



The University of Adelaide
Department of Geology and Geophysics

CONTRIBUTIONS TO
PALAEONTOLOGY AND STRATIGRAPHIC CORRELATION
OF THE LATE PRECAMBRIAN IN CHINA AND AUSTRALIA

by

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Frontspieces

Upper: Searching for fossils of the Late Precambrian Ediacara metazoan assemblage at the Ediacara Range, South Australia.

Lower: Mawsonites randellensis Sun, a new scyphozoan medusa of the Ediacara metazoan assemblage, from the Ediacara Range.



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SUMMARY

This thesis, consisting of six chapters, is based on an investigation of Late Precambrian (Proterozoic) reference sequences in selected key regions of China and Australia and on detailed studies of various macroscopic organic remains including not only new fossils from the famous Ediacara metazoan assemblage but also primitive animals and algae from different levels of strata dating from ca. 1000 million years before the present (Ma) to the beginning of the Cambrian Period.

Chapter 1, a general introduction, presents a progress review of recent achievements and existing problems in Late Precambrian research of China and Australia. The historical problem of the Late Precambrian correlation between the North China Platform and the Yangtze Platform is now solved to a certain degree by establishing a third reference section in the Huainan district on the southern margin of the North China Platform.

Chapter 2 deals with the palaeontological and chronostratigraphic significance of Late Precambrian macroscopic worm-like organisms found in the Huainan district. The Huainan and Feishui Groups are bracketed within the time range of ca. 900-700 Ma and the weathered top of the Feishui Group is covered by the Fengtai Formation, an equivalent of the latest Precambrian glacial deposits (Luoquan Tillite). Apart from the still enigmatic Sinosabellidites Zheng in the Liulaobei Formation of the Huainan Group, the metazoan worm-like organisms represented by Pararenicola Wang and Protoarenicola Wang in the Jiuliqiao Formation of the Feishui Group are further studied and claimed to be the oldest multicellular animals so far discovered in the world and the first possible evidence for the pre-Ediacarian evolutionary history of metazoan life.

Chapter 3 shows that knowledge of the previously enigmatic Chuaria Walcott and Tawuia Hofmann has progressed from morphological description and preliminary speculations to discovery of their component filamentous cellular structures. The Late Precambrian discoidal remains of Chuaria are now interpreted as comparable to the spherical colonies of the living filamentous bluegreen alga Nostoc in shape, size range, general configuration and perhaps living habit. Using Chuaria as an index fossil is possible but difficult in practice. However, the distinctive Chuaria - Tawuia macrofossil assemblage, with its recently known occurrences in Canada, China, Svalbard and India, has proved to be a significant, valid and convenient biostratigraphic index for the global correlation of the Late Riphean (ca. 1000-700Ma), predating the Varangian glacial event and the appearance of the Ediacara-type metazoan assemblages.

Chapters 4 and 5 shed fresh light on the hydrozoan and scyphozoan medusae in the Late Precambrian Ediacara metazoan assemblage of South Australia. Cyclomedusa Sprigg is shown to be a hydrozoan medusa, which can be compared with the living Aequorea in general pattern. Spriggia wadeae sp. nov. is interpreted as a very primitive evolutionary precursor of the living Porpitidae (Chondrophora). Mawsonites randellensis sp. nov., a scyphozoan medusa, is different from the living Coronatae in the lack of pedalia but otherwise similar to them. The morphological diversification among Cyclomedusa, Ediacaria, Brachina and Mawsonites indicates a relatively high level of evolution reached by the Ediacarian medusae. It is suggested that they represent ancestors of living Hydromedusae and of several orders of Scyphomedusae.

Chapter 6 further studies Paracharnia gen. nov., a sea pen recently described from the Dengying Formation in the Eastern Yangtze Gorge section in China. It differs from all previously known Late Precambrian pennatulids but resembles many living sea pens in its characteristic free-standing polyp leaves. The appearance of Paracharnia, together with abundant algal remains of Vendotaenia in the same stratigraphic unit facilitates a Late Precambrian correlation between the Dengying Formation of China, the Upper Vendian of the U.S.S.R. and the Pound Subgroup of Australia.

Chapters 4, 5 and 6 of these studies provide new evidence to show that the Ediacara-type metazoan assemblages are not the oldest forms of animal life. There must have been a prolonged evolutionary process prior to their appearance. New evidence for it is suggested by the fossils described in Chapter 2. Their age is discussed in Chapters 1, 2 and 3.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text of the thesis; and I consent to the thesis being made available for photocopying and loan if applicable if accepted for the award of the degree.

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Professor Glaessner took an active part in organization of supervising activities and directed most of my palaeontological research; he facilitated this project with the offer of a large number of valuable specimens from his collections in different countries and the use of his reference library; he also made it possible for me to get acquainted with and obtain constructive suggestions from specialists in the relevant fields. Dr. Daily and Dr. Jenkins guided my field work in Australia, including several trips to the Flinders and Mt. Lofty Ranges of South Australia and a trip to the Amadeus Basin of central Australia. Dr. Daily directed my study on the Late Precambrian and Cambrian stratigraphy of Australia and drew my interest to the significance of the basal Cambrian trace fossil assemblages. Dr. Jenkins, in co-operation with Professor Glaessner, directed my study on the Ediacara metazoan assemblage and the living invertebrates; he also helped me by drawing my attention to diverse opinions concerning problems related to my studies. I feel deeply grateful to my supervisors, who have ushered me into a new field and have made valuable contributions to the scientific cooperation between Australia and China.

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The manuscript of this thesis has been critically read by my supervisors.

Having benefited from a kind arrangement by Dr. J. Jones, this thesis was typed by Mrs. B. Elliott on a word processor and the contained plates were finally photographed by Mr. R. Barrett in the Department.

The whole of my five year research was carried out with the Overseas Graduate Scholarship from the Ministry of Education, People's Republic of China, while several of the field trips were financially supported by the Department and an Adelaide University Graduates' Union Award (1981).

INTRODUCTION

This thesis relates to the problem of palaeontology (mainly macrofossil assemblages) and stratigraphic correlation of the Late Precambrian (Proterozoic) in China and Australia. The relevant investigations have been carried out since 1977 when I graduated from Nanjing University, China. ,

In 1977-1978, I investigated Late Precambrian rock sequences in Anhui Province, East China, with special interest in stromatolites. Northern Anhui is situated on the southern margin of the North China Platform and southern Anhui on the northeastern margin of the Yangtze Platform, with the eastern extension of the Qinling-Dabie Tectonic Belt (Zone) lying in between. Stratigraphic correlation of the Late Precambrian between the North China Platform and the Yangtze Platform has long been a crucial problem because of the tectonic separation and stratigraphic discontinuity. While working at Anhui Institute of Geological Sciences, I participated geological excursions to a number of other districts on the North China Platform, including the stratotype of the Jixian section near Beijing (Peking) and sections in southern Liaoning Province, Northeast China. Since then, abundant and varied, macroscopic, carbonised, organic remains in the Huainan section of northern Anhui and the Fuxian section of southern Liaoning have attracted my interest concerning their origins and potential value in biostratigraphy.

After completing two years (September 1978 - July 1980) of postgraduate courses at Nanjing Institute of Geology and Palaeontology, Academia Sinica in Nanjing (Nanking), I was awarded an opportunity to study Late Precambrian palaeontology and stratigraphy in the Department of Geology and Geophysics, University of Adelaide, South Australia.

It is known that systematic description and palaeobiological analysis of the Ediacara soft-bodied metazoan assemblage from South Australia by Professor M.F. Glaessner and his colleagues, of the Bitter Springs microbiota from central Australia by Professor J.W. Schopf (U.S.A.) and others and of the stromatolitic organic sedimentary structures in Australia by Drs. M.R. Walter and W.V. Preiss are among the most remarkable achievements in the field of Late Precambrian palaeontology and biostratigraphy during the last two decades before 1980. Those achievements have benefited all who have been engaged in this field. As the first overseas student engaged in this field to study in Australia, I understand that my Ph.D. candidature is not merely to gain a higher degree for myself but more importantly to obtain valuable experience for further investigations in China.

Since December 1980, I have investigated the Late Precambrian (Adelaidean) and basal Cambrian rock sequences at many localities in the Adelaide "Geosyncline" of South Australia and in the Amadeus Basin of central Australia, and studied the famous Ediacara metazoan assemblage and some basal Cambrian trace fossils both in the field and laboratories. On a return trip to China from September 1982 to February 1983, I collected supplementary specimens of macroscopic algal remains and worm-like organisms from the Huainan section, and investigated the selected Late Precambrian - Early Cambrian sequences in the Eastern Yangtze Gorge, western Hubei Province, the Emei Mountain, western Sichuan Province and the Kunming district, eastern Yunnan Province on the Yangtze Platform. The material collected during that trip was brought to Australia and analysed at the University of Adelaide.

The investigations outlined above enabled me to reach a better understanding of the recent achievements and existing problems in studies of the Late Precambrian in both China and Australia, and allowed me to

select the problems that are of common interest and more potential value in both palaeobiology and biostratigraphy to deal with in detail as the component chapters of the present thesis.

Chapter 1 is a general introduction, presenting a progress review on the current knowledge and remaining problems in interregional and intercontinental stratigraphic correlation of the Late Precambrian in China and Australia. In addition a preliminary Late Precambrian correlation scheme between the North China Platform, the Yangtze Platform, the Adelaidean "Geosyncline" and the Amadeus Basin is put forward. Chapters 2-6 deal with several groups of macroscopic organic remains including not only new fossils from the Ediacara metazoan assemblage but also primitive animals and algae from different levels of strata ranging from ca. 1000 Ma to the beginning of the Cambrian Period. The major discoveries and conclusions of these studies are presented in the Summary in generalised form.

The conclusions reached in the independent but related Chapters 2-6 complement each other. They all have been submitted to academic journals for publication. Chapters 2, 4 and 6 have been accepted for publication by "Precambrian Research" (August 7, 1985); Chapter 3 has been submitted to "Palaeontographica (Section B)"; Chapter 5 has been accepted by "Alcheringa" (April 18, 1985). In accordance with the "Guidelines" of the University, these chapters in press are reorganized here for the presentation of the thesis, with changes in their figure and page numbers; however, the text of each chapter is substantially unchanged.

* Chapter 3 now has been accepted for publication by "Palaeontographica (Section B)" (December 8, 1985).



CHAPTER 1

SUBDIVISIONS AND CORRELATIONS OF THE UPPER PRECAMBRIAN IN CHINA AND AUSTRALIA : A BRIEF REVIEW

China and Australia are both famous for their widespread distribution of Late Precambrian sediments and a relatively long history of extensive and detailed studies. For generations, numerous investigators in both countries have increased our knowledge about the evolutionary history of the Earth during the Late Precambrian time. Stratigraphers have encountered enormous difficulties in correlating Late Precambrian sequences due to the rarity of diagnostic fossils. However, achievements made through intensive multidisciplinary studies during the last two decades have provided a new basis on which generalized interregional and even intercontinental Late Precambrian correlations have become possible.

BRIEF HISTORY OF STRATIGRAPHIC SUBDIVISION AND CLASSIFICATION OF THE UPPER PRECAMBRIAN ("SINIAN") IN CHINA.

The term "Sinian" was originally used in a stratigraphic sense by F. von Richthofen in 1882 (see Grabau, 1922). He referred the widespread Late Precambrian unmetamorphosed sediments in China, together with the Cambrian, to the "Sinische Formationsreihe".

