to 0.015 mm grain size, with a high percentage of terrigenous detritus (angular quartz silt of grain size 0.02 to 0.05 mm, and occasional mica flakes). Intraclasts up to 1 cm long, 2 mm thick, are locally present in the interspace, generally standing vertically or inclined.

(2) Yednalue. Here interspaces are filled with unlaminated sandy limestone. Quartz and feldspar grains vary from 0.1 to 1.0 mm in grain size, and are subrounded to well rounded; all have been embayed by the carbonate cement, which is hypidiotopic to idiotopic calcite, of grain size up to 0.6 mm. Sand grains are mostly tightly packed, but in places they are separated by a greenish argillaceous matrix.

Secondary Alteration

Specimens from Mt Remarkable consist entirely of dolomite, while those from Yednalue are calcite. Mt Remarkable specimens are, however, better preserved: the idiotopic and hypidiotopic dolomite probably formed during early diagenesis, but did not destroy the fine structure of the stromatolites. The dolomitic rock may have proved more resistant to later recrystallization, which has in both areas disrupted the fine lamination to a greater or lesser extent. In addition, cleavage is well developed at Yednalue, and the columns are slightly deformed, so that metamorphism may partly account for the greater recrystallization here. Occasional concordant slightly sutured stylolites follow the lamination, sometimes affecting several adjacent columns, but all are cross-cutting on a fine scale. Greenish argillaceous material is concentrated in the stylolites. Some stylolites follow column margins and thus remove the minor surface features of columns (Pl.17d). Tectonic veins are filled with quartz or calcite.

Comparisons:

The stromatolites are assigned to *Inzeria* because of their ribbed columns with projections, but they frequently resemble *Baicalia* in their tuberous shape; *Baicalia*, however, much more often has divergent branching, more overhanging laminae, and a distinctly banded microstructure.

In having some alpha-parallel branching, they resemble *Kussiella* Krylov and *Acaciella* Walter, but are distinguished by their frequent beta-parallel branching and branching from niches.

Inzeria multiplex is distinguished from *I. tjomusi* Krylov, *I. intia* Walter, and *I. conjuncta* Preiss by its very frequent branching, and rarer projections set in niches. In these features it resembles *I. toctogulii* Krylov and *I. djejimi* Raaben, but *I. toctogulii* has more regular, cylindrical columns, while *I. djemimi* has steeply convex laminae.

Distribution: Brighton Limestone equivalent; 5 miles north-west of Mt Remarkable (Fig.28), and $7\frac{1}{2}$ miles east of Yednalue (Fig.27), Southern Flinders Ranges, South Australia.

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

GROUP *JURUSANIA* Krylov

Jurusania Krylov (1963, p.81)

Jurusania (Raaben, 1964, p.93)

Jurusania (Krylov, in Rozanov et al., 1969, p.195)

Jurusania (Cloud & Semikhatov, 1969, p.1045)

Jurusania (Walter, 1970, p.174)

Jurusania (Semikhatov, Komar & Serebryakov, 1970, p.166)

Type Form: *Jurusania cylindrica* Krylov, from the Katav Suite of the Southern Urals.

Diagnosis: Even, parallel, subcylindrical columns with round or oval transverse sections and rare, dichotomous alpha-parallel branching. Columns may be partly walled, and partly bear downward directed peaks and overhanging laminae; they are frequently covered with an unlaminated selvage.

Content: *Jurusania cylindrica* Krylov, *J. tumuldurica* Krylov, *J. nisvensis* Raaben, *J. judomica* Komar & Semikhatov and *J. chewingsi* Walter. *J. sibirica* Jakovlev has been transferred by Krylov (1969) to a new group, *Aldania*, but Semikhatov, Komar & Serebryakov (1970) retain its assignment to *Jurusania*.

Age: Late Riphean to Vendian.

Jurusania burrensis f. nov.

Pls. 17e, 18; Fig. 14a to h

Material: Four specimens from one locality.

Holotype: S543 (Pl.18c,e; Pl.14d,e,f).

Name: After the Burr River, on the bank of which the stromatolites occur.

Diagnosis: *Jurusania* with smooth to gently bumpy, frequently walled columns and local, short peaks and overhanging laminae. Laminae vary in shape from gently convex to subconical, and are lenticular with diffuse, streaky microstructure. Columns are partly covered by an unlaminated selvage.

Description:

Mode of Occurrence

The stromatolites occur in extensive but lenticular beds consisting of contiguous spherical and subspherical bioherms up to 2 m in diameter (Pl.17e). The bioherms consist of 3 concentrically arranged zones, and are capped by an undulating to nearly flat, columnar zone. Bioherm cores are up to 50 cm thick and consist of irregularly pseudocolumnar and columnar-layered stromatolites of dark grey limestone, overlying sandy limestone with large, reworked intraclasts. The cores are surrounded by a concentrically laminated zone, from which long straight, parallel columns arise. At bioherm margins, columns become slightly inclined, rarely subhorizontal; generally columns remain subparallel throughout the bioherm, but show more bridging and coalescing at the margins. The spherical bioherms, which are mutually in contact, are overlain by a flat or broadly undulating, 1 metre thick bed of columns with numerous bridges and pseudocolumns.

Column Shape and Arrangement

Columns are long, straight, parallel or radially arranged, cylindrical or subcylindrical. In one specimen from near the base of a bioherm, columns are somewhat inclined, irregular, tuberous, and of strongly elliptical or lobate transverse section (Fig.14b,c); otherwise transverse sections are round or slightly elliptical. Columns are mainly smooth, with only occasional low, broad bumps (Pl.18a,b,c,d); single columns generally have constant diameter, varying from 5 to 10 cm for basal columns (Fig.14h) to 2 cm for upper, narrow columns (Fig.14d,e,f). Length of columns between branches may exceed 30 cm; the whole columnar zone of bioherms is up to 1 m thick.

Columns in the overlying undulating bed are rather short, and frequently bridged. They apparently arise from basal, flat-laminated stromatolites (Pl.18f; Fig.14a, specimen S481, but the exact location of this specimen is not certain).

Branching

Branching is rather infrequent especially in the narrow, uppermost columns, which may be up to 30 cm long between branches, but more often terminate their growth before branching. Branching is always dichotomous, and either alpha-, or slightly beta-parallel, i.e. columns widen only very gradually before branching into two narrower columns (Pl.18g; Fig.14g,h).

Occasionally, two neighbouring columns may coalesce, especially in the upper parts of the bioherms.

Margin Structure

Column margins are generally smooth, bearing only broad, low bumps several centimetres wide and of relief up to 5 mm (Fig.14a to h). Column margins may be either walled or unwalled. Laminae generally approach the margin at an acute angle, but the actual column margin is frequently removed by stylolites. In areas not affected by stylolites, the laminae either terminate at the column margin, or extend down for a distance of up to 1 cm to form a patchy wall (Pl.18e). In a few places, laminae overhang slightly to form small peaks, a few millimetres long (Fig.14e,f,g). Large overhanging peaks are developed only on the irregular columns (Fig.14b), from the lower parts of bioherms.

Considerable areas of the smooth columns are coated with a selvage, 0.2 to 1.0 mm thick, of unlaminated very fine grained calcite (Pl.18g).

Lamina Shape

Lamina shape varies to some extent with column width, but most are gently convex (85% have $^{h}/_{d}$ between 0.2 and 0.5, Fig.22k); a few narrow columns have steeply convex to subconical laminae (Fig.21k). Most laminae have a relief of about 1 cm. Laminae are of smooth curvature, and micro-unconformities are rare. Lamina shape is always inherited from the underlying laminae, so that no marked, rapid changes occur.

The fine scale structure of laminae is lenticular and very gently wavy, with a wavelength of 2 to 5 mm, amplitude 0.1 mm.

Microstructure

The dark limestone comprising the pseudocolumnar bioherm cores is almost entirely recrystallized, and even the lamination is rarely preserved.

Lamination in the columnar parts of bioherms is diffuse, streaky and consists of alternating, finely wavy, lenticular, dolomitized sparry pale laminae and darker, micritic laminae. The two lamina types grade into one another.

Micritic laminae are recrystallized to micro-spar, of grain size ranging from 0.005 to 0.015 mm, and xenotopic, polygonal, equigranular texture. The laminae have very vague boundaries, and vary in thickness from 0.2 to 0.5 mm over short distances. In places, laminae thin and terminate laterally, or consist of short, aligned lenses a few millimetres long.

The sparry laminae are 0.1 to 0.5 mm thick and also pinch and swell, but are more continuous across the column width. They consist of hypidiotopic to xenotopic calcite, varying in grain size from 0.01 to 0.03 mm, with scattered subhedral dolomite crystals, of grain size 0.015 to 0.06 mm. In places, the laminae are almost completely dolomitized, and consist of closely packed hypidiotopic dolomite with remnant interstitial sparry calcite. Sparry laminae may also be completely recrystallized, with little dolomitization, to a hypidiotopic mosaic of grain size up to 0.2 mm.

The unlaminated selvage present in places on column margins consists of a xenotopic calcite mosaic of grain size ranging from 0.005 to 0.02 mm; the origin of the selvage is not clear (see secondary alteration).

Interspaces

The distance between columns varies from 0.5 to 2.0 cm. Interspaces are filled with poorly bedded intramicrite, partially dolomitized. Intraclasts are mostly flat limestone pebbles, 0.5 to 3 mm thick and 2 to 30 mm long, generally lying parallel to the bedding, or standing vertically in the narrowest interspaces (Pl.18c). The flat pebbles, which commonly have rounded margins, consist of xenotopic, equigranular mosaic calcite of grain size up to 0.01 mm, and contain scattered, subhedral dolomite crystals ranging in size from 0.010 to 0.015 mm. Subrounded to well rounded quartz and feldspar sand grains occur in places.

Intraclasts are moderately loosely packed, so that some are in contact, some not; the sediment was probably matrix-supported. The matrix probably originally micritic calcite, is recrystallized to a xenotopic inequigranular texture, of grain size up to 0.015 mm, occasionally with scattered dolomite crystals. The matrix may be preferentially dolomitized.

In the specimen apparently from the undulating bed capping the bioherms, the interspaces are filled with markedly upward concave laminated, recrystallized lime mud, without intraclasts. The laminae are somewhat thicker (approximately 1 mm) and more regular than those of the stromatolite columns.

Secondary Alteration

Even the finest calcite laminae have probably undergone some recrystallization to form a very fine grained calcite mosaic. Dolomitization apparently post-dates this, as subhedral dolomite crystals cut across the calcite mosaic. In places, especially near column margins, laminae are completely reconstituted to a coarse, xenotopic, polygonal calcite mosaic, of grain size up to 0.5 mm; these, in turn, contain subhedral dolomite crystals, as well as disrupted remnants of micritic laminae.

The origin of the unlaminated selvage is not clear; wherever it was observed, laminae are somewhat coarsely recrystallized immediately adjacent to it inside the column, and the selvage may simply be the outermost lamina of the wall preserved from recrystallization. This is not certain, however, since the selvage is unlaminated, and laminae cannot usually be traced directly into it.

There are at least two generations of calcite veins; the earlier are more irregular, and finer grained, and contain dolomite rhombs, indicating that they pre-date at least one period of dolomitization. The younger veins are straight, more coarsely crystalline, and post-date dolomitization. Dolomitization in these stromatolites is at least in part, very late diagenetic.

Comparisons:

In having long, straight, infrequently branching columns without rapid changes in diameter, these stromatolites are distinguished from all but *Minjaria* Krylov and *Jurusania* Krylov. They are distinguished from other alpha- to beta-parallel branching stromatolites (*Boxonia* Korolyuk, *Acaciella* Walter and *Katavia* Krylov) by their infrequency of branching. *Minjaria* Krylov, however, has a ubiquitous wall and lacks peaks and overhanging laminae. *Jurusania* Krylov may have either a patchy wall or no wall, numerous peaks, and frequently a selvage covering columns. *J. burrensis* is intermediate between *Minjaria* and *Jurusania* but is assigned to the latter because of its patchy wall and the presence of peaks. *J. burrensis* differs from *J. cylindrica* Krylov in having a better developed wall, smaller and fewer peaks, and less well defined lamination; however, lamina shape is similar. J. tumuldurica Krylov is distinguished by its consistent, well defined ribs and general absence of a wall. J. burrensis is distinguished from J. nisvensis Raaben and J. chewingsi Walter by its much more even, smooth columns which do not grade into or alternate with pseudocolumns and laterally linked stromatolites; also, there are no sharp changes in lamina shape as in the latter two forms. J. judomica Komar & Semikhatov has larger, often strongly elongated columns, lacking a wall.

Distribution: Upper member of Wundowie Limestone, Burr Well, Northern Flinders Ranges, South Australia (Fig.25).

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

GROUP KATAVIA Krylov

Katavia Krylov (1963, p.94)
Katavia (Raaben, 1969a, p.83)
Katavia (Glaessner, Preiss & Walter, 1969, p.1057)

Type Form: Katavia karatavica Krylov, from the Katav Suite of the Southern Urals.

Diagnosis: Predominantly beta-parallel branching straight, subcylindrical, walled columns with a markedly bumpy margin structure.

Content of the Group: Katavia karatavica Krylov and Katavia costata Preiss.

Age: Late Riphean.

Katavia costata f. nov.

Katavia sp. nov. Glaessner, Preiss & Walter, 1969

Pls. 19, 20a,b; Fig. 14i to o

Material: Seven specimens from one locality.

Holotype: S175 (Pl.19c; Fig.14i,j,l,m,n,o).

Name: Latin costata, meaning "ribbed", refers to the short ribs present on the lateral surface of columns.

Diagnosis: Katavia with very closely spaced parallel columns, a thin wall, very indistinct, wrinkled laminae, and a prominently bumpy and ribbed margin structure with some very short, pointed projections.

Description:

Mode of Occurrence

The stromatolites form two lenticular bioherms, 5 m thick, and up to 100 m long, in the upper, pink dolomite member of the Brighton Limestone equivalent. The basal one metre consists of wrinkly flat-laminated dolomite, with concordant stylolites. This zone gives rise directly to narrow, parallel columns (Pl.20b; Fig.14k), which continue throughout the height of the bioherm (Pl.19a,b). At frequent intervals columns are cut by horizontal, concordant stylolites. The upper surfaces of the bioherms are not exposed. At the margins of the bioherms columns become inclined at about 45° (Pl.19a), but no horizontal columns were observed.

Column Shape and Arrangement

Columns are long, straight, very closely spaced, varying in diameter from 0.5 to 3 cm, most commonly 1 to 2 cm (Pl.19b). Most columns are vertical, except near bioherm margins. Cross-sections are round to polygonal, often resembling mud-cracked polygons (Pl.19d). Columns do not swell and constrict rapidly, but usually widen gradually before branching. Columns may be from 5 to 20 cm long between branches. Occasional columns are only a few centimetres long before terminating. Such columns may be rounded or pointed (Fig.14i,j,l,m,n,o).

Branching

Branching is moderately frequent, predominantly beta-parallel: a column 1.0 to 1.5 cm in diameter widens gradually to 2 to 3 cm, then divides into two, less often three, narrower columns (1 to 1.5 cm in diameter). Alpha-parallel branching from broad columns does not occur. Some branching is very slightly divergent.

Margin Structure

The lateral surface of columns is markedly bumpy and ribbed (Fig.14i to o). Equidimensional bumps, 0.3 to 1.0 cm in diameter, with a relief of 2 to 5 mm are most common. These grade into transversely elongated ribs, which partly surround the columns. Small, pointed projections up to 1 cm long, are moderately frequent (Fig.14j,l), and in places there are slight niches in the column margin (Pl.19c). Overhanging peaks are extremely rare, and bridges are absent in the specimens studied.

Near the column margin, laminae turn down steeply to cover the lateral surface for short distances, so that only two or three laminae form the wall (Pl.19c). The wall is developed almost everywhere, covering all bumps, ribs and projections.

Lamina Shape

Laminae in the basal, flat-laminated portion are poorly preserved, but appear to be wavy and wrinkled. The lowest narrow columns generally have gently convex, wavy and wrinkled laminae, but the degree of convexity increases upwards. Undulations have a wavelength of 2 to 5 mm. Fig.211 illustrates commonly occurring lamina shapes. Most laminae (62% of those measured) have $^{h}/_{d}$ between 0.3 and 0.5 (Fig.221). Most laminae are hemispherical, but some approach rectangular shape. Laminae near the most bumpy column margins are commonly strongly wavy.

Microstructure

The layering in all specimens is extremely indistinct. Where best preserved, it consists of alternating relatively lighter and darker, pale brownish stained dolomite laminae, many of the light laminae containing detrital quartz sand grains. The sand grains are restricted to the central parts of columns, and do not occur on the steep sides of laminae.

Light laminae have extremely indistinct boundaries. They vary in thickness from 0.3 to 2.0 mm, and thin markedly towards the column margins. The included sand grains are subrounded to subangular, and vary in diameter from 0.05 to 0.5 mm. The dolomite is hypidiotopic, of inequidimensional crystals, and of grain size ranging from 0.005 to 0.025 mm, often showing approximate rhombic outlines. There are variations in the intensity of the brownish pigmentation present in the crystals.

Dark laminae are extremely fine grained, and more densely stained reddish-brown. They vary in thickness from 0.05 to 0.5 mm, and are most clearly visible and thickest in the marginal portions of columns. In the central portion, they are thin, markedly wrinkled, and discontinuous, frequently consisting of lenses only 1 or 2 mm long. Towards the margin, dark laminae frequently merge.

Interspaces

The interspaces are extremely narrow, between 1 and 5 mm wide, most commonly 1 to 2 mm. The sedimentary filling is unlaminated and consists of equal proportions of sand and dolomite matrix. Quartz sand grains are subrounded, and commonly 0.2 to 0.5 mm in diameter, but a few are up to 2 mm. Feldspar and red, extremely fine grained, possibly igneous rock fragments are subordinate. The matrix consists of hypidiotopic to xenotopic dolomite, with equidimensional crystals ranging in size from 0.005 to 0.03 mm, patchily recrystallized to hypidiotopic sparry dolomite of 0.03 to 0.05 mm grain size.

Intraclasts of pale brownish fine grained dolomite, up to 5 mm long, 2 mm wide, occur in places mixed with sand grains. These probebly represent fragmented algal laminae.

Secondary Alteration

The generally poorly preserved microstructure of stromatolitic and interspace dolomite and its corrosion of quartz grains suggest that it is secondary. Small irregular patches of recrystallized, fine sparry dolomite are scattered throughout columns and interspaces. Layering in stromatolitic columns is extremely indistinct, and defined only by slight variations in grain size and pigmentation; this general homogeneity may be partly due to dolomitization. Dark laminae are in places disrupted, perhaps by recrystallization of the intervening light laminae.

All detrital quartz grains have corroded margins, usually surrounded by a thin rim of finely crystalline sparry dolomite. Authigenic chlorite is developed in places in the interspace sediment near column margins.

Small stylolites are developed locally near column margins but are unimportant. Frequent large stylolites, concordant with bedding, were seen in the field (Pl.19a). These are up to 1 cm wide, and contain marked concentrations of sand and authigenic chlorite. There is generally little displacement along stylolites.

Comparisons:

The stromatolites are assigned to the group Katavia because of their beta-parallel branching, bumpy, walled columns. They are distinguished from most other walled stromatolites by their markedly bumpy margin structure, and from Patomia Krylov by their predominant simple, beta-parallel branching. Like the illustrations of Katavia karatavica Krylov, K. costata has a few very short pointed projections. It is extremely similar to K. karatavica in its gross form, microstructure and margin structure, and is distinguished only by its more closely spaced columns and by the possession of short transverse ribs.

Distribution: In two bioherms, upper (dolomite) member of the Brighton Limestone equivalent, 2 mile NNW of Depot Flat H.S., Southern Flinders

Ranges (Fig.24).

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

GROUP *KULPARIA* Preiss & Walter

Patomia sp. nov., Glaessner, Preiss & Walter (1969, p.1057)

Type Form: *Kulparia* *kulparensis* Preiss, Etina Formation equivalent, Umberatana Group; Yorke Peninsula, South Australia.

Name: After the township of Kulpara.

Diagnosis: Long, nearly straight, parallel bumpy columns, erect or radially arranged with very frequent coalescing and bridging, moderately frequent alpha- and beta-parallel branching and a wall between bridges; projections may be moderately frequent.

Content: *K. kulparensis* Preiss and *K. alicia* (Cloud & Semikhatov) Walter.

Comparisons:

In gross form, Kulparia resembles *Minjaria* Krylov and *Boxonia* Korolyuk, but is distinguished by its bumpy column margins with frequent bridging and coalescing. Like *Katavia* Krylov and *Patomia* Krylov, it has a walled, bumpy margin structure; *Katavia* columns have beta-parallel branching, no bridges and they rarely coalesce, while *Patomia* has frequent slightly divergent branching and very numerous pointed projections. Some illustrations of *Patomia* *ossica* Krylov, from the Malokaroy Suite, resemble *Kulparia* in having bumpy, long subparallel columns with fewer projections, but lack the frequent coalescing and delicate bridges of *Kulparia*. *Kulparia* *kulparensis* was initially assigned to *Patomia* on the basis of this similarity (Glaessner, Preiss & Walter, 1969). *Kulparia* differs from *Linella* Krylov in lacking gnarled and tuberous columns, and from *Gymnosolen* Steinmann in lacking gamma-parallel branching. In gross form, *Kulparia* resembles the walled parts of *Inzeria intia* Walter but is distinguished by the absence of niches and elongated projections.

Distribution: Etina Formation equivalent, South Australia and Bitter Springs Formation, Central Australia.

Age: Adelaidean.

Kulparia kulparensis f. nov.

Pls. 20c to f, 21a,b,c,d & f: Fig. 15

Patomia sp. nov. Glaessner, Preiss & Walter (1969, p.1057)

Material: Eleven specimens from one locality.

Holotype: S380 (Pl.21b,c; Fig.15a,b,c,e,i).

Name: Type form, named after the township of Kulpara, Northern Yorke Peninsula.

Diagnosis: *Kulparia* with very frequent delicate bridges, moderately frequent pointed projections and variable lamina shape, from gently to steeply convex. Microstructure is diffuse, irregularly streaky.

Description:

Mode of Occurrence

The stromatolites occur in an extensive bed, traced for at least 400 m;

its northern extension is not known, while its termination in the south can be located only approximately, due to lack of exposure. The stromatolitic bed is up to 13 m thick, and occurs at the passage from flaggy pale grey clean limestone to massive, gritty, cross-bedded limestones.

The basal portion of the bed (A) (Fig.29j), commencing conformably upon the flaggy limestones, consists of short, partly divergently branching columns and pseudocolumns, in thin beds up to 15 cm thick, with numerous bridges and continuous, nearly flat-laminated layers. This is overlain by a broadly domed biostrome (C) of long, narrow, vertical, parallel, very closely spaced columns, arising from a laterally linked zone and short, broad, basal columns (B). The upper surface of the biostrome of long parallel columns bends downwards sharply at the junctions between domes, columns becoming inclined, and to some extent pseudocolumnar.

The domed biostrome pattern is repeated in the overlying undulose and pseudocolumnar bed (D), again passing up into long, parallel columns (E). This is once more overlain by laterally linked and pseudocolumnar layers (F). Gritty, cross-bedded limestone overlies the stromatolitic sequence.

(Note: contacts between the various units cannot be accurately placed in the field, due to poor exposure and lichen cover, but were partly deduced from laboratory study of specimens). (Fig.29j).

Column Shape and Arrangement

Unit (A) consists of short, vertical to slightly inclined columns, 5 to 20 mm wide branching frequently from a wavy laminated layer. Columns swell and constrict slightly, bear rounded bumps and occasional ribs, and coalesce frequently. Some columns terminate their growth as pointed projections (Fig.15j,k,l; Pl.20e).

The overlying unit (B) is in part columnar. If present, columns are broad, up to 6 cm wide, with very irregular, bumpy outlines and numerous massive bridges, and grade laterally and vertically into pseudocolumns with occasional interspaces.

In the main columnar units (C) and (E), columns are 1 to 3 cm wide, swelling and constricting slightly (Pl.20c, 21a,b,c). A few branches develop only into short, pointed projections (Fig.15f,g). The length of long, parallel columns between branches varies from 5 to 20 cm; the unit as a whole attains a thickness of up to 2 m, but columns are not continuous throughout, as pseudocolumnar horizons intervene. Transverse sections of columns are generally rounded polygonal, lobate, elongated or irregular; circular sections are relatively rare (Pl.20d).

At the dome edges, columns become slightly inclined (never at less than 60° to the horizontal), and are bridged to a greater extent, forming pseudocolumns resembling those in units (B) and (D) (Fig.15d,m). Horizontal or gently sloping columns do not occur.

Branching

The basal columns of unit (A) are characterized by frequent, slightly divergent branching (Fig.15j,k,l). The long, parallel columns of units (C) & (E) are entirely alpha- and beta-parallel branching. Near their bases, broad columns and pseudocolumns (4 to 6 cm wide) branch into several narrower (1 to 3 cm) columns (alpha-parallel branching). Above this level, alpha- and beta-parallel branching are moderately frequent. Coalescing of neighbouring columns occurs as frequently as branching.

Margin Structure

All columns have a markedly bumpy lateral surface; bumps 0.5 to 1.0 cm wide, with a relief of 1 to 5 mm are most common. Most are equidimensional, but some grade into short transverse ribs, others into short pointed projections (Fig.15f,g). Longer pointed projections (up to 3 cm) are moderately rare (Fig.15g).

Delicate bridges, composed of only one or two laminae, are very frequent, linking most adjacent columns (Pl.21b). They are usually depressed, U-shaped. (Note: only the more prominent bridges could be shown on reconstructions). Massive bridges up to 2 cm thick are moderately rare. Successive delicate bridges may in places be only 5 mm apart. Occasional very short peaks project down from the column margins.

Wherever peaks and bridges do not occur, a wall is well developed. The wall is most extensive in the long, narrow columns. Laminae thin towards the margin, and coat the surface for a distance of up to 1.5 cm. The wall is from one to five laminae thick (Pl.21f).

The short basal columns of unit (A) have only a patchy wall, as do dome of the long columns with gently convex laminae (Pl.20e).

Lamina Shape

Lamina shape is very variable; generally narrowest columns have steepest laminae, while broad basal columns and pseudocolumns have gently convex and rectangular laminae. Of the laminae measured, 69% have ratios of $^h/_d$ between 0.3 and 0.8, but narrow columns and projections usually have $^h/_d$ greater than 1.0 (Fig.22m). Fig.21m illustrates commonly occurring lamina shapes.

Most laminae are gently wavy, usually with wavelength of from 2 to 3 mm.

Microstructure

Lamination is indistinct and streaky (Pl.21f). Where best preserved, fairly continuous wavy dark laminae persist from wall to wall, and alternate with light laminae. Dark laminae are composed of very fine grained silty limestone, consisting of equidimensional xenotopic calcite of grain size varying from 0.003 to 0.01 mm, with included subrounded quartz and a little feldspar, of grain size up to 0.08 mm. The dark laminae vary in thickness from 0.05 to 0.4 mm, and are generally thickest in the central part of a column. Their boundaries are diffuse. At column margins, the dark laminae thin (to a thickness of about 0.05 mm) and coat the surface of the column. The intervening light laminae are thinned more, and lens out some distance down the wall, so that here the dark laminae merge.

Light laminae are up to 0.7 mm thick in the central parts of steeply convex laminated columns, but thin rapidly towards the edges. They consist of inequigranular xenotopic to hypidiotopic calcite of grain size from 0.015 to 0.05 mm, with minor rounded quartz silt, of grain size up to 0.08 mm.

In the short columns of unit (A) lamination is better preserved (Pl.20e). Dark, homogeneous laminae, 0.15 to 1.0 mm thick, are composed of pale brownish and greenish pigmented, almost equigranular xenotopic calcite, of grain size 0.003 to 0.01 mm, with inclusions of detrital quartz silt of grain size 0.02 to 0.04 mm. In places, they have sharp lower boundaries, but grade upwards into light laminae. Light laminae are 0.3 to 1.5 mm thick, but thin towards the column margins. They are composed of slightly coarser, silty, xenotopic calcite, of grain size from 0.015 to 0.02 mm. Detrital quartz grains are up to fine sand size (0.2 mm). All laminae extend uninterrupted across the width of columns, unlike laminae in the upper, long parallel columns.

Interspaces

The interspaces are generally very narrow (1 to 5 mm) in units (C) and (E), but wider in the basal columns of unit (A). Their sedimentary fill includes medium to coarse clastics, both terrigenous and carbonate. Generally, quartz is much coarser than that incorporated into columns. The approximate composition of the sediment is as follows:

Quartz: 40%	Well-rounded, of grain size from 0.5 to 3 mm, finer grains tending to be subangular.
Feldspar: 5%	Rounded to subangular cloudy microcline, up to 3 mm grain size.
Rock Fragments: 5%	Rounded fragments, up to 4 mm, of quartz-feldspar rock, quartzite and rare chert.
Carbonate Allochems: 30%	Includes flat pebbles, 2 to 4 mm long, flat pebbles coated with 3 or 4 pale and dark laminae, recrystallized ooids with dolomitic rims and

	rare composite grains cemented by dark dolomitic rims.
Cement: 20%	Sparry cement, of grain size 0.015 to 0.060 mm of hypidiotopic mosaic calcite, cements allochems and terrigenous detritus, in places replacing the rims of these grains.

The sediment is poorly bedded. The presence of a wall between bridges on columns indicates that sediment was filled in periodically. After one influx of sediment, a bridge formed over it, then the interspace remained vacant while the column grew another centimetre or so, before the next influx.

Secondary Alteration

During diagenesis, the carbonate of the long columns was partly recrystallized and dolomitized; some dark laminae were preferentially dolomitized, and apparently redistributed into a fine network of cracks and stylolites (Pl.21f). In places, the shape of laminae is completely disrupted. Near the dome margins, lenticular patches of sparry calcite occur within columns, either concordant with the laminae or at a high angle to them. These structures are earlier than clastic dykes which cut both stromatolite columns and interspace sediment (both of which must have been lithified at the time).

The filling of the dykes consists of angular to subrounded, poorly sorted quartz, ranging in grain size from 0.05 to 1 mm. The sand is tightly packed, the finest angular grains forming the matrix. Calcite cement is almost totally absent. Quartz grains are coated with iron oxide rims. In places, the filling has actively eroded the walls of dykes, so that disoriented fragments of the surrounding limestone occur as inclusions in the sand (Pl.20f, 21d; Fig.15m). The dykes probably formed by jointing of the already lithified stromatolitic bed, especially between adjacent domes.

Concordant stylolites, concentrated at definite levels in the structures, where they are only 1 or 2 mm apart, clearly post-date the sand-dykes. Stylolites partly follow the lamination, and partly cut across it.

Vertical calcite veins up to 1 cm wide, consisting of coarse, euhedral crystals, post-date the stylolites, and are especially prominent in the junctions between domes, which were persistently subject to jointing (Pl.21d). Dolomitization apparently post-dates the formation of veins and stylolites, and is therefore very late diagenetic.

Comparisons:

These stromatolites have already been compared to other groups. Kulparia kulparensis is distinguished from K. alicia (Cloud and Semikhatov) Walter, by its frequent delicate bridges, generally more steeply convex laminae, and by the presence of moderately frequent pointed projections.

Distribution: Etina Formation equivalent, Umberatana Group, 4 miles south of Kulpara, Northern Yorke Peninsula (Fig.29i).

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

GROUP LINELLA Krylov

Linella Krylov (1967, p.37)

Type Form: *Linella ukka* Krylov, from the Uk Suite of the Southern Urals.

Diagnosis: Bumpy, subcylindrical or tuberous columns with parallel to markedly divergent branching and numerous, often pointed, projections. Columns usually have walls.

Content: *L. ukka* Krylov. *L. simica* Krylov, *L. avis* Krylov and *L. munyallina* Preiss.

Age: Apparently only Vendian in the USSR, but in Central Australia, *L. avis* occurs in rocks correlated with the Late Riphean (Walter, 1970). In South Australia, *L. ukka* is probably youngest Late Riphean (See discussion, Ch.8).

Linella ukka Krylov (1967, p.39)

Pls. 21e,g, 22a,b,c,e; Fig. 16a to h

Material: Four specimens from one locality.

Description:

Mode of Occurrence

The stromatolites form lenticular beds, not more than 20 m long, consisting of adjoining 2 m diameter domed bioherms. The whole bed is never more than 0.5 m thick. In the centres of individual bioherms, columns are vertical or variously inclined (Pl.22a), but at the bioherm margins they become uniformly reclined (Pl.21g). Margins of adjacent bioherms are poorly defined. At one point, at the edge of a lenticular bed, the columns were observed to commence growth vertically, but then to curve over, and grow horizontally outwards.

Biohermal beds grade laterally into laterally linked hemispheroidal and pseudocolumnar stromatolites, which intertongue with the underlying intraclastic limestone. They are overlain by oolitic limestones or grey calcareous shales.

Column Shape and Arrangement

Columns are subcylindrical to tuberous, sometimes slightly flattened in various directions. Transverse sections are round, oval, rounded polygonal or complexly lobate, of diameter 1 to 8 cm. Columns may swell and constrict markedly over a length of a few centimetres. The length of columns between branches is usually less than 5 cm, but individuals reach a height of up to 30 cm (Fig.16a to h). Columns may be variously oriented, from vertical and parallel to inclined at up to 45^{0} to the vertical, but at bioherm margins columns are radially or horizontally arranged (Pl.21g).

Branching

Branching is frequent and varies in style from beta-parallel, to gamma-parallel, to slightly divergent, to markedly divergent. Moderately divergent branching is the most frequent (Pl.21e, 22b,c). Columns may be constricted at the base of branching (Fig.16a). Approximately 50% of branching does not result in new complete columns, but forms narrow, pointed, or sometimes slightly flattened outgrowths 1 to 4 cm long, generally less than 1 cm in diameter (Fig.16a to h). These pointed outgrowths are also variously oriented, and may project at a high angle from the main column.

Coalescing of adjacent columns is moderately frequent.

Margin Structure

Column margins vary from smooth to gently bumpy; occasionally bumps of approximately 1 cm diameter occur. Very short ribs are rarely present. Short overhanging peaks occur in a few places, especially near points of bridging. Bridges, where present, consist of many laminae. By far the greatest surface area of columns bears only smooth rounded bumps, and in places, short pointed projections.

A wall is present on the whole lateral surface not affected by peaks and bridges. Laminae of various shapes bend down steeply at the margins, and cover the lateral surface, to form a wall up to 3 mm thick. The number of laminae participating is difficult to estimate, due to secondary recrystallization (Pl.22e). Columns are sometimes coated with a selvage of fine sparry calcite, of xenotopic equigranular texture and grain size of 0.01 mm. The selvage is up to 1.5 mm thick and post-dates the formation of the wall, but pre-dates the filling of the interspace.

Lamina Shape

Lamina shape varies greatly within single columns, from almost flat or rectangular to very steeply convex (Fig.21n). The majority (79% of laminae measured) have $^{h}/_{d}$ between 0.2 and 0.6 (Fig.22n).

Laminae are very poorly preserved, so that their detailed shape is difficult to estimate. Most are smooth, but some are finely wavy, with a wavelength of 2 to 3 mm. Single laminae are difficult to follow across a whole column width. The degree of inheritance of lamina shape varies along a column length; in places laminae change rapidly from gently convex or rectangular to steeply convex.