Grabau (1922), the Chief Palaeontologist of the Geological Survey of China, defined the "Sinian System" as a sequence of unmetamorphosed or slightly metamorphosed sediments bracketed between the metamorphosed older rocks or basement and the trilobite-bearing Cambrian System. In this definition, all Late Precambrian supracrustal deposits were referred to his "Sinian System". During the first half of this century, most

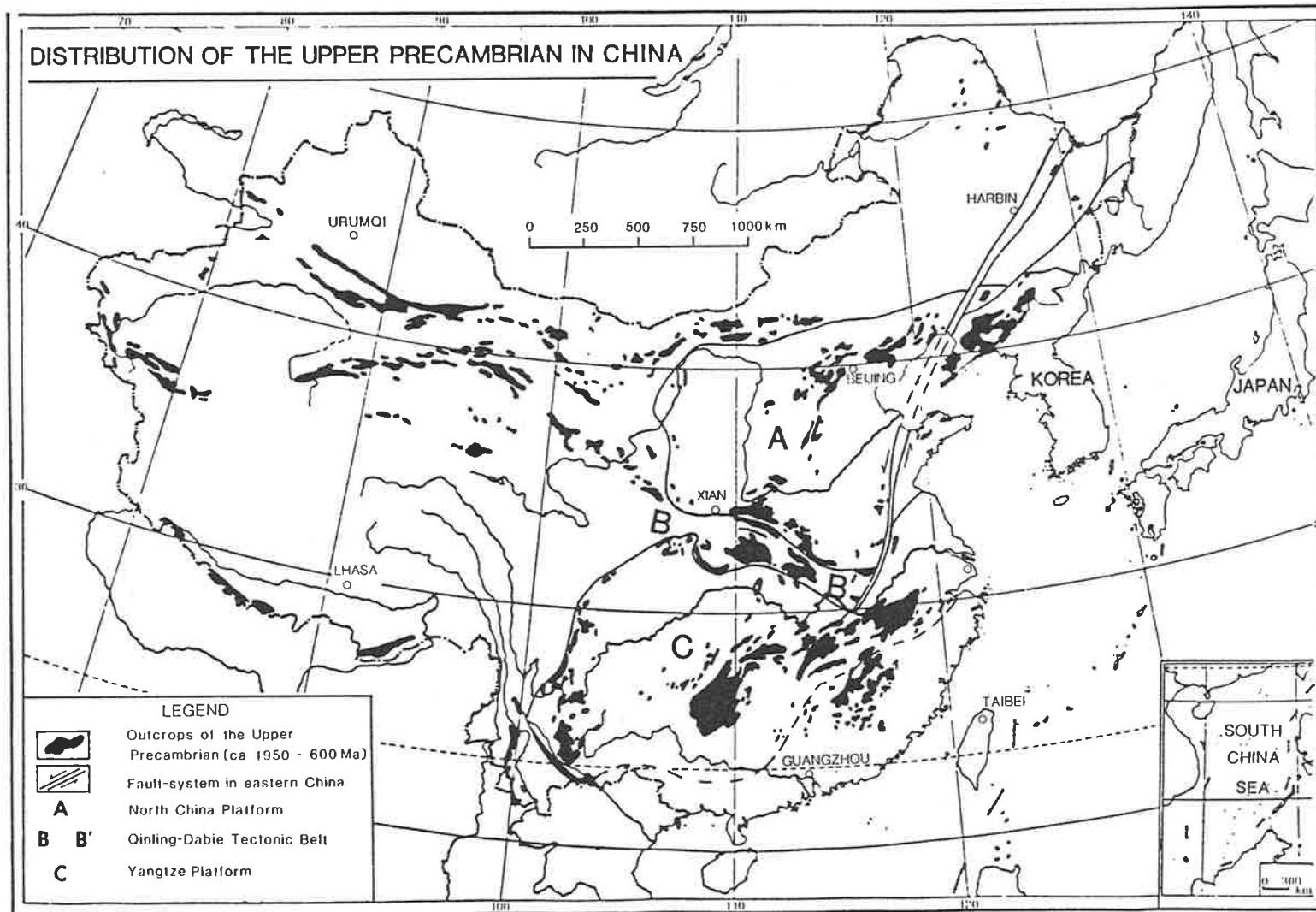


Fig. 1. Distribution of the Upper Precambrian in China. Note: The distribution of the outcrops is mapped after Wang Yuelun *et al.*, (1980); the term "Yangtze Platform" is used in its broad sense (modified from Huang Jiqing (Ed.), 1977, fig. 1); the Precambrian rocks in the Qinling-Dabie Tectonic Belt are metamorphosed.

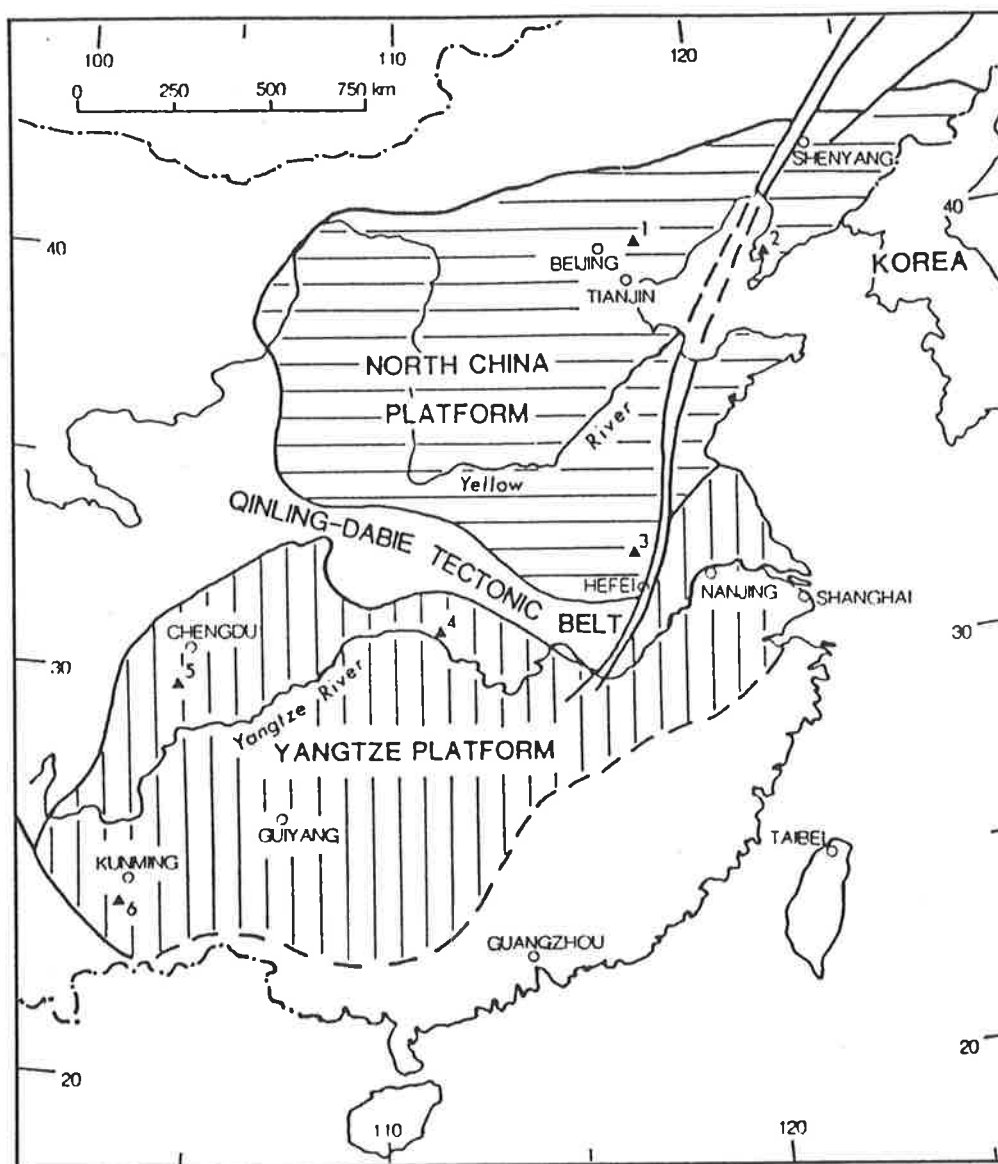


Fig. 2. Map showing regional tectonic settings and the geographic location of stratotype and reference sections in the districts of 1. Jixian (Tianjin), 2. Fuxian (Liaoning), 3. Huainan (Anhui) on the North China Platform, 4. E. Yangtze Gorge (Hubei), 5. Mt. Emei (Sichuan) and 6. E. Yunnan on the Yangtze Platform (in its broad sense).

		Ma
Palaeozoic	Cambrian System	
	600 ± 10	
Proterozoic	Upper	Sinian System
		800 ±
	Middle	Qingbaikou System
		1000 ±
		Jixian System
		1400 ± 50
	Lower	Changcheng System
		1900 ± 50
Archaean	Longquanguan Group	2500 ± 100
	Fuping Group and older	2800 ± 100

Fig. 3. "Precambrian time scale of China" recommended by the Geological Society of China (from Huang Jiqing, 1983, table 1), for discussion.

Fig. 4. LATE PRECAMBRIAN STRATIGRAPHIC SCALES OF CHINA

CHRONOSTATIGRAPHIC			LITHOSTRATIGRAPHIC (COMPOSITE)	AGE (Ma)
PALAEOZOIC		Cambrian System	Qiongzhusi Fm.	
PRECAMBRIAN	UPPER PROTEROZOIC	Xiadongian System	Xiadong Group	ca.600
			Nantuo Tillite	ca.700
	Qingbaikouan System	Feishui Group	ca.850	
		Qingbaikou Group	ca.1000	
	MIDDLE PROTEROZOIC	Jixianian System	Jixian Group	ca.1400
		Changchengian System	Changcheng Group	ca.1950
LOWER PROTEROZOIC & ARCHEAN			Qianxi Group	

geologists assumed a rather short time interval from the consolidation of the basement to the beginning of the Cambrian Period; Grabau also regarded that one system would be enough for that interval. Considering the lithological similarities between the "Sinian" and Cambrian, Grabau referred the "Sinian System" to the Lower Palaeozoic, with its age inferred to precede that of trilobite-bearing sediments.

Lee and Chao in 1924 established the first stratigraphic section of the "Sinian System" at the E. Yangtze Gorge on the Yangtze Platform (Fig. 2, Loc. 4). Ten years later, Kao et al. (1934) established another "Sinian" stratigraphic section at Jixian near Beijing (Peking), on the North China Platform (Fig. 2, Loc. 1). As the Jixian section is located in the classical region of Grabau's definition, it was traditionally regarded as the "standard section of the Sinian System" (Lee, 1939, p. 71). Establishment of two type sections was necessary for the subdivisions and correlations of the Upper Precambrian in northern and southern China respectively, because of conspicuous differences in many aspects of geology between the two regions. However, following Grabau's definition, the two type sections were both regarded as constituting the "Sinian System" and correlated with each other for many years.

A dramatic change occurred when the results of isotopic dating became available in the early 1960's. Wang Yuelun and Lu Zhongbin (1962) analysed the first set of newly obtained data and found that Sinian time was much longer than had been thought and that the whole E. Yangtze Gorge section could be younger than the Jixian section. This idea was later confirmed (Zhong Fudao, 1977) and gradually accepted by most Chinese geologists.

After a Symposium on the Precambrian of China in Beijing during 1975, it was proposed to refer all the "Sinian" strata to a new "Sinian

Suberathem" as part of the Proterozoic, to retain the E. Yangtze Gorge section as the stratotype for the revised "Sinian System" (younger than 800 Ma), and to rank the three major groups of the Jixian section (ca. 1950-850 Ma, Zhong Fudao, 1977) as three older successive "Systems" (Changcheng, Jixian and Qingbaikou). This proposal was adopted for the 1976 Geological Map of China. The term "Sinian Suberathem" appeared in many publications between 1976 and 1982, but this usage was strongly rejected by many other geologists because the term "Sinian" should not have been used for both a "System" and a "Suberathem" (Wang Yuelun et al., 1980). In 1982, the All-China Committee of Stratigraphy and the Geological Society of China decided to abandon the term "Sinian Suberathem" and recommended a new Precambrian Time Scale for China (Fig. 3).

COMMENTS ON THE LATE PRECAMBRIAN STRATIGRAPHIC SCALES OF CHINA

The Late Precambrian time scale recommended by the Geological Society of China (Fig. 3) has been provisionally adopted with reservation in Chapters 2, 3 and 6, which were completed earlier and are now in press.

The recommended scale presents two problems, which need comment. The first concerns the redefined "Sinian System" and the second relates to the Upper Precambrian correlation between northern and southern China. Both historical problems can now be clarified to a certain degree (Figs. 4, 10).

1. The redefined Sinian System.

As already reviewed, since 1975 the E. Yangtze Gorge section has been designated as the stratotype of the "Sinian System" while the Jixian section has been subdivided into three older systems. It is generally agreed that subdivision of Grabau's "Sinian System" is appropriate because it is far too big for a system, ranging for more than 1300

million years prior to the Cambrian System and consisting of both Upper and Middle Proterozoic as generally known (Figs. 3, 4). To retain the E. Yangtze Gorge section as the stratotype for the Sinian System seems supported by the first establishment of a "Sinian" stratigraphic section (Lee and Chao, 1924) of appropriate age and duration (younger than ca. 800 Ma and older than Cambrian). However, this procedure is in conflict with the fact that the Jixian section (Kao et al, 1934) is located in the classical region (Grabau, 1922) long regarded as the "standard section of the Sinian System" (Lee, 1939). The recent designation of a new stratotype (the E. Yangtze Gorge section) resulted in the embarrassing situation that the "Sinian System" would be missing in the classical region and the traditionally accepted standard section.

According to the International Stratigraphic Guide (I.S.G., Hedberg 1976, p. 20), "When a unit is divided into two or more units, the original name should not be employed for any of the subdivisions. The retention of the old name for one of the subdivisions would not only risk confusion but would also preclude use of the name in a term of higher rank". This principle should be respected, and thus subdivision of the "Sinian System" of Grabau (1922) agrees with the International Stratigraphic Guide. However, retaining the formal term "Sinian System" for the E. Yangtze Gorge section alone (Fig. 3) is inappropriate. The rejection of the term "Sinian Suberathem" by the Geological Society of China in 1982 refuted the very concept that Grabau (1922) established for his Sinian System, namely the unmetamorphosed cover sequences of China below the fossiliferous Cambrian. For this reason the informal usage of "Sinian strata" is employed in Fig. 4 in this thesis.