Microstructure

Microstructure is poorly preserved, and the lamination is extremely indistinct. There is little contrast between light and dark laminae, except a slight difference in pigmentation and in grain size.

Dark laminae are smooth to slightly wavy and lenticular, of thickness 0.1 to 0.4 mm. Single laminae cannot be traced right across columns, partly because of recrystallization. Upper and lower boundaries are very diffuse and more or less parallel. In most places, laminae are reduced to aligned lenses of fine grained carbonate. Dark laminae consist of hypidiotopic to xenotopic inequigranular calcite, of grain size ranging from 0.003 to 0.015 mm. Most crystals are slightly pigmented pale grey (possibly an organic pigment). In one specimen, dark laminae are dolomitized. Subangular quartz silt of grain size from 0.02 to 0.05 mm occurs in places in both dark and light laminae.

Light laminae are 0.2 to 0.6 mm thick, and as discontinuous as the dark laminae between them. They consist either of acicular, or equidimensional mosaic calcite. Acicular crystals are 0.01 to 0.02 mm wide, and are arranged perpendicular to the laminae, and often extend also into the dark adjacent laminae. They are therefore clearly secondary. The equidimensional calcite is xenotopic, of grain size from 0.02 to 0.04 mm.

Interspaces

Interspaces between columns are filled with poorly bedded intrasparite, with a few micrite bands. Allochems which include fine pellets of dense, dolomitized micrite, 0.02 to 0.1 mm in diameter, and small, flat, curved or irregular intraclasts up to 0.5 mm long, are packed and mostly in contact. They are cemented by transparent sparry, xenotopic calcite of grain size up to 0.2 mm. A few crude bands of dolomitized micrite, up to 1 cm thick, occur in places. These are extremely dense, fine grained, but contain some pellets and intraclasts.

Secondary Alteration

Stromatolite columns are severely recrystallized, especially near column margins (Pl.22e). Here laminae are severely disrupted by lenses and irregular patches of recrystallized, xenotopic to hypidiotopic sparry calcite, of grain size up to 0.2 mm. The laminae are reduced to small, irregular or curved, disoriented remnants; in places a secondary grumous texture is developed. In addition there are numerous irregular lenses, up to 3 to 4 mm thick, of nearly opaque, white, fine dolomite, aligned parallel to the lamination (Pl.21e). The dolomite is equigranular, hypidiotopic, of grain size ranging from 0.01 to 0.02 mm. Most intraclasts in the interspaces are also dolomitized, or at least surrounded by dolomitic rims, but the sparry cement is unaffected.

Straight and irregular calcite veins post-date the dolomitization. Stylolites occur in places cutting across all structures of the rock, but were not seen in thin sections. Nodules of coarsely crystalline calcite similar to those in Inzeria cf. tjomusi from Burr Well are locally present.

Comparisons:

The stromatolites are identified as Linella by their bumpy, subcylindrical and tuberous, parallel to markedly divergent branching, walled columns, and numerous pointed projections. Many specimens of Baicalia have similar gross shape, but lack the almost ubiquitous wall and the numerous pointed projections of Linella. They are assigned to Linella ukka Krylov on the basis of column shape, style of branching, and margin structure. Unlike L. simica Krylov, ribs are poorly developed or absent. Its columns are more broadly bumpy, more divergently branching, and less gnarled than those of L. avis Krylov. Longitudinal sections of the stromatolites are identical to those of Russian L. ukka (Pl.21e).

Microstructure is less well preserved than in the Russian specimens, but lamina shape is very similar.

Linella ukka from Burr Well is very similar in microstructure, margin structure, lamina shape and mode of preservation to Gymnosolen ramsayi from limestone clasts in the Tapley Hill Fm, but is distinguished by its bumpier, more tuberous, divergently branching columns. Krylov (1967) described Tungussia bassa as a separate form, but states that it occurs at the margins of Linella ukka bioherms. Similarly, at Burr Well, inclined and horizontal columns occur at bioherm margins, but these are here included in Linella ukka.

Distribution: Uk Suite of the Southern Urals and in beds correlated with the Klyktan Suite of the Central Urals, USSR; top of the Balcanoona Formation, Burr Well, Northern Flinders Ranges, South Australia (Fig.25). Linella aff. L. ukka (Cloud and Semikhatov, 1969) occurs in the Johnnie

Formation, South Ibex Hills, California, USA.

Age: Late Adelaidean; in the USSR it is apparently restricted to the Vendian.

Linella munyallina f. nov.

Pls. 22d,f,23,24,25,26a,b; Figs. 16i to q,17,18a to c

Material: Twenty-six specimens from seven localities.

Holotype: S495 (Pls.24d,26b; Fig.17f,g,i,j,k,l).

Name: After Munyallina Valley, where the stromatolites of the Arkaroola area occur.

Diagnosis: Linella with dominantly parallel branching, a wall that is discontinuous on some columns, and with highly variable lamina shape. Columns are gently bumpy, and pointed projections are subordinate.

Description:

Mode of Occurrence

These stromatolites are widespread in the Wundowie Limestone of the Northern Flinders Ranges, where they occur in domed biostromes and lenticular beds consisting of contiguous domed bioherms, commonly overlain by thin sandy limestones, and/or interbedded in green or red shales. The biostromes vary in thickness in different areas from 50 cm to 2 m, depending on the relief of the individual bioherms they comprise. At Burr Well, individual bioherms are isolated (Pl.24c,e) or contiguous, so that stromatolite beds are lenticular, and recur at different stratigraphic levels. The bioherms here are of ellipsoidal shape, with strongly inclined columns at their margins, and had a growth relief of about 1 m. Laminated shale or limestone fills the spaces between bioherms (Pl.24c,e); in places, sandy limestone laps on to the bioherm margins, and then covers the whole biostrome or bed (Pl.22d).

Transverse sections of bioherms are rarely seen, except where dips are gentle; e.g. near Myrtle Springs, oval bioherms occur (Pl.23b,d), while at Arkaroola, they are sinuous and irregular. Small, isolated bioherms only 30 cm wide also occur at Arkaroola. North of Patsy Springs H.S. (east of Copley), there occur domed bioherms similar to those of *L. munyallina*, but no columns are developed here (Pl.23f).

Column Shape and Arrangement

There is great variability of column shape even within single specimens. Most commonly, columns are vertical or inclined, gently curved, non-parallel and bumpy, varying from subcylindrical to tuberous (Pls.23c, 24,25,26a; Fig.17). Columns vary in diameter from 1 to 8 cm, and swell and constrict moderately throughout their length. Transverse sections are commonly oval, variously elongated, lobate or rounded-polygonal, occasionally circular. Columns are up to 10 cm long between branches, but individuals attain a height of about 50 cm. The terminations of columns may be either rounded or pointed (Fig.17d,f,g,i,l).

The origin of columns from wavy-laminated stromatolite of bioherm cores is illustrated in Fig.17r,s and Pl.25b (specimens from Willouran Ranges).

Columns are poorly developed in the bioherms at Arkaroola, where they are bridged over after a few centimetres of growth (Pls.24f,25c,e).

Branching

The mode of branching is variable, but most commonly subparallel. Both alpha- and beta-parallel branching are usually present, but some specimens have gamma-parallel and moderately divergent branches (Fig.16m; Pl.26a). Branching is very frequent.

In all specimens, there are a few branches which do not grow into large columns, but terminate as narrow, pointed projections, 1 to 4 cm long, often less than 1 cm wide (e.g. Fig.17d,e). These projections may either be parallel to the main column, or diverge from it laterally. Projections are subordinate to normal branches.

Margin Structure

Columns are moderately bumpy; in general the bumps are low, rounded, 1 to 3 cm in diameter and with a relief of usually less than 0.5 cm. Bumps may grade into short pointed projections. Some columns from Myrtle Springs are rather smooth (Fig.17f,i,l).

The margins of columns are mostly walled, but for short distances, the wall may be absent. Short overhanging laminae and peaks are present moderately frequently, while adjacent columns are sometimes linked by bridges of varying thickness. Some inclined columns at bioherm margins at Burr Well are largely unwalled (Pl.24g). In many outcrops, columns are seen to be bridged over at the top.

The wall is formed by the marginal portions of both steeply and gently convex laminae covering the lateral surface of columns. The number of laminae participating in the formation of the wall is difficult to estimate, due to recrystallization of the wall zone, but well preserved specimens from Myrtle Springs show that up to 20 laminae may be involved; the wall zone is up to 0.5 cm thick (Pl.26b).

Lamina Shape

Lamina shape is highly variable (Fig.21o), with a large spread of values of $^h/_d$ from 0.2 to 1.3; the greatest variability is seen in single specimens at Myrtle Springs, and laminae from other areas fall within this range. 76% of laminae measured have $^h/_d$ between 0.3 and 0.7 (Fig.22o). The most steeply convex laminae occur in the pointed columns at Myrtle Springs, where they approach subconical shape; otherwise laminae are smoothly domed, rarely rectangular or flattened.

On a finer scale, well-preserved laminae are smooth or very gently wavy; no primary wrinkling is seen, although in some specimens, recrystallization has embayed laminae so as to produce a secondary wrinkling.

Microstructure

Microstructure is best preserved in specimens from Myrtle Springs, where it is seen to consist of thin, even, light and dark laminae, which are generally continuous, but may be cut by small scale micro-unconformities. Both lamina types thin markedly and become more distinct towards the column margins. Laminae are especially prominent in the wall zone, where they are of uniform thickness of 0.05 to 0.1 mm, with smooth, parallel boundaries, but lens out gradually down the column margin (Pl.26b). Here dark laminae, composed of an interlocking mosaic of xenotopic calcite, of grain size from 0.006 to 0.02 mm, alternate with lighter laminae of similar texture and slightly coarser grain size (0.015 to 0.04 mm).

In the central portions of columns, laminae are 0.1 to 0.5 mm thick, the pale laminae generally being thicker than the dark. The laminae are of similar texture and grain size to those at column margins, but the light laminae contain abundant irregular, xenotopic dolomite crystals ranging in size from 0.03 to 0.05 mm. Microstructures from other areas are less well preserved; frequently the finest laminae have been obliterated by greater dolomitization (e.g. Roebuck Bore, Pl.26a), or by more pervasive recrystallization of the limestone (e.g. Arkaroola, Pl.25e). Small areas with unaltered very thin laminae usually occur as remnants of the original microstructure.

Interspaces

The sediment filling interspaces varies from area to area. At Myrtle Springs, columns are widely separated (from 1 to 10 cm apart), and the interspace sediment is layered, consisting of alternating bands of sand and micritic limestone. The micritic bands are homogeneous, 2 to 25 mm thick, and consist of slightly recrystallized xenotopic calcite of grain size from 0.003 to 0.01 mm with rare, scattered dolomite rhombs. In places algal laminae form continuous bridges capping the tops of columns, but also occur as upward-concave laminated sediment between walled columns, indicating that they post-date the column growth. Such algal laminae may in turn grade up into new columns (Pl.24d). Both the micrite and the algal laminae are scoured in places to a depth of up to 3 cm, and the channels so formed are filled with coarse sand, of grain size ranging from 0.5 to 2 mm, with ooids, minor lime mud, and cemented by fine, sparry and acicular calcite. The growth relief of columns must have exceeded about 5 cm above the surrounding sediment, which was formed by slow deposition of lime mud and periodic rapid deposition of coarse detritus. Intraclastic limestones (often sandy) occur at Roebuck Bore (Pl.26a) (here intraclasts are limestone while their matrix is dolomitized) and Burr Well (Pls.24g,25d). Intraclasts are randomly oriented, slightly rounded, structureless flat pebbles up to 1 cm long, consisting of recrystallized xenotopic calcite of grain size from 0.01 to 0.03 mm. The matrix consists of equigranular, xenotopic dolomite of grain size from 0.05 to 0.08 mm, with minor fine quartz sand and iron-stained dolomitic pellets.

Specimens from the middle member of the Wundowie Limestone at Arkaroola contain banded interspace sediment; the alternating bands, up to 1 cm thick, contain micrite and fine intrasparite respectively, suggesting periodic current action to rework lime mud fragments.

In the upper member of the Wundowie Limestone at Arkaroola, and also at Copley (Pls.25a,e,22f), interspaces are filled with homogeneous fine subangular quartz sand, cemented by minor calcite cement.

Secondary Alteration

Because of almost total removal of column margins by stylolites, specimens from the Wundowie Limestone at Copley cannot be assigned to Linella munyallina with certainty, the wall being only locally preserved. Stylolites along column margins are less prominent in other areas.

Specimens from Myrtle Springs are best preserved, the chief alteration here being partial dolomitization of light laminae.

Alteration of the wall zone by recrystallization of calcite is common in all areas; the outer portions of laminae are recrystallized to an equigranular, hypidiotopic calcite mosaic. Where recrystallization is slight, a few relics of dark laminae are preserved in a sparry calcite mosaic, of grain size varying from 0.03 to 0.05 mm, often with scattered dolomite crystals. With extreme recrystallization, the whole of a column may be affected, resulting in a coarse hypidiotopic mosaic of equidimensional, twinned calcite crystals 0.5 to 2 mm in diameter. A secondary, green clayey mineral forms an interstitial matrix between calcite crystals, and probably represents a segregation of impurities during recrystallization. Even in these cases, the wall is usually preserved as a thin layer of very fine calcite, and the interspace outside it is unaffected. These patches of coarse recrystallization, together with the fine calcite veins they grade into, apparently post-date the dolomitization of light laminae, since relics of this dolomite are preserved within them.

Specimens from Roebuck Bore are very largely dolomitized, appreciable amounts of calcite being preserved only in the columns and in some intraclasts. The interspace matrix is completely dolomitized, dolomitization pre-dating stylolites and calcite veins. The columnar stromatolites at Wundowie Bore have a similar mode of occurrence and gross column shape to *Linella munyallina*, but the margins of columns are totally removed by stylolites. These stromatolites are therefore of uncertain taxonomic position (Pls.23a,24a; Fig.18a to c).

Comparisons:

The stromatolites from the Wundowie Limestone at Myrtle Springs, Burr

Well, Roebuck Bore and the Willouran Ranges are identified as *Linella* on the basis of their branching, bumpy, tuberous columns and the presence of a wall and pointed projections. The specimen from Copley is probably to be included but the identification is uncertain due to the poor preservation of margin structure. Specimens from Arkaroola are also included, although here the columnar beds are thin, and columns rapidly coalesce or are bridged over by wavy-laminated stromatolites.

Linella munyallina is similar to *Kulparia kulparensis* Preiss and *Katavia costata* Preiss in having bumpy walled columns with pointed projections, but the columns of the latter are more closely spaced, subcylindrical and always parallel, with no divergent branching.

Linella munyallina is distinguished from *L. ukka* Krylov by its dominantly parallel branching, fewer pointed projections, the presence of moderately frequent peaks, bridges and unwalled patches of columns. *Linella simica* Krylov has ribbed columns, while *Linella avis* Krylov has more gnarled, thickly walled columns with very frequent pointed projections.

Distribution: Widespread in the Wundowie Limestone, Umberatana Group, of the Northern Flinders Ranges (Figs.25,26): near the West Mount Copper Mine and 3 miles east of West Mount Hut, Willouran Ranges; middle member of the Wundowie Limestone, 5 miles east of Myrtle Springs; lower member of the Wundowie Limestone, Burr Well; middle member of the Wundowie Limestone, Roebuck Bore; and lower and upper members of the Wundowie Limestone, 1 mile south of the Arkaroola Airstrip. Specimens from the Wundowie Limestone at Wundowie Bore and the Wundowie Limestone 2 miles east of Copley are possibly to be included. A small specimen from the South Australian Museum collection (recently supplied by Mr. N. Pledge), found in the Etina Formation near Artipena Hut (Fig.27), east of Martin's Well may also be *Linella munyallina*.

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

GROUP *OMACHTENIA* Nuzhnov

Collenia omachtensis Nuzhnov (1960, p.1422)
Omachtenia Nuzhnov (1967, p.131)

Type Form: *Omachtenia omachtensis* (Nuzhnov), from the Omakhtin Suite of the Uchur Basin, S.E. Siberian Platform.

Diagnosis: Cylindrical and subcylindrical unwalled columns, frequently widening upwards, with numerous cornices and bridges linking several columns. Branching is mainly alpha-parallel; columns are usually vertical, sometimes radiating or curved.

Content: *Omachtenia omachtensis* (Nuzhnov), *O. utschurica* Nuzhnov and *O. givunensis* Nuzhnov.

Age and Distribution: Early Riphean in the Uchuro-Maya region of the USSR, but in South Australia, *O. utschurica* is probably Late Riphean (see Ch.8).

Omachtenia utschurica Nuzhnov

Pls. 26c to f,27,28a to c; Fig. 18d to g

Material: Nine specimens from two localities.

Description:

Mode of Occurrence

The stromatolites form small lenticular bioherms repeatedly intercalated in the very finely laminated calcareous siltstones of the transition between the Tapley Hill Formation and the Brighton Limestone equivalent, south-western Flinders Ranges. Commonly, bioherms develop on erosional surfaces on the underlying laminated siltstones (Pls.26c,28b), and are closely associated with channels filled with imbricated flat-pebble breccias, often surrounding the bioherm. Bioherms are discrete, varying in width from 2 to several tens of metres; their thickness usually does not exceed 1 m. Large dome shaped individuals may occur within bioherms (Pl.26e). After bioherm growth, deposition of silt continued.

All gradations from flat-laminated (Pl.28b), to domed (Pl.27c), club-shaped, pseudocolumnar (Pl.27b) and columnar (Pl.27a) stromatolites exist. Where columns are developed, their axes are mostly vertical, but their sides may slope in various directions, and overhang the interspaces (Pl.27a,d).

Column Shape and Arrangement

Where columns are discrete, they are generally subcylindrical, sometimes widening upwards; they are either vertically or radially arranged. Columns are rarely completely discrete for more than a few centimetres, but are either linked by bridges or completely coalesced. Columns may pass laterally as well as vertically into laterally linked hemispheroids or flat-laminated stromatolites, which may in turn pass into flat-pebble breccia; at least some of the intraclasts are reworked chips of algal mats.

Columns commonly commence growth upon some irregularity of the substratum, e.g. on the erosional surface of the underlying silts (Pl.26c,d,f), or on upturned flat pebbles (Fig.18d).

Columns are mostly circular in cross section, with a diameter of 2 to 15 cm, but may be complexly lobate.

Branching

True branching into discrete columns is moderately rare, but may be multiple (Pl.27a). Branching may be alpha-, beta- or gamma-parallel, sometimes markedly gamma-parallel, or slightly divergent. Branched columns are frequently bridged over again, or coalesce, after a few centimetres.

Margin Structure

Column margins are extremely irregular with numerous short cornices, bridges and overhanging laminae, which drape over the periodically deposited interspace sediment (Pls.26d,27d). Bridges vary in thickness from one lamina to several centimetres. Over intervals without bridges or overhanging laminae, the column margin bears small ribs and bumps, which may represent periods of growth during which interspaces were not filled. Nowhere is a wall developed.

Lamina Shape

Laminae are never steeply convex; in most cases, they are flat-topped, with down-turned edges, i.e. rhombic or rectangular. They may grade both laterally and vertically into continuous flat laminae. Typical lamina shapes are illustrated in Fig.21p. Of 40 laminae measured, 83%

have $^h/_d$ between 0.2 and 0.4 (Fig.22p). If the growth of a column is asymmetrical, laminae are also asymmetrical, but growth always proceeds vertically; although column sides may be sloping, inclined and horizontal columns do not occur. Laminae are smooth, very rarely wrinkled or finely wavy, occasionally with micro-unconformities.

Microstructure

The stromatolite microstructure is distinctly banded and consists of an alternation of sparry and pelletal calcite laminae and fine, granular dolomite laminae (Pls.26d,f,27d,28a,c).

Dolomite laminae are 0.2 to 1.0 mm thick, and thin only slightly towards column margins. Their upper and lower boundaries are more or less parallel; the upper boundary is always sharp and often smooth, while the lower is usually gradational into pelletal laminae. Dolomite laminae contain almost no calcite; they consist of granular, equidimensional hypidiotopic to idiotopic dolomite of grain size ranging from 0.01 to 0.03 mm. At the boundaries, euhedral dolomite crystals protrude into the adjacent sparry laminae. In places, several thin dolomite laminae are grouped to form macrolaminae up to 2 mm thick; here the dolomite laminae are separated by thin, discontinuous lenses of sparry calcite, which may be open space fillings (Pls.27d,28c).

Dolomite layers are overlain with sharp and sometimes slightly eroded contact, by coarsely sparry calcite laminae, varying in thickness from 0.1 to 1.0 mm, which pinch and swell and may lens out laterally. The calcite is hypidiotopic to xenotopic and transparent, consisting of frequently twinned crystals of grain size from 0.04 to 0.2 mm. In places there are lenses of coarser, polygonal calcite of grain size up to 0.6 mm, and rarely, of acicular calcite. Scattered very small dolomite rhombs occur in places.

Sparry calcite laminae grade up into pelletal laminae, consisting of subrounded pellets 0.06 to 0.1 mm in diameter, of fine grained hypidiotopic dolomite (0.01 to 0.02 mm grain size), with clear, xenotopic calcite cement filling the voids. Pellets become more tightly packed upwards, so that they grade into homogeneous dolomite laminae. In one specimen (Pl.27f) pelletal laminae are poorly developed.

Interspaces

Interspaces between columns are filled with intrasparite and pelsparite, periodically interrupted by bridging laminae. Essentially the same sediment occurs outside the bioherms in channels cut into the underlying silts, but there it is bedded, and clasts are imbricated. In the interspaces, the sediment is largely unbedded (Pls.26d,27d); flat intraclasts up to several centimetres long, 1 to 4 mm thick, are randomly oriented and packed together with numerous round to ovoid pellets 0.15 to 0.3 mm in diameter. Pellets and intraclasts consist of equigranular hypidiotopic dolomite similar to that of the dolomite laminae; the intraclasts are likely to have been derived from the erosion of the flat-laminated variety of the stromatolites; pellets are interpreted as comminuted and rounded, repeatedly reworked dolomite intraclasts. Allochems are fairly loosely packed, and in part, must have been matrix supported, but only locally is a lime mud matrix preserved. Most grains are cemented by a clear, sparry cement of xenotopic inequigranular calcite, grain size up to 0.4 mm. What must have been primary lime mud supporting scattered intraclasts now consists of recrystallized hypidiotopic calcite ranging in grain size from 0.05 to 0.1 mm with scattered dolomite rhombs. In places, large allochems or overhanging column margins sheltered the underlying areas from settling mud, and these now filled with coarse, open space filling sparry calcite (Pl.27d).

Secondary Alteration

Dolomite pellets and intraclasts were probably reworked as dolomite, i.e. the original sediment was affected by early diagenetic dolomitization and then redeposited; many intraclasts are long and flat, and could not have withstood transport without being lithified. These allochems were partly supported by lime mud, and partly winnowed, leaving open spaces filled with sparry cement. The time of dolomitization of the dolomitic stromatolite laminae is not clear; dolomite pellets are cemented with sparry calcite, suggesting that the sediment was brought in as dolomite. But dolomite rhombs in the laminae appear to post-date the calcite cement. In addition, dolomite rhombs occur scattered throughout the recrystallized lime mud (now microspar), and the sparry, open space filling calcite. It is likely that minor secondary dolomitization affected the whole sediment after its deposition. Post-depositional pyrite cubes, 0.08 to 0.20 mm wide, are scattered throughout the rock.

Stylolites are rare, and are restricted to broadly conformable types which follow bridging laminae between columns.

In one specimen, there are conformable lenses up to 2 cm long, of acicular calcite (with crystals oriented perpendicular to the lamination). These are almost certainly open space fillings; the overlying lamina is wrinkled asymmetrically, and locally minutely overthrust. The spaces were therefore probably not gas bubbles, but were formed by lateral compression of the mat.

Comparisons:

The columnar and pseudocolumnar portions of this stromatolite accord with Nuzhnov's description of *Omachtenia* in having cylindrical or subcylindrical columns with frequent cornices and overhangs on the lateral surfaces, which are linked by numerous bridges and layers common to several columns. Branching in both is dichotomous or multiple, usually alpha-parallel. Columns are usually vertical or rarely, radiating. As the domed and flat-laminated stromatolites cannot be separated from the columnar and pseudocolumnar portions, these must be included as environmental variations of *Omachtenia*. The stromatolites differ from *Jurusania* Krylov and *Kussiella* Krylov in having more irregular, more frequently branching columns repeatedly linked by bridges. The repeated bridging and characteristic thick, pelletal laminae distinguishes them from the basal portions of *Inzeria conjuncta* and *Acaciella augusta*. *O. utschurica* Nuzhnov differs from *O. givunensis* Nuzhnov in having more gently convex laminae ($^h/_d$ less than 0.5). *O. omachtensis* Nuzhnov has generally narrower columns and some short, lateral outgrowths, and thinner, non-pelletal laminae. *O. utschurica* from the Brighton Limestone is extremely similar to *O. utschurica* from the Uchur River, in gross shape, type of bridges and lamina shape, and differs only in having slightly thicker laminae with pellets.

(Pellets may also be present in O. utschurica as in Nuzhnov, 1967, Pl.11(4)). Omachtenia closely resembles Schancharia Korolyuk in gross shape, lamination and bridging; Schancharia, however, apparently has a thin, one-layered wall (Korolyuk, 1960).

Distribution: The Omakhtin Suite of the Uchur River, S.E. Siberian Platform, and the Brighton Limestone equivalent, Depot Creek and Mundallio Creek, S.W. Flinders Ranges, S.A. (Figs.24,28).

Age: Early Riphean in the USSR, but here it is Late Adelaidean, in beds correlated by other stromatolites with the Late Riphean.

GROUP TUNGUSSIA Semikhatov

Collenia suchotungusica Semikhatov (1960, p.1481)
Tungussia Semikhatov (1962, p.205)

Type Form: Tungussia nodosa Semikhatov, from the Sukhotungusin Suite, Yenisei Mountains.

Diagnosis: Tuberous to subcylindrical, horizontal to vertical columns with frequent, multiple, markedly divergent branching; lateral surface is smooth or with small peaks, and at least locally with a wall.

Content:: T. nodosa Semikhatov; T. confusa Semikhatov; T. sibirica Nuzhnov; T. inna Walter and T. erecta Walter. T. bassa is a lateral variant of Linella ukka Krylov. T. enpiggeni Raaben and T. russa Raaben are insufficiently described and illustrated to allow comparison, and the description of T. arctica Raaben is unavailable. New forms are T. etina and T. wilkatanna.

Age: Middle to Late Riphean, and probably Vendian.

Tungussia etina f. nov.

Pls. 28d to f,29,30a,b; Figs. 18i to n,19

Material: Twenty-eight specimens from ten localities.

Holotype: S435 (Pl.29e; Fig.19c,e,i,j).

Name: After the Etina Formation, in which the stromatolites partly occur.

Diagnosis: *Tungussia* with a wide variation of branching style from subparallel to markedly divergent, a thin, interrupted wall, and thick, pinching and swelling, wavy laminae. Coarse detritus is incorporated in light laminae, if it was available during growth.

Description:

Mode of Occurrence

The stromatolites occur in irregular tonguing bioherms and lenticular beds in the Etina Formation and its extensions in the Northern Flinders Ranges. Exposures are often inadequate to determine the exact shape of the lenses, but generally they are discrete isolated bodies, surrounded by sandy and oolitic limestones.

In the occurrence near Mt Chambers Gorge, the columnar stromatolites overlie irregularly laminated sandy and oolitic limestone (the contact is now stylolitic), and form a lens up to 2 m thick in its thickest part. In places, growth continued on the top of the lens in the form of irregularly wavy and pseudocolumnar stromatolites. At the margins of the bioherm, columns grade laterally into pseudocolumns and wavy laminae, which intertongue with oolitic limestone.

At the Teatree O.S. the stromatolitic bed again intertongues with oolitic limestones, but here columns are more inclined at the bioherm margins than in their centres. Similar relations of stromatolitic bioherms intertonguing with sandy oosparite and intrasparite were observed in the Etina Formation in the Arkaba Hills, Enorama Creek (Pl.28f), Blinman and on the south-western flank of the Enorama Diapir. However, at many locations in the Central Flinders Ranges, the columnar portions are poorly developed.

Column Shape and Arrangement

Well developed columns persist vertically for more than 10 cm only in the sections at Mt Chambers, Enorama Diapir and at Teatree; elsewhere short, irregular columns quickly grade up into linked pseudocolumns. At Mt Chambers, the orientation of columns varies from vertical to variously inclined, to subhorizontal (Pls.28d,29a). Columns from the Teatree locality are also variously inclined, but rarely subhorizontal; some are subparallel (Fig.19b; Pl.28e).

Columns from all areas are tuberous, bumpy, swelling and constricting, or, less commonly, straight, subcylindrical. Short columns from Central Flinders localities are frequently bulbous (Fig.18h,i,j). Bumps and swellings are generally broad and rounded, while constrictions sometimes take the form of deep indentations into the main column, at points of branching (Fig.19d). Some columns branching from the main column are only a few centimetres long, with either pointed or rounded terminations (Fig.19e).

Columns vary greatly in diameter from 1 to 10 cm, the largest occurring at Mt Chambers. Transverse sections vary from elliptical to complexly lobate; circular sections are rare.

Branching

Branching is very frequent and highly variable; even within single specimens, both parallel and markedly divergent branching may occur. Specimens from Mt Chambers have predominantly multiple, markedly divergent branching, although columns may become subparallel soon after branching (Pl.29a; Fig.19a,h). At Teatree, markedly divergent branching and parallel or slightly divergent branching occur together (Pl.30a; Figs.18k, 19a,b,c). Columns from Enorama Creek are frequently truncated by stylolites parallel to overall bedding, so that the style of branching is obscured. Columns from this locality that allowed reconstruction (Fig.18h), show markedly divergent branching.

Margin Structure

Primary margin structure is frequently obscured by stylolites; in some specimens from Arkaba, Teatree and Mt Chambers, almost no column margins are preserved. Where columns are relatively unaffected by stylolites, they are seen to bear thin, interrupted walls, involving two or three laminae only, or very locally, multilaminate walls, e.g. Enorama Creek and Teatree (Pl.29b,c,e). But the latter are affected by pervasive recrystallization, so that commonly only the outer margin of the wall is preserved.

Adjacent columns frequently coalesce, or are linked by massive bridges up to several centimetres thick. Bridges and overhanging laminae are common on unwalled portions of columns, especially from Mt Chambers (Fig.19h).

Column margins are gently bumpy, with occasional short transverse ribs. Most of the surface irregularity of some specimens from Teatree is due to stylolitic solution of column margins (e.g. Fig.18k).

Lamina Shape

Laminae from all specimens are most commonly moderately steeply convex (Fig.21q). Measurement of $^h/_d$ ratio is difficult in some specimens due to removal of column margins by stylolitic solution; thus measured ratios may be too low in these cases. Of 131 laminae measured, 93% have ratios of $^h/_d$ between 0.2 and 0.7, the mode being between 0.3 and 0.4.

The fine scale structure of laminae is moderately to markedly wavy, the undulations having a wavelength of 3 to 10 mm, and amplitude 1 to 5 mm. Laminae are lenticular, and pinch and swell markedly over short distances; this irregularity is caused at least in part by erosional micro-unconformities (Pl.29c).

Microstructure

A broad, irregular lamination is well preserved in some specimens from Teatree, Blinman, Enorama Creek and Mt Chambers. Broad, wavy, pinching and swelling light laminae alternate with darker thin, fine-grained laminae frequently with clay or iron oxide impurities. Light laminae vary rapidly in thickness from 0.2 to 2.0 mm, and frequently lens out laterally; few extend across a full column width. Very commonly, the light laminae are truncated by erosion surfaces, especially in specimens from Mt Chambers (Pl.30b).

Light laminae are composed of equigranular xenotopic to hypidiotopic mosaic calcite, of grain size ranging from 0.006 to 0.03 mm. Occasionally, coarser detritus is incorporated, if it was available. For example, the Enorama Creek stromatolites contain up to 50% of ooids and coated grains, 0.3 to 1.0 mm in diameter, within their light laminae. Elongated ooids and coated grains are aligned parallel to the lamination, and are always supported by the finer detritus of the stromatolitic laminae. Ooids are extremely abundant in the interspaces. Specimens from Teatree contain very few ooids, but here the supply was not great, as seen from the preponderance of lime mud in the interspaces. At Mt Chambers, ooids are absent both in interspaces and stromatolite laminae, but fine sand present in interspaces is also incorporated into laminae. These observations suggest that the algal mats were capable of trapping coarser detritus, if it was brought to the site at the time of growth.

The thin, darker laminae separating the light laminae, are 0.05 to 0.15 mm thick, and composed of very fine micritic calcite, of xenotopic, equigranular texture and grain size varying from 0.003 to 0.01 mm. At Mt Chambers, the dark laminae are emphasized by very fine, hypidiotopic ferruginous dolomite concentrated along them (Pl.29c,e). In places (e.g. Blinman), dark laminae with sharp lower boundaries grade up into light laminae (Pl.29f). At Arkaba, the dark laminae are largely stylolitized (Pl.29d).

Interspaces

Columns are moderately closely spaced, interspaces varying in width from 5 mm to 2 cm.

The type of sediment filling the interspaces varies in the different areas, and its relation to the quantity of detritus in laminae has already been discussed. At Mt Chambers, interspaces are filled mainly with slightly dolomitized and recrystallized partly laminated lime mud, with a few bands up to 2 cm thick of very fine, subangular quartz sand. Flat intraclasts up to 2 cm long are in places stacked vertically in interspaces between walled columns, indicating a minimum relief of 2 cm. Discrete areas of intrasparite suggest that after column growth, coarser detritus was occasionally washed in, between times of settling of lime mud.

At Teatree, interspaces contain poorly bedded micritic limestone and oomicrite; in one specimen (Pl.29b), $\frac{1}{2}$ cm bands of oomicrite and micrite alternate. Ooids are commonly preserved only as moulds infilled with sparry calcite.

Unbedded fine or medium sand with a micrite matrix commonly fills interspaces in the Etina Formation. At Blinman, the sand contains rounded medium grained quartz, red feldspar and green pellets consisting of a chloritic mineral. Since little sand is incorporated into the stromatolitic laminae, the interspaces were probably rapidly filled after, not during, column growth. Interspaces at Enorama Creek are filled with oosparite exclusively - the allochems are chiefly superficial ooids (i.e. ooids with a single outer lamina) and coated, flat intraclasts. Oolitic laminae may be partly detached, perhaps due to the growth of sparry cement.

Secondary Alteration

Specimens from Blinman and Enorama Creek are the best preserved, the chief alteration being the formation of calcite veins, cut by later stylolites parallel to bedding. Dolomitization is restricted to specimens from Teatree and Mt Chambers; rhombs of dolomite varying in size from 0.01 to 0.015 mm, sometimes ferruginous, are scattered throughout both lamina types. Ferruginous dolomite is concentrated in the dark laminae and the interspace sediment at Mt Chambers. Small areas of recrystallization of fine grained calcite to grumous texture are present in all specimens; the wall zone especially may be almost totally recrystallized, leaving only the outer lamina preserved. Light laminae are completely recrystallized in one specimen from Mt Chambers.