In the past, a few attempts have been made to describe the E. Yangtze Gorge stratotype as representing an independent major unit. Wang Yuelun (1963) named the whole section the "Shanxia System" ("Three Gorges", in Chinese) and referred it to the "Eocambrian"; Zhong Fudao (1977) named

the sequence from the base of the Nantuo Tillite to the base of the Cambrian System to be the Xiadong Group (E. Yangtze Gorge, in Chinese) and referred it to the Lower Palaeozoic; Lu Yanhao (1975, but formally published in 1979) defined the sequence of the Xiadong Group as the Xiadong System because the term "Shanxia" had been preoccupied and referred it to the Phanerozoic. These suggestions have not yet received sufficient attention by the majority, but they may prove to be of potential value.

The alternative present suggestion (Fig. 4) is to maintain Grabau's original definition by using a general term, the "Sinian strata" (informal chronostratigraphic unit, see Hedberg, 1976, pp. 75-6) and to leave a chance for its possible formalization in future. Accordingly, the lithostratigraphic "Xiadong Group" and the chronostratigraphic "Xiadongian System" should be introduced into the Late Precambrian stratigraphic scales of China and at present place them in the uppermost Proterozoic (see below, "Problems of establishing a terminal Precambrian System"). The advantages of this suggestion are to save the scientific value of the previously published literature, particularly those works published before 1975; to remove the confusions from this field; and more importantly to emphasize the point of that the widespread occurrence of supracrustal sedimentation during the Proterozoic time is a prominent characteristic of the geology in China (compare Richthofen, 1882; Grabau, 1922; Lee, 1939; Wang Yuelun et al., 1980).

2. Correlations between northern and southern China

In the recommended scale (Fig. 3), the "Sinian System" whose stratotype is in the E. Yangtze Gorge section is placed immediately on the top of the "Qingbaikou System" whose stratotype is in the upper Jixian section. This proposal has been adopted in most publications

since 1976 when the Geological Map of China was published and the Sinian "Suberathem" was first divided into four systems (Wang Yuelun et al., 1980; Chen Jinbiao et al., 1981, table 1; see Chen Jinbiao, 1985).

The weathered top of the Qingbaikou Group is about 850 Ma old and the base (Liantuo Formation) of the E. Yangtze Gorge section is somewhat younger than 800 Ma (Zhong Fudao, 1977; Wang Yuelun et al., 1980; etc.).

Researchers of geochronology (Zhong Fudao, 1977) and stromatolite biostratigraphy (Zhu Shixing, 1982) suggested that there could be a considerable time break between the two stratotypes and proposed that a third reference section might be established in Northeast China, particularly in the Fuxian district, southern Liaoning Province (Fig. 2, Loc. 2) to cover the missing time interval. However, their suggestions needed to be proved because no appropriate datings have been obtained from that region (due to slight metamorphism) and the stromatolite assemblages have not yet provided sufficient evidence for the required solution.

This problem was further complicated when misidentified Cyclomedusa and other medusoids were reported from the Liaodong Peninsular in southern Liaoning Province by Xing Yusheng and Liu Guizhi (1979). The supposed "Liaodong metazoan assemblage" was used as evidence by many geologists to extend the correlation of the latest Precambrian (younger than the about 700 Ma old Nantuo Tillite) from the Yangtze Platform to the North China Platform (Xing Yusheng 1976; 1984; Wang Yuelun et al., 1980; Chen Jinbiao et al., 1981, p. 219).

As already reviewed, correlations of the Upper Precambrian between northern and southern China have long been known to be difficult because of tectonic separation and stratigraphic discontinuity. The

Qinling-Dabie Tectonic Belt separates the North China Platform from the Yangtze Platform (Fig. 2). This belt had undergone many phases of intense tectonic movement and metamorphism prior to the Mesozoic. Once regarded as a plate collision zone (Sun Weiguo, Seminar on the Late Precambrian of China, Sep. 30, 1981. Adelaide University), this "Belt" is now interpreted as being "composed of two opposite continental marginal tracts belonging respectively to the North China and the Yangzi (Yangtze) platforms, which are brought to mutual collision after the Indosinian (Mesozoic) orogenic movement" (Wang Hongzhen et al., 1982, p. 280). The two individual platforms may have been far from each other during the Precambrian time. As shown in Fig. 10, sedimentation of the North China Platform cover began more than 1000 Ma earlier than that covering the Yangtze Platform, while the break between the top of the Jixian section and the overlying Cambrian represents a time range longer than the duration of the whole E. Yangtze Gorge Precambrian cover.

However, the historical problem of correlation of the Upper Precambrian between the North China Platform and the Yangtze Platform can now be solved to a certain degree by establishing a third reference type section in the Huainan district on the southern margin of the North China Platform (Fig. 2, Loc. 3).

As shown in Fig. 10 and discussed in detail in Chapter 2, the Huainan and Feishui Groups in the Huainan district consist of a continuously deposited shallow marine sequence which is bracketed within a time range between 900-700 Ma. The Huainan Group can be compared with the Jingeryu Formation of the Qingbaikou Group within the top of the Jixian section, and the Xihe Group in the Fuxian section (see Fig. 14 in Chapter 2). This correlation is based on similar lithostratigraphic characters, radiometric datings and more importantly the common occurrence of the

macrofossil Chuaria (see Fig. 16 in Chapter 3). The strata represented by the type Jingeryu Formation are widespread over the North China Platform. Above this level, the Feishui Group in the Huainan district can be closely compared with the Wuhangshan Group in the Fuxian district of southern Liaoning based on the stratigraphic position, similar sedimentary characters and stromatolite assemblages and a distinctive assemblage of macroscopic worm-like fossils (Chapter 2). The Chuaria-Tawuia macroscopic fossil assemblage found in the Huainan district (Zhen Wenwu, 1980; Duan Chenhua, 1981) suggests a possible correlation between the sequence of the Huainan and Feishui Groups on the North China Platform and the Little Dal Group (top major unit of the Belt Supergroup equivalent) in the Mackenzie Mountains of northwestern Canada (Hofmann and Aitken, 1979). The Chuaria-Tawuia macrofossil assemblage has proved to be an important biostratigraphic index for the Late Riphean, about 1000-700 Ma ago (Chapter 3).

The top of the Feishui Group is weathered and disconformably covered by the glaciogene diamictites and conglomerates of the Fengtai Formation, which can be traced westwards into the Luoquan Tillite, which is distributed widely along the southern margin of the North China Platform. The correlation between the Luoquan Tillite and the Nantuo Tillite on the Yangtze Platform is possible but disputable (Chapter 2). The Luoquan Tillite and its equivalents are disconformably overlain by the Lower Cambrian (see Fig. 10).

On the North China Platform, all the known Precambrian rock sequences, except the Luoquan Tillite and its equivalents, are older than the about 700 Ma old Nantuo Tillite (Chapters 2, 3). Moreover, in the Huaibei district, a tectonically separate region to the north of the Huainan district in Anhui and in the Jinxian district, a tectonically separate region to the south of the Fuxian district in Liaoning, there

are Late Precambrian sequences (Xuhuai or Jinxian Group) which are probably younger (or partially younger, according to my brief observation) than the Feishui or Wuhangshan Group. They are still believed to be older than the time level of the Nantuo Tillite (Yang Qinghe et al., 1980; Chang Shaoquan, 1980; Cao Ruiji et al., 1985). There are no Precambrian tillites in southern Liaoning, but in adjacent districts of North Korea a comparable sequence is disconformably separated by the Pirandon glaciogenic diamictites which may be compared with the Luoquan Tillite (Chumakov, 1981; Chapter 4).

All of the palaeontological evidence ("Liaodong metazoan assemblage") which was once used for a supposed occurrence of the Xiadong Group equivalents on the North China Platform has been denied or reinterpreted ("Sabellidites", etc.) after recent investigations (Chapters 2-4).

On the Yangtze Platform, the Liantuo Formation and its equivalents disconformably underlie the Nantuo Tillite and generally consist of intermontaine basinal, fluvial and/or molasse-like, terrestrial deposits. As a marker of the beginning of platform sedimentation, the Liantuo Formation and its equivalents are widespread on the Yangtze Platform and unconformably cover either the moderately metamorphosed rocks or widely distributed granite bodies, which intruded some 800 Ma ago. The time range of the Liantuo Formation is therefore broadly bracketed between 800-700 Ma, and thus perhaps partially overlaps the time range of the Feishui Group on the North China Platform.

The Liantuo Formation is difficult to correlate with other units outside the Yangtze Platform because of its terrestrial origin and lack of fossils; while the Feishui Group together with the preceding Huainan Group can be correlated not only on the North China Platform but also with the sequences distributed in northwestern Canada, central India

and Svalbard based on the common occurrence of the distinctive marine Chuarina-Tawuia macrofossil assemblage (see Chapter 3).

The author has no hesitation in introducing the Huainan Group into the Late Precambrian lithostratigraphic scale of China (Fig. 4); however, whether a new "System" should be accordingly established between the Qinghaikouan and the Xiadongian System in the chronostratigraphic scale is uncertain. That is the reason why this problem was not discussed earlier in the previously finished Chapters (2, 3 and 6). The lithostratigraphic boundaries are, as now shown by some radiometric datings, diachronous from one district (Jixian) to other districts (Huainan and others) on the large North China Platform. A new System, supposedly the "Feishuiian", can not be defined with a proper chronostratigraphic lower boundary at present. Extension of the upper time limit of the Qingbaikouan System from the 850Ma time level (the top of the Qingbaikou Group in the stratotype of the Jixian section) to the 700 Ma time level (the base of the Xiadong Group in the stratotype of the E. Yangtze Gorge section) seems appropriate. However, if the boundary of the Xiadongian System is defined at the base of the Nantuo Tillite, it should be regarded as the upper boundary of the older (lower) adjacent chronostratigraphic unit - the Qingbaikouan System, thus avoiding difficulties in time-correlation which might leave gaps or overlaps between types (see Hedberg, 1976, p. 28, 83-6).

The separation of the North China Platform from the Yangtze Platform by the Qinling - Dabie Tectonic Belt makes it difficult if not impossible to demonstrate the relationship between the Jixian and E. Yangtze gorge stratotype sections. The Huainan section can now be used to solve this problem to a certain degree, even if the Luoquan Tillite can not be compared with the Nantuo Tillite, but further field and laboratory studies are required.

STRATIGRAPHIC SUBDIVISION AND CLASSIFICATION OF THE UPPER PRECAMBRIAN
(ADELAIDEAN) IN AUSTRALIA

The Adelaide "Geosyncline", consisting of the Adelaide region (Mt. Lofty Ranges) in its southern portion and the Flinders Ranges in its northern portion, is a large depositional basin of thick Late Precambrian and Cambrian rock sequences, which were folded during the Cambrian-Ordovician Delamerian Orogeny (Thomson, 1969). The regional type sections established in the Adelaide "Geosyncline" have provided the basis for the standard subdivision and interbasinal correlations of the widespread Late Precambrian (Adelaidean) deposits in Australia (see Preiss and Forbes, 1981; Plumb, 1985).

The term "Adelaide series" was first used in a stratigraphic sense by David in 1922 when he referred the sedimentary sequence between the crystalline basement and fossiliferous Cambrian in the Adelaide region.

In 1950, Mawson and Sprigg reclassified that sequence and defined the "Adelaide System" as a Proterozoic unfossiliferous (except for stromatolites) succession above the basement and below the fossiliferous Cambrian. Based on the classical type sections in the neighbourhood of Adelaide, Mawson and Sprigg divided the Adelaide System into three "Series": in ascending order, the Torrensian, Sturtian and Marinoan. Sprigg (1952) later added to the Adelaide System a pre-Torrensian unit, the Willouran Series, which was described from a sequence found in the northern Flinders Ranges.

Mawson and Sprigg (1950) referred the Pound Sandstone (or Quartzite) in the Flinders Ranges to the basal Cambrian. Following Chadwick's "Cryptozoic-Phanerozoic" concept they took the occurrence of the metazoan fossils found in the Pound Quartzite in the Ediacara hills, northern

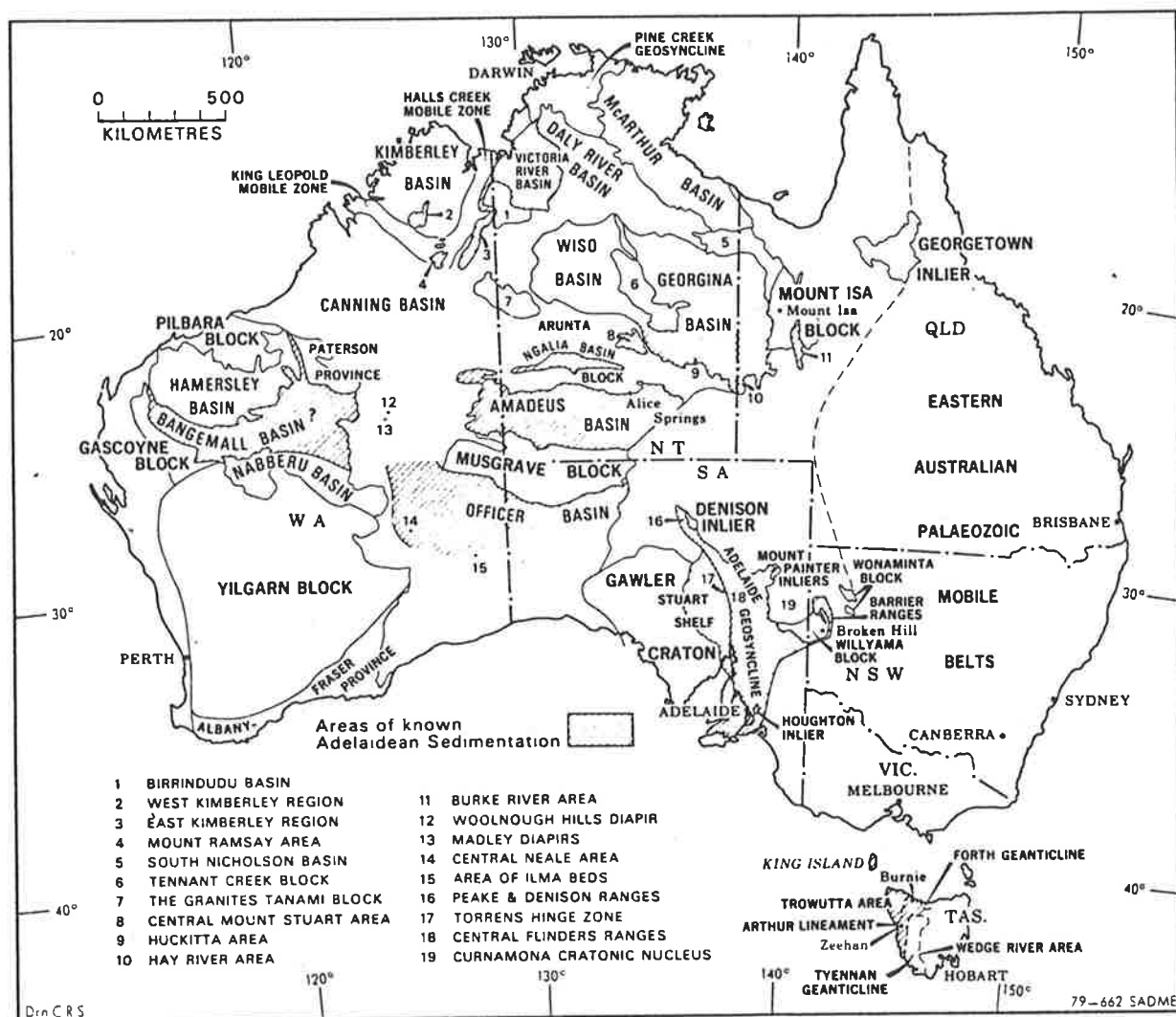


Fig. 5. Location of major Precambrian sedimentary basins, basement blocks and provinces in Australia, showing those basins that received Adelaidean sedimentation (after Preiss and Forbes, 1981).

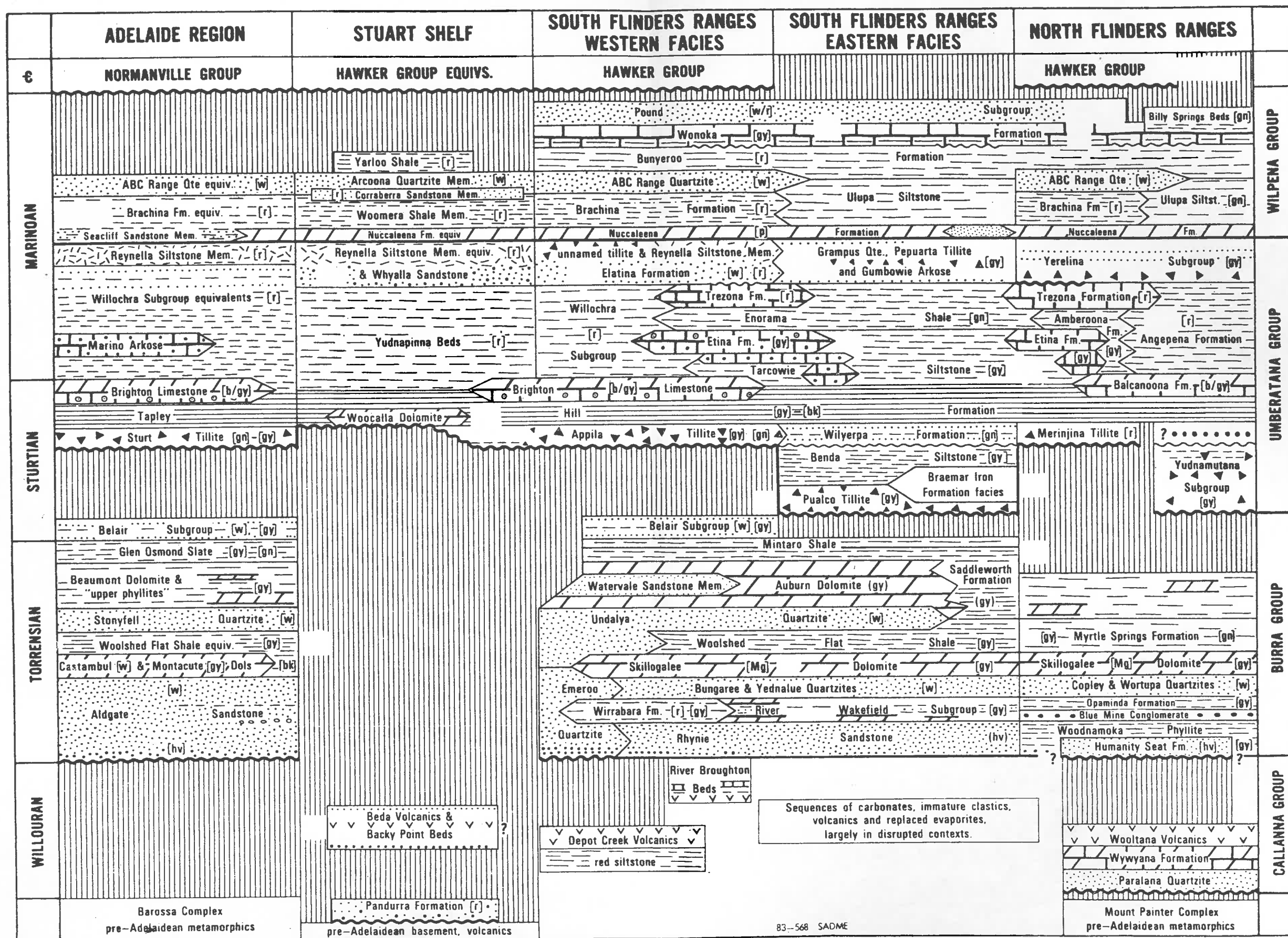


Fig. 6. Stratigraphic subdivision and correlation of the Upper Precambrian (Adelaidean) in the Adelaide Geosyncline (recommended by the Geological Survey of South Australia, 1983).

Fig. 7. **LATE PRECAMBRIAN
STRATIGRAPHIC SCALES OF AUSTRALIA**

CHRONOSTRATI- GRAPHIC			LITHOSTRATIGRAPHIC (COMPOSITE)		AGE (Ma)
CAMBRIAN SYSTEM			Uratanna Formation		
UPPER PROTEROZOIC	ADELAIDEAN	Marinoan	ADELAIDEAN	Wilpena Group	
	ADELAIDEAN	Sturtian		Umberatana Group	ca.680
				Marinoan tillites	ca.700
				interglacial sediments	ca.750
UPPER PROTEROZOIC	ADELAIDEAN	Torrensian		Sturtian tillites	ca.800
				Burra Group	ca.850
		Willouran		Callanna Beds	ca.1100

Flinders Ranges (Sprigg, 1947, 1949) as evidence for earliest Cambrian age. Glaessner and Daily (1959) concluded that the Ediacara fauna is distinct from all Cambrian metazoan assemblages and that the weathered top of the Pound Quartzite in the Flinders Ranges provides the base for the local Cambrian sediments (see Daily, 1973).

Daily (1963) regarded that the "Adelaide System" and its component "Series" were essentially lithostratigraphic rather than chronostratigraphic units and proposed that the correct lithostratigraphic terms, e.g. "Supergroup" and "Groups", be substituted. His suggestions, however, were not accepted by the Geological Survey of South Australia.

With rapid expansion of geological surveying and mapping over most major regions of the Adelaide Geosyncline, Thomson et al. (1964) proposed an independent lithostratigraphic subdivision for the "Adelaide System" on the basis of a more completely preserved, much thicker, composite stratigraphic sequence in the Flinders Ranges. They divided the "Adelaide System" into four major units, including the Callanna Beds at the base and the successive Burra Group, Umberatana Group and Wilpena Group. Meanwhile, the terms and definitions of the classical "Series" (Mawson and Sprigg, 1950; Sprigg 1952) were retained in a chronostratigraphic sense. The boundaries of the series are difficult to recognize outside the type region because of facies changes. Therefore, the lithostratigraphic subdivisions have proved to be useful, particularly for mapping. The Umberatana Group was defined with the Sturtian tillites in its lower part, a very thick sequence of interglacial deposits in its middle part and the Marinoan tillites or equivalent glaciogene deposits in its upper part. The rock sequence that is immediately below the Sturtian tillites (the lower tillites) can be

easily recognized as belonging to the Burra Group; while the rock sequence that grades upwards from the Marinoan tillites (the upper tillites) belonging to the Wilpena Group. Correlation of the widespread Sturtian and Marinoan glaciogene deposits extends the importance of this lithostratigraphic scheme over the whole Adelaide Geosyncline and to many other basins in Australia (see Preiss and Forbes, 1981, Figs. 3a-b).

The boundaries of chronostratigraphic and lithostratigraphic subdivisions have been placed at different levels (see Figs. 6, 7) and the time ranges of the chronostratigraphic subdivisions are not yet sufficiently well known.

Following Dunn et al (1966), "Adelaidean" has been widely used in preference to "Adelaide" for the System. The lower time limit of the Adelaidean System was once estimated to be about ca. 1400 Ma (Thomson, 1966) but more recent data suggest an age of ca. 1100 Ma for the beginning of Adelaidean sedimentation as represented in the Flinders Ranges (Preiss and Forbes, 1981).

At the Symposium on the Adelaide Geosyncline (Geological Society of Australia, Adelaide, 1983), the Geological Survey of South Australia presented a chart of subdivision and correlation of the Adelaidean System in the Adelaide Geosyncline. It is reproduced here in Fig. 6. The primary chronostratigraphic and lithostratigraphic subdivisions of the Adelaidean System are generalized in Fig. 7. According to Preiss and Forbes (1981), the time ranges of the four lithostratigraphic groups can be estimated as shown in Fig. 7.

When the Chinese geologists (1976 Geological Map of China) restricted the "Sinian System" to the stratotype of the E. Yangtze Gorge section, it was regarded that the "lesser Sinian", ranging from ca. 800 to the beginning of the Cambrian Period, could be accepted as a standard systemic unit in the chronostratigraphic scale (Xing Yusheng, 1976, 1984; see Harland et al., 1982).

A similar campaign has also been proceeding in the USSR for the Vendian (see Harland et al., 1982; Sokolov and Fedonkin, 1984).

Jenkins (1981) and Cloud and Glaessner (1982) respectively suggested the establishment of an Ediacaran or Ediacarian System to characterize an important evolutionary stage of the latest Precambrian animal life. Both Ediacaran and Ediacarian refer to separate stratotypes in the Bunyeroo Gorge, Flinders Ranges (Fig. 8). Jenkins (1981) defined the lower boundary of the Ediacaran System at the base of the Wonoka Formation in the middle of the Wilpena Group. Cloud and Glaessner (1982) defined the lower boundary of the Ediacarian System at the base of the Wilpena Group, i.e. the top of the Marinoan tillites.

Harland et al. (1982) ranked the redefined "Sinian" as the terminal Proterozoic Era, the Vendian as the terminal Proterozoic Period, and the Ediacaran as a terminal Proterozoic Epoch post-dating the Varangian Epoch (Fig. 9). In that scheme, the Ediacaran Epoch is of equal length to Cloud and Glaessner's Ediacarian Period.