Stylolites on column margins are very frequent at Teatree, Arkaba and Martin's Well, post-dating the recrystallization of laminae and replacement of ooids by sparry calcite, but apparently pre-dating dolomitization. Large solution cavities present locally are rimmed with zoned ferruginous dolomite rhombs, then filled with coarse, granular sparry calcite.

Comparisons:

The stromatolites are characterized by a very wide variation of gross morphology, especially branching, which distinguishes them from all parallel-branching stromatolites, although some resemble Inzeria Krylov in having deep indentations into the main column at branching. They are assigned to the group Tungussia on the presence of markedly divergent branching, and walled, subhorizontal columns, and thus differ from the other divergent branching groups Linella Krylov, Baicalia Krylov, Anabaria

Komar, Poludia Raaben and Parmites Raaben. Linella has very numerous pointed projections, and columns are subhorizontal only in the marginal portions of bioherms. Baicalia differs in having chiefly ragged, unwalled, margins, with frequent overhanging laminae. Anabaria has consistent slightly divergent branching, and cylindrical columns. The columns of Poludia are complexly curved and intertwined, while those of Parmites are anastomosing.

Tungussia etina differs from all other forms of the group in its great variation of branching style, and its microstructure. Some specimens closely resemble Tungussia inna Walter in having oolitic, wavy laminae, but T. etina is distinguished by its distinct thicker, pinching and swelling, lamination.

Distribution: Etina Formation and equivalents, Umberatana Group, Central and Northern Flinders Ranges: Balcanoona Formation at Mt Chambers Gorge, and perhaps Teatree O.S.; Wundowie Limestone at Teatree O.S.; Etina Formation near Blinman, Martin's Well, the S.W. flank of the Enorama Diapir, Enorama Creek and the Arkaba Hills area (Figs.25,27).

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

Tungussia wilkatanna f. nov.

Pls. 30c to f,31a to e; Fig. 20

Material: Five specimens from the two localities.

Holotype: S412 (Pl.31b,d; Fig.20a).

Name: After Wilkatanna H.S., 5 miles north-west of the type locality.

Diagnosis: *Tungussia* with smooth to gently bumpy subcylindrical to tuberous, frequently walled columns, with markedly divergent multiple branching and continuous thinly banded, smooth, hemispherical laminae.

Description:

Mode of Occurrence

The stromatolites occur in pale pink to white pure dolomites and possibly also in dark grey dolomites, as extensive biostromes, 0.3 to 2 m thick, interbedded in laminated siltstones and shales. The upper surfaces of biostromes are irregular, undulating, and in places, erosional. Stromatolitic columns arise from flat-laminated or cumulate bases (Pl.30d), growth frequently commencing upon the eroded surface of the underlying shale. In some beds, only the flat-laminated or cumulate stage of growth is attained, in others, up to 2 m thickness of columns develops. Columns are either bridged over at the top by laterally linked hemispheroids, or eroded. Columnar portions may grade laterally along the biostrome into laterally linked hemispheroids.

Column Shape and Arrangement

Columns are subcylindrical to tuberous, bumpy, with swellings and constrictions; portions of columns widen rapidly above a constriction (Fig.20a,b,f). The diameter of columns varies from 2 to 10 cm. Cross-sections vary from subcircular to highly lobate. The orientation of columns is highly variable, both horizontal and vertical columns being common. Bumps and swellings are generally low and broad. Individual columns are 5 to 20 cm high, but the whole structure may attain a height of 2 m.

Branching

Both vertical columns and broad cumuli may arise from the flat-laminated base. These typically give rise to a number of horizontal columns, from which in turn either vertical columns branch upwards, or the horizontal columns themselves turn sharply upwards (Pl.30c; Fig.20a). Columns are frequently constricted at branching, and then expand upwards rapidly. Multiple, markedly divergent, branching from one point is common.

Margin Structure

The lateral surface bears numerous broad bumps of up to several centimetres (Pl.31a,c), but in places columns are quite smooth (Pl.31b,d). Overhanging laminae are relatively rare, and any peaks and cornices present are only a few millimetres long (Fig.20d). A wall is usually present but may be absent; unwalled areas are relatively smooth or finely fringed, the laminae abutting against the column margin at various angles (Pl.31a). In walled areas, the laminae gradually thin and cover the surface for a distance of up to 1 cm. The wall varies in thickness from 1 to 10 laminae (Pl.31a to e). Bridges become prominent near the top of the structure.

Lamina Shape

Most laminae are hemispherical, but gently convex laminae occur in wide columns and in some horizontal columns, especially in unwalled portions. Laminae are smoothly curved, without sharp flexures; their shape is inherited from underlying laminae. Micro-unconformities occur, but are mostly only slight. Fig.21r illustrates some representative lamina shapes. 83% of laminae have $^h/_d$ between 0.2 and 0.5, the mode (33%) being between 0.3 and 0.4 (Fig.22r). In places laminae develop two crests, anticipating branching. Near the margins of columns, laminae thin, and either abut against the margin (in places eroded) or bend over to form a wall. On a fine scale, laminae are either smooth or very gently undulating, with amplitude not exceeding one millimetre.

Microstructure

The microstructure is best preserved in silicified portions of columns; it is finely banded, consisting of alternating thin continuous dark and light laminae; continuity is broken only by micro-unconformities (Pls.30f, 31b). In the less well preserved dolomitic stromatolites, the finest laminae are frequently obliterated and macrolaminae tend to predominate (Pl.31a).

Light laminae vary in thickness from 0.05 to 0.2 mm, most commonly 0.05 to 0.1 mm, but thin towards the column margins where they form the wall. The upper and lower boundaries are parallel, and usually distinct and smooth. No unequivocal detrital grains were seen; some thicker pale laminae are of finely grumous texture, representing partially recrystallized dark macrolaminae. Well preserved light laminae in silicified columns consists of extremely fine transparent chert - a xenotopic aggregate of equidimensional 0.001 to 0.01 mm diameter quartz grains. Where preserved as carbonate, the light laminae consist of xenotopic to hypidiotopic dolomite of equidimensional grains, ranging in size from 0.005 to 0.02 mm.

Dark laminae are generally thinner than the light laminae (0.02 to 0.2 mm, most commonly 0.02 to 0.08 mm). Where well preserved they have smooth, distinct boundaries, and are quite continuous, but in parts of dolomitic columns, they are preserved only as strings of elongated lenses, 0.1 to 0.5 mm long (Pl.31a). Silicified dark laminae consists of extremely fine, pale brownish-grey organic stained chert, of grain size from 0.001 to 0.005 mm. Carbonate laminae consist of xenotopic dolomite of equidimensional grains of size ranging from 0.003 to 0.005 mm.

Macrolaminae, 1 to 3 mm thick, consisting of up to 10 light-dark lamination pairs, occur only in the dolomitic portions of columns (Pls.30e,f, 31a). In places, the fine internal lamination of macrolaminae is obliterated almost entirely, but these grade laterally into unaltered light and dark, very thin laminae.

Interspaces

The distances between neighbouring columns vary from several millimetres to several centimetres. The interspaces are filled with almost completely unbedded intramicrite. Clasts vary in size from 0.5 to 2 cm; most are well rounded, and composed of homogeneous dolomicrite. Some are partially recrystallized to grumous-textured dolomite. Long, flat intraclasts, 0.5 to 1 mm thick, up to 2 cm long, are common near the base of one specimen - these are commonly replaced by coarse sparry hypidiotopic dolomite. Intraclasts are randomly oriented, loosely packed, and generally matrix-supported.

Secondary Alteration

All definite occurrences are found in pale pink to white dolomites; (other specimens from dark grey dolomites at Depot Creek probably also belong to this group but are inadequate for reliable identification: Pls.30e,f,31e). The dolomite generally preserves most fine structure (as in the Skillogalee Dolomite of other areas), but in places is significantly recrystallized.

Silicification of portions of columns occurred after the growth of whole columns, but before partial alteration of the surrounding carbonate, since it best preserves the finest lamination. In places it is possible to trace unaltered very thin laminae from silicified to carbonate portions of columns; in the latter, only broad light and dark macrolaminae are preserved.

The dolomitic nature of the whole unsilicified sediment suggests either penecontemporaneous dolomitization (during stromatolite growth) or trapping of dolomitized lime mud. Silicification therefore probably post-dates dolomitization.

Grumous textures are developed sporadically throughout stromatolite and interspace sediment, and probably formed by partial recrystallization during later diagenesis.

Irregular stylolites, both cutting columns and following column margins, post-date the development of grumous texture. They are commonly rich in limonite, and, in places, pale green chlorite.

Comparisons:

The stromatolites are assigned to the group *Tungussia* on the basis of their multiple, markedly divergent branching and frequent horizontal and gently inclined columns. These characters, in addition to a consistently smoother margin structure and frequent presence of a wall, distinguish them from *Baicalia burra* which occurs elsewhere in the Skillogalee Dolomite.

Tungussia wilkatanna is differentiated from *T. nodosa* Semikhatov by its smoother column margins, smoother, consistently hemispherical and never disharmonic laminae. It resembles *T. sibirica* Nuzhnov in having numerous horizontal columns with upturned ends, but is distinguished by its smoother margin and presence of a wall. *T. wilkatanna* is distinguished from *T. bassa* Krylov in lacking long horizontal columns, and in occurring independently, not as a lateral variant of *Linella ukka* Krylov. Unlike *T. erecta* Walter, it lacks long erect columns, and is distinguished from *T. inna* Walter by its smooth laminae. *T. wilkatanna* most closely resembles *T. confusa* Semikhatov, but is distinguished by its thinner, more continuous laminae of predominantly hemispherical shape. *T. wilkatanna* has more regular and discrete columns of constant shape and branching than *T. etina*, and has thinner, more continuous, smoother laminae.

Distribution: Within the lower third of the Skillogalee Dolomite, Burra Group; South-western Flinders Ranges: Depot Creek and Mundallio Creek (Fig.28). Small specimens possibly to be included, come from near the base and near the top of the formation.

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

Miscellaneous Stromatolites and Stromatolite-like Structures

Pls. 31 to 36

This section is devoted to brief descriptions of interesting occurrences of non-columnar stromatolites, stromatolites which are poorly known, and to problematical stromatolite-like structures.

1. Non-columnar Stromatolites

(a) Stromatolites from the Trezona Formation

Pls. 32a,b,c,e,f; 33d

These are the most interesting non-columnar stromatolites from an environmental viewpoint, as they may be used to determine current directions.

Location: The stromatolites are widespread in the Trezona Formation, chiefly in the Central Flinders Ranges; they were examined in detail in Enorama Creek, and similar forms were observed at Mt Chambers, Wundowie Bore and north of Blinman (Figs.25,27).

Description:

Mode of Occurrence and Gross Morphology

In Enorama Creek, the stromatolites form massive pink limestone beds intercalated with green and purplish shales, and "hieroglyphic limestone" intraformational breccia beds. The lowest bed consists of contiguous large, elongated, cumulate stromatolites, approximately 1 m wide and 3 m long, and with a growth relief of up to 30 cm. The elongation trends consistently in a direction of 170° (Pl.32b). In addition, a series of cuspate ridges, 1 to 2 cm apart, occurs on the surface of each cumulus, perpendicular to the major elongation. Longitudinal sections show that the cusps persist downwards (see thin sections, Pl.32c). Successive crests show a northerly displacement, but it is uncertain if this is due to the influence of north-flowing currents. Similar structures at Mt Chambers also show a major elongation trending N-S (Pl.32a).

Analogous structures have been recorded in the literature. For example, Goldring (1938) noted the elongation of stromatolites apparently growing in rill channels, which she interpreted to be perpendicular to the shoreline. Similarly, Logan (1961) demonstrated that the Recent elongated cumulate stromatolites of Shark Bay are shaped by tidal run-off, perpendicular to the low water mark. Davies (1970) described tufted mats from the Gladstone Embayment of Shark Bay; these are thin mats with subparallel ridges formed by tangled algal filaments. Logan (1970, pers. comm.) has noted that the tufted ridges are sometimes oriented parallel to the shoreline. The thinness of these mats makes them readily subject to disruption, whereby they become detached from the substrate and curled. If reworked, these would form a deposit analogous to the "hieroglyphic" limestones of the Trezona Formation (p.289). Thus the sediments of low depressions in the intertidal zone of the Gladstone tidal flat, subject to frequent wetting and low sediment influx, are a modern analogue of the Trezona Formation sediments, but further measurements are required in the Trezona Formation to determine the regional distribution of current directions, and to test whether an analogy with Shark Bay leads to a meaningful palaeogeographic reconstruction.

Commonly, the cumuli commence growth upon erosional highs on the underlying calcareous siltstones and shales, in which the laminae commonly become domed by compaction (cf. the occurrence of Omachtenia utschurica at Depot Creek, Pl.26c).

At higher levels in the Trezona Formation, elongated cumuli trend at about 150°, but are then replaced by pseudocolumnar beds up to 1 m thick. Pseudocolumns are generally subcylindrical, and range in diameter from 5 to 50 cm, and laminae vary in shape from very gently convex to parabolic; occasionally they are sharply flexed or even subconical. In places short interspaces, commonly filled with fine intraformational breccia, are developed between pseudocolumns. Transverse sections of columns and pseudocolumns are generally circular (Pl.33d).

Microstructure

All Trezona Formation stromatolites are characterized by banded, wavy lamination, irrespective of whether they are pseudocolumnar or cumulate.

Light laminae, consisting of hypidiotopic equigranular calcite, ranging in grain size from 0.015 to 0.03 mm, are 0.2 to 1.0 mm thick, and have slightly wavy, often embayed boundaries, in places to the extent that the laminae are dismembered into discrete, rounded lenses (Pl.32e). The dark laminae with which they alternate are of grain size from 0.003 to 0.01 mm, the calcite being xenotopic to hypidiotopic, and reddish-brown coloured. Dark laminae are 0.1 to 0.5 mm thick, and almost always thinner than the adjacent light laminae. In specimens with cuspate lamination, concordant stylolites commonly follow the dark laminae (Pl.32c). Euhedral to subhedral rhombs of dolomite of size ranging from 0.01 to 0.02 mm may be common in the light laminae.

Where interspaces are developed, they are filled either with homogeneous reddish lime mud, or with intramicrite (Pl.32f). Intraclasts are small flat or subrounded pebbles of slightly dolomitized limestone, of identical texture and thickness to the light laminae, but are surrounded by a 0.02 to 0.03 mm thick micritic envelope. The matrix is mostly slightly recrystallized lime mud. Both matrix and intraclasts may be locally leached and replaced by sparry calcite, but the micrite envelopes are always preserved.

The occurrence of light laminae as intraclasts in interspaces, and the partial disruption of light laminae in columns may be related. If so, the disruption suggests that the light laminae were lithified during growth, and occasionally reworked into the interspaces. The light laminae cannot therefore be a later cement, but must be either indurated fine detritus or precipitated lime.

Comparisons:

The unbranched subcylindrical columns and pseudocolumns may be compared to *Colonnella* Komar, but discrete columns are rarely developed. Although not *Conophyton*, the Trezona Formation stromatolites have a microstructure closely resembling that of *Conophyton metula* Kirichenko (emend. Komar, Raaben & Semikhatov).

(b) Stromatolites from the Woocalla Dolomite, Pernatty Lagoon

Pl. 32d

Location: These stromatolites are exposed on low salt flats on the western shore of Pernatty Lagoon, near the Port Augusta - Woomera road (Fig.29g).

Stratigraphy: The Woocalla Dolomite in which they occur is of uncertain stratigraphic position, but Thomson & Johnson (1968) have shown that in the Woomera Bore, the Woocalla Dolomite disconformably overlies the Pandurra Formation (considered to be pre-Sturtian) and is in turn disconformably overlain by the basal Whyalla Sandstone Member of the Tent Hill Formation (Wilpena Group equivalent).

Description:

Mode of Occurrence and Gross Morphology

The stromatolites occur in a horizontal bed, poorly exposed on a salt flat, and their shape and extent in vertical section are not known. Transverse sections are 5 to 20 cm in diameter, and vary from round to oval to lanceolate, the elongation trending approximately N-S. The structures may be continuous or separate; occasionally two or three may become confluent.

Longitudinal sections show that the structures are chiefly pseudocolumns with lamina shape varying from gently convex to hemispherical to subconical, frequently resembling gothic arches (Pl.32d). Growth commences with flat-laminated dolomite, at least 5 cm thick, which passes up into small mounds and then pseudocolumns.

Pseudocolumns are almost always linked by continuous laminae; however, the depressions between them may receive a small amount of fine detritus. One example was seen on a large flat-pebble standing vertically between two pseudocolumns, with bridging laminae abutting against it.

Microstructure

Lamination is extremely even, smooth and continuous, with 0.5 to 0.8 mm thick light laminae alternating uniformly with slightly darker laminae, 0.5 to 2.0 mm thick. Even in subconical laminae, there is almost no increase of thickness in their crests; there is thus no differentiated crestal zone as in Conophyton. The lighter laminae consist of hypidiotopic dolomite of grain size varying from 0.01 to 0.02 mm, with finely dispersed 0.001 to 0.005 mm diameter limonite grains. The dark laminae are diffuse, but slightly finer grained. In addition, the lamination is emphasized by patchy limonitization, commonly following the boundaries between light and dark laminae or affecting the whole of a light lamina. Limonite appears to be concentrated along boundaries between dolomite crystals.

Comparisons:

Woocalla Dolomite stromatolites closely resemble the pseudocolumnar forms from the Trezona Formation in their gross shape and uniform lamination, but the Trezona forms have more wavy, frequently more gently domed laminae. They are distinguished from Conophyton by the absence of a crestal zone, although some have subconical laminae.

(c) Conical-Domed Stromatolites from the Cambrian at Lake Torrens
Parkin et al. (1969): Handbook of South Australian Geology, Fig.36, p.90. Pl. 33a,b.

Location: On the northern extremity of Lake Torrens, in the Lower

Cambrian Andamooka Limestone (Fig.29b).

Description:

Mode of Occurrence and Gross Morphology

Parkin et al. (p.90) state that:

> "At the western-most exposure of Cambrian sediments at Yarrawurta Cliff, where the equivalent of the Wilkawillina Limestone is referred to as Andamooka Limestone (Johns, 1968), cherty dolomite and algal limestone are very typical lithologies of this interval."

Three specimens collected for me by Mr. B. Murrell show that the structures are laterally linked domes with lamina shape varying from hemispherical to low-conical (Pl.33a,b). Individual domes persist vertically for only a few centimetres, and thus never form pseudocolumns (Pl.33a).

Microstructure

Microstructure is poorly preserved, due to total dolomitization, and laminae are indistinct. The rock now consists of equigranular, xenotopic to hypidiotopic dolomite, comprising equidimensional crystals of 0.05 to 0.1 mm grain size. Lamination is preserved only as slight, frequently clotty, concentrations of pigment, and is not related to the texture of the dolomite. Stylolites are very numerous, and may either follow or cut across the lamination (Pl.33b).

Comparisons:

The stromatolites resemble basal portions of Conophyton in having laterally linked hemispheroids and cones, but differ in lacking a differentiated crestal zone and in the absence of vertically persistent columns or pseudocolumns.

(d) Stromatolites from the Callanna Beds of the Peake and Denison Ranges

Pl. 32h

Location: The oldest stromatolites of the Adelaide Geosyncline occur low in the Callanna Beds, a few feet above the basal unconformity over the basement Peake Metamorphics, 5 miles S.E. of Nilpinna Station, Peake and Denison Ranges (Fig.29a).

Description:

Gross Morphology

The stromatolites occur in a lenticular outcrop, interbedded with siltstones of the Lower Callanna Beds. The whole bed is secondarily silicified, but gross lamination is well preserved. The structures are chiefly laterally linked hemispheroids with well defined parallel subcylindrical pseudocolumns 1 to 5 cm wide. Some parts are columnar-layered, in places with interspaces up to 5 cm long, and numerous bridges.

Laminae are smooth to broadly wavy, and commonly gently convex. In places, the edges of laminae may extend down the column margin for short distances.

Microstructure

Lamination is defined by changes in grain size of the chert, concentrations of finely dispersed limonite along grain boundaries, and in places, concentrations of granular opaques in some laminae.

Laminae are frequently lenticular (Pl.32h), although some transparent light laminae, consisting of chert of grain size from 0.1 to 0.3 mm extend across the full column width. Light laminae vary in thickness from 0.3 to 1 mm, and individual laminae may pinch and swell rapidly. Dark laminae are composed of finer grained chert (of grain size from 0.01 to 0.03 mm), often stained greenish-yellow or brown, and may be up to 2 mm thick. They are frequently embayed by the coarser chert of the adjacent light lamina.

Comparisons:

The columnar-layered portions of these stromatolites resemble parts of *Acaciella* bioherms, but no persistently columnar occurrences were seen.

In addition, a very continuous 1 m thick bed of dolomitic laterally linked hemispheroids up to 15 cm wide was noted higher in the Callanna Beds sequence (in the Duff Creek Formation).

(e) Stromatolites from the lower part of the Balcanoona Formation

Columnar-layered and pseudocolumnar stromatolites were observed in Nepouie Creek and at Burr Well (Fig.25). In gross form and mode of occurrence those from Nepouie Creek (Pl.27c,e) partly resemble *Omachtenia utschurica* from the basal Brighton Limestone at Depot Creek. A small specimen examined from the Geology Department collection lacks the pelletal laminae of the latter.

At Burr Well, similar stromatolites have more discrete columns with parallel to slightly divergent branching and numerous bridges. Interspaces are totally dolomitized, as are the marginal portions of columns. The positions of column margins are uncertain (Pls.32g,33e), due to dolomitization and stylolitization.

Irregularly columnar, frequently bridged stromatolites occur in the middle part of the Balcanoona Formation in Nepouie Creek (Pl.35e). Columns are unwalled, gamma-parallel branching, and have markedly rectangular laminae, up to 2 mm thick. Micritic and pelsparite laminae alternate, the micritic laminae frequently having sharp upper and gradational lower boundaries. Pellets are 0.05 to 0.1 mm in diameter, of ovoid to irregular shape, and contain a pale brownish ?organic pigment.

Stylolites and veins of acicular calcite cut across columns, sometimes accompanied by a considerable amount of solution of rock.

Interspaces are filled with recrystallized intrasparite, alternating with thin micritic layers. Intraclasts are coarser than the pellets in columns (up to 0.5 mm), probably reflecting the inability of the mats to trap detritus coarser than about 0.1 mm.

2. Poorly Preserved Columnar Stromatolites

(a) Stromatolites from Termination Hill

Two small specimens of pale brown dolomite, in the Geology Department collection, contain partially silicified stromatolites. Columns are subcylindrical, parallel, rarely branching, and of 0.5 to 1.5 cm diameter.

Microstructure is poorly preserved, and even column margins are very indistinct. Columns consist of limonite-stained dolomite of hypidiotopic texture and grain size up to 0.1 mm. Lamination is indicated only by concordant stylolites. Columns may be wholly or partly replaced by chert, of grain size ranging from 0.01 mm when dispersed to 0.5 mm when in small nodules. Interspaces are filled with hypidiotopic equigranular dolomite of grain size from 0.01 to 0.02 mm.

The location and stratigraphy of these stromatolites is uncertain (Fig.26). According to the Myrtle 1-mile Sheet no carbonates occur at the locality given (S.W. end of Termination Hill, S.A.) but to the south is a diapir and to the north-west is the Skillogalee Dolomite. The lithology and stromatolites are unlike any known occurrences of Skillogalee Dolomite. Mr. B. Murrell (pers. comm., 1970) has reported a similar dolomite from the base of the Tapley Hill Formation north of Termination Hill, but has found no stromatolites.

(b) Dolomitized Stromatolites from the Balcanoona Formation

Pls. 34f, 35f

Buff-coloured very massive dolomites occur in the Balcanoona Formation at Arkaroola, Angepena, Burr Well, Wundowie Bore and other places in the Northern Flinders Ranges where a great thickness of Balcanoona Formation is developed. The dolomite is clearly secondary and cross-cutting, replacing oolitic and stromatolitic limestones; despite the destructive nature of the dolomitization, poorly preserved relict stromatolites were observed at Angepena and in float at Arkaroola (Fig.25).

The stromatolites are parallel columnar, or columnar-layered, and those from Arkaroola are probably walled, where columns are free from bridging and coalescing. Columns at Angepena are radially arranged, possibly on hemispherical bioherms.

Lamination is preserved only by concentrations of limonite, the dolomite being of uniform hypidiotopic, equigranular texture, and of grain size ranging from 0.01 to 0.02 mm.

None is sufficiently well preserved to allow detailed comparisons with other stromatolites (Pls.34f,35f).

3. Poorly Known Columnar Stromatolites

The following are isolated specimens which are inadequate for identification.

(a) Etina Formation, south of the Enorama Diapir (Fig.27)
Pl. 31f

A thin bed of frequently coalescing columns, with parallel to moderately divergent branching, occurs interbedded in the calcareous grits and conglomerates of the Etina Formation, above the occurrence of *Tungussia etina*. Column margins are badly altered by stylolites, and laminae are mostly gently convex, very thin and uniform (Pl.31f). Dark laminae, emphasized by finely dispersed limonite, are 0.05 to 0.15 mm thick, and generally continuous across a column width. Light laminae contain a little fine quartz sand.

These indeterminate stromatolites bear some similarity to the anastomosing Late Riphean form *Parmites concrescens* Raaben.

(b) Stromatolites from the Umberatana Group of the Willouran Ranges (Fig.26)

A specimen of stromatolitic limestone collected by Mr. C. R. Dalgarno from West Mount shows parallel branching columns with some bridges, and lenticular laminae. Columns may be partly walled, but this is uncertain due to inadequate preservation. The limestone is likely to be Wundowie Limestone equivalent. Mr. B. Murrell has collected specimens nearby, herein identified as *Linella munyallina*. In addition, two small specimens of smooth, walled, parallel branching stromatolites (Fig.17n,p) may also be included, but their stratigraphic position is uncertain. A specimen from 5 miles N.W. of Termination Hill (Fig.17t) is badly recrystallized, and margins are obliterated by stylolites. Interspaces have been dolomitized and partially dedolomitized. In gross shape columns resemble some *L. munyallina* specimens.

(c) Stromatolites from the Wonoka Formation, Bunyeroo Gorge (Fig.27)

A very small specimen of columnar stromatolites from the transitional beds between the Wonoka Formation and the Pound Quartzite at this locality was supplied by Dr. B. G. Forbes, unfortunately too late to be included in this study.

4. Laminated Structures of Doubtful Origin

(a) Structures from the upper dolomitic member of the Brighton Limestone, Adelaide and Depot Creek

Concave-upward laminated structures occur in several limestone quarries south of Adelaide (Fig.29k) and in a similar stratigraphic level at Depot Creek (Fig.24).

The dolomite is buff to reddish coloured, finely laminated, and with numerous thin interbeds of intraformational breccia. Laminae are deformed into acutely pinched crests, separated by gently concave troughs, 10 to 20 cm wide. Crests are successively stacked one above the other, involving up to 50 cm of sediment (Pl.34d). Erosional unconformities at the tops of crests, overlain by nearly flat-laminated dolomite, show that the deformation is syn-depositional.

Pl.34e is a longitudinal section of a crest and its adjacent troughs. Crests may be asymmetrical, but the sense of inclination of a crest changes upwards. Individual laminae may or may not continue across a crest (many are obliterated by tectonic fractures). Intramicrite layers are more common in the Depot Creek specimens (Pl.34a,c), where they dominate over muddy layers, but at Adelaide they are sparse, being restricted to intervals after erosion. Intraclasts are derived from the erosion of partly lithified mud laminae.

A transverse section (Pl.35a) shows that crests are folds with sinuous axial traces, in places refolded.

The origin of the structures is problematical; firstly, the lamination might be interpreted as an algal mat, but Depot Creek specimens show microcross-bedding within some muddy layers (Pl.34a,c). Secondly, the dolomite must be diagenetic, since there are dolomitic ooids and coated grains, but the fine preservation of detailed structure suggests that dolomitization was very early, perhaps contemporaneous with deposition. Periodic syndepositional slumping on very slight slopes is the probable cause of the deformation of the sediment, but another possible factor is compression due to volume changes accompanying lithification and dolomitization. Following each slump or compression, the crests were partly eroded and the derived intraclasts redeposited together with more micritic sediment. If dolomitization and cementation by dolomite proceeded synchronously, then the sediment was probably semi-lithified at the surface, facilitating the fracturing of laminae and formation of intraclasts. Some thin muddy laminae between intramicrite layers were semi-plastic, and remained continuous across crests (Pl.34b,c). The possibility exists that these were algally bound, but they contain no direct evidence of this (such as the accentuation of substrate irregularities, or preservation of filament moulds).

Very similar structures were found in the Skillogalee Dolomite at Weekeroo (Pl.36a; Fig.29e).

(b) Dolomites interbedded in tillite, Depot Creek

Dolomitic grits, sandstones and conglomerates are interbedded with diamictite in the glacigene sequence at Depot Creek. In addition, laminated silty dolomites associated with them, show broadly undulose bedding, thus resembling some continuously laminated stromatolites. The microstructure is, however, totally unlike any stromatolites; the laminae are extremely uniform on a fine scale: 1 to 3 mm thick laminae of very angular, coarse quartz silt and minor dolomite matrix alternate with dolomicrite laminae, up to 0.2 mm thick. Silty laminae commonly have gradational upper and sharp lower boundaries. The lamination is therefore more likely to be varved than stromatolitic.

(c) Montacute Dolomite, Torrens Gorge, near Adelaide

In the type section of the Montacute Dolomite (Fig.29k), laminated dark grey dolomites are interbedded with intraformational magnesite breccias. The dolomites are frequently wavy bedded, but the intense folding in the area makes it difficult to distinguish sedimentary from tectonic structures. Several specimens were collected which show what might be interpreted as deformed and recrystallized columnar stromatolites (Pl.33c). The lamination is preserved by silicification, but column margins cannot be located. In a search for stromatolitic structures in a less deformed section in Kangaroo Creek, south-east of the Houghton Inlier (Fig.29k), none was found.

Chapter 8

THE TEMPORAL DISTRIBUTION OF STROMATOLITES AND STROMATOLITE CORRELATIONS

Having summarized the results of recent Russian research on stromatolites (Ch.4), we must now consider the temporal distribution of Russian stromatolites in relation to the sequences established by Walter (1970) for Central and Western Australia, by Cloud & Semikhatov (1969) for parts of the USA, southern Africa, and northern Australia, and in the present study for South Australia.

Table IX summarizes the temporal distribution of all described Russian stromatolites, ranging in age from Early Riphean to Cambrian, but it must be pointed out that there are minor discrepancies between some authors as to the precise limits of the time ranges. The following is a discussion of the assemblages which characterize each of the Russian subdivisions.

Early Riphean

The Early Riphean is characterized by an abundant development of forms of *Kussiella*, especially *K. kussiensis*, which is restricted to it, in the Ural Mountains (Krylov, 1963) and in northern Siberia (Komar, 1966). Komar also recorded *K. vittata* and *Microstylus perplexus*, the latter possibly being a secondarily recrystallized variant of *Kussiella*. The group *Kussiella* as a whole is not restricted to the Early Riphean; Raaben (1964) described *K. enigmatica* from the Late Riphean of Southern Timan.

The unbranched columnar forms *Colonnella laminata* Komar and *C. discreta*

Komar occur in the Early Riphean of northern Siberia, while the group *Omachtenia* Nuzhnov has been described only from the Early and oldest Middle Riphean of south-eastern Siberia. *Conophyton* is well developed in the Early Riphean: *C. cylindricum* Maslov (emend. Komar, Raaben & Semikhatov) and *C. garganicum* Korolyuk (emend. K. R. & S.) extended throughout the Early and Middle Riphean, but the occurrence of *C. lituum* Maslov (emend. K. R. & S.) from the Early Riphean is uncertain.

No single group of columnar stromatolites is restricted to the Early Riphean. Therefore a sequence can be inferred to be of Early Riphean age only if it contains an abundance of the above forms, and lacks all Middle and Late Riphean forms.

Middle Riphean

The Middle Riphean is characterized by the first appearance of the divergent branching groups *Baicalia* Krylov, *Tungussia* Semikhatov, *Svetliella* Shapovalova and *Anabaria* Komar, the elongated-columnar group *Platella* Korolyuk and the branching conophyton-like group *Jacutophyton* Shapovalova. Nuzhnov (1967) shows the early Riphean forms *Kussiella* f. and *Omachtenia omachtensis* to extend into the oldest Middle Riphean, overlapping with the earliest *Baicalia*.

Krylov, Nuzhnov & Shapovalova (1968) subdivided the Middle Riphean into three units on the basis of forms of *Baicalia* and *Jaoutophyton*. In the oldest (the Svetlin Complex) occur *Svetliella svetlica* Shapovalova, *Colonnella kyllachi* Shapovalova, *Baicalia baicalia* Maslov, *B. prima* Semikhatov and *Omachtenia* f. The second (the Tsipandin Complex) contains many forms of *Baicalia*: *B. prima* Semikhatov, *B. aimica* Nuzhnov, *B. baicalica* (Maslov) Krylov, *Tungussia* f., *Conophyton* f. and *Jacutophyton multiforme* Shapovalova. The youngest complex, the Lakhandin, is characterized by *Jacutophyton ramosum* Shapovalova, *J. multiforme* Shapovalova, *Conophyton cylindricum* Maslov, *C. lituum* Maslov, *C. metula* Kirichenko, *Baicalia prima* Semikhatov and *B. ingilensis* Nuzhnov in its lower two sub-suites, and *B. lacera* Semikhatov, *B. maica* Nuzhnov and *Tungussia sibirica* in the third. But the fourth sub-suite already contains representatives of the Late Riphean assemblage, as well as forms of *Baicalia* present throughout the Lakhandin.

Late Riphean

The Late Riphean contains the greatest diversity of columnar stromatolites known from the Russian Precambrian. The beginning of Late Riphean time is marked by the first appearance of the very distinctive groups *Inzeria* Krylov, *Gymnosolen* Steinmann, *Minjaria* Krylov, *Jurusania* Krylov, *Boxonia* Korolyuk and *Katavia* Krylov, while *Poludia* Raaben and *Kotuikania* Komar first appeared slightly later.

Semikhatov (1962) recorded *Baicalia unca* only in the earliest part of the Late Riphean, and *B. lacera* extending into it from the Middle Riphean, but this is not confirmed by Komar & Semikhatov (1969), who state that *Baicalia* actually occurs below the Late Riphean forms.

Conophyton is less abundant in the Late than the Middle Riphean. *C. miloradovici* Raaben and *C. baculum* Kirichenko appeared for the first time in the Late Riphean, while none of the Middle Riphean forms persisted.

Raaben (1969b) recognized three subdivisions of the Late Riphean, but the youngest of these is in fact what other authors term the Vendian. The older of the two Late Riphean (i.e. per other authors) subdivisions (the Biryan) is characterized by an assemblage of abundant *Inzeria tjomusi* Krylov, with lesser *Jurusania cylindrica* Krylov, *J. nisvensis* Raaben and *Gymnosolen furcatus* Komar; Raaben accepts that some forms of *Baicalia* persisted into this lower subdivision.