Cloud (1984) suggests the extension of the lower Phanerozoic and Palaeozoic boundary downwards to the base of the Ediacarian System on account of the "Phanerozoic" characters of the Ediacara-type soft-bodied

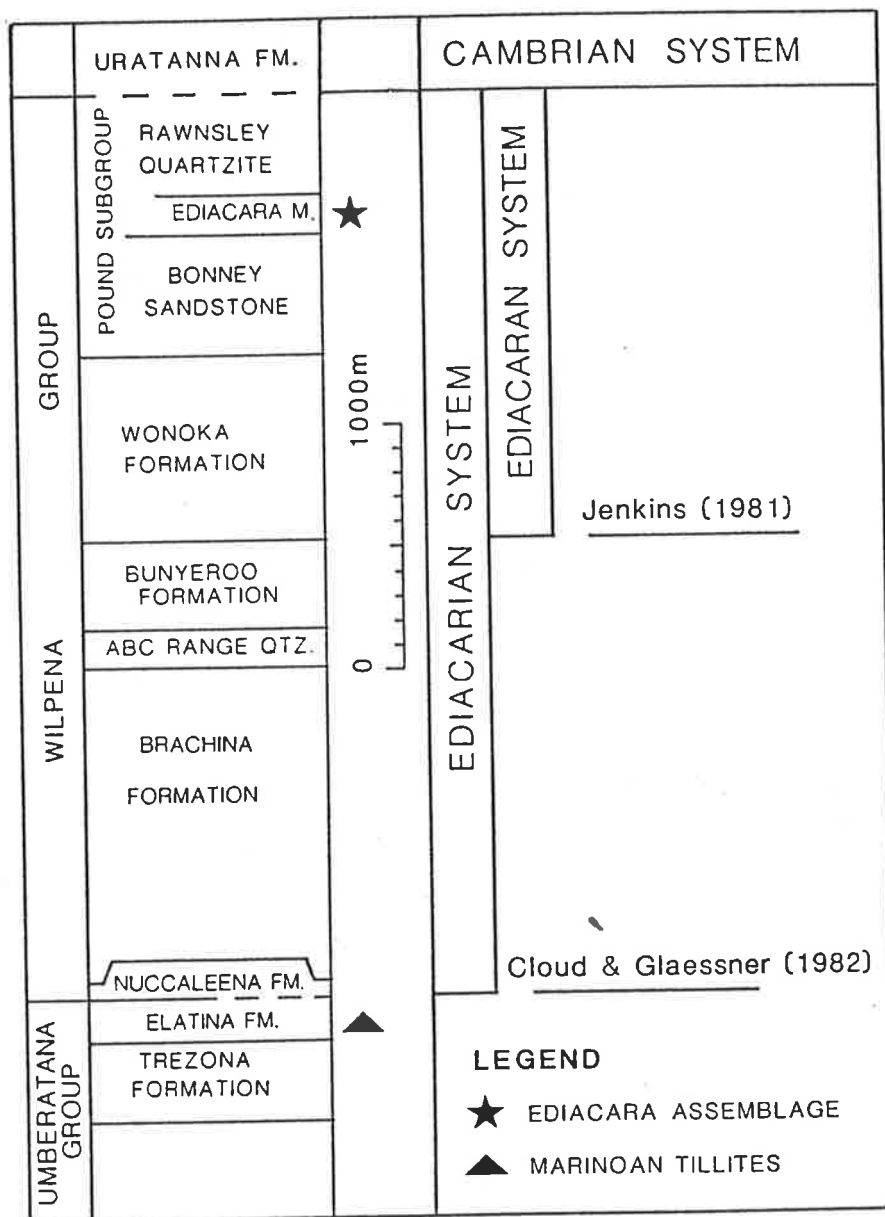


Fig. 8. Difference in stratigraphic scope between the Ediacaran System of Jenkins (1981) and the Ediacarian System of Cloud and Glaessner (1982).

Eon	Era	Period Epoch (Some possibilities)		Ma
Phanerozoic (Ph)	Paleozoic (Pz)	Cambrian (E)	Caerfai (CrI)	~ 590
Proterozoic	Pt ₃	Sinian (Z)	Vendian (V)	~ 670
			Sturtian (U)	~ 800
	Pt ₂	Riphean (R)	"R ₃ "	
			R ₂ Yurmatin (Y)	
			R ₁ Burzyan (B)	
	Pt ₁			2100
	(Pt)		Huronian (H)	2400
	Ar ₃		Randian (Ra)	2630
	(?) 2900			2800
Archean	Ar ₂	Swazian		3060
	(?) 3500			
	Ar ₁	Sw	Isuan (I)	3800
	(Ar)			
Priscoan (Pr)		Harlean (Hc)		

Fig. 9. "Precambrian time scales" quoted from Harland et al., (1982) for discussion.

metazoans. Similar opinions have been expressed proposing assignment of the Vendian and the "Sinian" (E. Yangtze Gorge section) to the Palaeozoic.

Glaessner agrees with Cloud interpreting from the viewpoint of evolution of life that Ediacarian time is a transitional interval from the Proterozoic to the Phanerozoic but maintains the Ediacarian Period in the Vendian Era at the end of the Late Proterozoic (Precambrian Supereon) of the standard stratigraphic scale (Glaessner 1984 a, table 4; 1984b "Geochronostratic scale of the Precambrian-Cambrian transition"; 1985).

Chadwick's "Cryptozoic-Phanerozoic" concept has become obsolete in stratigraphy. The definitions of Proterozoic and Archeozoic, or Archean, have never been clarified properly (Hedberg, 1976). The currently accepted time range for the Proterozoic, 2500-570 Ma as recommended by the IUGS Subcommissions on the Precambrian Stratigraphy, is known to be much longer than the Precambrian evolutionary history of animal life (since ca. 1000 Ma ago, as inferred by Glaessner, 1983) and even than the earliest evolution of eucaryotic life (as old as 1500-1300 Ma ago, as regarded by Schopf and Oehler, 1976; Cloud, 1983). Moreover, at the present stage of knowledge, assignment of Ediacarian, Vendian, "Sinian" (Xiadongian), etc. to the Palaeozoic will result in a situation that the Varangian glaciation will be used for defining the base of the Palaeozoic; it may result in more difficulties and problems than presently encountered in choosing a proper stratotype and point for the lower boundary of the Cambrian System. It is not envisaged by the Working Group on the Precambrian-Cambrian Boundary of the International Stratigraphic Commissions.

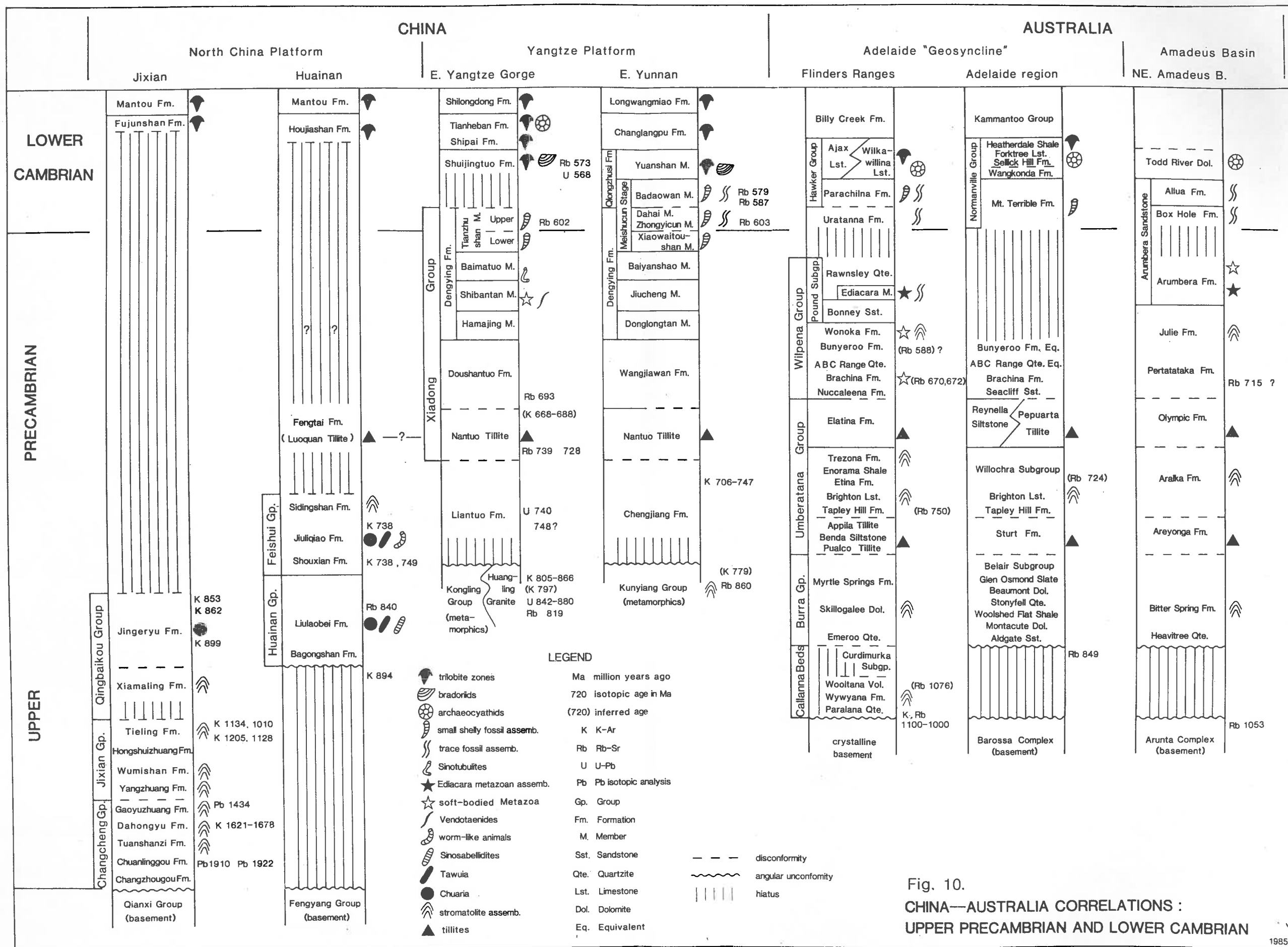
The chronostratigraphic and lithostratigraphic subdivisions of the Upper Precambrian in China and Australia recommended by national geological societies are still regional stratigraphic scales (Figs. 3, 4,

6, 7). The lithostratigraphic scale is suitable for the type regions of the component units but may or may not be suitable for other regions. The chronostratigraphic scale facilitates national (regional) stratigraphic and time correlations. According to the International Stratigraphic Guide (Hedberg, 1976, pp. 81-2), regional chronostratigraphic scales will probably always be needed; "It is better to refer strata with accuracy to local or regional units rather than to strain beyond the current limits of time-correlation in assigning these strata to units of a global scale"; "Local chronozones of whatever rank, defined by boundary-stratotypes, will furnish units useful for local Precambrian history regardless of any worldwide scheme. They will also constitute the best possible foundation for regional, continental and worldwide units if, as, and when these can be established with reasonable assurance". Nevertheless, a Global Standard Precambrian Chronostratigraphic Scale has not yet been recommended by the relevant committees of the International Union of Geological Sciences.

CORRELATIONS OF THE UPPER PRECAMBRIAN IN CHINA AND AUSTRALIA

Stratigraphic correlations are considered to be the only route through which knowledge about the geologic record in individual regions can contribute to the understanding of the general evolutionary history of the Earth. This means that correlations should start with objective investigations in the appropriate regions and then, following an integrational analysis of data, reach an interpretation of the possible time relationships of the relevant stratigraphic sequences. As regional investigations continue, all the previously obtained interpretations tend to be confirmed or revised.

During the early preparation of this thesis, a number of Upper Precambrian (Proterozoic) Lower Cambrian sedimentary sequences in the



selected key regions of China and Australia were examined unit by unit in the field. Among them, the most important ones include the Jixian and Huainan sections on the North China Platform (Fig. 2), the E. Yangtze Gorge section and sections (Meishucun and Wangjiawan, etc.) in eastern Yunnan Province on the Yangtze Platform (Fig. 2), the sections in the Flinders Ranges and Adelaide region in the Adelaide Geosyncline, South Australia (Fig. 5) and the sections in the northeastern portion of the Amadeus Basin in central Australia (Fig. 5). They provide ideal examples for the correlations of the Upper Precambrian in China and Australia (Fig. 10).

Except for the Huainan section (see Chapter 2), all the other sections have already proved to be of global significance. References concerning the description, current subdivision and nomenclature of these sections are: Wang Yuelun et al. (1980) and Chen Jinbiao et al. (1980; 1981) on the Jixian section; Zhao Zhiqiang et al. (1980), Cowie (1985) and Sun Weiguo (Chapter 6) on the E. Yangtze Gorge section; Cao Renguan et al. (1980), Xing Yusheng and Luo Huilin (1984) and Cowie (1985) on the Upper Precambrian and the Precambrian - Cambrian boundary stratotype in the sections of E. Yunnan; Chang Wentang (1980) on the Lower Cambrian of China; Preiss and Forbes (1981) on the three selected Australian sections; Jenkins (1984) on the Wilpena Group in the Flinders Ranges; Daily (1972, 1976 a, b) and Cloud and Glaessner (1982) on the Lower Cambrian and the Precambrian-Cambrian boundary in Australia.

On the basis of previous work and recent investigation, the stratigraphic columns in Fig. 10 are furnished with biostratigraphic, chronometric and lithostratigraphic (tillites) indices for interpretation, and the relative horizontal positions of the adjacent columns are arranged in consideration of their possible time-correlation.

In China, the Changcheng and Jixian Groups (ca. 1950-1000 Ma) are mostly confined to the central portion of the North China Platform, outside which sequences of this time range are either missing or metamorphosed.

In Australia, the distribution of the Callanna Beds is limited to several isolated localities in the northern Adelaide Geosyncline. The Callanna Beds are invariably disrupted by local tectonics; their stratigraphic order is uncertain in its type area (the Willowran Ranges) and elsewhere (Forbes et al. 1982, p. 39).

Therefore, the correlations of the Upper Precambrian between China and Australia will only be discussed in relation to the Upper Proterozoic (less than 1000 Ma old).

A. 1000-700 Ma.

Data of geochronology, (Zhong Fudao, 1977; Chen Jibiao et al., 1980), stromatolite biostratigraphy (Cao Ruiji et al., 1980; 1985; Zhu Shixing, 1982; Zhu Shixing, 1982) and macroscopic algal remains of Chuar and Tawuia (Duan Chenghua, 1982) consistently suggest a late Riphean age ca. 1000-700 Ma for the sequences of the Qingbaikou Group and the Huainan-Feishui Groups on the North China Platform (Chapters 2, 3).

In Australia, Walter (1972) suggested a late Riphean age for the Bitter Spring Formation in the Amadeus Basin on the basis of his analysis of stromatolite assemblages; more recently, it has been widely agreed that the sequences including the Burra Group and most of the Unburatana Group (excluding the Marinoan tillites) should be Late Riphean in age as suggested by radiometric datings and stromatolite biostratigraphy (Preiss, 1976; Walter et al., 1979; Preiss and Forbes, 1981; Glaessner and Walter, 1981).

As the Chuar-Tawua macrofossil assemblage has proved to be a valid and convenient biostratigraphic index for the Upper Riphean (Chapters 2, 3), attempts have been made to find this assemblage in Australia and to confirm the correlations mentioned above. These efforts have not yet succeeded. Ford and Breed (1973; followed by many others) considered that a specimen figured by Wade (1969, pl. 69, fig. 10) from the latest Precambrian Central Mt. Stuart Beds, central Australia could be Chuar; however, on re-examination this proved to be unfounded (see Chapter 3). In the course of this research, the shale members of the Myrtle Springs Formation in the Flinders Ranges, the Woolshed Flat Shale and Glen Osmond Slate in the Adelaide region and the Bitter Spring Formation in the Amadeus Basin have been specially examined but neither Chuar nor Tawua has been found. Dr. B. Daily suggested to me that a possible occurrence of this assemblage could be somewhere within the interglacial deposits of the Umberatana Group because, as shown in Fig. 10, the stratigraphic distribution of this assemblage in China can extend upwards closer to the level below the Nantuo Tillite (Chapter 3). This investigation will be continued in the future (Dr. M.R. Walter, pers. comm., Sep. 1985). Strata of similar lithological characters as the Chuar - rich Liulaobei Formation in the Huainan district of China are found not uncommonly below the level of the Marinoan tillites in Australia.

B. Nantuo - Marinoan glaciations

The Nantuo Tillite on the Yangtze Platform in China and the Marinoan tillites in the Adelaide Geosyncline, Amadeus Basin and other basins in Australia have been respectively regarded as key beds for regional or even intercontinental correlations. Chumakov (1981) referred both the Marinoan and Nantuo as well as the Luoquan to the Varangian Glaciation. Using glaciogene deposits for interregional and intercontinental correlations poses many problems. Particularly, the diachronous distribution of tillites and the lack of precision of the relevant

radiometric datings have to be considered. These problems result in protracted disputation and uncertainty. However, a careful analysis of the data available at present may suggest that the glacial event represented by either the Nantuo or Marinoan tillites may have happened probably around 700 Ma ago, and that the tentative correlation between the Nantuo Tillite and the Marinoan tillites may provide an index level more precise than other levels in the correlations of the Upper Precambrian between China and Australia. Without suggesting precise synchronicity, it may suggest a common cause in the palaeoclimatic history of the two regions.

In Australia, the age of the Marinoan glaciation (the upper tillites) may be inferred to be approximately 700 Ma ago, broadly bracketed within 670 and 720 Ma time range. By means of stratigraphic correlation, the Brachina Formation has been given two Rb-Sr whole rock isochron ages: 670 ± 70 and 672 ± 84 Ma; the Willochra Subgroup has been dated at $724 \text{ Ma} \pm 40$ also by the Rb-Sr method on shales (quoted by Preiss and Forbes, 1981).

In China, most geologists believe that the Nantuo glaciation could have occurred from 740 to 700 Ma ago (Wang Yuelun et al., 1980; 1981; Chen Jinbiao et al., 1981; etc.) because the dating of the middle member (Datangpu Shale) of the Nantuo Tillite has produced a Rb-Sr age of 739 Ma and that of the overlying Doushantuo Formation has resulted in a Rb-Sr age of 693 Ma (constants for all Rb-Sr ages are internationally standard). However, the supposed duration and the substantial value of the quoted figures are questionable. The main concern is about the potential errors due to the possible presence of older detrital minerals in the dated shale samples. Cowie (1985, to be published by Cowie and Johnson) recently obtained another series of dating from the Yangtze Gorge area, including Rb-Sr ages of 727 ± 9 , 691 ± 29 and 700 ± 5 Ma for

the Doushangtuo Formation, 728 ± 27 Rb-Sr age for the Nantuo Tillite (Datangpuo Shale) and a 740 ± 16 U-Pb age for the Liantuo Formation. Moreover, "An age of 748 ± 12 Ma from zircon (by ion probe techniques) of the Middle Liantuo Formation was obtained by W. Compston" (quoted from Lu Songnian *et al.*, 1985, p. 58). If the last figure is confirmed, it should not be used for the determination of the age of the base of the Nantuo Tillite, but should be used as evidence that the Liantuo Formation must be younger than 748 ± 12 Ma and the Nantuo Tillite is even younger because the zircons dated were detrital in the sandstone of the Liantuo Formation.

Concerning the age of the Nantuo glaciation, attention may be drawn to the observation that in Sichuan Province (see Fig. 2, near Loc. 5) the equivalent of the Doushantuo Formation is underlain by volcanics cut by granite intrusions with an average K-Ar age of 680 Ma (668–668 Ma; constants 4.72, 0.585, 1.22; Zhong Fudao, 1977), and that in E. Yunnan, the Chengjiang Formation is overlain by the Nantuo Tillite (Fig. 10) and intruded by the Eshan granite which yields an average biotite K-Ar age of 722 Ma (706–747 Ma; constants : 4.72, 0.585, 1.22; Zhong Fudao, 1977; Chao Renguan *et al.*, 1980). These data derived from igneous rocks are considered to be more reliable than the more recently obtained ages from the shales by the Rb-Sr whole rocks isochron method. The estimation of a 700 ± 20 Ma age for the beginning of the Nantuo glaciation (Zhong Fudao, 1977) seems more acceptable.

Since 1980, a hypothesis of three Sinian glaciations have prevailed among Chinese Precambrian researchers (Wang Yuelun *et al.*, 1980; 1981; Chen Jinbiao, *et al.*, 1981; etc.). It appears to have been accepted by Harland (Harbery and Harland, 1981; Harland *et al.*, 1982). According to this idea, there could be a pre-Nantuo glaciation in southern China (the Changan glaciation, 800–760 Ma), a post-Nantuo glaciation on the southern

margin of the North China Platform (the Luoquan glaciation, 640–600 Ma) and a sequence showing these three glaciations in Xinjiang, northwestern China (see Fig. 1, the area to the west of Urumqi). More recently, that hypothesis was modified. "The Gucheng and Nantuo ice ages are assigned to the Lower Sinian (740–700 Ma) and the Luoquan ice age is tentatively placed between about 640 Ma and 580 Ma" by Lu Songnian *et al.* (1985). They suggested that the previously called "Changan glaciation" could be related to the Gucheng tillites, the lower member of the Nantuo Tillite in the Yangtze Gorge area; accordingly they divided the Nantuo Tillite into Gucheng, Datangpuo and Nantuo Formations. This proposal was accepted by Cowie (1985, p. 95, table 2).

These two hypotheses are completely unacceptable. The proposed subdivision of the originally known Nantuo glaciation into two glaciations and one interglacial period overlooked the relatively short period of the whole Nantuo glaciation and the possible variation of the glaciogene deposits in sedimentary facies even in a limited area. The speculation of a terminal Precambrian or initial Cambrian age for the Luoquan Tillite disregards the fact that there is a regional disconformity between the Luoquan Tillite and the overlying Cambrian. Along the southern margin of the North China Platform, the Luoquan Tillite is slightly metamorphosed in places but not the overlying Cambrian. A recent radiometric dating indicates that in Shanxi Province the Luoquan Tillite was locally metamorphosed 709–720 Ma ago (Rb–Sr method; dated by Luo Wancheng of Yunman Institute of Geology, pers. comm. Nov. 1982). Moreover, the two hypotheses ignored the regional tectonic separation between the Yangtze Platform, the North China Platform and the remote Xinjiang area. The supposed three Late Precambrian glaciations in Xinjiang may (or may not) have regional significance; however it has not been shown in adjacent areas. Using that sequence for the interpretation

of the possible relationship between the far distant Nantuo and Luoquan glaciations seems a very dangerous approach at the present stage, without further investigations.

C. The terminal Precambrian period (= the "Ediacarian", Cloud and Glaessner, 1982).

The global distribution of the Ediacara assemblage and similar assemblages of soft-bodied metazoan fossils has provided the most important biostratigraphic index for the terminal Precambrian, postdating the Varangian glacial event(s). So far the occurrences of these assemblages have been found in more than twenty regions of the world and all of them fall in the time range between 680 Ma and the beginning of the Cambrian (Glaessner, 1971, 1984a).

In South Australia, the type Ediacara metazoan assemblage (Glaessner and Wade, 1966) in association with simple horizontal burrows (Glaessner, 1969) has been found at many localities in the Flinders Ranges (see Fig. 21 in Chapter 4). The findings are confined to the Ediacara Member (Jenkins, 1975; Jenkins et al., 1983), the basal unit of the Rawnsley Quartzite, Pound Subgroup. Below this level, metazoan occurrences of probable medusoids and other fossils have been recently described by Jenkins (1984) from the Wonoka Formation; the occurrence of Bunyerichinus in the Brachina Formation was first described as a trace fossil (Glaessner, 1969), then regarded by Jenkins et al. (1981) as a pseudofossil, and more recently reinterpreted by Glaessner (1984a) as a body impression of a medusa. In the Amadeus Basin, central Australia, a small sea pen specimen of the Ediacara assemblage has been found in the Arumbera Formation, the lower unit of the Arumbera Sandstone (Glaessner, 1969; Daily, 1972). Also from the Arumbera Formation, Glaessner and Walter (1975) described Arumberia as an originally cup-shaped but now flattened metazoan body structure. Jenkins et al. (1981) questioned the

organic nature of Arumberia, but the interpretation of it as a pseudofossil is disagreed by Glaessner (1984a). However, Dr. B. Daily (pers comm., Nov. 1985) has stated that in several sites in the Northern Territory Arumberia can be shown to be a sedimentary structure produced by current action and in some cases being unidirectional through a thickness of at least 0.5m of sandstone strata. Wade (1969) described Hallidaya, Skinneria and other medusoid fossils from the Central Mt. Stuart Beds, Mt. Skinner, central Australia. On the basis of utilizing the few known fossils, Daily (1976) suggests that the Mt. Skinner metazoan assemblage is slightly younger than the type Ediacara assemblage and the Central Mt. Stuart Beds can be compared with the upper part of the Precambrian Arumbera Formation (see Fig. 10; Walter, 1981).

In China, the occurrence of the Late Precambrian Ediacara-type metazoan assemblage is represented by a sea pen, Paracharnia (Chapter 6; "Charnia dengyingensis Ding and Chen, 1981) in the Dengying Formation, E. Yangtze Gorge section. The close association of the pennatulid Paracharnia and abundant macroscopic algal remains of Vendotaenia in the Shibantan Member, the occurrence of Cloudina-like, vermiform, tubular structures of Sinotubulites in the lower Baimatuo Member, and their sequential relationship with the successive small shelly fossil assemblages in the Tianzhushan (= Huangshandong) Member characterize the Precambrian - Cambrian transition recorded by the Dengying Formation (Chapter 6). These data suggest a direct correlation of the Dengying Formation with the Late Vendian Valdai Group on the Russian Platform and an indirect correlation of it with the Pound Subgroup in the Flinders Ranges of South Australia (Chapter 6), considering that many forms of the Ediacara metazoan assemblage of South Australia have been recently found in the inferred lower part of the Valdai Group (Fedonkin, 1981; Cloud and Glaessner, 1982; Sokolov and Fedonkin, 1984).

D. Precambrian - Cambrian boundary.

The Meishucun section in eastern Yunnan, Yangtze Platform, has been chosen as the most favoured candidate for the global Precambrian - Cambrian boundary stratotype (Cowie, 1984) but "The whole question is still being actively discussed" (Cowie, 1985, p. 94).

The Chinese Working Group (Xing Yusheng and Luo Huilin, 1984; Xing Yusheng et al., 1984) suggested placing the boundary point at the base of the Xiaowaitoushan Member of the Meishucun Stage (Qian Yi, 1977), i.e. at the level of the oldest known shelly fossil assemblages. However, the "oldest" can only represent the level of our present knowledge.

The International Working Group (Cowie, 1984) recommended placing the boundary point in the top of the Zhongyicun Member, i.e. at the contact between the Anabarites - Circotheca Zone (1) and the Paragloborilus - Siphogonuchites Zone (2). However, this proposal will assign a number of characteristic Cambrian forms to the Precambrian.