The younger subdivision (the Minyar) contains *Gymnosolen ramsayi* Steinmann, *Inzeria djejimi* Raaben, *Minjaria uralica* Krylov, *Kussiella enigmatica* Raaben and *Poludia polymorpha* Raaben. *Tungussia* Semikhatov persisted throughout the Late Riphean. Raaben quotes ages of 960 to 900 m.y. for the Biryan, and 760 to 680 m.y. for the Minyar subdivisions.

Vendian

The Vendian is characterized by *Conophyton gaubitza* Krylov, *Linella* Krylov and *Patomia* Krylov, all of which are apparently restricted to it, and some forms of *Boxonia* and *Jurusania*. Certain microphytoliths are regarded as first appearing in the Vendian (*Vesicularites bothrydioformis* Krasnopeeva and *V. lobatus* Reitlinger) but great caution is urged in using these for biostratigraphy.

Recently, Semikhatov, Komar & Serebryakov (1970) proposed a two-fold subdivision of the Vendian, based on the distribution of forms of *Boxonia* and *Jurusania*. The older assemblage has *Boxonia grumulosa* Komar, and *Jurusania judomica* Komar & Semikhatov, *B.* (*Jurusania*) *allahjunica* Komar & Semikhatov, *Jurusania* (*Aldania*) *sibirica* Jakovlev and *Linella simica* Krylov.

In addition, certain laterally linked and cumulate forms persisted throughout the Vendian. The authors quote ages ranging from 624 to 673 m.y. for the older subdivision and one of 580 m.y. for the younger.

The time ranges of *Linella* and *Patomia* are controversial in that *L. avis* Krylov and *P. ossica* Krylov occur together in the Kurgan and Malokaroy suites, correlated by Krylov (1967) with the Vendian but Keller & Semikhatov (1967, Fig.2), show *Patomia* spanning the Late Riphean-Vendian boundary, and *Linella* as restricted to the Vendian.

Cambrian

Korolyuk (1960) described laterally linked stromatolites and the columnar forms *Collumnacollenia tigris* Korolyuk and *Schancharia tenuiseptata* from the Cambrian, while Sidorov (1960) described *Ilicta composita*. Both *I. composita* and *C. tigris* are characterized by a vermiform microstructure, also found by Walter (1970) in the Cambrian *Madiganites mawsoni* Walter.

Vetella uschbasica Krylov is known only from the Cambrian, but is very similar in gross morphology to *Patomia* Krylov. "*Boxonia*" *divertata* Sidorov (Korolyuk & Sidorov, 1969) is apparently Cambrian, but lacks the well developed wall characteristic of other forms of *Boxonia*.

Stromatolites outside the USSR

The first extensions of the Russian methods to stromatolites outside the USSR were made by Glaessner et al. (1969) and Cloud & Semikhatov (1969). The latter authors described several new taxa of pre-Riphean age, and showed that the scheme can be extended to the older rocks. *Gruneria biwabikia* was found in both the Biwabik Iron Formation of Ontario (about

1900 m.y. old) and in the Mt Jope Volcanics of Western Australia (about 2200 m.y. old). *Katernia africana* occurs in the Dolomite Series of South Africa (about 1900 to 2300 m.y. old) and probably also in the 1650 to 1900 m.y. old Nash Formation of Wyoming.

Of Riphean forms, they described *Baicalia* from the lower Abenab Formation of northern South-West Africa and *Conophyton ressoti* Menchikoff from the upper Abenab Formation. The Abenab Formation is possibly about 1000 m.y. old. *Eucapsiphora paradisa* occurs in the approximately 1600 m.y. old Paradise Creek Formation, north-west Queensland. In North America, *Conophyton cylindricum* Maslov occurs in the Siyeh Limestone and Missoula Group, Belt Series, Montana (possibly older than 1000 m.y.) and the Mescal Limestone, Apache Group, Arizona (1200 to 1400 m.y. old), the latter also containing *Tungussia*. *Kussiella* f.? was identified in the Elgee Siltstone (older than 1800 m.y.) of Western Australia.

From the Bitter Springs Formation, Central Australia, they recorded *Jurusania alica* (transferred by Walter, 1970, to the group *Kulparia*), *Inzeria* cf. *tjomusi* (transferred by Walter, 1970, to *I. intia*), inferring a Late Riphean age, and a new form of *Anabaria* (*A. juvensis*), but Walter (1970, p.310) expressed doubt about this identification. *Inzeria tjomusi* was also described from the 600 to 700 m.y. old Hinde Dolomite, and the possibly much older Dook Creek Formation, Northern Territory.

In California, *Linella* and *Boxonia* occur in the Johnnie Formation, whose age is probably youngest Precambrian.

Recently Valdiya (1969) attempted the correlation of Indian Precambrian sequences with the Riphean subdivisions, but his identifications of stromatolites were based only on field examination, not reconstruction. Much material is available in India for future detailed studies.

The conclusions of Walter's (1970) extensive study of Bitter Springs Formation stromatolites concurred with Cloud and Semikhatov's conclusion of its Late Riphean age. If the identification of *Anabaria* is in fact incorrect, then there may be no need to extend the range of this group into the Late Riphean as Cloud and Semikhatov have suggested. The assemblage of the Bitter Springs Formation (*Tungussia erecta* Walter in the (lower) Gillen Member; *Acaciella australica* (Howchin) Walter, *Linella avis* Krylov, *Inzeria intia* Walter, *Boxonia pertaknurra* Walter, *Basisphaera irregularis* Walter, *Kulparia alicia* (Cloud & Semikhatov) Walter, *Jurusania chewingsi* Walter and *Minjaria pontifera* Walter in the (upper) Loves Creek Member) contains the groups *Inzeria*, *Boxonia*, *Minjaria* and *Jurusania* which characterize the Late Riphean of the USSR. But a correlation with the Late Riphean necessitates a downward extension of the time range of *Linella avis*.

The assemblage of the Bangemall Group, Western Australia (*Baicalia capricornia* Walter and *Conophyton garganicum australe* Walter) indicated a correlation with the Middle Riphean which is in agreement with the radiometric estimate of its age of about 1100 m.y.

The McArthur Group (dated at between 1280 m.y. and 1750 m.y.) contains *Conophyton garganicum* var. indet., among other, unidentified stromatolites (Walter, 1970) suggesting an Early to Middle Riphean age (1600 to 950 m.y.).

The above correlations by stromatolites of Riphean age leads to no conflict with known radiometric dates. A problem arises in some well-dated pre-Riphean sequences, with stromatolites similar to those found in the youngest Precambrian rocks. For example, Walter (1970) identified *Patomia* f. indet. from the approximately 2000 m.y. old Wyloo Group, Western Australia. *Pilbaria perplexa* Walter has some of the distinctive characters of both *Inzeria* and *Minjaria* (Walter, 1970, p.217). Hofmann identified possible *Gymnosolen* (*G.*? *ferrata* Grout & Broderick) from the Biwabik Iron Formation, Minnesota and Ontario (1969a) and *Katavia* from the Aphebian Manitounuk Group, Hudson Bay (1969b). Parallel branching walled stromatolites, so characteristic of the Late Riphean of the USSR, were already present in early Proterozoic times, but seem to have been absent in the intervening period. Two alternatives exist: (1) The pre-Riphean stromatolites are the same as the Late Riphean ones, in which case they may be either convergent as suggested by Walter (1970, p.315), or long ranging. This can be decided only by more detailed studies, in particular of stromatolites of the intervening period (the Early and Middle Riphean). (2) The pre-Riphean stromatolites are similar in general appearance but not identical to the Late Riphean ones. If it is not known whether a sequence of rocks is of Riphean or pre-Riphean age, then it is not possible to date that sequence on the basis of the general appearance of the stromatolites alone, without doing detailed identifications.

Stromatolites studied in this thesis

The preliminary results of the present study were reported by Glaessner, Preiss & Walter (1969). It was noted that in the Adelaide

Geosyncline two assemblages occur: the older (from the Burra Group and possibly Callanna Beds) containing *Baicalia* and *Conophyton garganicum* was correlated with the Middle Riphean, and the younger (from the Umberatana Group) with the Late Riphean and partly the Vendian, on the basis of the stromatolites *Patomia*, *Katavia*, *Inzeria* and *Gymnosolen*. The widely accepted correlation of the Skillogalee Dolomite and Bitter Springs Formation was rejected. These conclusions will now be amplified.

For the purpose of this thesis the sequence in the Adelaide Geosyncline is amenable to a simple two-fold time-subdivision: the Early Adelaidean is taken as the Callanna Beds plus Burra Group (i.e. all beds up to the pre-tillite unconformity) while the Late Adelaidean includes all beds from the base of the lower tillite to the base of the Cambrian. These subdivisions correspond to the two stromatolite assemblages defined by Glaessner, Preiss & Walter (1969).

Early Adelaidean

In the lower part of the Burra Group, the Skillogalee Dolomite contains very widespread occurrences of *Baicalia burra* Preiss and local *Tungussia wilkatanna* Preiss. *B. burra* very closely resembles *B. maica* Nuzhnov and *B. rara* Semikhatov, both of which occur in the youngest (Lakhandin) subdivision of the Middle Riphean. Although the commonly accepted age of the end of the Middle Riphean is 950 ± 50 m.y., Nuzhnov (p.141) quotes an age as young as 890 m.y. for the youngest beds of the Middle Riphean; *B. maica* occurs in these beds (Nuzhnov, 1967, p.141), as do apparently *Inzeria tjomusi* and *I. confragosa* (Raaben, 1969a, p.91). *T. wilkatanna* is most similar to *T. confusa* Semikhatov, which occurs in late Middle Riphean and early Late Riphean beds of the Yenisei Mountains. The B. burra - T. wilkatanna stromatolite assemblage and the absence of typical Late Riphean forms suggest that the Skillogalee Dolomite is best correlated with the Lakhandin subdivision of the Middle Riphean, and therefore an age of about 950 to 1000 m.y. is preferred. However, the age could be as young as about 890 m.y.

Conophyton garganicum garganicum which in the USSR does not persist into the Late Riphean, is now reliably identified from a dolomite raft in the Paratoo Diapir, which intrudes upper Burra Group sediments. The stromatolites could have been derived from either the Callanna Beds or the lower part of the Burra Group, but a derivation from the Callanna Beds is preferred in view of the total absence of similar stromatolites in the Burra Group elsewhere. This occurrence strengthens the correlation of the Early Adelaidean with the Middle Riphean.

Direct confirmation of these correlations by radiometric means is not possible at the present time. As was discussed in Ch.2, an estimate of the age of the base of the Adelaide System requires a choice between accepting either the unreliable age of 850 ± 50 m.y. for the Wooltana Volcanics or a correlation of these with the well-dated 1345 ± 30 m.y. old Roopena Volcanics. The Middle Riphean stromatolite assemblage of the Early Adelaidean supports the older estimate, but the recent data of Cooper & Compston (1970, in press) support the younger. However, the conflict between stromatolite correlation and the age determination may not be as great as first appears: if the second alternative stated on p.35 is accepted, and if C. garganicum comes from the lower Callanna Beds, then that stromatolite may be as old as about 1300 m.y. The assemblage of the Skillogalee Dolomite is probably about 950 to 1000 m.y., but could be as young as about 890 m.y., which is not much older than the maximum age of 867 ± 32 m.y. for the Burra Group estimated by Cooper and Compston. However, if the first alternative (p.35) is correct, then *Conophyton garganicum* would have to be less than 870 m.y. old, which conflicts with its time range established in the USSR.

Late Adelaidean

Most stromatolites described from this interval occur in sequence in the Umberatana Group, but a few are found as clasts in boulder beds. The occurrence of boulders of *Acaciella* f. indet. as erratics in the lower tillite may indicate deposition of stromatolitic carbonates somewhere inside or outside the presently exposed basin, during Late Riphean time (by correlation with the Bitter Springs Formation), but such carbonates may since have been eroded away. *Gymnosolen ramsayi* occurs in limestone boulders in a conglomerate in the Tapley Hill Formation; these cannot be younger than that part of the Tapley Hill Formation, but a penecontemporaneous origin is considered likely, perhaps growing in shoals above a rising diapir (see p.292). In the USSR, *G. ramsayi* characterizes the Minyar subdivision of the Late Riphean (760 to 680 m.y. old).

The Brighton Limestone equivalent of the Southern Flinders Ranges contains *Omachtenia utschurica* Nuzhnov, *Acaciella augusta* Preiss, *Inzeria conjuncta* Preiss, *I. multiplex* Preiss, *Boxonia melrosa* Preiss and *Katavia costata* Preiss. *Inzeria*, *Boxonia* and *Katavia* are all characteristic of the Late Riphean of the USSR, while *Acaciella* occurs together with other Late Riphean stromatolites in the Bitter Springs Formation. The occurrence of *O. utschurica* in the Brighton Limestone must be taken to indicate an upward extension of its time range into the Late Riphean.

In the Central and Northern Flinders Ranges, rocks of approximately the same age or slightly younger contain stromatolites typical of the Late Riphean and Vendian. The Etina and Balcanoona Formations and the Wundowie Limestone contain *Tungussia etina* Preiss, which is similar in some features to *T. inna* Walter from the approximately coeval Ringwood Member of the Pertatataka Formation of Central Australia. The Balcanoona Formation also contains *Linella ukka* Krylov which is characteristic of the Vendian of the USSR. But a direct correlation with the Vendian is not favoured because the Balcanoona Formation is older than the Wundowie Limestone which contains the typical Late Riphean form *Inzeria* cf. *tjomusi*, as well as *Jurusania burrensis* Preiss and *Linella munyallina* Preiss, and because Walter (1970) has shown that the time range of *Linella* Krylov extends down into the Late Riphean. *Kulparia kulparensis* occurs in the equivalent of the Etina Formation at Kulpara; *Kulparia* in the Bitter Springs Formation is Late Riphean. The stromatolite assemblage therefore suggests a Late Riphean age for most of the Umberatana Group.

The upper beds of the Umberatana Group could well be close in age to the Late Riphean - Vendian boundary. The stromatolites occur not far below the Elatina Formation, which, if a correlation with the younger glacials of the Kimberley Region is accepted, is about 665 ± 45 m.y. old (p.33). Whereas the ages of the Late Precambrian tillites throughout the world have not been well established, it seems that in Australia, the lower tillites are probably of Late Riphean age and the upper tillites Vendian (the Late Riphean-Vendian boundary in the USSR is dated at 680 ± 20 m.y.). Thus both on radiometric and palaeontological evidence, the stromatolitic part of the Umberatana Group below the upper tillite, is probably best correlated with the youngest Late Riphean, but this does require an extension of the time range of Inzeria tjomusi, which in the USSR is known only from the older subdivision of the Late Riphean.

The stromatolites of the Wonoka Formation (p.225) were unfortunately discovered too late to be included in this study. Their stratigraphic position, well above the younger glacials and just below the fossiliferous Pound Quartzite (Table VI) necessitates a Vendian age for the Wonoka Formation.

The only Cambrian stromatolites studied here are Acaciella angepena. The group Acaciella, first recognized by Walter in the Late Riphean is now known to extend into the Lower Cambrian. Thus Mawson's (1925) contention of the great similarity of these Cambrian stromatolites to "Cryptozoon" (i.e. Acaciella) australicum Howchin is fully supported by this study.

Conclusions

The results of Russian studies of the last 15 years show that if rigorous methods of classification and identification are applied to stromatolites, then they can be used to subdivide and correlate the Late Precambrian (Riphean) sections of the USSR. Cloud & Semikhatov (1969) and Walter (1970) have extended this scheme to both Riphean and pre-Riphean sequences in North America, southern Africa, and northern Australia, and the resulting correlations accord well with most known radiometric data.

In this study, stromatolites were examined and identified by the same methods, and the conclusion of the previous authors as to their applicability to Precambrian correlations was confirmed. Of the two Adelaidean assemblages, the older (Baicalia burra, Tungussia wilkatanna, Conophyton garganicum garganicum) suggests a correlation of the Callanna Beds and the lower part of the Burra Group with the Middle Riphean, and of the lower part of the Burra Group at least, with the youngest subdivision of the Middle Riphean. The correlation of the Skillogalee Dolomite with the Bitter Springs Formation of Central Australia is rejected; the stromatolite assemblage of the latter has seven groups in common with the Late Adelaidean assemblage (from the Umberatana Group), and both of these are correlated with the Late Riphean. However, the Bitter Springs Formation and the Umberatana Group are not equated exactly, since in the two basins, they are respectively below and above the lower tillites, a correlation of which is accepted. Table X summarizes the stromatolite correlations with the USSR, and may be compared with the age framework suggested on radiometric evidence only (Table VII).

Part III

THE ENVIRONMENTS OF STROMATOLITE GROWTH

Chapter 9

INTRODUCTION

Whereas stromatolite research in the USSR during the last decade has concentrated almost exclusively on taxonomic and biostratigraphic considerations, western investigators have until very recently (Cloud & Semikhatov, 1969) consistently refuted the possibility of stromatolite zonation, except for local correlation (Rezak, 1957). Their approach has been rather to examine the environmental aspects of stromatolites, both in the Precambrian and the Phanerozoic - in the latter case especially, stromatolites have often been of only marginal interest to sedimentologists and stratigraphers engaged in carbonate petrology and basin analysis in the search for petroleum. Hoffman (1969) gave an outstanding example of such a basin study in the Precambrian.

The use of stromatolites for environmental interpretations was given impetus by studies of modern analogues, whose similarity to fossil forms has, however, sometimes been greatly overstated (e.g. Bathurst, 1967, p.458).

Interest in stromatolite environments commenced with Black's classic study of algal mats on Andros Island, Bahamas (Black, 1933). Black found that much of the algal mat consists of detrital material trapped by filaments, and that complex associations of species form the algal communities in the mats. Moreover, different algae are restricted to definite habitats, green algae being subtidal, and various associations of blue-green species occupying the intertidal and supratidal zones. Four types of sediment modification were noted: flat-laminated mats (type A), isolated domes (type B), mudcracked polygons with renewed algal growth (type C) and detached mudcracked polygons (type D). Type A was found in areas frequently flooded by sea water, while the more distinctive type B occurs locally at high water mark. Types C and D occur inland bordering freshwater lakes and between limestone ridges.

Monty's re-examination (Monty, 1967) of the algal mats of Andros Island greatly extended knowledge of the role of algae. In particular, Black had underestimated the importance of lime-precipitation by the algae. Monty distinguished four environments: the supratidal and brackish intertidal (terrestrial), marine intertidal and infralittoral. In the supratidal, *Scytonema myochrous* - *Schizothrix calcicola* laminated mats, including Black's types C and D, form in temporarily flooded or marshy areas, not subjected to prolonged immersion, thus accounting for the alternation of the terrestrial alga *Sc. myochrous* and the subaquatic *Sch. calcicola*. The brackish intertidal bordering creeks and tidal marshes is a quiet environment with marked salinity fluctuations, and supports unlaminated diatom mats, crusty *Sch. calcicola* flakes and laminated *Sc. crustaceum* mats. Blue-green algae generally occupy an intermediate belt in the marine intertidal zone, where they both bore into the rocky substratum and build mats. In the intertidal, stunted *Schizothrix calcicola* binds sand into unlaminated mats, which are thoroughly desiccated at low tide, since the rocky substrate does not retain moisture. But in the lower intertidal to infralittoral zone, *Schizothrix calcicola* forms well developed laminated mats and domes. Entirely infratidal *Lyngbya* and *Schizothrix* mats exist, but face the constant threat of burial by shifting sands. Monty considered that lack of rapid lithification may have prevented the algae from colonizing rough waters.

In contrast, Shark Bay, Western Australia is an environment in which modern algal mats form domed, columnar and club-shaped structures. Logan (1961) considered early lithification by interstitial precipitation of aragonite to be responsible for the relief of the stromatolites.

Shark Bay stromatolites as reported by Logan are restricted to the intertidal and supratidal zones; this environmental restriction of stromatolites has often been assumed to be universally valid. Logan recognized a form-zonation within the intertidal and supratidal zones of Shark Bay: the supratidal zone is characterized by flat-laminated mats and sinuous domes, frequently desiccated. Reef structures are restricted to the intertidal zone, the mature height of the stromatolites being determined by tidal range, so that the tallest are at low water mark. The club-shaped stromatolites decrease in height landward, and in the upper intertidal, they become confluent.

In their classic review of stromatolite nomenclature, Logan, Rezak & Ginsburg (1964) summarized the ecological distribution which they considered to be generally applicable to modern and fossil stromatolites: laterally linked forms (LLH) in the protected intertidal mud-flats, discrete columns (SH) in exposed intertidal headlands, and oncolites (SS) in agitated lower intertidal zones.

The apparent restriction of modern stromatolites to the near-intertidal zone has frequently been used in subsequent palaeogeographic and environmental studies. Recently, however, the occurrence of subtidal stromatolites has become recognized, both in modern and ancient environments. For instance, Achauer & Johnson (1969) have used the intimate association of stromatolites with hydrozoa in the deepest biofacies of the cores of Lower Cretaceous reef complexes, and the absence of associated mud-cracks and breccias, to demonstrate that these stromatolites were subtidal; emersion would have killed the hydrozoans. Playford & Cockbain (1969) proved the subtidal growth environment of stromatolites in a Devonian reef of Western Australia. Here stromatolites grew on the fore-reef slope to a depth of 45 m below the equivalent reef crest; the degree of depositional dip of the fore-reef beds was determined from geopetal structures - partly mud-filled hollow shells such as brachiopods and molluscs.

Gebelein (1969) has described in detail the growth of Recent subtidal stromatolites in Bermuda. Four facies were recognized: (1) the submerged rock facies, affected by heavy wave surge or swift currents, is encrusted by red algae, bryozoans, gastropods and worms; (2) the rippled sand facies, without surface mats, (3) the algal mat facies, and (4) the grass bed facies. Two types of stromatolites were noted, i.e. "biscuits" (low, oval to ellipsoidal domes) and large domes, which may themselves be covered with "biscuits". The mat may be broken into flat chips which are redeposited into depressions and ripple troughs. In the grass bed facies, the thick algal mats are disrupted by grass blades. Mats are widespread over the subtidal zone, and are absent only on the submerged rock facies, or where sediment is continually being shifted. Thus mat thickness increases in deeper water where there is reduced sediment movement.

Sufficient light is still available here for algal growth. Moreover, algal flat-pebble conglomerates were found at depths of more than 30 feet, so that these cannot be regarded as diagnostic of the intertidal zone.

Gebelein found that laminae are asymmetrically thickened over exposed downslopes of grass beds, and that thickening of biscuit laminae occurs on the up-current side of the biscuit. This fact had been recognized earlier by Hoffman (1967), who used it as a criterion for current directions in the Aphebian Pethei Formation, Northwest Territories, Canada. Hoffman found an excellent correlation between current directions derived from these asymmetrical cumulate stromatolites and those from ripple marks, cross-bedding, rill channels and clast orientation.

Stromatolites are almost always found in carbonate rocks. As trapping of detrital grains has been found to be an important mechanism in their growth, there is in theory no reason why detritus other than carbonate cannot be trapped. Therefore the presence of relatively large quantities of quartz sand in some stromatolite laminae is not surprising, e.g. in _Katavia costata_, Brighton Limestone, Depot Creek. Stromatolites composed entirely of quartz sandstone are very rare; one such occurrence was recently described by Davis (1968) from the Lower Ordovician of Minnesota. These stromatolites, consisting of large, laterally linked domes, were interpreted as having formed "at or near the maximum seaward extent of blue-green algae which trapped the quartz grains." Nearby, carbonate stromatolites occur.

I have observed blue-green algae trapping and stabilizing beach sand at Port Vincent, Yorke Peninsula, South Australia. The port is situated in a sheltered bay on the western shore of St Vincent Gulf; algal mats are restricted to a belt about 200 m long on the southern side of Streak Point, a small promontory one mile north of the township. The algae, identified with the help of Dr H. Womersley as Schizothrix arenaria, colonize the upper part of the intertidal zone. The sediment trapped consists mainly of fine subangular to subrounded quartz, of grain size varying from 0.10 to 0.25 mm, with minor fine, broken shell debris and some forams. The mats are subjected to mild erosion, as is seen in the formation of small, irregular mesas, standing some 5 cm in relief above the surrounding rippled sands. The upper surfaces of mats may themselves be rippled. Immediately below the surface, the bound sediment is not obviously laminated, and the organic material is black, and in a state of decay under reducing conditions.

The chances of preserving such a loosely bound mat on a beach would be slight. They occur at Port Vincent only because of the low wave energy in the sheltered bay; slightly greater wave action would probably completely destroy the mat and redistribute the sand. Moreover, the poorly laminated or unlaminated nature of the mat makes it unlikely that it would be distinguishable in a sandstone, even if it were preserved.

Cloud (1968) has made use of Logan's (1961) recognition of the environmental restriction of Shark Bay stromatolites, to argue for greater tidal ranges in the Precambrian. If Logan's observations are universally applied, the maximum relief of stromatolites over the surrounding sediment surface determines the tidal amplitude. Cloud has used observations of large cumulate stromatolites to indicate tidal ranges from 2.5 to 6 m or more in the Precambrian between 1000 and 2000 m.y. ago. The stromatolites were chosen because the relief could be proved by tracing single laminae. But it is unlikely that such cumulate stromatolites are restricted to the intertidal, as Playford & Cockbain (1969) have described "contorted-bulbous" and "mound-shaped" stromatolites from their fore-reef facies.

These observations make it clear that the presence of stromatolites in the record cannot be used as an unequivocal indicator of intertidal or supratidal environments. Stromatolite growth is restricted to shallow depths of water, probably less than 50 m, the limiting factor being the intensity of light transmitted to the sea floor. In clear water, light penetration may be considerable; moreover, some algae have photosynthetic pigments which absorb and utilize the shorter (blue-green) wavelengths of light, transmitted to greater depths of water (Strain, 1951, p.256). It is possible that algal growth at this depth may have been sufficiently prolific to allow the formation of stromatolites. Stromatolites by themselves cannot be used to recognize specific shallow-water zones; it is necessary to evaluate all floral, faunal and sedimentological evidence.

In the Precambrian sections of the Flinders Ranges, only sedimentological evidence is available, and even this may be partly obliterated by diagenesis and incipient metamorphism. Sedimentary structures and carbonate petrology of associated rocks may be used to infer the energy of the environment. Studies of stromatolites in longitudinal thin sections sometimes show the relationship between growth of algal laminae and the filling of the interspaces. The nature of the interspace sediment is related to environmental energy, as is the presence of contemporaneous erosional features within the stromatolites. Sometimes a minimum depth of water may be deduced from the relief on domed or spherical bioherms; thus minimum depths of one metre or more are indicated for many Umberatana Group bioherms.

In discussing the environments of the South Australian Precambrian stromatolites, it will be necessary to consider the overall sedimentation patterns throughout the basin at times of stromatolite growth. This involves palaeogeographic reconstruction, which is hampered by the following difficulties: (1) lack of precise time-correlation between stratigraphic sections, (2) the sparse distribution of directional features in the carbonate and argillaceous rocks (they are well developed in the sandstones) and (3) the general absence of fossils (other than stromatolites) by which to recognize specific environments.

In its regional mapping programme, the South Australian Geological Survey has consistently correlated rock units over large areas according to similarities of lithology and general stratigraphic position. That such correlations have a time significance has been either implied or explicitly stated. For instance, in Parkin et al. (1969) Handbook of South Australian Geology, p.49, it is stated that

> "Although isotopic dating is at present very sparse, systematic regional mapping within the Geosyncline has now shown a number of very persistent regional marker beds, which are believed to be highly time significant. The terms Marinoan, Sturtian, Torrensian and Willouran which were originally defined by

Mawson and Sprigg (1950) and Sprigg (1952) are still retained as time terms...."

The marker beds referred to include not only the glacial sediments, whose time significance would generally be admitted, but also widespread occurrences of specific facies, e.g. black shales, or magnesite conglomerates. Except in rare cases where rock units have been shown to intertongue, the time-parallelism of formations has been assumed. While rock correlations are an essential part of Precambrian stratigraphy, and provide a broad time framework (such as that used in stromatolite biostratigraphy), it may be argued that they must lead to invalid palaeogeographic reconstructions.

An extreme form of this viewpoint has been expressed by Shaw (1964) in an all-embracing criticism of current practices of rock-correlation. Shaw concluded that all widespread non-volcanic rock units deposited in epeiric seas must be diachronous, both for sediments derived from within the basin and outside it. Clearly, environment, including nearness to shore, was the only factor considered to determine sediment type: as the environment shifts in time, so the rock unit becomes progressively spread over a larger area. But this neglects factors such as climate or changes in the relief of source areas, which may have an instantaneous effect on sedimentation over the whole or most of the basin. Certainly, many facies are deposited side-by-side at any one time, and the formations comprising them are diachronous, but such relations should be determined where possible by mapping of facies changes, or by tracing volcanic markers, or by palaeontological correlation.

The discussion is particularly pertinent to the Adelaide Geosyncline - itself a deeply subsiding, but bathymetrically shallow epeiric basin. The Precambrian of the Adelaide Geosyncline contains no volcanic markers, nor is it likely that any technique of Precambrian palaeontology will ever have sufficient resolving power to demonstrate the diachrony of any of the widespread formations. Three methods which may be applied to palaeogeographic reconstruction are (1) the detailed mapping of intertonguing relationships, (2) the use of Walther's Law (Walther, 1894), i.e. that a vertical succession of facies in a complete sequence, reflects the lateral facies distribution at any one time, and (3) mapping the regional distribution of lithofacies. In addition, if widespread glacial deposits are present, and these can be correlated intra-regionally with confidence, they may be used to define broad time planes. Current direction data may aid in interpreting basin shape and patterns of sediment transport.

In the present study, detailed mapping has been carried out only for part of the Umberatana Group at Depot Creek, Southern Flinders Ranges (Fig.24). Regional facies changes have been mapped at this horizon by Binks on the Orroroo 1:250,000 Sheet and by Coats on the Mt Painter Province map. Supplemented by detailed measured sections of the carbonate and associated sediments in critical areas (see Appendix II), these maps may be interpreted to form broad palaeogeographic reconstructions, although precise time control is not available. I have attempted to combine this regional approach with a petrographic study of samples collected from the measured sections, to propose a model for the palaeogeography of part of the Umberatana Group, as presented in Ch.11.

The interpretation of the Skillogalee Dolomite is more difficult. The formation is very widespread, and while facies changes exist, they are not readily mappable. There is no direct evidence as to whether it is diachronous or not. Forbes (1955) has used various parameters such as thickness, percentage of sand, thickness of beds, and directional structures to interpret the environments of deposition.

Methods

Field work was concentrated on relevant sections of the Umberatana Group, mainly in the south-western part of the Northern Flinders Ranges; measured sections were located at stromatolite occurrences and at other accessible sites. Where possible, sections were measured from the top of the Tapley Hill Formation to the top of the Umberatana Group. The only detailed section measured in the Skillogalee Dolomite was at Depot Creek, Southern Flinders Ranges (see Appendix II).

Sections were measured by means of a 100 ft tape, Silva Compass and an Abney Hand Level. My wife kindly assisted by holding the end of the tape, which facilitated rapid measurement. By measuring the direction, distance and declination between successive points and recording the attitudes of bedding, sufficient data are obtained for section plotting, irrespective of dip or topography. Thicknesses were obtained graphically by plotting profiles perpendicular to the strike, assuming concentric folding, by the method of Busk (1929).

Lithologies, sedimentary structures, stromatolites and bedding attitudes were determined where possible. Rarely, it was possible to measure current directions from sedimentary structures, chiefly ripple marks, but insufficient data were obtained for statistical representation.

The distinction between dolomite and limestone in the field was not always easy, except in some cases in the Umberatana Group, where dolomite is crystalline, cross-cutting, and tends to destroy limestone fabrics. Typically, dolomites weather to a buff or brown colour. Otherwise, dolomite can be identified only by reaction with acid, staining, or X-ray diffraction.

In the laboratory, thin sections of representative rock types were prepared and examined. Carbonate rocks were stained with Alizarin Red Stain: the thin section was lightly etched in 10% HCl then washed and immersed for 30 seconds in alizarin red solution. In doubtful cases, carbonates were identified by X-ray diffraction. A few peels were prepared from etched, acetone-wetted rock surfaces, on thin plastic sheets, but these were of limited success, due mainly to the presence of minute air bubbles.

Measured sections were used to draw a fence diagram for part of the Umberatana Group (Fig.39). Supplementary thicknesses were calculated approximately from published maps. These were combined to compile isopach maps of the Brighton Limestone equivalents, of the Etina Formation, and of the Tapley Hill Formation to Elatina Formation interval (inclusive).

Chapter 10

ENVIRONMENTAL INTERPRETATION OF THE SKILLOGALEE DOLOMITE

The interpretations presented in this chapter are largely based upon Forbes' Ph.D. thesis and two publications (Forbes, 1960, 1961).

Regional Distribution and Stratigraphy

The Skillogalee Dolomite was originally defined by Wilson (1952, p.136) as "a sequence of .... cream coloured fine to medium grained dense dolomites with occasional interbedded dolomitic shales" in the Riverton-Clare region, and was correlated with the Castambul Dolomite-Montacute Dolomite sequence of the Torrens Gorge Torrensian type section. Forbes (1960, 1961) referred to magnesites and dolomites at this stratigraphic level throughout the Adelaide Geosyncline as the Montacute Dolomite, but since then the Mines Department has applied Wilson's name to all these occurrences. Since "Skillogalee Dolomite" is the currently applied term, it will be used here.

In the Adelaide region, the Aldgate Sandstone, basal formation of the Torrensian Series of Mawson & Sprigg (1950), is overlain by pale dolomites (Castambul Dolomite), followed by phyllites, then dark grey dolomites with chert and fragmental magnesite (Montacute Dolomite). In the Riverton-Clare region, the pale coloured dolomite marbles overlying the Rhynie Sandstone appear to correspond to the lower (Castambul) dolomite while the upper Montacute Dolomite is not developed. However, in the Burra region to the east, dark, cherty dolomites, in part stromatolitic, overlie pale dolomites; thus the lower and upper members of the Skillogalee Dolomite correlate with the Castambul and Montacute Dolomites respectively.

A predominantly pale dolomite lower member and dark, cherty, dolomite upper member of the Skillogalee Dolomite have also been observed in many sections in the Flinders Ranges: Spalding, Mundallio Creek, Depot Creek, Yatina, and Myrtle Springs.

Dolomites, frequently with fragmental magnesite are extremely widespread throughout the Adelaide Geosyncline at the horizon of the upper member. Forbes (1960) has rarely observed lateral facies changes, and reports the great continuity of individual beds. Carbonates are replaced laterally by shales in the Adelaide region, where carbonates are restricted to the Torrens Gorge-Montacute region, and a few minor occurrences south of Adelaide (Thomson & Horwitz: Barker 1:250,000 Sheet), and in the Para River-Gawler region. The Skillogalee Dolomite becomes continuous north of Rhynie. Fig.30 illustrates the distribution and thickness variation of the Skillogalee Dolomite over the Adelaide Geosyncline (modified from Forbes, 1961). Also shown are the localities from which I have collected stromatolites.

The following comments may be made about the distribution of facies:

(1) The Skillogalee Dolomite is thickest (over 2000 ft) in the Port Germein-Beetaloo and Arkaroola-Copley-Witchelina regions.