The boundary marked in Fig. 10 is calibrated at the base of the Zhongyicun Member, below which only a few small shelly fossils have been found in the 8.2m thick dolomite of the Xiaowaitoushan Member. The assemblage consists dominantly of Anabarites primitivus, A. trisulcatus, Circotheca and Protohertizina, etc. Above, abundant, diverse small shelly fossils occur in the phosphatic deposits of the Zhongyicun Member. The differentiation in lithological and palaeontological characters below and above this boundary is conspicuous in the Meishucun section and many other sections on the Yangtze Platform. An analysis of the data provided by Xing and Luo (1984, p. 147, fig. 4, descriptions pp. 151-4) suggests that this boundary clearly demonstrates the previously disputable relationship between the Nemakit-Daldin Horizon (older) and the Tommotian Stage (younger), which were described respectively from

separate sections on the Siberian Platform of the USSR (see Rozanov and Sokolov, 1982). This boundary is worth consideration, particularly when the International Working Group tends to define the boundary point between two characteristic fossil zones. The door is still open to other appropriate suggestions.

No matter at which level the boundary will be finally defined, correlations of the Meishucun stratotype boundary section with the Lower Cambrian reference sections in Australia can be achieved on the basis of sufficient fossil evidence. The common occurrence of the trilobite Eoredlichia near the top of the Qiongzhusi Formation (Stage) in E. Yunnan, China (Chang Wentang, 1980) and in the Faunal Assemblage II of the Wilkawillina (Ajax) Limestone in the Flinders Ranges of South Australia (Daily, 1972) provides a distinctive index for the correlation. Below it, the tracefossil assemblage of the upper part of the Badaowan Member in E. Yunnan is dominated by Plagiogmus arcuatus (initially found by Dr. B. Daily in 1979; Jiang Zhiwen et al., 1982); in Australia, P. arcuatus occurs in the upper levels of both the Parachilna Formation in the Flinders Ranges and the Allua Formation (upper Arumbera Sandstone) in the Amadeus Basin (Glaessner, 1969; Daily, 1972, 1976 a,b; see Plate 21). Further below it, the tracefossil assemblage in the upper phosphatic beds of the Zhongyicun Member in E. Yunnan is characterized by Didymaulichnus (first recognized by Dr. B. Daily in 1979; Jiang Zhiwen et al., 1982; see Plate 21); in Australia, Didymaulichnus occurs in the upper levels of both the Uratanna Formation in the Flinders Ranges (Daily, 1973) and the Box Hole Formation (middle Arumbera Sandstone) in the Amadeus Basin (Glaessner, 1969; Daily, 1972, 1976 a,b; see Plate 21).

The above correlations indicate that the gap between the Wilpena Group and the overlying Lower Cambrian in the Flinders Ranges and the

Amadeus Basin is relatively short. The remaining uncertainty is related to the weathered top of the Wilpena Group, in which the oldest known shelly fossil assemblage of Anabaritas and Protohertzina has not yet been found, probably either because of the sedimentary break or due to the unsuitable preservational environment of the sandstone facies.

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CHAPTER 2

MACROSCOPIC WORM-LIKE BODY FOSSILS
FROM THE UPPER PRECAMBRIAN (900-700 MA),
HUAINAN DISTRICT, NORTH CHINA PLATFORM

ABSTRACT

Abundant and varied, macroscopic, worm-like body fossils from the late Precambrian Liulaobei Formation, Huainan Group and the Jiuliqiao Formation, Feishui Group in the Huainan district, northern Anhui Province, China are further investigated through this progress report, following the initial discovery by Zheng Wenwu (1980) and a recent study by Wang Guixiang (1982).

Sinosabellidites Zheng in the Liulaobei Formation is a worm-like organism of questionable metazoan origin. It has merely a superficial resemblance with the tubes of Late Vendian - Early Cambrian true Sabelliditida but has much in common with the accompanying macroscopic algal remains of Tawuia Hofmann. Both Pararenicola Wang and Protoarenicola Wang are representatives of primitive worm-like animals in the Jiuliqiao Formation. Their macroscopic size, elongate cylindrical body, anterior aperture and apparatus, prominent and elastic annulations are characteristic for their metazoan origin, although they lack sufficient evidence for their definite relationship with any known kind of living worms.

The Liulaobei Formation and the Jiuliqiao Formation are dated at about 850 Ma and 740 Ma respectively. Regional geology and stratigraphic correlation and the occurrence of the distinctive Chuarina - Tawuia assemblage suggest a time range between less than 900 Ma and over 700 Ma

for the whole shallow water marine sedimentary sequence of the Huainan and Feishui Groups; this latter group is disconformably covered by the drop-stone facies diamictites and tillites of the late Precambrian Luoquan Glaciation.

Apart from the enigmatic Sinosabellidites, both Pararenicola and Protoarenicola are claimed to be the oldest multicellular animals so far discovered in the world and the first reliable evidence for the pre-Ediacarian evolutionary history of manifest metazoan life.

INTRODUCTION

Knowledge about the oldest known multicellular animals has so far been confined to the late Precambrian soft-bodied metazoans, mainly cnidarians (e.g. medusae and pennatulids) and some annelids and arthropods, which are represented by the Ediacara faunal assemblage in South Australia and similar assemblages sporadically distributed in a number of regions outside Australia (Glaessner, 1971, 1984). A recent comprehensive review of the worldwide occurrences of the Ediacara-type metazoan assemblages indicates that they are all more or less younger than 670 Ma, postdating the late Precambrian (Varangian) glaciation evidenced by the tillites of the Marinoan in Australia, the Varangian in Europe and the Nantuo in southern China, etc. (Cloud and Glaessner, 1982).

Palaeontological data of the pre-Ediacarian (Cloud and Glaessner, 1982; Glaessner, 1983) metazoan diversification are extremely limited. All previously supposed pre-Ediacarian metazoan remains, perhaps except few questionable small trace fossils (see Glaessner, 1983), have later been proved to be either misdated or not metazoan in origin or pseudofossils (Cloud, 1968; Cloud and Glaessner, 1982). Only a few kinds of macrofossils such as Chuarina Walcott 1899 and Tawuia Hofmann 1979 have been known from the pre-Ediacarian sediments and they are possibly related to algae rather than animals (Ford and Breed, 1973; Walter et al., 1976; Hofmann and Aitken, 1979).

Significant discoveries of abundant and varied macroscopic carbonaceous body fossils, including Chuarina and Tawuia and distinctive worm-like organisms, were recently reported from the late Precambrian Liulaobei (older) and Jiuliqiao (younger) Formations in the Huainan district, northern Anhui province, eastern China (Initial discovery by Zheng Wenwu in the early 1960's; first reported without description by

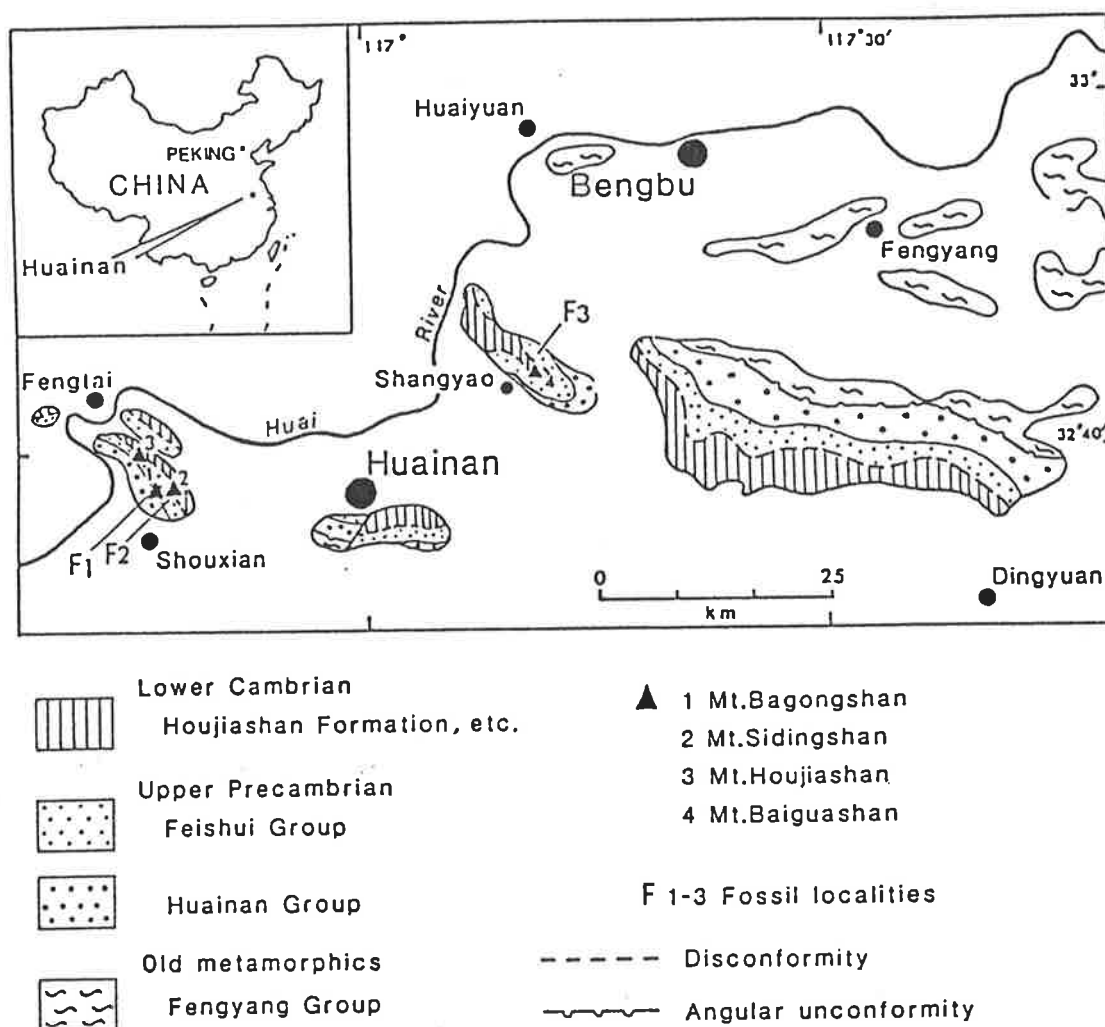


Fig. 11. Index map and regional geology of the Huainan district, Anhui Province, China, showing the distribution of the late Precambrian Huainan and Feishui Groups, and the known localities of the macroscopic worm-like body fossils. The irregularly distributed late Precambrian Fengtai Formation conglomerate is omitted in this map because of the small scale.

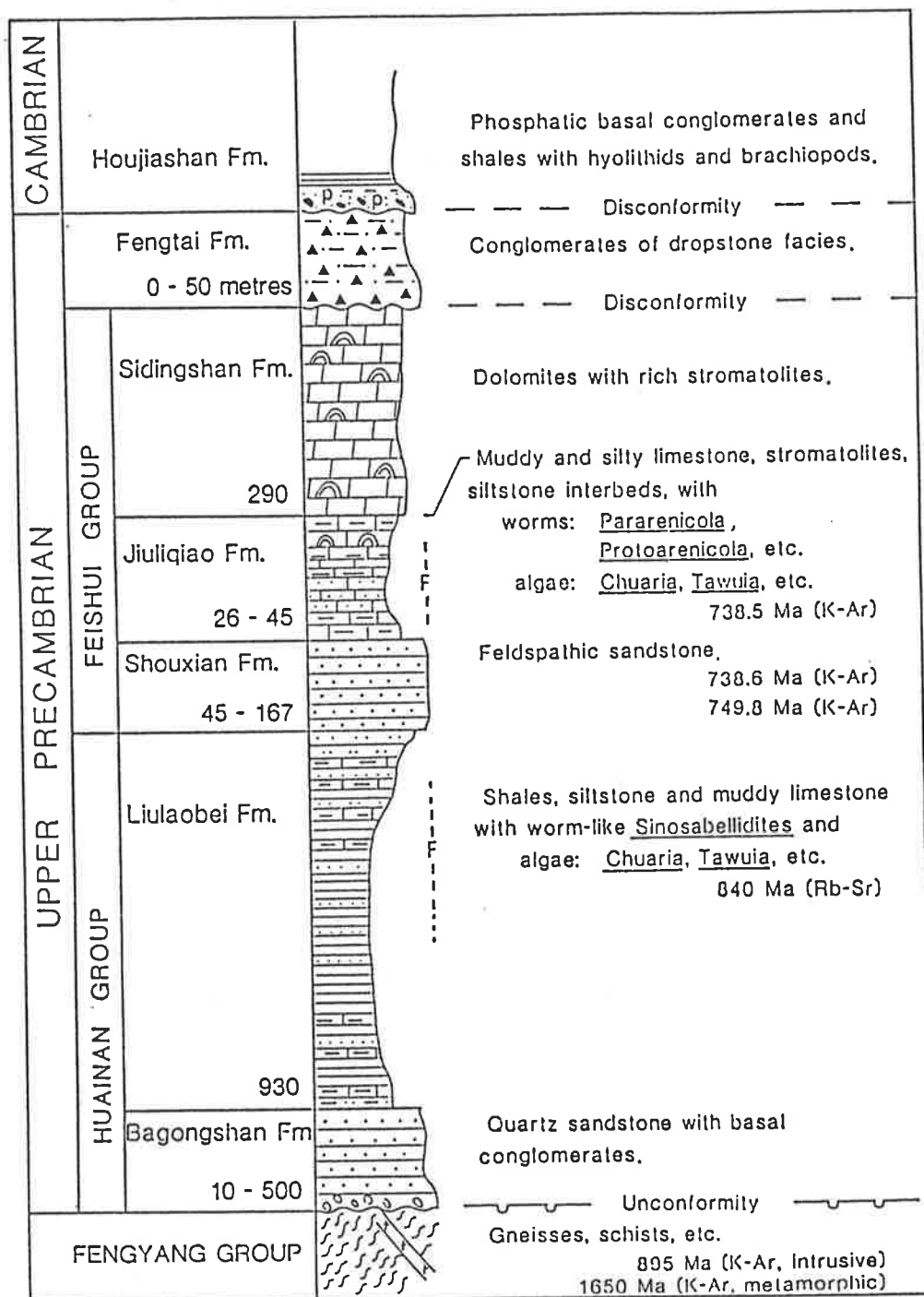


Fig. 12. Generalized stratigraphic column of the Upper Precambrian in the Huainan district, Anhui Province, China. The stratigraphic occurrences of macroscopic fossils are marked by "F" and the extending vertical lines.