(2) Columnar stromatolites _Baicalia burra_ and/or _Tungussia wilkatanna_ are well developed in the northern region, especially Depot Creek, Hawker (near the Worumba Diapir) and Witchelina, while occasional biostromes were found at Copley, Arkaroola, Mundallio Creek and the Burra-Robertstown region. A float specimen was found in the River Broughton, near Spalding. No

definite stromatolites were found south-west of a line joining Mundallio Creek and Robertstown; wavy bedded dolomites in Port Germein Gorge are more likely to be slump folded than stromatolitic. Concave-upward laminated structures from Weekeroo have already been mentioned (p.227).

(3) Magnesite is most abundant in the Copley region (17% of the section) but magnesite conglomerate beds are also well developed at Mundallio Creek, Johnburg, Hawker and Arkaroola. Although Forbes records only 1%, I have observed a considerable number of magnesite conglomerate beds in the Witchelina area. Occasional magnesite conglomerate beds also occur in the Weekeroo area (the most easterly occurrence of the Skillogalee Dolomite).

(4) Sand forms the greatest proportion of the section (more than 30%) in the Witchelina and the Crystal Brook regions, while between 10 and 30% sand occurs at Adelaide, Bundaleer (near Spalding), Beetaloo (near Gladstone), Port Germein and Johnburg.

From the distribution of sand in the section, Forbes concluded that there were highlands to the west of Beetaloo, Similarly, greater sand proportions at Witchelina than Copley and Arkaroola might suggest a landmass to the north-west.

The map (Fig.30) also indicates the present distribution of the Skillogalee Dolomite, largely controlled by the tectonism which occurred in pre-tillite times. In some areas, especially on anticlines with diapiric cores, Mines Department mapping has shown that local uplift caused angular unconformities or stripping of the Skillogalee Dolomite. Such major local uplifts occur at Mt Remarkable, Yednalue, Worumba, and possibly, north of Witchelina. North of Mt Painter, a low-angle unconformity indicates stripping of the Skillogalee Dolomite (and lower units) prior to the deposition of the tillite. East of the Paralana Fault, the tillite directly overlies the Willouran Wooltana volcanics. Similarly, the Burra Group is totally removed in part of the Weekeroo area by a 30° unconformity (Talbot, 1967), while to the north-east, the tillite directly overlies basement. Thus at least in post-Skillogalee times, there were uplifts on the northern and eastern margins of the basin, but the general absence of facies changes in the vicinity of the local uplifts suggests that these were not active during sedimentation.

Since no Skillogalee Dolomite is preserved on the Stuart Shelf, and sand is concentrated in the western Flinders Ranges, it may be argued that the western basin margin was near the present Lake Torrens-Spencer Gulf area. But the northern and eastern margins of the basin at this time cannot be defined.

Stratigraphy of the Depot Creek Area

The section at Depot Creek is typical of many areas, and was the one most intensely studied. Appendix II(1) is a stratigraphic column for the lower part of the Skillogalee Dolomite, including the most richly stromatolitic beds.

The contact between the Emeroo Quartzite (Mawson, 1947) and the Skillogalee Dolomite is gradational; over a thickness of 114 ft (35 m), medium and coarse grained feldspathic sandstones are progressively replaced by flaggy grey and pink dolomites, partly with disrupted bedding.

One such dolomite band contains small ellipsoidal vughs, up to 1 cm long, lined with drusy dolomite, and lastly filled with coarsely crystalline quartz. The origin of these structures is uncertain: superficially, they resemble birdseyes, but their cross-cutting relationship to some silty laminae suggests that they are secondary solution voids (Pl.37a). However, in places, laminae are deflected around them. The voids lack sedimentary floors. An origin by the dissolution of gypsum nodules is possible.

Polygonal mudcracks and current ripple marks on reddish shale partings are rather common in the sandstone interbeds, and easterly flowing currents are indicated (directions measured were 107°, 97°, and 137°).

Laminated green and reddish (weathered) shales become prominent above this level, and are interbedded with flaggy, sandy dolomites, stromatolitic dolomites and wavy- or cross-bedded dolomites. Irregular chert lenses are more common in the upper part of the section, and always occur replacing dolomite. Minor sandstones with dolomitic cements persist.

About 300 ft (100 m) above the base of the lowest dolomite bed, shales and siltstones predominate; in one instance, cubic halite casts were noted in poorly bedded dark grey mudstone. Pink to buff coloured dolomites occur as partly laminated, partly massive interbeds. The more massive beds are frequently biostromal, or consist of contiguous bioherms, up to 1 m in diameter. The thickest biostromes, up to 2 m thick, occur at approximately 250 ft (80 m) above the base of the shale-dolomite section, and comprise the stromatolite Tungussia wilkatanna. The upper boundary of the biostrome is an erosional surface, on which the transverse sections of columns are exposed. Shale deposition resumed after this diastem, and was gradually replaced by influx of sand. A 24 ft (8 m) bed of felspathic sandstone may be traced throughout the area.

The upper member of the Skillogalee Dolomite, above this marker sandstone, is predominantly dark coloured, and contains numerous magnesite conglomerate beds, which are rare or absent in the lower member. Stromatolites occur only at isolated horizons, separated by platy and laminated but thick-bedded dolomites. Black chert either forms moderately continuous beds or irregular pods and lenses in dolomite. At least some of the chert is of late diagenetic origin, since it cuts across bedding or stromatolite columns. Interbedded magnesite conglomerate beds vary in thickness from a few centimetres to 1 metre. Magnesite clasts vary in diameter from 1 to 2 mm to 15 cm; in the latter case they are large, rounded curled mudflakes, which would have withstood virtually no transport. The *in situ* occurrence of small cumulate stromatolites within these conglomerates indicates that they were able to grow in essentially the same environment as that in which magnesite was forming. Forbes' suggestion that magnesite intraclasts were broken up by desiccation is especially applicable to these coarse conglomerates, in which many fragments are still curled. Other beds, however, are rather better sorted conglomerates with well rounded magnesite clasts 2 to 20 mm in diameter; such conglomerates are also more common in other areas.

The Skillogalee Dolomite grades up into an essentially arenaceous sequence. Arkosic sandstones with well rounded quartz grains and a dolomite cement predominate. Current ripple marks and mud-cracks are common, and there are minor interbeds of shale and yellow-weathering dolomite.

Comparison with other areas

The distribution and lithologies of the Skillogalee Dolomite have already been outlined. The following is a summary of additional observations at other stromatolite localities.

In the Burra area (Fig.29h), Baicalia burra occurs in biostromes up to 2 m thick, near the top of the upper member of the Skillogalee Dolomite. Magnesite is rare (possible magnesite arenite was noted in a thin bed at Scrubby Range, near Robertstown). Dolomites are generally very fine grained, except where recrystallized by metamorphism, and the sediment in stromatolite interspaces is predominantly micritic, with very rare intraclasts and ooids. This suggests growth in a relatively low-energy environment. Correspondingly, stromatolite columns are relatively regular and subcylindrical, with little evidence of contemporaneous erosion.

In the River Broughton near Spalding (Fig.29d), magnesite conglomerates are common in the upper member, but stromatolites are rare (the only specimen found was in float).

The Skillogalee Dolomite is thin in the Yatina section (Fig.28). Here Baicalia burra forms small, lenticular bioherms up to 1 m in diameter, which had relief over the surrounding depositional surface. Small intraclasts are common in interspaces, and there are slight micro-unconformities in the stromatolitic layering. The surrounding platy dolomites are micritic and dark coloured. Magnesite was not seen in the section, but the lower member, which here is flaggy rather than massive as is common elsewhere, contains on some bedding planes, rectangular markings resembling gypsum crystal casts.

Magnesites are very abundant in the Worumba section (Fig.27), where stromatolite columns are more tuberous and irregular, and have more numerous micro-unconformities than at Burra or Yatina. The occurrences are biostromal, though the upper surfaces of biostromes are undulating; growth was concentrated at certain points along the bed. Magnesite conglomerate beds are frequently intercalated. Ooids and fine intraclasts are common in interspaces, suggesting intermediate energy conditions.

Similar conditions prevailed at Arkaroola (Fig.25), where stromatolite beds are much rarer. Here the lower member, shown as a separate, unnamed formation on the Mt Painter Province Map consists dominantly of interbedded quartzites and siltstones, with pale coloured dolomite marbles at the base. Ripple marks and mud-cracks are very common in the quartzites. The upper member contains abundant magnesite conglomerates, with interbedded laminated dark grey dolomites, but biostromes of Baicalia burra were noted at only one horizon. Similarly, at Copley (Fig.26), magnesites are extremely abundant, but stromatolite biostromes are restricted.

To the north, however, between Myrtle Springs and West Mount Hut (Fig.26), biostromes of Baicalia burra are prolifically developed, with lesser magnesite. Stromatolites grew in relatively the highest energy environment of all Skillogalee Dolomite occurrences; intrasparites fill interspaces between columns, and substantial erosional unconformities are evident in the stromatolitic layering. Frequently large fragments of columns accumulated in interspaces and formed the base for new growth of columns. Biostromes are intercalated in laminated green shales, frequently mudcracked, representing lower energy phases.

Palaeogeography

Forbes' (1955) conclusions regarding the depositional environments of the magnesitic rocks may be summarized as follows:

(1) The frequent exposure and erosion of muds indicated by mudcracks and intraformational conglomerates, suggests a paralic environment.

(2) Dolomite was considered the closest approximation to a normal marine sediment, either as a primary precipitate, or more probably, as a penecontemporaneous replacement of calcium carbonate.

(3) Magnesite formed in the terrestrial environments, possibly by the admixing of continental alkaline water, and magnesium-rich sea water, and was frequently eroded.

(4) The low carbon content of magnesite (compared to the dolomite rock) suggests that the magnesitic environment was unfavourable to life.

(5) Repeated transgressions and regressions explain the cyclic alternation of marine and terrestrial sediments. During transgression, magnesite formed in marginal lagoons, while during regression, these sediments were eroded and reworked seawards, forming reverse-graded beds.

(6) Fig.30, modified from Forbes (1961), shows the interpreted

palaeogeography of the Adelaide Geosyncline during the deposition of the Skillogalee Dolomite. The central portion of the basin received magnesite detritus reworked from marginal lagoons during regressive phases, and dolomite muds during transgressions.

(7) Marginal uplifts, postulated from the relative amounts of terrigenous sedimentation, occur to the west and north of the Flinders Ranges; these are consistent with the known distribution of the Skillogalee Dolomite, and the positions of post-depositional unconformities. Marginal highlands apparently had the greatest relief in the Whyalla vicinity, as deduced from the greatest proportion of sand in the Beetaloo-Port Germein sections.

In general,these conclusions are supported by my observations, but a few points should be noted. Forbes suggested that the magnesitic environment was unfavourable to life, but at Depot Creek, stromatolites occur within a bed of little-transported magnesite clasts. Moreover, at the present day, blue-green algae are abundant in the hydromagnesite lagoons of the Coorong, South Australia. Forbes' marginal zone without magnesite (1961, Fig.5) is poorly documented and therefore questionable; magnesite conglomerates do occur in the Witchelina region, which Forbes showed as lying outside the magnesitic area. Dolomites without magnesite conglomerates are common at both Crystal Brook and Robertstown, so that Crystal Brook is unlikely to have been less marine than Robertstown. To the contrary, if stromatolites are exclusively intertidal, as has been claimed, then their presence in the vicinity of Robertstown should indicate that the latter was a shallower environment. The basin of deposition is likely to have extended northwards from the Willouran Ranges, since Skillogalee Dolomite also occurs in the Peake and Denison Ranges.

Throughout the area of the present Flinders Ranges, there must have extended a wide, extremely level platform of carbonate deposition. The absence of major lateral facies changes, such as those characterizing the Umberatana Group carbonates discussed in the next chapter, suggests that there was little variation in water depth from the margins to the centre of this platform, but deeper conditions probably persisted in the southern regions. Transgressions of the sea across the platform probably advanced northwards from the predominantly marine southern area. During transgressions, dolomite formed in extensive lagoons on the platform, and magnesite in the most hypersaline marginal areas.

The origin of the dolomite and magnesite remains problematical; some may be formed syngenetically, but much of the carbonate is probably reworked. Alderman & Skinner (1957) reported primary dolomite precipitating from the Coorong lagoon waters, but current opinion favours the formation of syngenetic dolomite by the very early replacement of calcium carbonate (Friedman & Sanders, 1967, p.294). Hydromagnesite forms in two ephemeral lagoons in the Coorong (Von der Borch, 1965), but again its mode of origin is obscure. In the Persian Gulf, early diagenetic dolomite is reported associated with evaporites in sabkha (supratidal mud-flat) environments (Illing, Wells & Taylor, 1965) and an analogy could be drawn with dolomite with possible gypsum casts at Yatina. The association of bedded dolomites and conglomeratic magnesites appears to have no direct modern analogue. Magnesite, formed in coastal lagoons, was eroded during regressions and redeposited seawards as intraformational conglomerate. Much of the very fine grained dolomite, especially that forming the stromatolites, may also be of detrital origin, since there is no evidence of dolomitization and fine structures are excellently preserved. The Depot Creek area is likely to have been marginal at times as is suggested by the little transported magnesite intraclasts, but pebbles from other areas are usually well rounded.

Studies of the stromatolitic lamination, gross form, and interspace filling suggest highest energy environments in the Willouran Ranges area, and the lowest energy near Burra. The Willouran Ranges area was subject to strong wave and current action, and the stromatolites may have grown on exposed headlands, as do the columnar stromatolites of Shark Bay. On the other hand, the Burra region may have been either lagoonal or a barred embayment, or slightly deeper water (Forbes suggested a marine environment), but a depth below normal wave base is precluded by the presence of stromatolites. In any case, the important point is that in these two extremes of environment, the one stromatolite form, Baicalia burra occurs. But the occurrences are not identical: the degree of regularity of columns and the presence or absence of contemporaneous erosional features are differences that can be ascribed directly to the energy of the environment.

Chapter 11

ENVIRONMENTAL INTERPRETATION OF PART OF THE UMBERATANA GROUP

This chapter is concerned primarily with conditions of sedimentation throughout the basin during the interval of time between the two major Late Precambrian glaciations of South Australia. This is the period during which stromatolite growth was most prolific, both in areal extent and diversity. The sediments are preserved over very large areas, so that a regional palaeogeographic reconstruction can be attempted.

Patterns of Sedimentation

Isopach maps are useful indicators of basin shape and morphology, insofar as maximum sedimentation can occur in the most deeply subsiding areas. Therefore an isopach map for a given time interval will delimit the approximate basin axis and suggest the positions and trends of shorelines during that time.

The interval between the top of the lower tillite and the top of the upper (and its equivalents) is chosen because its boundaries are easily recognizable, and because it is a unit which, as a whole, is unlikely to be markedly diachronous. Moreover, it represents the time during which stromatolite growth was most prolific. Fig.31 is an isopach map compiled for this interval from sections measured from published Mines Department maps. Although the measurements are extremely approximate, and the map is therefore subject to considerable error, some trends are evident:
(1) the overall axis of the basin is meridianal, but ridges and troughs within it are frequently oriented E-W, (2) the zone of maximum subsidence

is a NNW-SSE trending trough, centred in the south-eastern Central Flinders Ranges, (3) depth of subsidence decreases from here to the east and west, a ridge occurring between the trough and the western margin, (4) in the south (Adelaide, Burra and southern Orroroo 1:250,000 Sheets) troughs and ridges are oriented E-W, and (5) in the Northern Flinders Ranges, a trough parallels the fold trends, and shallows to the north, east and south, suggesting a land mass peripheral to the north-eastern margin of the presently exposed sediments. Here the distances between the isopachs have probably been compressed at right angles to the fold axes, thus accentuating the E-W trend, but compression due to folding cannot explain the E-W trends on the Adelaide, Burra and Orroroo 1:250,000 Sheets, where the axes of folding are meridianal. These isopachs must represent depositional trends.

No rocks belonging unequivocally to this time interval have been found west of Lake Torrens, where Wilpena Group equivalents unconformably overlie earlier sediments (Pandurra Formation and Woocalla Dolomite) (Thomson, 1966a). The fact that within the Adelaide Geosyncline, the isopachs show rapid thinning to the west, suggests that Umberatana Group sediments were never deposited on the stable platform; the basin margin may have been situated somewhere near Lake Torrens and Spencer Gulf. A similar thinning occurring along the northern and eastern margins of the Northern Flinders Ranges, similarly suggests a land mass in these regions (the present basement inliers at Mt Painter and Olary are not remnants of this land mass, since they are overlain by a considerable thickness of Umberatana Group cover). In the south-eastern part of the Copley 1:250,000 Sheet, the Umberatana Group is thin, suggesting proximity to the basin margin. The interpretative cross-section (Fig.32) across the Orroroo 1:250,000 Sheet illustrates the relationships and thickness variations of rock units from the margins to the centre of the basin in the Southern Flinders Ranges. These suggestions, based upon the patterns of thickness variation, are very largely confirmed by a study of the sediments themselves.

Descriptive Stratigraphy

As now defined, the Umberatana Group commences with the Sturt Tillite and its equivalents (Yudnamutana Sub-Group), which rest unconformably upon eroded Burra Group sediments. The glacial sediments are commonly interpreted as having been deposited in shallow seas (see Parkin et al., 1969, p.65), but direct evidence for this is not always present. Laminated shales with dropped boulders occur in some regions, e.g. north-east of the Enorama Diapir, and at Merinjina Well, indicating subaqueous deposition, but commonly the glacigene sequence consists of diamictites, conglomerates, grits, sandstones and shales. At Depot Creek, Southern Flinders Ranges, cross-bedded grits and conglomerates occur as channel fills, interbedded with diamictites, shales and dolomites; such channels and the sorted reworked glacial debris in them are more likely to be of terrestrial origin.

The stratigraphy of the interval between the top of the lower tillite and the top of the upper is described below.

Tapley Hill Formation

This unit is extremely widespread and occurs over almost the whole basin, overlying the lower tillite with a sharp conformable or disconformable contact. The dominant lithology, a dark grey, very thinly and evenly laminated siltstone, is present in all sections; in addition, various carbonate units may be interbedded.

Parkin et al. (1969, p.66) state that:

> "The (Farina) Sub-Group commences with the Tindelpina Shale Member, a dark, extremely finely laminated shale, frequently with thin dolomite layers. This marker unit persists, except for rare 'pinch-outs' due to local erosion, over the whole of the Geosyncline."

The persistence of this black shale at the base of the Tapley Hill Formation is perhaps overstated, since in many areas, e.g. Depot Creek, the Tapley Hill Formation sequence is siltstone throughout, except for the basal dolomites.

Thinly bedded grey dolomites, outcropping as 2 to 8 cm thick flags, occur interbedded in basal Tapley Hill Formation along the western margin of the basin (as seen at Depot Creek, Southern Flinders Ranges, and Sturt Gorge, south of Adelaide). In these areas, the sequence commences with dolomite, and passes up gradationally with interbedding into siltstone. In Sturt Gorge, the dolomites are dark, organic-rich dolomicrites. At Depot Creek, they are banded, dolomitic intrasparites and intramicrites containing fine rounded intraclasts and pellets. Bands are commonly slightly graded. The dolomites represent a higher energy environment and more rapid deposition than the interbedded silts, so that periods of strong current action alternated with calm periods of slow settling of terrigenous silt.

The dolomites are always stratiform, not cross-cutting, and contain well preserved primary depositional textures with an idiotopic sparry dolomite cement. The pellets and intraclasts may have been transported as dolomite, and been cemented in a dolomite forming environment, or the whole sediment could have been affected by very early diagenetic dolomitization. In either case, they could have formed only in very shallow water; this together with the relatively high energy conditions represented suggests a littoral environment. No stromatolites are known from this facies.

No such environmental restriction applies to the thin dolomicrites similar to those of the Adelaide region; they are much more widely distributed than the pelletal dolomites of Depot Creek, and may extend far to the north and east: I have observed them in the Mt Rose vicinity, Northern Flinders Ranges, and very silty dark fine grained dolomites occur east of Orroroo (D. Tucker, pers. comm.) and near Eudunda. In these rocks, the dolomite is probably detrital, in which case they could have been deposited in any depth of water.

The siltstones interbedded with the dolomites are dark grey, very thinly and uniformly laminated. Current structures are generally absent. The lamination is an alternation of 0.05 to 0.1 mm thick quartz-rich silt laminae and thinner, organic-rich clayey laminae. Small amounts of carbonate cement are present.

This lithology is maintained almost throughout the Tapley Hill Formation; however, current effects are visible in some places. In the type section south of Adelaide, much of the Tapley Hill Formation contains abundant current ripples, which indicate a fairly consistent south easterly current flow (Fig.33). Most of the ripple marks are isolated ripples (Walker, 1965) and contain slightly coarser silt-sized sediment. Rippled beds are separated from each other by evenly laminated silts several centimetres or tens of centimetres thick (Pl.36c). Similar ripple marks near Clare indicate easterly-moving currents (Fig.33). The constancy of direction of the currents suggests that they are not tidal currents.

In the far north-eastern part of the Flinders Ranges, the Tapley Hill Formation is apparently absent (Coats et al., Mt Painter Province Map); here the Balcanoona Formation (normally above the Tapley Hill Formation) rests directly on the lower tillite. It is not clear whether this is due to unconformity, or whether dolomite deposition in this area was contemporaneous with siltstone deposition elsewhere.

The following features characterize the Tapley Hill Formation: (1) its extremely widespread, continuous distribution, (2) its very fine, uniform lamination, (3) its dark colour (ths silts are often pyritic) and (4) the presence, locally, of isolated current ripples. These features suggest very slow deposition under reducing conditions, by settling of silts and clays. Occasionally, bottom currents laden with very little sediment, flowed down the palaeoslope towards the basin axis. The Tapley Hill Formation is best regarded as a basinal marine facies; its deposition, below wave base, is likely to have been in moderately deep water.

The interbedded dolomites of the basal Tapley Hill Formation are problematical. Since they probably formed in very shallow water, and the overlying silts in deeper water, the succession from dolomites to laminated silts is considered to mark a rapid marine transgression, perhaps related to a eustatic rise of sea-level after the cessation of the first major (Sturtian) glaciation.

In most areas, the siltstones of the Tapley Hill Formation grade upwards into calcareous siltstones and silty banded limestones (Yankaninna Formation and equivalents). This unit is commonly cross-bedded; near Adelaide, south-easterly currents persist. At Maynards Well, Northern Flinders Ranges, large scale ripple marks of 15 cm wavelength consistently indicate south-westerly currents.

Brighton Limestone (and its approximate equivalents)

In most areas, the upper part of the Tapley Hill Formation becomes markedly calcareous, occasionally with thin limestone or dolomite interbeds (e.g. the Wockerawirra Dolomite of the Central Flinders Ranges). Well defined, thick limestone units occur above the Tapley Hill Formation near Adelaide and along the western margin of the Southern Flinders Ranges (Brighton Limestone and equivalents), while the Balcanoona Formation of the Northern Flinders Ranges is of similar facies and probably corresponds in age, at least in part, to the Brighton Limestone (Table VI).

Fig.33 is an isopach map of the Brighton Limestone and its equivalents in the southern part of the Adelaide Geosyncline; their distribution has been deduced from 1:250,000 maps and from sections measured in the field (see Appendix II). The map shows that the Brighton Limestone equivalent is mainly restricted to the western margin of the basin, and thins rapidly towards the east. At approximately latitude 32°, the Brighton Limestone lenses out to the north, as it does also south of latitude 33°. South of this latitude, there are lenticular limestone occurrences near Booborowie, near Kapunda, and at the type area south of Adelaide. The Brighton Limestone of the type section is probably not continuous with its equivalents in the north, which should therefore preferably be renamed as separate formations. East of the main outcrop of Brighton Limestone equivalent in the Southern Flinders Ranges, a very thick limestone lens occurs centred near Yednalue. The isopachs also show two centres of maximum limestone deposition near Melrose and near Depot Creek, separated by a reduced section immediately east of Port Augusta.

Where the Brighton Limestone lenses out, its time-equivalents are either calcareous, Tapley-like siltstones, with minor dolomites and greywackes (Yankaninna Formation and Sunderland Greywacke to the north) or wavy bedded and sandy siltstones (Tarcowie Siltstone to the south and east).

In the type section near Adelaide the upper, calcareous part of the Tapley Hill Formation grades into scoured and cross-bedded silty limestones, which are overlain by pinkish and blue-grey, partly cross-bedded oolitic and intraclastic limestones (Pl.37d) with minor local rippled green shale beds. This is the dominant facies of the Brighton Limestone. Mostly, the sediments are strongly winnowed, and consist of 30 to 70% ooids and/or fine intraclasts (some intraclasts are reworked, cemented ooids), generally closely packed, and cemented by sparry calcite.

The uppermost member of the Brighton Limestone is a pink to buff coloured laminated dolomite, containing flat-pebble breccias and oolites. Allochems are supported by a micritic matrix, but the whole rock is dolomitized. Intraclasts are tabular, with well rounded edges. The laminated dolomites with broad, concave-upward structures up to 20 cm wide, have been described in Ch.7.

The upper beds of these buff-coloured dolomites are thinly interbedded with green silts and gradually the deposition of terrigenous clastics became dominant. The overlying beds are thinly bedded grey and green siltstones with frequent purple, ripple-marked and desiccation-cracked mud laminae.

In the Southern Flinders Ranges, an essentially similar sequence of facies is observed. The section at Depot Creek is typical (Appendix II (2)). Unlike the Adelaide section, the transition from Tapley Hill Formation to Brighton Limestone does not occur by increased carbonate content in the siltstones, but by periodic cessation of terrigenous sedimentation, accompanied by stromatolite growth. At the base of each stromatolite bioherm (Omachtenia utschurica Nuzhnov) is a diastem; the surface of the silts was scoured, and stromatolites grew on the elevated points, while channels were filled with imbricated flat-pebble breccias (Pl.26c,d,f). In places, columns are slightly elongated in an east-west direction. Typically, the stromatolites commence as domes (Pl.26c) on erosional highs in the underlying silts, and frequently the lamination in the silts is also domed; this is interpreted as a compaction effect. Silt deposition was frequently resumed during the late stages of stromatolite growth, as indicated by intertonguing.

The flat-pebble breccias filling the erosional channels around the periphery of bioherms are poorly sorted, either with lime mud supported intraclasts (Pl.36f), i.e. wackestones of Dunham (1962), or pellets and large intraclasts with sparry cement. The intraclasts are randomly stacked, or in places irregularly imbricated, and frequently cover spaces sheltered from lime mud sediment, but now filled with sparry calcite. In addition, sparry calcite and pellets of authigenic chlorite fill voids left by the selective leaching of intraclasts. Davies (1970) recorded flat-pebble breccias from the intertidal zone of the Gladstone Embayment, Shark Bay, W.A., formed by brecciation and upwedging of indurated crusts. These pebbles may in turn be reworked during storms. A similar origin is plausible in the Brighton Limestone example, but here the pebbles are chiefly dolomitic, unlike the aragonitic crusts of Shark Bay.

Oolitic-Intraclastic Limestone Member

The transitional zone between the Brighton Limestone and the Tapley Hill Formation is followed by very massive limestones including large bioherms and thick oolitic-intraclastic beds. The bioherms of Acaciella augusta and local Inzeria conjuncta, occupying various lateral and vertical positions in this unit (see map, Fig.24), have been described above in Ch.7.

The dominant rock type of the oolitic-intraclastic facies is a poorly bedded oosparite with approximately 30% calcite ooids, 50% intraclasts and 20% sparry cement. A few intraclasts are small, eroded lime mud flakes, generally less than 1 mm long, but most are themselves large reworked oomicrite fragments (Pl.37g). These intraclasts are up to 5 cm long, of irregular outlines, and consist of ooids 0.25 to 0.75 mm in diameter, of slightly recrystallized calcite, supported by limonitic lime mud matrix. The fragments are coated with an extremely thinly laminated

0.1 to 0.2 mm thick oolitic layer which drapes over individual entire ooids (Pl.37g), showing that they suffered little abrasion before the renewed growth. They resemble the botryoidal lumps of Illing (1954). Ooids in the matrix between intraclasts generally have a sparry calcite core sometimes with authigenic dolomite rhombs, and an extremely thinly laminated outer zone. Ooids are cemented by relatively coarse, twinned, sparry calcite (Pl.36e), but many of the large, coated intraclasts are surrounded by a thin drusy layer, earlier than the sparry cement. The possibility that much of the sparry calcite is recrystallized lime mud cannot be rejected, but is unlikely in view of the preservation of lime mud as matrix within the large intraclasts, and the good preservation of the fine structure of the ooids.

The ooids are most probably of inorganic origin, though a few resemble forms described by some Russian authors as oncolites, presumably of algal origin (Zhuravleva, 1964; Narozhnykh, 1967); in particular one specimen (Pl.36d) has a small "blister" under its outer laminae, suggesting that the grain was surrounded by a cohesive algal film. Alternatively, a small detrital grain, since leached out and replaced by sparry cement, may have been incorporated in the outer laminae. Moreover, lenticular swellings between laminae do occur in Recent ooids from the Bahamas (Newell, Purdie & Imbrie, 1960, pl.1A). (See p.56 for a discussion of oncolites). Small fine grained intraclasts, up to several millimetres long, are frequently surrounded by a thin dark, micritic lamina, which could be interpreted as micritization due to algal boring (Bathurst, 1966).

At many levels throughout the oolitic limestone sequence, there is evidence of contemporaneous scouring and cross-bedding. Cross-bedding in channel fills indicates easterly and south-easterly flowing currents. Oosparite filling channels contains fewer large intraclasts than the surrounding sediment, and is crudely banded, oosparite laminae alternating with silty micrite laminae. Foresets slope at up to 25°, and are truncated above by further poorly bedded oosparite.

The oolitic-intraclastic facies contains within it, bioherms of greatly varying dimensions (map, Fig.24). Some are domed, and stood above the surrounding sediment surface with a relief of at least one metre, but most interfinger with the oolitic limestones, so that their relief at any one time must have been much less.

In the Melrose area, bioherms of Inzeria multiplex and Boxonia melrosa are surrounded by similar oolitic and intraclastic limestones to those at Depot Creek, but here the field relations are less clear, due to poor exposure. At Yednalue, an essentially similar facies, again thoroughly winnowed (thin section, Pl.37f), occupies a great thickness below the thick Inzeria multiplex beds. In the extreme south of the Brighton Limestone equivalent outcrop, near Tarcowie (south of Orroroo), strongly recrystallized oosparites contain up to 20% quartz and feldspar sand.

The oolitic-intraclastic facies of the Brighton Limestone represents a very shallow marine environment of high energy, to provide the agitation necessary to form regularly laminated ooids and to deposit them in thick beds, often with large scale cross-bedding and scouring. Moreover, the sediment is generally well-winnowed, again indicating strong current or wave action. The environment is interpreted as very shallow subtidal or littoral, in the zone of maximum wave action.

In places at Depot Creek, the oolitic-intraclastic facies is dolomitized. The dolomite has extremely sharp, irregular and discordant boundaries, and is interpreted as being late diagenetic or epigenetic, perhaps related to minor faulting. Since here the dolomitization is complete and cross-cutting it is probably not related to the selective dolomitization of dark laminae in stromatolite bioherms. Both ooids and sparry cement are completely replaced by hypidiotopic to idiotopic dolomite; frequently rhombs 0.1 mm in diameter are set in a finer matrix. Small structureless granules in the dolomite may represent relics of impure ooid nuclei. Small, scattered sparry calcite patches are probably late infillings of secondary voids due to dolomitization. One specimen (Pl.37c) shows a replacement dolomite vein at the calcite-dolomite contact.

In the Horrocks Pass-Pichi Richi Pass area, the Brighton Limestone is thin and sandy. In Horrocks Pass, the uppermost part of the Tapley Hill Formation contains at least one small, lenticular channel fill of cross-bedded, sandy limestone, indicating approximate northerly current flow. A thin, intraformational breccia bed, interbedded in siltstones, is poorly winnowed, poorly laminated, and contains small intraclasts with up to 20% quartz silt and sand. But the dominant facies is a large-scale cross-bedded sandy and gritty limestone. In Pichi Richi Pass, the Brighton Limestone is reduced to three massive 6 ft (2 m) thick sandy dolomite beds. The sandy lithofacies may have formed in a small delta.

Dolomite Member

The upper member of the Brighton Limestone, as seen at Depot Creek, Buckaringa Hill or Mundallio Creek, is entirely dolomitic. Massive pink to buff coloured dolomites overlie the intraclastic-oolitic facies, and grade up by interbedding of reddish dolomicrites into the overlying Willochra Formation (dominantly red-beds). Sandy, fine intraclastic, and oolitic dolomite facies grade into each other both vertically and laterally.

The lowest unit of the dolomitic sequence is a pink dolomitized fine grained limestone up to 40 ft (13 m) thick, with thin interbedded silty bands. In the northern part of the map area (Fig.24), channel-fill lenses and more extensive beds of partly cross-bedded, poorly sorted, dolomite-cemented sandstone occur interbedded with and above the dolomitized limestone. The bioherms of Katavia costata are intercalated between two sandstone beds. Insufficient cross-bedding was visible to allow any generalization about current directions, but north, north-westerly and westerly flows were noted.

Overlying the sandstones in the north and the dolomitized fine limestone in the south, is a very continuous, 6 ft (2 m) thick unit of thickbedded oolitic and finely intraclastic dolomite. Intraclasts are small flat pebbles, 0.5 to 5.0 mm long, lying parallel or at a low angle to the bedding. Many are coated grains, with 0.1 mm thick rims of micritic dolomite, which might be interpreted either as algal boring or dolomitized superficial oolites (Illing, 1954). True ooids also occur, but their fine structure is largely obliterated by dolomitization. The sediments are frequently poorly sorted. Allochems are mostly supported by fine grained hypidiotopic dolomite, of 0.006 to 0.02 mm grain size, interpreted as dolomitized lime mud, but some specimens are better winnowed and sorted, with up to 15% quartz and/or feldspar sand, cemented by sparry dolomite. The proportion of terrigenous clastics increases towards the north of the Depot Creek area. In places, voids up to 5 mm long, lined with drusy dolomite cement, occur between ooids (Pl.37b), and are filled with a second generation of very coarse, sparry dolomite.

The origin of the voids is not clear; they cannot be formed by the simple winnowing out of mud, since their roofs could not have been self-supporting. An origin by partial desiccation or expulstion of water, akin to the formation of birdseyes in lime muds (Shinn, 1968) seems plausible. In the Adelaide region, well sorted dolomitized oosparites contain similar calcite-filled voids, but in at least one specimen, there is evidence that the voids were formed by solution, since all gradations exist between undissolved dolomitized ooids, ooids with all but dolomitic rims dissolved, and the larger open spaces (Pl.36b).

A transitional sequence of interbedded pink dolomites and thin purple shales passes up gradationally into the overlying Willochra Formation, in which thin dolomites persist for up to 50 ft (16 m). Typically, the dolomites are thinly bedded alternating sandy intrasparites, laminated intramicrites and thin layers of reddish dolomicrite. Most intraclasts are large and of tabular form, and frequently grade laterally into undisturbed micritic layers, but small, coated grains and some true ooids also occur. Micritic layers were apparently disrupted, perhaps by desiccation, and redeposited as intraclasts more or less _in situ_ (Pl.34a,c). Davies (1970), considered that indurated crusts may be brecciated in place by thermal expansion and contraction, and by volume changes due to induration.

In places, the micritic layers are arched up to form adjacent concave-upward structures (similar to those of the Adelaide Region), but here the arching frequently left voids which are now filled with sparry dolomite (description, Ch.7). These structures suggest lateral compression of cohesive, partly indurated, dolomitized lime mud layers. The interbedded intrasparites are largely cross-bedded on a fine scale, with alternating intrasparite and quartz-silt laminae.

Large void spaces are common, especially in the fine grained, silty and micritic sediments. The cavities are usually concordant with laminae and intraclasts, but occasionally their floors truncate laminae. Drusy quartz or dolomite commonly lines the cavities, which are filled with coarse, idiotopic dolomite or single dolomite crystals. The cavities resemble the planar birdseye structures of Shinn (1968), which he attributed to the repeated shrinking and swelling of lime mud in the intertidal and supratidal environments.

Dolomitization in the upper member of the Brighton Limestone is always stratiform, not cross-cutting, and has affected all carbonate sediments, so that no limestones are preserved. The presence of dolomitic ooids proves that the dolomite is secondary, not detrital, since ooids are precipitated as aragonite. The good preservation of fine structures and the fine grain size of the dolomite suggest a very early diagenetic replacement of lime sediments, probably in a supratidal mud-flat environment similar to the modern sabkhas of the Persian Gulf (Illing, Wells & Taylor, 1965 and Kendall & Skipwith, 1968). The pink and reddish colours of the dolomites are consistent with deposition under oxidizing conditions, as is suggested by the red-bed sequence above.

Willochra Formation

The overlying Willochra Formation consists of lenticular-bedded silts and sands, often poorly sorted, with very numerous thin, wavy, purple clay laminae, 1 to 5 mm thick. The rock frequently parts along these laminae, and where partings are well exposed, oscillation ripple marks, and mudcracks are observed extremely frequently. Mudcracks, often superimposed on ripple marks, are usually of sharply V-shaped cross-section, and filled with silt and fine sand. Most are polygonal, while some display a round or concentric pattern. Oscillation ripple marks generally have meridianal axes, both at Depot Creek and Adelaide, and the few that are slightly asymmetrical indicate both easterly and westerly current directions. Occasional interference ripples trend NW-SE.

The clay laminae owe their purple colour to extremely finely disseminated haematite which, together with the mudcracks, indicates frequent exposure to the atmosphere. The influx of coarser terrigenous clastics was resumed periodically. Sandy layers are commonly graded, and pass up into purple clay laminae. An extensive lagoonal or mud-flat environment of low energy is envisaged, periodically flooded, perhaps by storm waves, which deposited the graded silty and sandy beds. During the following quiescent periods, muds were deposited in extremely shallow water under very mild wave action, producing the small-scale oscillation ripple marks. The mud-flats were then exposed and desiccated, before the next inundation and deposition of coarser clastics. Dolomite deposition was still important at the gradational base of the formation, but was entirely replaced higher in the sequence by clastic sedimentation.

The facies of the Willochra Formation is replaced to the north and east by green and grey beds, lacking evidence of subaerial exposure. The rippled and lenticular bedded Tarcowie Siltstone and the massive-bedded Uroonda Siltstone (occurring east of the Willochra Plain) are interpreted as slightly deeper water equivalents of the Willochra Formation. To the north of Warrakimbo (Parachilna 1:250,000 Sheet), the Willochra Formation passes into thinly laminated green silts and shales (part of the Etina Formation).

Etina Formation

In the type section south of Adelaide, the equivalents of the Lower Willochra Formation (the lowest purple slates immediately above the Brighton Limestone), are overlain by cross-bedded gritty and sandy limestones (the Marino Arkose), characterized by abundant large, fresh, red feldspar grains. Cross-bedding indicates varying current directions, both northerly and southerly, while interference oscillation ripple marks trend both E-W and NNW-SSE (Fig.34(1)). These varying directions suggest deposition in extremely shallow water, under the effects of tidal currents, and perhaps long-shore drift.

In the Quorn region, lenses of similar cross-bedded gritty limestones are scattered at various levels in the Willochra Formation. Near Buckaringa Gorge to the north, these become continuous, and then thicken continuously northward; they form the southern extension of the Etina Formation of the Central Flinders Ranges. The distribution and thickness variations are shown on the isopach map of the Etina Formation (Fig.34).

On the Parachilna 1:250,000 Sheet, gritty limestone interbeds in a predominantly green shale sequence, increase in number and thickness towards the north, so that the whole Etina sequence reaches a maximum thickness of nearly 4000 ft (1300 m) in the Oraparinna region. North of the vicinity of Arkaba, stromatolitic and oolitic limestones also become important. It is very probable that in the Central Flinders region, Etina deposition commenced long before it did near Quorn; the Etina Formation here may be partly time-equivalent to the Brighton Limestone in the south. North of Blinman, the Etina Formation thins gradually, and may be differentiated into a lower thick, partly dolomitized member and an upper member consisting of green shales with interbedded, thin limestone or, in places, dolomitized limestone bands. These are to be correlated with the Balcanoona Formation and the Wundowie Limestone respectively, whose type area is near Balcanoona H.S. In the Northern Flinders Ranges, a thick wedge of Balcanoona-Wundowie sequence runs west from Balcanoona through Burr Well and Wundowie Bore, on the northern margin of an area of thin Umberatana Group sedimentation. To the north of this, the Balcanoona Formation and Wundowie Limestone thin and lens out.

The Balcanoona Formation of the Northern Flinders Ranges occupies a similar position to the Brighton Limestone in the south, and is in general of similar facies. In particular, in the Balcanoona area, a transition from laminated silts (Tapley Hill Formation) through limestones to dolomites and red shales (Angepena Formation) is analogous to the section at Depot Creek. In Nepouie Creek, for example, five miles north of Balcanoona H.S., the Tapley Hill Formation is overlain by flaggy dark grey limestones, flat pebble breccias and bioherms of columnar-layered and pseudocolumnar stromatolites, partly resembling Omachtenia (see p. and Pl.27c,e). The overlying massive bedded dark grey limestones consist of irregularly columnar, wavy and laterally linked stromatolites (Pl.35e), and pass up into buff coloured dolomites with interbedded red shales.

To the west, the red shales of the Angepena Formation pass into green shales of the Amberoona Formation (see Coats et al., Mt Painter Province map). Fig.39 is a fence diagram showing the relationships of the Balcanoona Formation, Wundowie Limestone and the red and green shale units of the Northern Flinders Ranges. It will be seen that the bedded, buff-coloured dolomites of the top of the Balcanoona Formation pass westwards into predominantly oolitic limestones, occasionally with stromatolitic interbeds. Here dolomitization does occur (e.g. at Angepena, Burr Well or Wundowie Bore), but the dolomite is coarse-grained, cross-cutting and clearly late diagenetic or epigenetic.

The oolitic limestones of the Balcanoona Formation are typically well-washed, even grained oosparites, with ooids chiefly 0.75 to 1.0 mm in diameter, cemented firstly by drusy and then by granular sparry calcite cement. Composite ooids are also common. Authigenic quartz may replace ooid nuclei. Various micritic intraclasts, sometimes recrystallized, are incorporated in the sediment, but are generally of small size (less than 5 cm). Partial or complete dolomitization of ooids and cement may be observed in various specimens, but always the dolomite is secondary. In many places, the gross structures of the rock, even the bedding, may be obliterated by dolomitization.

The Wundowie Limestone is dominantly of stromatolitic facies.

Commonly, individual limestone beds consist of adjacent domed bioherms of *Linella munyallina*, while at Burr Well *Inzeria* cf. *tjomusi* and *Jurusania burrensis* are also found in similar modes of occurrence. Associated gritty limestones either overlie or underlie the stromatolites; in places bioherms were rapidly buried by the deposition of the coarse clastics. At Burr Well, cross-bedding and current ripple marks indicate mainly southerly flowing currents, while at Roebuck Bore, the gritty limestones are deposited in SE to south trending channels. The Wundowie Limestone is likely to be markedly diachronous, as is suggested by its highly variable stratigraphic position relative to the Balcanoona and Elatina Formations. Moreover at Burr Well, stromatolitic beds and lenticular gritty limestone beds intertongue at various levels with the interbedded green shales.

The environments of deposition of the Etina Formation, Balcanoona Formation and Wundowie Limestone are likely to have been very shallow subtidal. The abundance of stromatolites limits the depth of water to about 30 m (see Ch.10), while the well washed oosparites indicate a high energy regime, probably under intense wave action. There is no evidence of subaerial exposure; but in the Balcanoona area to the east, the uppermost bedded dolomite of the Balcanoona Formation may be supratidal or intertidal; this area is considered to represent the eastern basin margin. The cross-bedded gritty limestones, frequently filling scour structures in the Etina and Wundowie Limestone are likely to have formed in tidal channels.

The overall extent of these formations, as seen in Fig.34, suggests shallow-water conditions over most of the northern part of the Adelaide Geosyncline at this time, thus distinguishing it from the southern region, where very shallow-water facies are restricted to the western margin.

However, the bulk of the sediment of the Etina Formation and its equivalents is grey-green shale, which tells little of its environment of deposition. The limestone units are probably diachronous at least in part, so that areas of shallow water may have migrated laterally in time, within a slightly deeper basin. These shoals which were the sites of lime-deposition may have been in the form of E-W off-shore banks, which, in turn probably sheltered the intervening areas of mud deposition from current and wave action. Thus the evenly laminated green shales may have accumulated in rather shallower water than if formed in the open sea.

A possible method by which the depth of water for these shales could be estimated is to examine the nature of the margins of some major carbonate units. For example, on the Serle 1-mile sheet (Parkin et al., 1953), the Balcanoona Formation (unnamed on this map) is shown to lens out from the west to the east. An examination of the lateral contacts might reveal whether the limestone and the shale intertongue, or whether the limestone is a reef which grew above the level of the surrounding shales. Unfortunately, I have not had the opportunity of studying these areas.

Amberoona and Enorama Formations

The laminated green and grey silts and shales of the Amberoona and Enorama Formations (Thomson et al., 1964), are identical to those interbedded with limestones in the Etina Formation and its equivalents. If the above depositional model is accepted for the Etina Formation, then the absence of these sandy and oolitic limestones or other high-energy sediments in the overlying shales would indicate an overall deepening of the basin, though not necessarily synchronously everywhere.

Trezona Formation

The Enorama Formation of the Central Flinders Ranges is overlain by shales with interbedded stromatolitic and intraclastic limestones of the Trezona Formation (the "Hieroglyphic Limestone" of Mawson, 1938). Although the extent of this formation has not been accurately delimited, it is apparently restricted to the central portion of the Adelaide Geosyncline, being thickest in the Wilpena-Blinman region.

The "hieroglyphic" beds are commonly reddish coloured limestones, consisting of curled minute mudflakes set in a sparry calcite matrix. Nearly all the mudflakes are now replaced by sparry calcite, apparently filling cavities left by their dissolution. Their formation is interpreted as follows: (1) lime mud was deposited as very thin laminae, perhaps thin algal mats, (2) under conditions of exposure, the laminae cracked and curled, and were covered with a film of fine grained haematite, (3) the curled mudflakes were redeposited after little transportation, in a lime mud matrix, probably under renewed immersion, (4) in places, geopetal structures formed, as mud-curls were partly filled with micritic sediment (Pl.37e) and (5) mud-curls were dissolved out and the voids filled with sparry calcite. Several generations of sparry calcite are likely.

The stromatolitic beds of the Trezona Formation have already been described (p.213). Without further work, the environmental significance of these structures cannot be fully evaluated. Although mound-shaped and cumulate stromatolites have been noted in the Trezona Formation in several areas, the large, consistently oriented elongated mounds have been studied only at Enorama Creek. Here the stromatolites occur at several levels, interbedded in laminated shales, near the base of the Trezona Formation. The elongated cumuli are consistently oriented with their long axes at 162°. The cuspate ridges described in Ch.7 trend at an azimuth of 60°, i.e. approximately perpendicular to the major elongation. The environmental significance of these structures and their analogy with the tufted mats of Shark Bay have already been discussed (p.214). Similarly elongated cumuli were seen at Mt Chambers Gorge (Pl.32a), where the elongation also trends N-S. At this stage the regional significance of these observations cannot be assessed; moreover, no independent evidence for current directions has so far been found in the Trezona Formation, as Hoffman has done in the Pethei Formation of Canada (Hoffman, 1967).

Elatina Formation

The various facies of the Elatina Formation, and its tillitic equivalents, form the youngest unit of the Umberatana Group. A discussion of these formations is beyond the scope of this thesis.

Notes on Diapirism

Coats (1965) showed that diapiric movement occurred in some areas during sedimentation, or was associated with minor angular unconformities at the base of the lower tillite. He quoted the presence in the sediments surrounding a diapir of detritus derived from the diapir as evidence of its activity during sedimentation. An example of this is the occurrence of conglomerate wedges on the flanks of the Enorama diapir, in the limestones of the Etina Formation. Thus diapiric activity during Etina deposition is established. But the Enorama, Oraparinna and Blinman Diapirs all lie in the axis of a trough of maximum deposition of Etina Formation. Despite spasmodic uplift on diapirs, the basin continued to subside in this area, although no sediment could have accumulated over the actual diapirs during their shedding of detritus.

Fig.34(1) is an overlay showing the distribution of diapirs relative to the Etina Formation and its extensions in the north. The close correlation between them is evident. It is suggested that the diapirs, which are concentrated in the thick axial zone of the Adelaide Geosyncline, may have been the factor responsible for periodic shallowing in this part of the basin. During periods of subsidence, green and grey muds would have settled in relatively deeper water; periodic diapiric uplift would have brought the sea floor above wave base, allowing the accumulation of sediments characteristic of shallow, agitated water, i.e. the sandy limestones of the Etina Formation. Provenance studies may reveal how much of the terrigenous detritus is derived from diapirs. In the south-eastern part of the basin, where the Mt Grainger and Paratoo are the only diapirs, the Etina Formation is absent. Here relatively deeper water conditions persisted throughout the time between the glaciations.

A Palaeogeographic Synthesis

The facies and distributions of some rock units forming part of the Umberatana Group have been described above. Their interpretation in terms of palaeogeography is speculative, owing to the difficulties outlined. If a model of the Adelaide Geosyncline as an intracontinental, epeiric basin is accepted, then much of the lateral and vertical facies variation should be explicable in terms of transgressions and regressions of the sea. In general, the marginal areas will be the shallowest, and the central portion deeper, unless other factors intervene to raise or lower the basin floor.

The palaeogeographic interpretations are summarized by the maps A to H, Figs.35 to 38. Map A represents the beginning of Tapley Hill time. The meridianal trend of the basin is already established, with land masses on the west (the Gawler Platform) and the north-east ("Paralania" of Sprigg, 1952). A trough probably extended north-westwards in the present

Willouran Ranges. Following the cessation of glaciation, the melting of ice caused a widespread transgression; almost the whole basin was inundated, but the glacial sediments deposited near the shores of "Paralania" were probably emergent. The western margin of the basin, marked by the presence of pelletal dolomites probably deposited in the littoral zone, was near the present western margin of the Flinders Ranges. A small diapir near Wilson (W1), contributed coarse detritus to conglomerate lenses in the laminated silts. Included were indurated boulders of Gymnosolen ramsayi limestone (p.129); these are totally different from diapir-derived detritus elsewhere, and may have grown penecontemporaneously with the Tapley Hill Formation in a shallow water environment not now preserved, perhaps above the rising diapir.

During the middle part of the Tapley Hill time (Map B), relatively deep water conditions persisted over the area, but the marginal zone near "Paralania" may have received carbonate sedimentation. The western shoreline is unknown, but may have been far to the west of Lake Torrens and Spencer Gulf. Perhaps the Woocalla Dolomite (of post-Pandurra Formation and pre-Wilpena Group age) of the Pernatty Lagoon area could be a marginal facies of the basinal Tapley Hill Formation. The stromatolites (p.216) unfortunately give no guidance as to its age, but rather resemble forms found in the Trezona Formation.

At this stage the transgression had reached its furthest extent, and laminated silts and muds were laid down by settling over wide areas. Periodically, sediment-impoverished currents flowed eastwards down the basin floor in the southern region. In the north-eastern part of the

Flinders Ranges, dropstones have been found in the Tapley Hill Formation by Drs B. Daily and V. Gostin (pers. comm., 1970), who therefore consider that a cold climate persisted in the interval between the two major glaciations. Similar occurrences are not generally recorded in the literature from other areas. It is possible that the dropstones originated from a local glaciation, especially if "Paralania" was mountainous at the time.

The following stage (Map C) was a general regression, marked by shallowing of water in the western and north-eastern regions. In the type area south of Adelaide, silts were now mixed with significant amounts of lime mud, and deposited well within the depth zone of active, easterly flowing currents. In the Depot Creek (DC) region, sedimentation ceased periodically, and Omachtenia utschurica bioherms grew in shallow water on small erosional mesas, while flat pebbles and pellets derived from the local erosion of algal mats, accumulated in the intervening channels. Bioherms possibly similar to these grew on the north-eastern margin of the basin near Balcanoona (BA). Elsewhere, in the basin centre, slightly deeper conditions persisted, but even these were periodically disturbed during the next phase (Map D).

By now the basin had re-established its former restricted extent, with shallow marginal zones in the west and north-east, and a deeper central and south-eastern zone, near the basin axis. In the areas near Adelaide (A), Melrose (M) and Depot Creek (DC), well-washed and sorted oolites were deposited in the littoral or shallow subtidal zones under intense wave action. Stromatolite bioherms grew in the Depot Creek (Inzeria conjuncta, Acaciella augusta) and Melrose (I. multiplex and Boxonia melrosa) regions, while in the intervening Port Augusta (PA) vicinity, sandy limestones accumulated, perhaps in a delta with a western river supply. Thick bands of oolitic limestone similar to those of Depot Creek accumulated at Orroroo (O) and east of Yednalue (Y). Deeper water persisted elsewhere (except for minor limestones at Booborowie (B) and Kapunda (K)), but in the northern half of the basin, in the zone of the largest diapirs (few diapirs occur outside it), water depth was shallowed periodically by diapiric uplift. The sea floor was brought above wave base, and carbonate deposition, principally oolitic, commenced. Stromatolite bioherms grew in places, and local influxes of sand may have been derived from the erosion of diapirs.

The final phases of the regression (Maps E and F) affected only the marginal zones of the basin. Near Adelaide (A), Depot Creek (DC) and Baloanoona (BA), supratidal dolomites were deposited, with a mild influx of quartz sand. Thick stromatolitic limestones (Inzeria multiplex) grew on the oolite bank near Yednalue (Y). Intermittent limestone deposition in the deeper central portion of the basin was encroaching further south, while the deposition of laminated silts continued elsewhere.

Terrigenous clastics now replaced dolomites in the supratidal flats of the basin margins, and carbonate deposition was reduced in the central part of the basin (Map F). In the western zone, storm waves brought sands, silts and muds onto the flats - subsequent exposure oxidized and desiccated the muds above each coarse cycle. At the next stage (Map G), the western and north-eastern belts of red muds were still marginal, with tidal channel deposits occurring in the sandy limestones near Adelaide (A), Kulpara (KU) and Buckaringa Hill (BU). The south-eastern part was a shallow marine basin, while the northern central part continued to be shallowed periodically by diapiric activity. By now, the shallow water limestones extended through most of the axial part of the basin in which diapirs occur.

Oolitic limestones, bioherms of *Linella munyallina*, *Tungussia etina*, *Jurusania burrensis* and *Inzeria* cf. *tjomusi*, and sandy limestone channel fills predominated in sediments formed in the agitated zone. After each burst of local diapirism, the basin floor again subsided, allowing more silts and clays to be deposited below wave base. Thus although diapirs rose periodically, shallowing the basin floor, the overall tendency was for the basin to sink, allowing a great accumulation of sediment. The greater overburden in turn facilitated diapirism.

Map H shows the basin during a minor transgression which ensued. Limestone deposition ceased almost entirely. On the western margin, the land mass of the Gawler Platform probably rose and supplied the sands and silts of the Upper Willochra Formation, while to the east, only silts persisted (Tarcowie Siltstone). The remainder of the basin received laminated green muds and silts (Enorama Formation), in moderately deep water (except for oxidized red muds in the north-eastern marginal zone). Diapirs were inactive, but may have subsequently been reactivated in the Central Flinders Ranges, thus shallowing the basin there, and allowing the deposition of the Trezona Formation, in the area shown.

Chapter 12

THE PALAEOECOLOGY OF SOUTH AUSTRALIAN STROMATOLITES

In the previous two chapters, the interpretation of the environments of deposition of the Precambrian stromatolite-bearing sequences was discussed, and an attempt was made to follow progressive palaeogeographic changes in the Adelaide Geosyncline. With this background, certain conclusions may be drawn regarding the ecology of particular stromatolite groups and forms. Hopefully, such a study will eventually make it possible to distinguish those characters which are environmentally rather than genetically controlled, and to delimit the range of variation for particular form taxa, which is due to environmental modification. This approach has not been fully exploited by recent Russian authors who employ a formal binomial classification, although Maslov (1960) studied the stromatolites and sediments of the Ust'-kut suite of the Ordovician of the Siberian Platform, in order to establish the relations between stromatolite types and facies. He concluded that salinity, amount of terrigenous influx, depth of the basin and the intensity of water movement are all important factors in determining stromatolite types. Conditions most favourable to growth were shallow, well aerated seas with little clastic sediment influx, in warm climates. Different stromatolites were found in different facies zones. Recently, Semikhatov, Komar & Serebryakov (1970) discussed the relations of stromatolite forms to facies in the Yudoma Complex of the Uchoro-Maya type region.

The observations presented below are of a very preliminary nature only, but partly support the concept of form taxa which are relatively stable to environmental changes. Semikhatov, Komar and Serebryakov have independently drawn a similar conclusion from their study. A further study is needed to clarify many uncertainties, and may lead to a less arbitrary stromatolite classification, in which environmentally controlled characters can be recognized and allowed for.

Skillogalee Dolomite Stromatolites

The distribution and relative abundance of stromatolites in the Skillogalee Dolomite of different areas is difficult to relate to particular sedimentological associations. Although Baicalia burra is almost ubiquitous in the Flinders Ranges, its abundance varies greatly. At Copley and Arkaroola, the stromatolites have been found only in one horizon, but are much more abundant at Myrtle Springs, the Witchelina region, and Worumba. Magnesite conglomerates are common in all of these regions. At both Yatina and the Burra region, magnesite is almost entirely absent, yet B. burra is rare at Yatina and moderately abundant at Burra. Stromatolites were found neither in the magnesitic sequence in Port Germein Gorge, nor at Crystal Brook where magnesite is absent. At Depot Creek, small cumulate stromatolites grew within a magnesite conglomerate bed (Pl.35b). These observations show that the presence or absence of magnesite has little bearing on the stromatolite distribution. A magnesite-forming environment appears to be quite favourable to blue-green algae; in the Coorong of South Australia, blue-green algae are forming flat-laminated stromatolites in two hypersaline ephemeral lagoons, whose sediments are aragonite and hydromagnesite muds (Von der Borch, 1965).

It is possible that depth of water was a controlling factor in the distribution of stromatolites. If the water was too deep in some areas for stromatolites, it would necessitate the transport of detrital dolomite mud to the site of deposition, since syngenetic dolomitization at such depths has never been reported. The stromatolites themselves give little indication of minimum depth, since whole biostromes are only a few tens of centimetres thick. Being closer to what Forbes interpreted as the marine basin, the Crystal Brook-Port Germein region may have been under deeper water than the stromatolitic environments to the north.

It has been shown (Ch.10) how the energy of the environment modifies the growth form of B. burra. Specimens from the Willouran Ranges are generally large and irregular, with frequent coalescing and bridging. Columns were subject to erosion, and therefore probably stood in relief above the sediment surface. Large eroded fragments of columns fell into the interspaces and acted as elevated points for renewed algal growth. The high energy conditions of this area may have been those of exposed headlands on a shoreline while the lower energy environment represented by the stromatolites in the Burra area is more likely to be lagoonal. The same stromatolite form grew in these two extremes of environment. Moreover the occurrence of the same form in dark, organic rich dolomites (e.g. Yatina, Worumba, Copley) and pale, pure dolomites (e.g. Myrtle Springs, Dutton's Trough) suggests that the stromatolite morphology was unaffected by the oxidizing or reducing conditions of the environment.

The walled, markedly divergent branching form Tungussia wilkatanna has been observed only at Depot Creek and Mundallio Creek. The intramicrite interspace sediment is unbedded; intraclasts are mud-supported and randomly oriented, suggesting a minimum of current activity. The intraclasts themselves may be of very local origin, perhaps formed by the desiccation of algal mat, and therefore may not have required currents to transport them. *T. wilkatanna* may have grown in subsiding lagoons (the biostromes are up to 2 m thick) rather than on exposed shorelines. One biostrome was subjected to slight erosion before the deposition of the overlying shale.

Umberatana Group Stromatolites

It was suggested (Ch.11) that following the cessation of the first (Sturtian) glaciation, a eustatic rise in sea-level caused a widespread marine transgression, during which basinal marine conditions prevailed over the whole Adelaide Geosyncline. During the following regression, the marginal areas of the basin were subjected to marked shallowing of water, and the littoral zones shifted basin-wards. This provided an environment favourable to the growth of stromatolites, in what is now the SW and NE Flinders Ranges.

At Depot Creek the initial stages of the regressions were marked by repeated minor diastems, and small, lenticular bioherms of *Omachtenia utschurica* utilized the low, erosional remnants between channels cut into the marine silts, as high points on which to commence growth. Flat pebbles in the channels are variously imbricated; the frequent reversals of direction suggest the influence of tidal currents. Varying energy conditions are represented by winnowed grainstones (intrasparites) and muddy wackestones (intramicrites). In interspaces, flat pebbles and comminuted pellets are partly winnowed, partly mud-supported, but always randomly packed. Columns probably acted as baffles preventing imbrication by currents. Columns and cumuli are frequently slightly elongated in response to E-W currents.

The dolomitic nature of the dark laminae poses a problem. At least some of the dolomite is detrital, since pellets and intraclasts were transported as dolomite. The origin of the idiotopic, granular dolomite in the dolomitic (darker) laminae is not clear; it may be diagenetic, or detrital (Logan, 1970, pers. comm. has reported detrital, idiotopic dolomite in Recent sediments at Shark Bay). Dolomite laminae alternate with well winnowed pelsparite laminae, which had considerable void space, and grade down in places into lenticular spar-filled voids (Pl.28c), resembling the fenestral structure of some Recent intertidal stromatolites at Shark Bay. The best explanation is that carbonate sediments were dolomitized penecontemporaneously in the supratidal zones, and during the periodic cessation of terrigenous silt influx, these were reworked, possibly several times, and the detritus was incorporated into stromatolites and interspace sediment. Many flat pebbles are probably lithified chips of algal mats. But the mats were incapable of binding material coarser than sand size, so that the larger intraclasts remained in the interspaces. Shrinkage of laminae may have played a part in forming fenestral voids.

The occurrence of winnowed flat-pebble breccias, variously imbricated, and voids in the stromatolitic lamination are suggestive of the intertidal zone of deposition, but the general absence of desiccation features in situ suggests rare exposure. An upper subtidal or low intertidal position is therefore envisaged, but sea-level probably fluctuated, with alternating cycles of terrigenous marine deposition, non-deposition and carbonate deposition.

Omachtenia utschurica had little more than 1 or 2 cm of growth relief between columns and interspaces, as indicated by the numerous bridging laminae; sedimentation in the interspaces kept up with stromatolite growth, but was periodic. Larger mounds with hemispherically domed laminae, had at least 10 to 30 cm of relief above the surrounding erosional channels.

The stromatolites *Acaciella augusta* and *Inzeria conjuncta* (which differ only in gross morphology, not microstructure) occur within the oolitic-intraclastic facies of the Brighton Limestone, in bioherms much larger than those of *Omachtenia utschurica*. In the Melrose region, *Boxonia melrosa* and *Inzeria multiplex* occur in a similar sedimentological situation.

These stromatolite bioherms are not localized to erosional highs, but extended laterally for up to 2 km. At the margins, the bioherms either intertongue with the surrounding sediment, indicating the contemporaneity of growth of the stromatolites and sediment buildup, or stood in relief above the sediment surface.

The interpretation of depth of water is limited by the presence of oolites to the intertidal and shallowest subtidal zones. The sediments were distributed by strong, easterly flowing currents (this is interpreted as basin-wards). Intraclasts of oomicrite, partially dolomitized, were probably exposed and lithified nearer to shore, and reworked by these basinward currents. Alternatively, the ooid grainstones could be beach ridge deposits laid down by ebb tides. Thus the bioherms accumulated in an essentially littoral environment.

Some *Acaciella augusta* bioherms are hemispherical with radially arranged columns at their margins. Their growth relief is up to 2 m. For the tops of these bioherms to avoid total desiccation, they must have been covered at least at high tide, indicating a low intertidal to subtidal environment. Others, in which continuous mats extend (as bridges) throughout the bioherm at various repeated levels, and protrude as tongues into the surrounding sediment, there was virtually no growth relief. Such bioherms may have formed in the shallowest intertidal zone. Thus *Acaciella augusta* formed bioherms, possibly throughout the whole intertidal to shallowest subtidal interval. The distributions of *Inzeria conjuncta* and *Inzeria multiplex*, so far found only in isolated occurrences, are insufficiently known to allow any generalizations, but at Depot Creek, *I.conjuncta* does have inclined, elongated columns at bioherm margins, suggesting some growth relief above the surrounding sediment surface. The exposure is unfortunately inadequate to estimate how much relief there was (Pl.15b).

Dolomite is present in all stromatolites from the oolitic-intraclastic facies. *A. augusta* and *I. conjuncta* contain alternating green dolomite laminae (idiotopic to hypidiotopic, fine silt size) and calcite microspar laminae. The green laminae were probably more porous, coarser detrital laminae, and subject to dolomitization, while the microspar laminae may have originally consisted of micrite. Alternatively, the dolomite could be detrital, but then a regular alternation of dolomite and calcite/aragonite detritus would have to be envisaged.

Energy conditions between columns varied, but were generally lower than outside the bioherms. The lamination of the interspace sediment indicates its accumulation after the growth of the adjacent portion of column, but this does not necessitate a high relief between column and sediment. Under low energy conditions, micrite accumulated in the interspaces, but periodically, small flat pebbles were introduced and stacked randomly. These intramicrites are still mud-supported. Intraclasts are found in varying states of dolomitization, and may represent lithified, eroded algal mats reworked from higher levels. Columns were sufficiently closely spaced to dampen the high energy conditions prevailing outside the bioherms, and ooids were rarely transported into them.

The upper dolomitic member of the Brighton Limestone represents the shallowest zone of deposition, and also marks the first appreciable influx of terrigenous detritus. Lime mud sediment was penecontemporaneously dolomitized at the surface, preserving most fine structure. Deposition on supratidal flats is envisaged, and here algal mats were not conspicuously developed. They may have been present, but if so have left no recognizable trace in any modification of the sediment.

If a continuous shallowing is assumed between the oolitic-intraclastic facies and the laminated supratidal dolomites, then the bioherms of Katavia costata must have occupied an intermediate position, perhaps in the higher intertidal zone. But the bioherms had substantial relief, up to about 1 m, as is shown by downturned growth-surfaces at their margins. Thus they characterize a zone shallow enough to be subject to total dolomitization but deep enough for their upper surfaces to remain moist; this may have been achieved in the upper intertidal or in the lower supratidal zone during storm tides.

Katavia costata is a poorly laminated stromatolite. The question arises whether this is a primary feature, or the lamination was obliterated by dolomitization. The good preservation of lamination in the non-stromatolitic supratidal dolomites suggests that *Katavia costata* may have had indistinct lamination originally. Logan (1970, pers. comm.) has reported poorly laminated pustulose mats from the shallower intertidal zones of Shark Bay. If an analogy can be drawn, it would confirm the interpretation of a slightly shallower environment for *K. costata* than for *Acaciella augusta* or *Inzeria conjuncta*.

The absence of stromatolites in the Brighton Limestone near Adelaide is problematical. The essential similarity of the Tapley Hill Formation-Brighton Limestone-Willochra Formation sequence in the Adelaide and SW Flinders Range areas suggests that these two areas passed through the same successive changes in water depth (though not necessarily synchronously). Thus at least at *some* stage of the regression the water must have been of a suitable depth for stromatolite growth. By analogy with Depot Creek, stromatolites should be expected as bioherms in the oolitic facies, but none has been found. Present-day stromatolites are restricted to hypersaline environments, but this can be interpreted as a biological restriction by browsing predators (Garrett, 1970) which generally find the hypersaline environment uninhabitable. Such predators were rare or absent during the Precambrian, so that we may not expect the present salinity restrictions to apply. A climatic factor may have been responsible, but if so, has left no trace in the sedimentary record.

Kulparia kulparensis occurs only in the Etina Formation equivalent on Northern Yorke Peninsula, in a bed whose precise extent cannot be determined, due to poor exposure. There was considerable influx of coarse terrigenous detritus, and current activity was sufficiently strong to transport coarse sands and grits to the site of stromatolite growth. Although quartz silt and fine sand were incorporated into the stromatolitic laminae, the algal mats were incapable of binding the coarser detritus, which accumulated in the interspaces as winnowed grainstones. A very high energy environment is therefore suggested, even within the stromatolite bed.

Columns of Kulparia kulparensis had little relief over the sediment surface; bridges are frequent on all columns, and indicate a relief of between 0.5 and 5 cm. The presence of a wall shows that columns projected above the interspaces by this full amount. This indicates that the influx of interspace sediment was periodic.

The occurrence of sand dykes in the stromatolite bed suggests rapid lithification, before the deposition of the overlying sand bed. Fracturing was concentrated along the contacts between individual stromatolitic domes in the bed.

There is little evidence of the precise environment of these stromatolites. The absence of desiccation features and of penecontemporaneous dolomitization argue for an environment which was seldom if ever subaerially exposed. A shallow subtidal location, subject to strong wave action from the open sea to the east is envisaged.

In the Central Flinders Ranges, the Etina Formation thickens markedly in the basin centre. It was suggested that periodic diapiric activity shallowed the basin in this region, allowing the sea floor to come above wave base, and carbonate sediments to accumulate. The interbedded shales were thought to represent normal marine conditions. Stromatolitic limestones are an important facies of the very shallow environments of the Etina Formation and its northern extensions.

Of the stromatolites occurring in this interval, Tungussia etina and Linella munyallina have been found to be very widespread. But the forms Linella ukka, Inzeria cf. tjomusi and Jurusania burrensis are apparently restricted to Burr Well.

Tungussia etina first appears in the vicinity of Arkaba, where it forms tonguing bioherms which interfinger with oolitic limestones. The columns are irregular and closely spaced, and have interspaces filled with quartz sand. Further north in Enorama Creek, the quartz sand supply was less, but ooids occur in abundance in the interspaces (as oosparites) and incorporated in the lamination of the stromatolites.

Tungussia etina was formed by mats which were able to trap significant amounts of medium sand-size detritus, if it was available. However, there is a limit to the amount that can be incorporated and still preserve the laminated microstructure due to algal binding. If excessive detritus is washed in, this microstructure is lost, and mechanically deposited oosparites are formed, which are continuous with the interspace sediment.

Highly irregular columns and bulbous cumuli of T. etina occur east of Blinman (Pl.29f) where they consist of red-coloured distinct, wavy-banded laminae. Interspaces are filled entirely with lime-cemented quartz sand. However, to the north of Blinman, lower energy conditions appear to have prevailed at the sites of stromatolite growth, and here the columns are more regular, though still complexly branched and coalesced. At Mt Chambers, for example, interspaces between the variously oriented columns are filled predominantly with micrite and fine sand lenses, with sparse intraclasts, although oosparite limestones occur immediately below the stromatolite horizon. In the Wundowie Limestone near Teatree O.S., Tungussia etina again occurs in tonguing bioherms which overlie and interfinger with oolitic limestones, but here there is greater variation of gross morphology, especially branching (Figs.18k,19a,b,d show both parallel and markedly divergent branching columns). The interspace sediment is predominantly micrite, with scattered ooids.

These observations suggest an overall decrease in the energy of water movement in the northern areas. The sediment filling interspaces cannot directly indicate the energy of the environment surrounding the bioherm, since the columns with any substantial growth relief must act as baffles reducing current velocities within the bioherm. Thus interspaces might be expected to accumulate more fine detritus than the areas surrounding bioherms. This has already been noted for Acaciella augusta bioherms. For coarse detritus to be brought into the interspaces and to cover the algal mats, as in the Central Flinders Ranges T. etina, very high current or wave activity is required. In the north, strong current or wave action persisted only outside bioherms, but was reduced within them.

Commonly, the tonguing margins of bioherms contain only irregularly cumulate and laterally linked stromatolites, which pass into columns in the central portions. If the above deductions about environmental energy are correct, it would suggest that the continuously laminated forms were subjected to higher energy conditions than the central, columnar parts of bioherms. This is contrary to the present day relation of stromatolites to environmental energy as observed at Shark Bay (Logan, 1961) where columns and "heads" grow on exposed headlands and laterally linked forms in the protected areas. A comparison is, however, limited by the different mode of occurrence: *T. etina* forms domed, discrete tonguing bioherms which may have had up to 50 cm of relief above the surrounding sediment surface at their centres, but their margins had no relief.

Linella munyallina is the most widespread stromatolite from the Northern Flinders Ranges, and possibly occurs locally in the Central Flinders Ranges. Its mode of occurrence differs from the tonguing bioherms of *Tungussia etina*. The stromatolites form domed biostromes and lenticular beds, generally more extensive than those of *T. etina*, consisting of juxtaposed hemispherical to ellipsoidal bioherms, with a relief of at least 1 metre above the surrounding sediment. At Burr Well, where such bioherms occur in isolation or terminal to biostromes, their relation to the surrounding sediment is seen. The bioherms grew to a height of about 1 metre, with inclined columns at their recurved margins. There was negligible influx of coarse detritus. After the bioherms had reached their full thickness, the surrounding area gradually accumulated fine, laminated muddy sediments (either micritic limestone or shale). Interspaces are also filled with fine micrite, but contain a few locally derived intraclasts. Similar bioherms at Myrtle Springs contain sandy lenses in the interspace sediment, showing an occasional influx of coarse terrigenous detritus. Sand predominates in interspaces at Arkaroola, Wundowie Bore and Copley. The one form, *Linella munyallina*, grew both in areas of high and low sand influx.

At Burr Well and Roebuck Bore, the stromatolites probably grew in a calm environment with little terrigenous sediment influx. In the overlying bed, the environment changed radically, and cross-bedded gritty limestones were deposited, partly in south-trending channels.

From the palaeogeographic model suggested for the Etina Formation and its extensions, it follows that basinal conditions prevailed in the Northern Flinders Ranges at this time, although these conditions were periodically interrupted. It was during these interruptions that the basin floor was brought above wave base, and stromatolites were able to grow. Much of the coarse terrigenous clastics present in the cross-bedded limestones in the basin centre may have actually been derived from the erosion of diapirs rather than transported from land.

Conditions varied in response to local diapiric movement, so that different parts of the basin rose and subsided at different times. The calm environment envisaged for Linella munyallina may reflect the presence of off-shore barriers, themselves either sand bars or stromatolitic bioherms.

Linella ukka, known only from Burr Well, occurs in low, domed bioherms, juxtaposed to form lenticular beds. Growth relief of the full bioherm thickness (0.5 m) is probable, since columns are radially arranged to subhorizontal at bioherm margins (Pl.21g), and the continuously laminated stromatolite at the top of the bioherm is completely curved over. In other places, the columnar zones grade laterally into wavy-laminated stromatolites, which intertongue with the underlying oolitic and intraclastic limestones. It is possible that the type of bioherm margin is determined by its orientation relative to the dominant current directions; thus the abrupt, raised margins may have faced up-current (cf. the asymmetry of the cumulate stromatolites described by Hoffman (1967)).

Interspaces are filled with intrasparite and minor bands of dolomitized micrite, suggesting alternating quiet and highly agitated conditions even within bioherms.

Above the lower members of the Wundowie Limestone with *Linella munyallina* at Burr Well, the middle and upper members are entirely stromatolitic. *Inzeria* cf. *tjomusi*, in the middle member, shows a similar relationship of bioherm margins to that of *Linella ukka*. In a westerly direction the bed lenses out gradually, but in the east columns pass into flat-laminated stromatolites, similar to those underlying columns. Lower energy conditions than for *Linella ukka* are indicated by the absence of ooids, and the predominantly silty and muddy interspace filling.

Jurusania burrensis in the upper member, is the only known South Australian stromatolite to form subspherical bioherms. The contiguous bioherms are capped by an undulating layer of columnar stromatolites identical to those in the bioherms. The stromatolites forming the spherical bioherms grew around an irregular stromatolitic core (now so recrystallized that its original nature cannot be determined); when growth had proceeded so far that bioherms were in contact, they were covered with the draping columnar layer.

Interspaces between *Jurusania burrensis* columns are predominantly filled with intramicrite; intraclasts are mainly thin flat-pebbles, possibly locally derived from the erosion of mats. The muddy nature of the sediment suggests low energy conditions, which persisted throughout the following period of silt and mud deposition, under conditions of basin subsidence.

The next stratigraphically higher stromatolitic unit, the Trezona Formation, has already been discussed. This is the most striking instance of control of stromatolite elongation by currents. The similarity of mat type to the tufted mats of Shark Bay has been noted, but a direct analogy with the environment of the Gladstone Embayment is not possible. The Trezona Formation is apparently a lenticular body, centred in the Central Flinders Ranges and lensing out to the north and south, passing laterally into probable marine shales. It does not appear to be a marginal facies of the Adelaide Geosyncline.

The distinction between the large cumulate stromatolites and the smaller domed to subconical pseudocolumnar forms may be environmentally controlled; the former probably represent conditions of stronger currents of constant direction.

Cambrian Stromatolites

The only Cambrian stromatolite studied, Acaciella angepena, commonly occurs in dark, organic-rich limestones, suggesting reducing conditions. The domed and tabular bioherms, which had a relief of up to 1 m, were not seen to intertongue with the surrounding thinly bedded dark limestones. The specimen from Old Wirrealpa is haematitic, and was therefore subjected to oxidizing conditions either during or after deposition. The sedimentological association of the stromatolites suggests low to moderate energy conditions.

At Angepena, the stromatolites directly overlie oolitic limestones which grade down into the Parachilna Formation, interpreted as transgressive by Dalgarno (1964). The thinly bedded and mottled Parara Limestone immediately overlying the stromatolites may have been deposited in deeper water, in which case the whole sequence could be interpreted as transgressive.

Table XI summarizes some tentative conclusions that may be drawn about the environmental conditions of growth of the better known South Australian stromatolites. Of the environmental parameters listed, the first five are purely observational; the remainder are interpretative.

The following remarks should be made:

(1) The modes of occurrence were described in the systematic descriptions of the stromatolites.

(2) The relief of columns is the relief of any particular lamina above the interspaces during growth. The height between bridges gives the maximum possible relief, while the vertical extent of single laminae in a wall-zone indicates a reliable minimum.

(3) The relief of bioherms is estimated from their marginal structure: tonguing bioherms had virtually no relief, while domed or spherical bioherms had a relief gauged by the shape of single growth surfaces at any one time.

(4) Diastems and/or erosion may affect the sediment underlying the stromatolite columns, the columns themselves, or the whole bed after the cessation of growth.

(5) The amount of terrigenous clastic present is estimated from both interspaces and stromatolite columns.

(6) Current and wave energy cannot generally be differentiated except where consistent directional current structures are closely associated with the stromatolites. The energy of the environment is deduced from the depositional textures of the surrounding sediments and the interspace filling, but conditions within bioherms were probably less energetic than outside, due to the baffling action of columns.

(7) Depth of water is very difficult to determine, but relief of bioherms, degree of agitation and general palaeogeographic position give guidance. Penecontemporaneous dolomitization is interpreted as diagnostic of the shallowest intertidal and supratidal zones.

(8) The only evidence for salinity is the type of carbonate present. Calcium carbonate sediment is regarded as forming under conditions of normal salinity, while penecontemporaneous dolomitization probably represents elevated salinities (Friedman & Sanders, 1967). Magnesite conglomerates indicate hypersaline waters closely associated with stromatolites.

(9) The colour of the sediments and the presence of organic matter and oxide or sulphide minerals give an indication of the oxidizing or reducing conditions of the environment - dark coloured organic-rich carbonates with sulphides are taken to indicate reducing conditions, while pale coloured or reddish sediments, especially if haematite is present, suggest oxidizing conditions.

(10) The palaeogeographic settings and transgressive or regressive

nature of the sequences were discussed in the previous chapters.

Stromatolitic Environments in other Australian Precambrian Basins

The Adelaide Geosyncline is but one of many large shallow sedimehtary basins which existed in Australia during Proterozoic time. The following is a brief review of what is known of the environments of stromatolites in some other basins.

Probably the best known is the Amadeus Basin, a Late Proterozoic to Palaeozoic E-W trending feature of Central Australia. Walter (1970) has given a detailed account of the stromatolites, and has commented on the lithofacies associations of many of these. Of special interest here are those which closely resemble South Australian forms, viz. *Acaciella australica* (Howchin) Walter, *Boxonia pertaknurra* Walter, *Inzeria intia* Walter, *Kulparia alicia* (Cloud & Semikhatov) Walter, *Linella avis* Krylov, *Tungussia inna* Walter and *Tungussia erecta* Walter. All except *T. inna* occur in the widespread Bitter Springs Formation, where they form tabular or domed biostromes, or very rarely, isolated bioherms. Interspace sediments are frequently dolomitized, but where well preserved, they are seen to contain intraclasts, ooids, lumps and a muddy matrix. All the stromatolites occur in very similar sedimentological situations, and in some cases biostromes were traced for up to 2.5 km.

Walter considered the modern environment of Shark Bay as analogous to the Bitter Springs Formation, although the dominant sediment of Shark Bay (calcareous bioclastic grains) was absent in the latter. A special comparison was made between the juxtaposed bioherms of the Bitter Springs Formation and the large, cumulate stromatolites of Shark Bay, but a less energetic environment was envisaged. At Shark Bay, red gypseous silts of the Wooramel River Delta overlie the stromatolitic carbonates, while in the Bitter Springs Formation, red silty carbonates similarly overlie the stromatolites.

Walter also concluded from the lithofacies associations that the stromatolites from the Nullagine Basin similarly formed in a near intertidal environment.

Webby (1970) described Late Precambrian trace fossils from the Torrowangee Group, outcropping east of the Willyama Block, New South Wales. In his paper, he noted the occurrence of stromatolites in a "relatively continuous limestone band in the Euriowie Beds" (below the upper tillite) and possible stromatolites in the Teamsters Creek Beds and the Fowlers Creek Beds (above the upper tillite). Lamination, cross-lamination and small-scale slumping were noted in the limestones and local dolomites.

Dow & Gemuts (1969) recorded stromatolites identified as *Conophyton cylindricus* and *Collenia frequens* by H. S. Edgell from the Early Adelaidean or Late Carpentarian Bungle Bungle Dolomite of the Kimberley Region, in which "*Collenia frequens*" bore an encrusting relationship to *Conophyton cylindricus*. The stromatolites are associated with regularly bedded dolomites, dolomitic shales, minor limestones and sandstones.

Stromatolites also occur associated with oolites in the abundant dolomites immediately above the Moonlight Valley Tillite. Dow and Gemuts considered that this did not require tropical seas in the interglacial period, since the erosion of many dolomitic units during the glaciation probably caused a saturation of sea water in carbonate.

Stromatolites were also recorded in the Boonall Dolomites, above the upper glacials (Egan Glacials).

Logan & Chase (1961) studied the detailed stratigraphy of the Late Precambrian Moora Group in a small rift basin occurring along the Darling Fault, north of Perth. Stromatolites occur in the Coomberdale Chert, a sequence of bedded cherts, chert breccias, orthoquartzites and silicified limestones. Oolites, cross-bedding and ripple marks are abundant and a shallow neritic to littoral environment was suggested. The stromatolites were identified by Logan and Chase as "Collenia undosa" (forming biostromes), "Collenia columnaris" and "Cryptozoon frequens" (biohermal), but have not been studied by the modern methods.

Stromatolites are prolifically developed in the Western Geosyncline of the Precambrian fold belt of NW Queensland. The Paradise Creek Formation, consisting chiefly of dolomite, with minor dolomitic sandstones and siltstones and silicified beds, overlies the red silts of the Gunpowder Creek Siltstone (Robertson, 1960). Stromatolites were also reported in the quartzitic Judenan Beds, below the Gunpowder Creek Siltstone, but the illustrations are not suggestive of stromatolites. True stromatolites, including "cylindrical" forms occur in massive development in silicified biostromal beds. Robertson regarded the stromatolites as originally porous, thus facilitating dolomitization and silicification. By analogy with Recent blue-green algae, Robertson postulated a shallow shelf or lake environment, and suggested that mechanically stable wavy laminated forms grew in turbulent water, while "cylindrical" forms were better adapted to areas of rapid precipitation. These concepts, however, were based on theoretical considerations, not sedimentological observations. Ripple marks, cross-bedding and mudcracks in the underlying formations were used to support the interpretation of a shallow water environment.

Cloud & Semikhatov (1969) assigned the columnar Paradise Creek stromatolites to a new Group, *Eucapsiphora*, but did not comment on environmental considerations.

In the Cambrian Skewthorpe Formation, Bonaparte Gulf Basin, Kaulback & Veevers (1969) described a rhythmic succession of quartz sandstones, sandy dolomites, and stromatolitic dolomites, interpreted as strand, lagoonal and reef facies respectively. They attributed this cyclic sedimentation to repeated transgressions and regressions.

The foregoing discussion indicates that little study has been carried out on the palaeoecology of Australian Precambrian stromatolites, either in regional or detailed form, but all authors agree that they formed in very shallow water, as they did in the Adelaide Geosyncline. Similar environments to those suggested for South Australian stromatolites may be represented in the other basins, but the evidence is scanty. The association of stromatolites with diapiric uplifts in basinal areas has not been reported elsewhere.

Conclusions

The present contribution is an account of preliminary field and laboratory observations of Adelaide Geosyncline stromatolites, combined with an interpretation of all published stratigraphic data for the stromatolite-bearing interval. The conclusions regarding palaeogeography are tentative, but they are consistent with what I believe is the present state of stratigraphic knowledge of the South Australian Precambrian, and the geotectonic framework envisaged for the Adelaide Geosyncline (see Parkin et al., 1969). Similar studies are urgently required in the other Precambrian basins.

Within the Adelaide Geosyncline there is almost unlimited scope for further detailed sedimentological studies of the stromatolitic units, to help prove or disprove the suggestions made in this thesis. In addition, the lateral variation of stromatolitic beds will need to be studied in relation to changes of lithofacies. Only then will it be possible to precisely delimit the environmentally controlled variation of stromatolites and to use particular stromatolite features as specific environmental indicators. The following generalizations are the main results of the present study.

(1) Modern work on Recent stromatolites shows that stromatolites predominantly occupy the intertidal and lower supratidal zones but there there is mounting evidence that they also extend into the subtidal, both in the Recent and in the geological record. Many Adelaide Geosyncline forms may have grown in the shallow subtidal zone, but there is no evidence of growth in water deeper than this.

(2) Types of algal mats are controlled both by the types of algae forming them, and by environmental factors. Therefore it is reasonable to assume that both factors are important in determining stromatolite morphology. A study of stromatolite palaeoecology may eventually lead

to a more natural taxonomy, in which environmental factors are allowed for.

(3) Shallow basins of deposition were common in Precambrian times in Australia, and all contain stromatolitic sediments. These may provide more of the information needed, if adequately studied.

(4) The biostromal stromatolites of the Skillogalee Dolomite (*Baicalia burra* and *Tungussia wilkatanna*) grew on a broad carbonate-depositing platform in a variety of calm and highly agitated environments, probably ranging from lagoons to exposed headlands. The morphology of *Baicalia burra* is consistent under these varying conditions, supporting the idea that its diagnostic characters are genetically rather than environmentally controlled, but it displays minor modifications of column irregularity and contemporaneous erosion with increased environmental energy.

(5) Following the Sturtian glaciation, a possible eustatic rise of sea-level caused an extensive marine transgression. During the following regression, the marginal western and north-eastern areas became favourable sites for stromatolite development.

(6) In the western areas the biohermal stromatolites *Omachtenia utschurica*, *Acaciella augusta*, *Inzeria conjuncta* and *Inzeria multiplex* grew in shallow subtidal to intertidal zones, while *Katavia costata* occupied a shallower interval (upper intertidal to supratidal). The degree of agitation of water was high, at least outside the bioherms.

(7) In the northern part of the central deeper basin, marine conditions of sedimentation were periodically interrupted by diapirism, thus

producing off-shore an environment favourable to stromatolites. Here *Tungussia etina* and *Linella munyallina* are widespread, forming tonguing bioherms and juxtaposed domed bioherms respectively. Energy conditions varied, but were always higher than for the interbedded thinly laminated shales.

(8) Although environment plays a role in shaping the gross morphology of stromatolites, and perhaps even their microstructure, the forms identified from South Australia are relatively stable in relation to environmental changes. The same form may be recognizable in different environments, while conversely, similar environments supported a variety of stromatolites. This in turn confirms the conclusion that since stromatolites change systematically in time, they probably reflect control by evolving characters of the algae or assemblages of algae forming them.

GENERAL CONCLUSIONS

This study of Precambrian stromatolites from South Australia has confirmed the value of columnar stromatolites for intercontinental correlations, but these must be based on assemblages, rather than single forms. Although it necessitates minor extensions of the time ranges of a few taxa, the scheme of correlation with the Russian sequence is in good agreement with all known stratigraphic and radiometric data except the most recent of Cooper & Compston (1970). The correlations have therefore helped to elucidate the ages of the Precambrian rocks of South Australia.

The Adelaide Geosyncline may be interpreted as a large, deeply subsiding epeiric basin. The duration of sedimentation, which may have been very long, is conveniently divided into the Early Adelaidean and the Late Adelaidean, each period being characterized by a different assemblage of stromatolites. The Early Adelaidean sediments, which are older than the onset of the first glaciation, contain an assemblage characteristic of the Middle Riphean, while the post-tillite Late Adelaidean has a typical Late Riphean to Vendian assemblage.

Baicalia burra was collected from the very widespread Early Adelaidean Skillogalee Dolomite, Burra Group, while Tungussia wilkatanna occurs in the same formation in the western part of the Southern Flinders Ranges only. A pre-upper Burra Group dolomite raft in the Paratoo Diapir contains Conophyton garganicum garganicum. B. burra and T. wilkatanna are both new forms, but very closely resemble B. maica Nuzhnov and T. confusa Semikhatov respectively. This assemblage suggests correlation of the Skillogalee Dolomite with the youngest subdivision of the Middle Riphean, about 950 to 1000 m.y. old, but possibly as young as 890 m.y. If the data of Cooper & Compston (1970) are correct, the Burra Group is less than 870 m.y. old; this conflicts with the stromatolite evidence, which rather supports the older age estimate which is a consequence of the correlation of the Wooltana Volcanics (in the Lower Callanna Beds) with the Roopena Volcanics reliably dated at 1345 ± 30 m.y.

Conophyton garganicum garganicum is likely to be derived from the Callanna Beds, suggesting a correlation of these also with the Middle Riphean. If it comes from the Lower Callanna Beds, the unconformity between the Lower and Upper Callanna Beds could represent an extremely long time.

The correlation often suggested between the Bitter Springs Formation and the Skillogalee Dolomite is rejected, since they have only one group, the long-ranging *Tungussia* in common, and the Bitter Springs Formation is correlated with the Late Riphean.

The Late Adelaidean Umberatana Group contains an assemblage similar to that of the Bitter Springs Formation, with seven groups in common. But the two rock units are not directly correlated, since the former overlies and the latter underlies the lower tillites, which are correlated between the two basins. The assemblage of the Late Adelaidean, *Omachtenia utschurica*, *Acaciella augusta*, *Inzeria conjuncta*, *I. multiplex*, *I.* cf. *tjomusi*, *Jurusania burrensis*, *Gymnosolen ramsayi*, *Boxonia melrosa*, *Katavia costata*, *Linella ukka*, *L. munyallina*, *Tungussia etina* and *Kulparia kulparensis*, suggests that the age of the Late Adelaidean is youngest Late Riphean, i.e. about 760 to 680 m.y. old. This is supported by all radiometric data on tillites in Australia, but requires an upward extension of the time-ranges of O. utschurica and I. tjomusi.

The Lower Cambrian stromatolite Acaciella angepena does not differ grossly from the other forms of the group, which are Precambrian, but a patchy development of vermiform microstructure, interpreted as due to algal boring, was not found in the other forms.

Studies of stromatolite palaeoecology were carried out with the aim of determining which characters are environmentally controlled and should therefore be allowed for in taxonomy. Discussion of stromatolite environments required a study of the regional palaeogeographic setting of the stromatolite-bearing sequences.

In the Skillogalee Dolomite, the very widespread stromatolite Baicalia burra grew on an extremely level carbonate-depositing platform across the northern half of the Adelaide Geosyncline. Varying environmental conditions are represented: the same form is recognizable in high and low energy environments, and possibly under different conditions of salinity and degree of oxidation. Contemporaneous erosion and greater degree of irregularity of columns were a result of higher current and wave action in the northernmost areas.

The stromatolites of the Umberatana Group partly grew in marginal areas of the Adelaide Geosyncline, in water depths ranging from shallow subtidal to low supratidal. Others formed in off-shore carbonate banks, in the centre of the basin. These banks vary greatly in thickness, and are interpreted to have formed in water shallowed by intermittent diapiric uplift. Stromatolites are closely associated with oosparites, intrasparites, intramicrites and sandy limestones filling tidal channels. Bioherms commonly grew in highly agitated water, but water movement was usually dampened within bioherms, due to the baffling effects of very closely spaced columns.

The variety of environmental conditions that one form may exist under, and the number of forms present in the same palaeoecological setting, support the argument that environment alone does not control stromatolite morphology.

References

Aohauer, C. W. & J. H. Johnson, 1969 : Algal stromatolites in the James Reef Complex (Lower Cretaceous), Fairway Field, Texas. J. sedim. Petrol. 39, 1466-1472.

Aitken, J. D., 1967 : Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southwestern Alberta. J. sedim. Petrol. 37, 1163-1178.

Alderman, A. R. & H. C. W. Skinner, 1957 : Dolomite sedimentation in the South-East of South Australia. Am. J. Sci. 255, 561-567.

Barghoorn, E. S. & J. W. Schopf, 1966 : Microorganisms three billion years old from the Precambrian of South Africa, Science, 152, 758-763.

Bathurst, R. G. C., 1966 : Boring algae, micrite envelopes and lithification of molluscan biosparites. Geological Journal 5, 15-32.

Bathurst, R. G. C., 1967 : Depth indicators in sedimentary carbonates. Marine geol. 5, 447-471.

Bausch, W. M., 1968 : Clay content and calcite crystal size of limestones. Sedimentology 10, 71-75.

Bertrand-Sarfati, J., 1966 : Essai de classement d'échantillons de stromatolites des séries précambriennes de l'Ahaggar occidental. Bull. Soc. géol. Fr. 7(8), 158-164.

Bertrand, J., 1968 : Les édifices stromatolitiques précambriens de la "série à stromatolites" du Nord-Ouest de l'Ahaggar (Sahara). Bull. Soc. géol. Fr. 7(10), 168-178.

Bertrand, J., 1969 : Étude comparative des édifices stromatolitiques de plusieurs horizons calcaires du précambrien supérieur de l'Ahaggar occidental (Tanezrouft et Ahnet). Bull. Soc. d'Hist. Nat. de l'Afrique de Nord, 60, 21-37.

Bertrand-Sarfati, J. & M. E. Raaben, 1970 : Comparaison des ensembles stromatolitiques du Précambrien Supérieur du Sahara Occidental et de l'Oural (Summary). Comptes Rendus, Soc. géol. Fr. 6, p.193.

Binks, P. J., 1968 : The Orroroo 1:250,000 Sheet

Binns, R. A. & J. A. Miller, 1963 : Potassium-Argon age determinations on some rocks from the Broken Hill region of New South Wales. Nature 199, 274-275.

Bissell, H. J. & G. V. Chilingar, 1967 : Classification of sedimentary carbonate rocks in Chilingar, G. V., H. J. Bissell & R. W. Fairbridge, Carbonate Rocks. Developments in Sedimentology 9A, 87-168.

Black, M., 1933 : The algal sediments of Andros Island, Bahamas. Phil. Trans. R. Soc., ser.B, 222, 165-192.

Bradley, W. H., 1929 : Algae reefs and oolites of the Green River Formation. Prof. Pap. U.S. geol. Surv. 154, 203-223.

Brunnschweiler, R. O., 1956 : Geological observations in the Westernmost Flinders Ranges between Port Augusta and Lake Torrens, South Australia. Aust. J. Sci. 18, 162-164.

Buchbinder, B. & G. M. Friedman, 1970 : Selective dolomitization of micritic envelopes: a possible clue to original mineralogy. J. sedim. Petrol. 40, 514-517.

Busk, H. C., 1929 : Earth Flexures. Cambridge University Press, 106p.

Campana, B., 1953 : The Gawler 1:63,360 Sheet

Campana, B., 1954 : Absolute age of the uraniferous granite and Precambrian tillite in the Crocker Well area (Olary district, South Australia). Aust. J. Sci. 16, 240-241.

Carozzi, A. V., 1962 : Observations on algal biostromes in the Great Salt Lake, Utah. J. geol. 70, 246-252.

Chapman, F., 1927 : On a new genus of calcareous algae, from the Lower Cambrian (?), West of Wooltana, South Australia. Trans. R. Soc. Aust. 51, 123-125.

Chapman, F., 1929 : Some fossil remains from the Adelaide Series of South Australia. Trans. R. Soc. S. Aust. 53, 5-6.

Chaudhuri, A., 1970 : Precambrian stromatolites in the Pranhita-Godavari Valley (South India). Palaeogeog. Palaeoclim. Palaeoecol. 7, 309-340.

Clarke, E. de C. & C. Teichert, 1946 : Algal structures in a Western Australian Salt Lake. Am. J. Sci. 244, 271-276.

Cloud, P. E., 1942 : Notes on stromatolites. Am. J. Sci. 240, 363-379.

Cloud, P. E., 1968 : Atmospheric and Hydrospheric Evolution on the primitive Earth. Science 160, 729-736.

Cloud, P. E. & M. A. Semikhatov, 1969 : Proterozoic stromatolite zonation. Am. J. Sci. 267, 1017-1061.

Coats, R. P., 1965 : Diapirism in the Adelaide Geosyncline. Aust. Petr. Explor. Ass. Journ. (1965), 98-102.

Coats, R. P., 1967 : The "Lower Glacial Sequence" - Sturtian Type Area. Quart. geol. Notes, geol. Surv. S. Aust. 23, 1-3.

Coats, R. P., R. C. Horwitz, A. R. Crawford, B. Campana, D. Thatcher, 1969 : The Mount Painter Province Sheet

Compston W. & P. A. Arriens, 1968 : The Precambrian geochronology of Australia. Can. J. Earth Sci. 5, 561-583.

Compston, W., A. R. Crawford & V. M. Bofinger, 1966 : A radiometric estimate of the duration of sedimentation in the Adelaide Geosyncline, South Australia. J. geol. Soc. Aust. 13, 229-276.

Cooper, J. A. & W. Compston, 1970 : Rb-Sr dating within the Houghton Inlier, South Australia. J. geol. Soc. Aust. (in press).

Crawford, A. R., 1963 : The Wooltana Volcanic Belt, South Australia. Trans. R. Soc. S. Aust. 87, 123-154.

Daily, B., 1963 : The fossiliferous Cambrian succession on Fleurieu Peninsula, South Australia. Rec. S. Aust. Mus. 14, 579-601.

Dalgarno, C. R., 1964 : Report on the Lower Cambrian stratigraphy of the Flinders Ranges, South Australia. Trans. R. Soc. S. Aust. 88, 129-143.

Dalgarno, C. R., 1966 : Structures from Proterozoic carbonate rocks, Adelaide Geosyncline. Quart. geol. Notes. geol. Surv. S. Aust. 17, 14-15.

Dalgarno, C. R. & J. E. Johnson, 1965 : The Oraparinna 1:63,360 Sheet

Dalgarno, C. R. & J. E. Johnson, 1966 : The Parachilna 1:250,000 Sheet

Dalgarno, C. R. & J. E. Johnson, 1968 : Diapiric structures and Late Precambrian-Early Cambrian sedimentation in Flinders Ranges, Sotth Australia. Am. Ass. Petrol. Geol. Memoir No.8, 301-314.

David, T. W. E. & W. Howchin, 1896 : Note on the occurrence of casts of Radiolaria in Pre-Cambrian (?) rocks, South Australia. Proc. Linn. Soc. N.S.W. 21, 571-583.

David, T. W. E., 1922 : Occurrence of remains of small Crustacea in the Proterozoic (?) or Lower Cambrian (?) rocks of Reynella, near Adelaide. Trans. R. Soc. S. Aust. 46, 6-8.

David, T. W. E., 1929 : Further notes on the newly-discovered fossils in the Adelaide Series (Lipalian or Proterozoic), South Australia. Trans. R. Soc. S. Aust. 53, 1-4.

David, T. W. E., 1932 : Explanatory notes to accompany a new geological map of the Commonwealth of Australia. Sydney, Commonwealth Council for Scientific and Industrial Research, 177p.

David, T. W. E. & R. J. Tillyard, 1936 : Memoir on fossils of the late pre-Cambrian (Newer Proterozoic) from the Adelaide Series, South Australia. Angus & Robertson, Sydney, 122p.

David, T. W. E. & W. R. Browne, 1950 : The Geology of the Commonwealth of Australia. London, Edward Arnold & Co., 3 vols.

Davies, G. R., 1970 : Algal laminated sediments, Gladstone Embayment, Shark Bay, Western Australia in Carbonate Sedimentation and Environments, Shark Bay, Western Australia. Am. Ass. Petrol. Geol. Mem. 13, 169-205.

Davis, R. A., 1966 : Quiet water oolites from the Ordovician of Minnesota. J. sedim. Petrol. 36, 813-818.

Davis, R. A., 1968 : Algal stromatolites composed of quartz sandstone. J. sedim. Petrol. 38, 953-955.

Dawson, J. W., 1896 : Note on Cryptozoon and other ancient fossils. Can. Rec. Sci. 7, 203-219.

Dmitrieva, E. V., G. I. Ershova, V. E. Librovitch, O. I. Nekrasova & E. I. Oreshnikova, 1969 : Atlas tekstur i struktur osadochnykh gornykh porod. (Atlas of textures and structures of sedimentary rocks). Vsesoyuz. nauchno-issled. geol. Inst., Mosc., 707p.

Donahue, J., 1969 : Genesis of oolite and pisolite grains: an energy index. J. sedim. Petrol. 39, 1399-1411.

Donaldson, J. A., 1963 : Stromatolites in the Denault Formation, Marion Lake, Coast of Labrador, Newfoundland. Bull. geol. Surv. Can. 102, 33p.

Dow, D. B. & I. Gemuts, 1969 : Geology of the Kimberley Region, Western Australia: The East Kimberley. Bull. Bur. Miner. Resour. Geol. Geophys. Aust. 106, 135p.

Dunham, R. J., 1962 : Classification of carbonate rocks according to depositional texture. in W. E. Ham (Ed.) Classification of Carbonate Rocks, a Symposium, Am. Ass. Petrol. Geol. Mem. 1, 108-121.

Dunn, P. R., K. A. Plumb & H. G. Roberts, 1966 : A proposal for time-stratigraphic subdivision of the Australian Precambrian. J. geol. Soc. Aust. 13, 593-608.

Eardley, A. J., 1938 : Sediments of the Great Salt Lake, Utah. Bull. Am. Ass. Petrol. Geol. 22, 1305-1411.

Edgell, H. S., 1964 : Precambrian fossils from the Hamersley Range, Western Australia, and their use in stratigraphic correlation. J. geol. Soc. Aust. 10, 235-262.

Engel, A. E. J., B. Nagy, L. A. Nagy, C. E. Engel, G. O. W. Kremp & C. M. Drew, 1968 : Alga-like forms in Onverwacht Series, South Africa: Oldest recognized lifelike forms on Earth. Science 161, 1005-1008.

Etheridge, R., 1890 : On some Australian species of the Family Archaeocyathinae. Trans. R. Soc. S. Aust. 13, 10-22.

Fairbridge, R. W., 1950 : Precambrian algal limestones in Western Australia. Geol. Mag. 87, 324-330.

Fenton, C. L. & M. A. Fenton, 1931 : Algae and algal beds in the Belt Series of Glacier National Park. J. Geol. 39, 670-686.

Fenton, C. L. & M. A. Fenton, 1933 : Algal reefs or bioherms in the Belt Series of Montana. Bull. geol. Soc. Am. 44, 1135-1142.

Fenton, C. L. & M. A. Fenton, 1936 : Walcott's "Pre-Cambrian Algonkian algal flora" and associated animals. Bull. geol. Soc. Am. 47, 609-620.

Fenton, C. L. & M. A. Fenton, 1937 : Early algae as environment indications and index fossils. Int. Geol. Congress, 17th, Moscow, Abstracts, p.215.

Fenton, C. L. & M. A. Fenton, 1939 : Pre-Cambrian and Palaeozoic algae. Bull. geol. Soc. Am. 50, 89-126.

Folk, R., 1962 : Spectral subdivisions of limestone types in Ham, W. E. (Ed.) Classification of Carbonate Rocks, a Symposium. Am. Ass. Petrol. Geol. Mem. 1, 62-84.

Forbes, B. G., 1955 : Proterozoic sedimentary magnesite of South Australia. Ph.D. Thesis, University of Adelaide.

Forbes, B. G., 1960 : Magnesite of the Adelaide System: petrography and descriptive stratigraphy. Trans. R. Soc. S. Aust. 83, 1-9.

Forbes, B. G., 1961 : Magnesite of the Adelaide System: a discussion of its origin. Trans. R. Soc. S. Aust. 85, 217-222.

Forbes, B. G., 1967 : Unconformable base of the Appila Tillite west of Pekina. Quart. geol. Notes, geol. Surv. S. Aust. 24, 6-8.

Friedman, G. M. & J. E. Sanders, 1967 : Origin and occurrence of dolostones in Carbonate rocks, Developments in Sedimentology, 9A, 267-348.

Garrett, P., 1970 : Phanerozoic stromatolites: non-competitive ecological restriction by grazing and burrowing animals. Science 169, 171-2.

Garris, M. A., G. A. Kazakov, B. M. Keller, N. I. Polevaya & M. A. Semikhatov, 1964 : Geochronological scale of Upper Proterozoic (Riphean, Vendian), in Absolute age of Geological formations . Repts. of Soviet Geologists to the Internat. Geol. Cong. 22nd, India, Problemy 3, Nauka (Moscow), 431-455.

Garris, M. A. & D. V. Postnikov, 1967 : Geochronologiya dokembriya vostoka Russkoy platformy i miogeosinkinal'noy oblasti Urala (Geochronology of the Precambrian of the eastern Russian Platform and the miogeosynclinal region of the Urals). Trudy Komissii po opredelen absolyutnogo vostrasta geol. formatsiy, Nauka, Mosc.

Gebelein, C. D., 1969 : Distribution, morphology, and accretion rate of recent subtidal algal stromatolites, Bermuda. J. sedim. Petrol. 39, 49-69.

Germann, K., 1969 : Reworked dolomite crusts in the Wettersteinkalk (Ladinian, Alpine Triassic) as indicators of early supratidal dolomitization and lithification. Sedimentology 12, 257-277.

Ginsburg, R. N., 1960 : Ancient analogues of Recent stromatolites. Proc. Int. Geol. Congr. 21st, Copenhagen, Pt.22, 26-35.

Glaessner, M. F., H. G. Raggatt, C. Teichert & D. E. Thomas, 1948 : Stratigraphical nomenclature in Australia. Aust. J. Sci. 11, 7-9.

Glaessner, M. F., 1958a : New fossils from the base of the Cambrian in South Australia. Trans. R. Soc. S. Aust. 81, 185-188.

Glaessner, M. F., 1958b : The oldest Fossil Faunas of South Australia. Geol. Rundschau 47, 522-531.

Glaessner, M. F., 1959 : Precambrian Coelenterata from Australia, Africa and England. Nature 183, 1472-1473.

Glaessner, M. F. & B. Daily, 1959 : The Geology and Late Precambrian fauna of the Ediacara Fossil Reserve. Rec. S. Aust. Mus. 13, 369-401.

Glaessner, M. F., 1960 : Precambrian fossils from South Australia: Rept. XXI, Int. Geol. Congr. Norway, 22, 59-64.

Glaessner, M. F., 1961 : Pre-Cambrian animals. Scientific American 204(3), 72-78.

Glaessner, M. F., 1962 : Pre-Cambrian Fossils. Biol. Rev. 37, 467-494.

Glaessner, M. F., 1963 : The base of the Cambrian. J. geol. Soc. Aust. 10, 223-241.

Glaessner, M. F., 1965 : Pre-Cambrian life - problems and perspectives. Proc. geol. Soc. 1626, 165-169.

Glaessner, M. F., 1966a : Precambrian Palaeontology. Earth-Sci. Rev. 1, 29-50.

Glaessner, M. F., 1966b : The first three billion years of life on Earth. J. geogr., Tokyo, 75, 307-315.

Glaessner, M. F. & M. J. Wade, 1966 : The late Precambrian fossils from Ediacara, South Australia. Palaeontology 9, 599-628.

Glaessner, M. F., 1969 : Trace fossils from the Precambrian and basal Cambrian. Lethaia 2, 369-393.

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

Goldring, W., 1938 : Algal barrier reefs in the lower Ozarkian of New York with a chapter on the importance of coralline algae as reef builders through the ages. Bull. N.Y. St. Mus. 315, 3-75.

Golovanov, N. P. & M. E. Raaben, 1967 : Analogi verkhnego rifeya na arkhipelaga Spitsbergen (The counterparts of the Upper Riphean in the Spitzbergen Archipelago). Dokl. Akad. Nauk. SSSR, 173, 1141-1144. (Transl. Dokl. Acad. Sci. USSR, 173, 58-61).

Greenhalgh, D. & P. M. Jeffery, 1959 : A contribution to the pre-Cambrian chronology of Australia. Geochim. cosmochim. Acta, 16, 39-57.

Grout, F. F. & T. M. Broderick, 1919 : Organic structures in the Biwabik iron-bearing formation of the Huronian in Minnesota. Am. J. Sci. 48, 199-205.

Gürich, G., 1906 : Les spongiestromidés du Viséen de la province de Namur. Mém. Musée d'Hist. natur. Belg., Bruxelles (3), 1-55.

Gutstadt, A. M. & J. W. Schopf, 1969 : Possible algal microfossils from the Late Precambrian of California. Nature 223, 165-167.

Hall, J. D., 1883 : Cryptozon (proliferum) n.g. (and sp.). Rep. N.Y. State Mus. 36, pl.6 & caption

Hoffman, P. F., 1967 : Algal stromatolites: use in stratigraphic correlation and paleocurrent determination. Science 157, 1043-1045.

Hoffman, P. F., 1969 : Proterozoic paleocurrents and depositional history of the East Arm fold belt, Great Slave Lake, Northwest Territories. Can. J. Earth Sci. 6, 441-462.

Hofmann, H. J., 1969a : Stromatolites from the Proterozoic Animikie and Sibley Groups, Ontario. Geol. Surv. Pap. Can. 68-69, 77p.

Hofmann, H. J., 1969b : Attributes of stromatolites. Geol. Surv. Pap. Can. 69-39, 58p.

Hommeril, P. & M. Rioult, 1965 : Étude de la fixation des sédiments meubles par deux algues marines: Rhodothamniella floridula (Dillwyn) J. Feldm. et Microcoleus chtonoplastes Thur. Marine Geol. 3, 131-155.

Horwitz, R. C., 1962 : Some features of the lower part of the Marinoan Series of the Adelaide System. Aust. J. Sci. 24, 355-356.

Hossfeld, P. S., 1935 : The geology of part of the North Mount Lofty Ranges. Trans. R. Soc. S. Aust. 59, 16-67.

Howchin, W., 1897 : On the occurrence of Lower Cambrian Fossils in the Mount Lofty Ranges. Trans. R. Soc. S. Aust. 21, 74-86.

Howchin, W., 1904 : The geology of the Mount Lofty Ranges, Pt.I. Trans. R. Soc. S. Aust. 28, 253-280.

Howchin, W., 1906 : The geology of the Mount Lofty Ranges, Pt.II. Trans. R. Soc. S. Aust. 30, 227-262.

Howchin, W., 1907 : A general description of the Cambrian Series of South Australia. Australas. Ass. Adv. Sci. (Adelaide Meeting) 11, 414-422.

Howchin, W., 1914 : The occurrence of the genus Cryptozoön in the (?) Cambrian of Australia. Trans. R. Soc. S. Aust. 38, 1-10.

Howchin, W., 1920 : Autoclastic, intraformational, enterolithic, and desiccation breccias and conglomerates, with reference to some South Australian occurrences. Trans. R. Soc. S. Aust. 44, 300-321.

Howchin, W., 1921 : Pseudocryptozoön structure. Trans. R. Soc. S. Aust. 45, 27-28.

Howchin, W., 1922 : A geological traverse of the Flinders Ranges from the Parachilna Gorge to the Lake Frome Plains. Trans. R. Soc. S. Aust. 46, 46-82.

Howchin, W., 1924 : The Sturtian Tillite in the Willouran Ranges, near Marree (Hergott), and in the north-eastern portions of the Flinders Ranges. Australas. Ass. Adv. Sci. 17, 67-76.

Howchin, W., 1928 : The Sturtian Tillite and associated beds on the western scarps of the Southern Flinders Ranges. Trans. R. Soc. S. Aust. 52, 82-94.

Howchin, W., 1929 : The geology of South Australia. Gillingham & Co. Ltd., Adelaide, 320pp.

Howe, W. B., 1966 : Digitate algal stromatolite structures from the Cambrian and Ordovician of Missouri. J. Paleont. 40, 64-77.

Illing, L. V., 1954 : Bahamian calcareous sands. Bull. Am. Ass. Petrol. Geol. 38, 1-95.

Illing, L. V., A. J. Wells & J. C. M. Taylor, 1965 : Penecontemporaneous Dolomite in the Persian Gulf. Soc. Econ. Pal. Miner. 10-13, 89-111.

Johns, R. K., M. N. Hiern, L. G. Nixon, B. G. Forbes & J. G. Olliver, 1964 : The Torrens 1:250,000 Sheet

Johnson, J. H., 1937 : Algae and algal limestone from the Oligocene of South Park, Colorado. Bull. geol. Soc. Am. 48, 1227-1236.

Johnson, J. H., 1940 : Lime-secreting algae and algal limestones from the Pennsylvanian of Central Colorado. Bull. geol. Soc. Am. 51, 571-596.

Johnson, J. H., 1957 : Bibliography of fossil Algae: 1942-1955. Colo. Sch. Mines Q. 52(2), 92p.

Johnson, J. H., 1966 : A review of the Cambrian algae. Colo. Sch. Mines Q. 61(1), 162p.

Kalkowsky, E., 1908 : Oolith und Stromatolith im norddeutschen Buntsandstein. Z. dt. geol. Ges. 60(1), 68-125.

Karaulov, V. B., 1967 : O nakhozhdeniyakh drevneyshikh onkolitov i katagrafiy v paleozoye Shantarskikh Ostrovov. (Discoveries of ancient oncolites and catagraphs in Paleozoic sediments of the Shantar Islands). Dokl. Akad. Nauk. SSSR, 175, 1115-1118. (Engl. trans. Dokl. Acad. Sci. USSR, 175, 85-88).

Kaulback, J. A. & J. J, Veevers, 1969 : Cambrian and Ordovician geology of the southern part of the Bonaparte Gulf Basin, Western Australia. Rep. Bur. Miner. Resour. Geol. Geophys. Aust. 109, 80p.

Kay, M., 1947 : Geosynclinal nomenclature and the craton. Bull. Am. Ass. Petrol. Geol. 31, 1289-1293.

Kazakov, G. A. & K. G. Knorre, 1970 : Geochronology of the Upper Precambrian of the Siberian Platform, Uchur-Maja Region. Eclogae geol. Helv. 63, 173-183.

Kazakov, G. A. & A. I. Tugarinov, 1963 : Absolyutnyy vosrast verkhnego dokembriya (Absolute age of the Upper Precambrian) in "Stratigrafiya SSSR", 2, Mosc. Gosgeoltekhizdat.

Keller, B. M., G. A. Kazakov, I. N. Krylov, S. V. Nuzhnov & M. A. Semikhatov, 1960 : Novyye dannyye po stratigrafii rifeyskoy gruppy (Verkhniy Proterozoy). (New data on the stratigraphy of the Riphean Group (Upper Proterozoic). Izv. Akad. Nauk SSSR, Ser. Geol. 1960 No.12, 26-41 (Transl. Izv. Acad. Sci. USSR geol. Ser. 1960 No.12, 21-34).

Keller, B. M. & M. A. Semikhatov, 1967 : Opornye razrezy rifeya materikov (Supporting sections of the Riphean on the continents). Itogi Nauki, Ser. Geol. Stratigrafiya Paleontologiya 1967, 108p.

Kendall, C. G., St. C. & Sir Patrick A. d'E Skipwith, 1968 : Recent algal mats of a Persian Gulf Lagoon. J. sedim. Petrol. 38, 1040-1058.

Kleeman, A. W., 1946 : An age determination on samarskite from Mount Painter, South Australia. Trans. R. Soc. S. Aust. 70, 175-177.

Knight, S. H., 1968 : Precambrian stromatolites, bioherms and reefs in the lower half of the Nash Formation, Medicine Bow Mountains, Wyoming. Contr. geol. Univ. Wyoming. 7(2), 73-116.

Komar, Vl. A., 1966 : Stromatolity verkhnedokembriyskikh otlozheniy severa Sibirskoy platformy i ikh stratigraficheskoe znachenie (Stromatolites of the Upper Precambrian deposits of the North Siberian platform and their stratigraphic significance). Trudy geol. Inst., Leningr. 154, 122p.

Komar, Vl. A., M. E. Raaben & M. A. Semikhatov, 1965 : Konofitony Rifeya SSSR i ikh stratigraficheskoe znachenie (Conophytons of the Riphean of the USSR and their stratigraphic significance). Trudy geol. Inst. Leningr. 131, 72p.

Komar, Vl. A. & M. A. Semikhatov, 1969 : Stromatolity v detalizatsii stratigrafii verkhnego proterozoya (Stromatolites in the detailing of the stratigraphy of the Upper Proterozoic). Dokl. Sovet. Geol. Internat. Geol. Cong. 21st Sess. Prague, 100-105.

Korolyuk, I. K., 1960 : Stromatolity nizhnego kembriya i proterozoya Irkutskogo amfiteatra (Stromatolites from the Lower Cambrian and Proterozoic of the Irkutt Amphitheatre). Trudy. Inst. Geol. Razrab. Goryuoh. Iskop. Akad. Nauk SSSR, (1), 161p.

Korolyuk, I. K., 1963 : Stromatolity verkhnego dokembriya (Stromatolites of the Upper Precambrian) in the book "Stratigrafiya SSSR" (Stratigraphy of the USSR). Vol. 2. Gosgeoltekhizdat.

Krüger, L., 1969 : Stromatolites and oncolites in the Otavi Series, South West Africa. J. sedim. Petrol. 39, 1046-1056.

Krylov, I. N., 1959 : Rifeyskiye stromatolity ostrova Kil'dina (Riphean stromatolites of Kil'din Island). Dokl. Akad. Nauk SSSR, 127, 888-891.

Krylov, I. N., 1963 : Stolbchatye vetvyashchiesya stromatolity rifeyskikh otlozheniy Yuzhnogo Urala i ikh znachenie dlya stratigrafii verkhego dokembriya. (Columnar branching stromatolites of the Riphean deposits of the Southern Urals and their significance for the stratigraphy of the Upper Precambrian). Trudy. geol. Inst., Leningr. 69, 133p.

Krylov, I. N., 1967 : Rifeyskie i nizhnekembriyskie stromatolity Tyan'-Shanya i Karatau (Riphean and Lower Cambrian stromatolites of Tien-Shan and Karatau). Trudy geol. Inst., Leningr. 171, 76p.

Krylov, I.N., S. V. Nuzhnov & I. G. Shapovalova, 1968 : O stromatolitovykh kompleksakh srednego rifeya (On the stromatolitic complexes of the Middle Riphean). Dokl. Akad. Nauk SSSR, Ser. Geol. 181, 426-429.

Lindholm, R. C., 1969 : Detrital dolomite in Onondaga Limestone (Middle Devonian) of New York: its implications to the "Dolomite Question". Bull. Am. Ass. Petrol. Geol. 53, 1035-1042.

Logan, B. W., 1961 : Cryptozoon and associate stromatolites from the Recent, Shark Bay, Western Australia. J. Geol. 69, 517-533.

Logan, B. W. & R. L. Chase, 1961 : The stratigraphy of the Moora Group, West Australia. J. R. Soc. W. Aust. 44, 14-31

Logan, B. W., R. Rezak & R. N. Ginsburg, 1964 : Classification and environmental significance of algal stromatolites. J. Geol. 72, 68-83.

Maslov, V. P., 1937a : Nizhne-paleozoyskie porodppbrazuyushchie vodorosli vostochnoy Sibiri (Lower Palaeozoic rock-building Algae of Eastern Siberia). Problemy Paleont. 2-3, 249-314. (Engl. summary, 314-325).

Maslov, V. P., 1937b : O rasprostranenii karbonztnykh vodorosley v vostochnoy Sibiri (On the distribution of calcareous algae in Eastern Siberia). Problemy Paleont. 2-3, 327-342.

Maslov, V. P., 1938 : O prirode stromatolita Conophyton (On the nature of the stromatolite Conophyton). Problemy Paleont. 4, 325-332.

Maslov, V. P., 1939a : Popytka vozrastnogo opredeleniya nemykh tolshch urala, pomoshch'yu stromatolitov (An attempt of the age determination of unfossiliferous beds of the Urals with the aid of stromatolites). Problemy Paleont. 5, 277-281. (Engl. transl. 281-284).

Maslov, V. P., 1939b : Rod Collenia (The genus Collenia). Problemy Paleont. 5, 297-310.

Maslov, V. P., 1960 : Stromatolity (ikh genezis, metod izucheniya, svyaz' s fatsiyami i geologicheskoye znachenie na primere ordovika sibirskoy platformy). (Stromatolites; their genesis, methods of study, connection with facies, and geologic significance in the example of the Ordovician of the Siberian Platform). Trudy Geol. Inst., Leningr. 41, 188p.

Matthew, G. F., 1907 : Note on Archeozoon. Bull. Nat. Hist. Soc. New Brunswick, 25, 547-552.

Mawson, D., 1912 : Geological investigations in the Broken Hill area. Mem. R. Soc. S. Aust. 2, 211-319.

Mawson, D., 1925 : Evidence and indications of algal contributions in the Cambrian and Pre-cambrian limestones of South Australia. Trans. R. Soc. S. Aust. 49, 186-190.

Mawson, D., 1926 : The Wooltana basic igneous belt. Trans. R. Soc. S. Aust. 50, 192-200.

Mawson, D., 1927 : Geological notes on an area along the north-eastern margin of the north-eastern portion of the Willouran Range. Trans. R. Soc. S. Aust. 51, 386-390

Mawson, D., 1934 : The Munyallina Beds. A Late-Proterozoic Formation. Trans. R. Soc. S. Aust., 58, 187-196.

Mawson, D., 1936 : Centenary Address No. 7: Progress in knowledge of the geology of South Australia. Trans. R. Soc. S. Aust. 60, p.lvi-lxv.

Mawson, D., 1938 : The Mount Caernarvon Series of Proterozoic age. Trans. R. Soc. S. Aust. 62, 347-351.

Mawson, D., 1939 : The Late Proterozoic sediments of South Australia. Trans. Australas. Ass. Adv. Sci. 24, 79-88.

Mawson, D., 1940 : The Adelaide Series. Aust. J. Sci. 3, 25-27.

Mawson, D., 1941a : The Wilpena Pound Formation and underlying Proterozoic sediments. Trans. R. Soc. S. Aust. 65, 295-303.

Mawson, D., 1941b : Middle Proterozoic sediments in the neighbourhood of Copley. Trans. R. Soc. S. Aust. 65, 304-311.

Mawson, D., 1947 : The Adelaide Series as developed along the western margin of the Flinders Ranges. Trans. R. Soc. S. Aust. 71, 259-280.

Mawson, D., 1948 : The Late Precambrian ice-age and glacial record of the Bibliando Dome. J. Proc. R. Soc. N.S.W. 82, 150-174.

Mawson, D., 1949 : The Elatina Glaciation: a third recurrence of glaciation evidenced in the Adelaide System. Trans. R. Soc. S. Aust. 73, 117-121.

Mawson, D. & E. R. Segnit, 1949 : Purple slates of the Adelaide System. Trans. R. Soc. S. Aust. 72, 276-280.

Mawson, D. & R. C. Sprigg, 1950 : Subdivision of the Adelaide System. Aust. J. Sci. 13, 69-72.

Mirams, R. C., 1964a : A Sturtian glacial pavement at Merinjina Well, near Wooltana. Quart. geol. Notes, geol. Surv. S. Aust. 11, 4-6.

Mirams, R. C., 1964b : The Burra 1:250,000 Sheet

Monty, C. L. V., 1967 : Distribution and structure of Recent stromatolitic algal mats, eastern Andros Island, Bahamas. Annls. Soc. géol. Belg. 90(3), 55-99.

Murray, G., 1895 : Calcareous pebbles formed by algae. Phycol. Mem. p.74.

Narozhnykh, L. I., 1967 : Oncoliths and Catagraphs of the Yudoma Suite in the Uchur-Maya area. Dokl. Acad. Sci. USSR 173(4), 55-57. (Engl. transl.).

Nelson, H. F., C. W. Brown & J. H. Brinoman, 1962 : Skeletal limestone classification in Ham, W. E. (Ed.) Classification of Carbonate Rocks, a symposium, Am. Ass. Petrol. Geol. Mem. 1, 224-252.

Newell, N. D., E. G. Purdie & J. Imbrie, 1960 : Bahamian oölitic sand. J. Geol. 68, 481-497.

Nixon, L. G. B., 1965 : Paratoo copper deposit. Min. Rev. S. Aust. 123, 8-20.

Nuzhnov, S. V., 1960 : Stromatolity pozdnedokembriyskikh i kembriyskikh otlozheniy vostochnykh sklonov Aldanskogo shchita (Stromatolites of the Late Precambrian and Cambrian deposits of the eastern flanks of the Aldan shield). Dokl. Akad. Nauk SSSR, 132, 1421-1424.

Nuzhnov, S. V., 1967 : Rifeyskie otlozheniya yugo-vostoka Sibirskoy platformy (Riphean deposits of the south-east Siberian platform). Inst. Geol. Yakutsk. Filial Sibirsk. Otdel. Akad. Nauk SSSR; Moscow, 160p.

Nuzhnov, S. V. & I. G. Shapovalova, 1968 : Raschlenenie Yakutskogo Kompleksa (Srednego Rifeya) po stromatolitam v Uchuro-Mayskom rayone (Subdivision of the Yakut Complex (Middle Riphean) by stromatolites in the Uchur-Maya region). Dokl. 17 nauch. Sess. Yakut. fil. Sibir. otd. Akad. Nauk SSSR, "Tektonika, stratigrafiya i litologiya osadochnykh formatsiy Yakutii, 91-97.

Offler, R. & P. D. Fleming, 1969 : A synthesis of folding and metamorphism in the Mt. Lofty Ranges, South Australia. J. geol. Soc. Aust. 15, 245-266.

Parkin, L. W., M. L. Reyner, R.K. Pitman & R. K. Johns, 1953 : The Serle 1:63,360 Sheet

Parkin, L. W. (Ed.), 1969 : Handbook of South Australian Geology. Geol. Surv. S. Aust. Govt. Printer, Adelaide.

Pia, J., 1926 : Pflanzen als Gesteinbildner. Berlin, 355p.

Pia, J., 1933 : Die rezenten Kalksteine. Zeitschrift für Krystallographie, Mineralogie und Petrographie. Abt. B., Mineralogische und petrographische Mitteilungen, Ergänzungsband. Leipzig, 418p.

Playford, P. E. & A. E. Cockbain, 1969 : Algal stromatolites: deepwater forms in the Devonian of Western Australia. Science 165, 1008-1010.

Plumley, W. J., G. A. Risley, R. W. Graves & M. E. Kaley, 1962 : Energy index for limestone interpretation and classification in Ham, W. E. (Ed.) Classification of Carbonate Rocks. Am. Ass. Petrol. Geol. Mem. 1, 85-107.

Preiss, W. V. & I. P. Sweet, 1966 : The geology of the Depot Creek area, Flinders Ranges, South Australia. Unpublished Honours Thesis.

Raaben, M. E., 1964 : Stromatolity verkhnego rifeya Polyudova kryazha i ikh vertikal'noye raspredelenie. Byull. mosk. Obshch. Ispyt. Prir., otd. geol. 39 (vyp.3), 86-109.

Raaben, M. E., 1969a : Stromatolity verkhnego rifeya (Gimnosolenidy) (Upper Riphean stromatolites (Gymnosolenida). Trudy geol. Inst., Leningr. 203, 100p.

Raaben, M. E., 1969b : Columnar stromatolites and Late Precambrian stratigraphy. Am. J. Sci. 267, 1-18.

Rezak, R., 1957 : Stromatolites of the Belt Series in Glacier National Park and vicinity, Montana. Prof. Pap. U.S. geol. Surv. 294D, 127-154.

Robertson, W. A., 1960 : Stromatolites from the Paradise Creek Area, Northwestern Queensland. Rep. Bur. Miner. Resour. Geol. Geophys. Aust. 47, 12p.

Rothe, P., 1970 : Aragonitic "algal lapilli" from lagoonal environment (Lobos, Canary Islands). J. sedim. Petrol. 40, 497-499.

Rozanov, A. Yu., V. V. Missarzhevskiy, N. A. Volkova, L. G. Voronova, I. N. Krylov, B. M. Keller, I. K. Korolyuk, K. Lendzion, R. Mikhnyak, N. G. Pykhova & A. D. Sidorov, 1969 : Tommotskiy yarus i problema nizhney granitsy kembriya (Tommotian Stage and the Cambrian lower boundary problem). Trudy geol. Inst., Leningr. 206, 380p.

Schopf, J. W., 1968 : Microflora of the Bitter Springs Formation, Late Precambrian, Central Australia. J. Paleont. 42, 651-688.

Schopf, J. W. & E. S. Barghoorn, 1969 : Microorganisms from the Late Precambrian of South Australia. J. Paleont. 43, 111-118.

Scoffin, T. P., 1970 : The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini Lagoon, Bahamas. J. sedim. Petrol. 40, 249-273.

Segnit, R. W., 1929 : Geological notes from the Hundred of Adams, Flinders Range. Trans. R. Soc. S. Aust. 53, 10-17.

Segnit, R. W., 1939 : Geology of part of Pichi Richi Pass, Flinders Range, Hundreds of Woolundunga and Davenport. Geol. Surv. Bull. 18, Pt.1, 13-40.

Semikhatov, M. A., 1960 : O vertikal'nom raspredelenii stromatolitov v rifeye Turukhanskogo rayona (On the vertical distribution of columnar stromatolites in the Riphean of the Turukhan Region). Dokl. Akad. Nauk SSSR 135, 1480-1483.

Semikhatov, M. A., 1962 : Rifey i nizhniy kembriy Yeniseyskogo Kryazha (The Riphean and Lower Cambrian of the Yenisei Mountains). Trudy geol. Inst., Leningr. 68, 242p.

Semikhatov, M. A. & Vl.A. Komar, 1965 : O primenimosti formal'nikh vidov stolbchatykh stromatolitov dlya mezhregional'noy korrelyatsii rifeyskikh otlozheniy (Applicability of form species of columnar stromatolites to the interregional correlation of Riphean sediments). Dokl. Akad. Nauk SSSR 165, 1383-1386. (Engl. transl. Dokl. Acad. Sci. USSR, Earth Sci. Secn. 165, 102-105).

Semikhatov, M. A., Vl. A. Komar & S. N. Serebryakov, 1970 : Yudomskiy Komplex Stratotipicheskoy Mestnosti (The Yudomian Complex of the Stratotypical Area). Akad. Nauk SSSR, Trudy 210, 207p.

Serebryakov, S. N., 1968 : O veshchestvennom sostave stromatolitovykh biogermov rifeya vostchnoy Sibiri (On the composition of stromatolitic bioherms of the Riphean of Eastern Siberia). Izv. Akad. Nauk SSSR, Ser. Geol. 12, 130-135.

Shapovalova, I. G., 1968 : O novoy gruppe stromatolitov *Jacutophyton* iz verkhnego proterozoya vostochnogo sklona Aldanskoy anteklizy (On a new group of stromatolites *Jacutophyton* from the Upper Proterozoic of the eastern slopes of the Aldan anticlize). Dokl. 17 nauch. Sess. Yakut. fil. Sibir. otd. Akad. Nauk SSSR, "Tektonika, stratigrafiya i litologiya osadochnykh formatsiy Yakutii, 97-103.

Shaw, A. B., 1964 : Time in Stratigraphy. McGraw-Hill, N.Y., 365p.

Shinn, E. A., 1968 : Practical significance of birdseye structures in carbonate rocks. J. sedim. Petrol. 38, 215-223.

Sidorov, A. D., 1960 : Novyy nizhnekembriyskiy stromatolit vostochnoy Sibiri (A new stromatolite from the Cambrian of Eastern Siberia). Paleont. Zh. 4, 104-107.

Sprigg, R. C., 1947 : Early Cambrian (?) jellyfishes from the Flinders Ranges, South Australia. Trans. R. Soc. S. Aust. 71, 212-224.

Sprigg, R. C., 1949 : Early Cambrian "jellyfishes" of Ediacara, South Australia, and Mount John, Kimberley District, Western Australia. Trans. R. Soc. S. Aust. 73, 72-99.

Sprigg, R. C., 1952 : Sedimentation in the Adelaide Geosyncline and the formation of the continental terrace in Sir Douglas Mawson Anniv. Vol., Univ. of Adel., 153-159.

Sprigg, R. C. & B. Campana, 1953 : The age and facies of the Kanmantoo Group. Aust. J. Sci. 16, 12-14.

Steinmann, G., 1911 : Über Gymnosolen ramsayi, eine Cölenterate von der Halbinsel Kanin. Bull. Soc. géogr. Finlande 31, 18-23.

Strain, H. H., 1951 : The pigments of algae in G. M. Smith, Manual of Phycology, 244-262. Ronald Press.

Szulczewski, M., 1968 : Stromatolity jurajskie w Polsce (Jurassic stromatolites of Poland). Acta geol. Pol. 18(1), 1-82. (Engl. summary 83-90).

Talbot, J. L., 1967 : Subdivision and structure of the Precambrian (Willyama Complex and Adelaide System), Weekeroo, South Australia. Trans. R. Soc. S. Aust. 91, 45-58.

Tate, R., 1878 : The anniversary address of the President. Trans. & Proc. Phil. Soc. Adelaide, 2, xxxix-lxxv.

Thomson, A. F. & M. R. Thomasson, 1969 : Shallow to deep water facies development in the Dimple Limestone (Lower Pennsylvanian), Marathon Region, Texas in Friedman, G. M. (Ed.). Depositional Environments in Carbonate Rocks, a Symposium. Soc. Econ. Pal. Miner. Sp. Publ. 14, 57-78.

Thomson, B. P., 1966a : Stratigraphic relationships between sediments of Marinoan Age - Adelaide Region. Quart. geol. Notes, geol. Surv. S. Aust. 20, 7-9.

Thomson, B. P., 1966b : The lower boundary of the Adelaide System and older basement relationships in South Australia. J. geol. Soc. Aust. 13, 203-228.

Thomson, B. P., 1969 : The Adelaide 1:250,000 Sheet

Thomson, B. P., R. P. Coats, R. C. Mirams, B. G. Forbes, C. R. Dalgarno & J. E. Johnson, 1964 : Precambrian rock groups in the Adelaide Geosyncline. A new subdivision. Quart. geol. Notes, geol. Surv. S. Aust. 9, 1-19.

Thomson, B. P. & R. C. Horwitz, 1962 : The Barker 1:250,000 Sheet

Thomson, B. P. & J. E. Johnson, 1968 : Marinoan stratigraphy, Port Augusta Region. Quart. geol. Notes, geol. Surv. S. Aust. 25, 4-7.

Trompette, R., 1969 : Les stromatolites du "Precambrien Superieur" de l'Adrar de Mauritanie (Sahara Occidental). Sedimentology 13, 123-154.

Twenhofel, W. H., 1919 : Pre-Cambrian and Carboniferous algal deposits. Am. J. Sci. 48, 339-352.

Valdiya, K. S., 1969 : Stromatolites of the Lesser Himalayan carbonate formations and the Vindhyans. J. geol. Soc. India. 10, 1-25.

Voisey, A. H., 1959 : Australian geosynclines. Aust. J. Sci. 22, 188-198.

Vologdin, A. G., 1962 : Drevneyshie vodorosli SSSR (The most ancient algae of the USSR). Moskva, Izdat. Akad. Nauk SSSR, 656p.

Von der Borch, C. C., 1965 : The distribution and preliminary geochemistry of modern carbonate sediments of the Coorong area, South Australia. Geoch. Cosmochim. Acta. 29, 781-799.

Wade, M. J., 1968 : Preservation of soft-bodied animals in Precambrian sandstones at Ediacara, South Australia. Lethaia, 1, 238-267.

Walcott, C. D., 1914 : Cambrian Geology and Paleontology II: Pre-Cambrian Algonkian algal flora. Smithson. misc. Collns, 64, 78-156.

Walker, R. G., 1965 : The origin and significance of internal sedimentary structures of turbidites. Proc. Yorks. geol. Soc. 35, 1-32.

Walter, M. R., 1970 : Stromatolites and the biostratigraphy of the Australian Precambrian. Unpubl. Ph.D. Thesis, University of Adelaide.

Walther, J., 1894 : Einleitung in die Geologie als historische Wissenschaft - Beobachtungen über die Bildung der Gesteine und ihrer organischen Einschlüsse, 1, Jena, G. Fischer Verlag. 535-1055.

Webby, B. D., 1970 : Late Precambrian trace fossils from New South Wales. Lethaia, 3, 79-109.

White, A. J. R., W. Compston & A. W. Kleeman, 1967 : The Palmer Granite - a study of a granite within a regional metamorphic environment. J. Petrology 8, 29-50.

Wilson, A. F., 1952 : The Adelaide System as developed in the Riverton-Clare Region, Northern Mount Lofty Ranges, South Australia. Trans. R. Soc. S. Aust. 75, 131-149.

Wilson, A. F., W. Compston & P. M. Jeffery, 1960 : Radioactive ages from the Pre-Cambrian rocks of Australia. Ann. N.Y. Acad. Sci. 91, 514-520.

Wolf, K. H., 1965 : Littoral environment indicated by open-space structures in algal limestones. Palaeogeog. Palaeoclim. Palaeoecol. 1, 183-223.

Young, R. B., 1933a : The occurrence of stromatolithic or algal limestones in the Campbell Rand Series, Griqualand West. Trans. geol. Soc. S. Afr. 35, 29-36.

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

Young, R. B., 1935 : A comparison of certain stromatolitic rocks in the Dolomite Series of South Africa, with modern algal sediments in the Bahamas. Trans. geol. Soc. S. Afr. 37, 153-162.

Young, R. B. & E. Mendelssohn, 1949 : Domed algal growths in the Dolomite Series of South Africa, with associated fossil remains. Trans. geol. Soc. S. Afr. 51, 53-62.

Zabrodin, V. Ye, 1968 : Stratigraphic subdivision of Min'yar-Uk deposits of the Urals by microphytoliths. Dokl. Acad. Sci. USSR 182(2) 47-49. (Engl. transl.).

Zhuravleva, Z. A., 1964 :Onkolity i katagrafii rifeya i nizhnego kembriya Sibiri i ikh stratigraficheskoe znachenie (Oncolites and catagraphia from the Riphean and Lower Cambrian of Siberia and their stratigraphic significance). Trudy geol. Inst., Leningr. 114, 72p.

Zhuravleva, Z. A. & N. M. Chumakov, 1968 : Katagrafii, onkolity, i stromatolity iz pozdnego dokembriya Vostochnoy Belorussii (Catagraphs, oncoliths and stromatoliths from the Upper Precambrian of Eastern Belorussia). Dokl. Akad. Nauk SSSR 178, 668-671. (Engl. Transl. Dokl. Acad. Sci. USSR 178, 48-50).

Zhuravleva, Z. A., I. N. Krylov & E. S. Postel'nikov, 1969 : O stratigrafii i organicheskikh ostatkakh Dashkinskoy Svity Oslyanskoy Serii (Verkhniy Dokembriy Yeniseyskogo Kryazha) (On the stratigraphy and organic remains of the Dashkin Suite of the Oslyan Series (Upper Precambrian of the Yenisey Mountains). Izv. Akad. Nauk SSSR 1969 (7), 125-130.