Xing Yusheng, 1976; Zheng Wenwu, 1980; Duan Chenghua, 1982; Wang Guixiang, 1982).

The diverse macroscopic worm-like organisms in this assemblage are of particular interest. Zheng Wenwu (1980; also compiled in Yang Qinghe et al., 1980) referred them to the order Sabelliditida Sokolov and described Sinosabellidites Zheng 1980 from the Liulaobei Formation. Further discoveries from both Liulaobei and Jiuliqiao Formations were described by Wang Guixiang (1982), who established 7 species (one undetermined) under different genera and assigned most of them to the families Arenicolidae (Annelida) and Sabelliditidae (Pogonophora). The age of the fossiliferous sequence was not certainly known (Chen Jinbiao et al., 1981); regional geology and a few radiometric datings suggested that the Liulaobei and Jiuliqiao Formations may be about 850 Ma and 740 Ma old respectively (Yang Qinghe et al., 1980; Wang Guixiang, 1982). Xing Yusheng (1976, 1980) correlated the whole sequence with the Sinian System as represented by the Yangtze Gorge section in southern China. More recently, the identification of the supposed sabelliditids gave rise to the assumption that this sequence and its equivalents on the North China Platform might be very late Precambrian in age (Chen Meng'e et al., 1982). Glaessner (1983) and the present author (Sun Weiguo) examined the photographed material presented by Zheng Wenwu and Wang Guixiang, and considered that the supposed sabelliditids might resemble the Vendian - Cambrian true Sabellidites tubes only superficially.

The problems here considered are whether they are metazoans and what time range the fossiliferous sequence represents.

Sun Weiguo restudied the Upper Precambrian in the Huainan district on a return trip to China in 1982. Supplementary specimens were collected from three known localities (Fig. 11), 1. the Liulaobei Formation on the western slope of Mt Bagongshan, Shouxian County; 2. the Jiuliqiao Formation at Jiuliqiao, Shouxian County and 3. the Jiuliqiao Formation on the northern slope of Mt Baiguashan, Huaiyuan County. The previously figured collections (Wang Guixiang, 1982, pls. 1-2) were jointly re-examined with Wang Guixiang and Zhou Benhe at the Institute of Geological Sciences of Anhui Province, Hefei, China. The studies were completed at the Department of Geology, University of Adelaide, South Australia.

Repositories of studied specimens. The studied specimens with numbers prefixed "P82" are deposited in the Nanjing Institute of Geology and Palaeontology, Academia Sinica, China; those with numbers prefixed "A79-" are deposited in the Anhui Institute of Geological Sciences, Hefei, China; those with numbers started with "62" are deposited at the Department of Geology, Hefei Multitechnological University, Hefei, China. The specimens of typical Sabellidites that have been prepared for SEM examination are deposited at the Department of Geology, University of Adelaide, South Australia.

GEOLOGIC SETTING AND STRATIGRAPHY

The Huainan district, i.e. the vicinity of Huainan City, Anhui Province is situated on the southern margin of the North China Platform and separated from the Yangtze (Southwest China) Platform by the eastern extension of the Qinling-Dabie Tectonic Zone to the south. The late Precambrian sedimentary sequence is well developed in this district and is extensively exposed on a chain of hills south of the Huai River. The

sequence is up to about 2000m thick, resting unconformably on the Fengyang Group metamorphic complex and disconformably covered by the Lower Cambrian Houjiashan Formation (Xie Jiayong, 1947; subsequent works referred to by Yang Qinghe et al., 1980).

The Upper Precambrian in the Huainan district (Fig. 12) consists of two continuously deposited sedimentary cycles including five lithostratigraphic formations (Zhu Zhaoling et al., 1964), in addition to the disconformably separated Fengtai Formation conglomerate at the top (Chang Wentang et al., 1979).

The lower sedimentary cycle is made up of the Bagongshan and Liulaobei Formations and here redefined as the Huainan Group (The name Huainan Group was first used for the sequence from the Bagongshan to the Jiuliqiao Formation by Yang Qinghe et al., 1980). The Bagongshan Formation consists mainly of supratidal and intertidal quartz sandstone and glauconitic sandstone, with hematite layers and basal conglomerate in the lower part, varying from several meters to 500m in thickness and forming a clastic sheet over the erosion surface of the unconformably underlying Fengyang Group gneisses and schists. The succeeding Liulaobei Formation is characterised by yellowish green shales and alternations of siltstone, shales and argillaceous limestone layers, generally of shallow quiet water neritic facies, up to 930m thick. Abundant and well preserved macroscopic carbonaceous fossils, including Chuarina circularis Walcott, Tawuia dalensis Hofmann, T. sinensis Duan and worm-like Sinosabellidites huainanensis Zheng, occur at numerous levels, particularly in the middle part of the Liulaobei Formation.

The upper sedimentary cycle comprises, in ascending order, the Shouxian, Jiuliqiao and Sidingshan Formations, which are here defined as

the Feishui Group after the Feishui River near the type section from Mt Bagongshan to Mt Sidingshan, Shouxian County. The Shouxian Formation is dominated by thick - bedded feldspathic and calcareous sandstone with glauconites, 45-167m thick. Prominent cross - bedding and trough - bedding structures suggest a high energy intertidal sedimentary environment of this formation, in which no macroscopic fossils have been found. The Jiuliqiao Formation is composed of thin - bedded and laminated argillaceous limestone, stromatolitic limestone and calcareous siltstone interbeds, 26 - 45m thick and prevailingly indicating subtidal origin. Numerous specimens of macroscopic worm-like body fossils, represented by Pararenicola huaiyuanensis Wang and Protoarenicola baiguashanensis Wang, occur together with less abundant Chuarina and Tawuia in the Jiuliqiao Formation. It grades upwards into the Sidingshan Formation, which is represented by intertidal-flat carbonate deposits, mainly stromatolitic dolomites with chert layers and concretions, about 300m thick.

The top of the Sidingshan dolomite is an erosional surface indicating a regional sedimentary hiatus. Its irregular relief controls the distribution of the overlying Fengtai Conglomerate, which reaches its maximum thickness (more than 50m) at Mt Houjiashan, Fengtai County (Fig. 11). It varies markedly over a short distance and disappears completely to the east of Huainan City. The Fengtai Conglomerate is poorly stratified and contains abundant coarse clasts scattered in grey, yellowish or pinkish dolomitic silts, mudstones or carbonates. The clasts are angular to subangular, mostly less than 10cm but occasionally more than 70cm in size, unsorted, unoriented, mainly composed of dolomite derived from the immediately underlying Sidingshan Formation and less commonly but still importantly of quartz sandstone and variegated

siltstone characteristic of the strata older than the Sidingshan dolomite. Dropstone structures (Plate 1:A-C) are developed at several levels, showing that laminae of silty matrix are prominently distorted by isolated pebbles. The diamictite and dropstone structures combined suggest that the Fengtai Conglomerate is of glaciogene origin. This interpretation is principally in agreement with Ren Yunshen (1982), who considered the Fengtai conglomerate as a tillite, and is contrary to Liu Hangyun et al. (1980) and others, who regarded it as a probable intraformational carbonate conglomerate.

The Precambrian - Cambrian boundary is represented by the regional disconformity between the Fengtai conglomerate and the overlapping lower Cambrian Houjiashan Formation (Chang Wentang et al., 1979). The base of the Houjiashan Formation is marked by black phosphatic basal conglomerate and other phosphatic deposits, providing a marker bed for the onset of a Cambrian transgression on the southern margin of the North China Platform. Brachiopods and hyolithids occur from the base upwards. The Hsuaspis and Megapaleolenus trilobite zones of this formation belong to the middle Lower Cambrian Changlangpu Stage, the lowest Cambrian stage found over the whole North China Platform.

MACROSCOPIC WORM-LIKE BODY FOSSILS

The macroscopic worm-like body fossils in the late Precambrian Liulaobei Formation of the Huainan Group and the Jiuliqiao Formation of the Feishui Group are black, membranous, carbonaceous remains of various elongate, cylindrical, annulated organisms, occurring together with macroscopic algal remains of Chuar Walcott and Tawuia Hofmann. Many of them are preserved as compressions flattened between and parallel to the laminae of shales, calcareous siltstones and argillaceous limestone. The

specimens are generally less than 3mm wide, up to a few centimeters long, and the wall is less than 0.01 mm thick. They can be easily seen on fresh bedding planes with the naked eye. Their distinct annulations, though very fine and closely spaced, are relatively conspicuous when the specimens are wetted with liquid paraffin, alcohol or water and examined with a hand lens or under a binocular microscope.

The material available for this study includes about 50 specimens recently collected from the Liulaobei and Jiuliqiao Formations, the specimens previously described by Wang Guixiang (1982, pls. 1-2) and the photographs of those named Sinosabellidites by Zheng Wenwu (1980, pl. 2, figs. 14, 16-23). Additionally, two borehole samples with numerous fragments of typical Sabellidites cambriensis Yanishevsky from the Blue Clay of the Lower Cambrian Baltic Stage in the Leningrad district, USSR were obtained through the courtesy of Professor M.F. Glaessner and were studied for a better understanding of the difference between Sabellidites and Sinosabellidites.

Systematic Palaeontology

The late Precambrian macroscopic worm-like body fossils from the Huainan district were previously described under as many as 8 species of different genera and assigned to Annelida and Pogonophora respectively by Zheng Wenwu (1980) and Wang Guixiang (1982). In the course of the present study, much effort has been made to understand the palaeontological and preservational characters of the so far collected specimens and to probe further into their possible origins and diversification. The previously established taxa are now re-identified as consisting of 3 monotypic genera.

The previous assignments of these fossils, as implied by the generic names, have been revised. Sinosabellidites proved not to belong to the Sabelliditidae, and neither Pararenicola nor Protoarenicola can be understood as primitive Arenicolidae. These fossils are different from all other known macroscopic fossils from the late Precambrian sediments and there are no sufficient diagnostic characters for them to be referred to any of the phyla represented by the living worms. Various Phanerozoic organic remains of macroscopic size, with elongate and cylindrical body and distinct annulations or segments are commonly considered to be worms though their classification in many cases is very difficult because of incomplete preservation and deformation during fossilization (see Howell, 1962, p. W144-176). Considering the potential significance of these unusual late Precambrian worm-like body fossils representing the oldest multicellular animals so far known and providing first body fossil evidence for the little known pre-Ediacarian metazoan evolution, a careful investigation of their possible relations, metazoan or algal, was certainly wanted.

Worm-like fossils of uncertain affinities

Group A:

Genus Sinosabellidites Zheng, 1980

1980 Sinosabellidites Zheng, p.63.

1982 Huainanella Wang, p.11.

Diagnosis. As for type species.

Type Species. Sinosabellidites huainanensis Zheng.

(The replacement of the first published generic name because the fossil is not a sabelliditid is not in accordance with the International Code of Zoological Nomenclature).

Age and distribution. Late Precambrian (about 800-850 Ma, see Fig. 14), North China Platform.

Sinosabellidites huainanensis Zheng, 1980

Plate 2:A,B.

1980 Sinosabellidites huainanensis Zheng, p. 63, pl. 2. figs. 14, 16-23.

1982 Huainanella cylindrica Wang, p. 12, pl. 1. figs. 5 and 9.

Holotype 62030 (Plate 2: A 1,2; refigured from the specimen of Zheng Wenwu, 1980, pl. 2. figs. 20a and 20b).

Material and preservation. Eleven specimens are all preserved as flattened ribbon-like compressions with perfect outlines, straight or slightly bent but not strongly curved nor twisted. The specimens occur sporadically on bedding planes, often accompanied by macroscopic algal remains of Chuarina and Tawuia.

Horizon and locality. Liulaobei Formation of Huainan Group, western slope of Mt Bagongshan, Shouxian County, Anhui Province.

Diagnosis. Black ribbon-like compressions of elongate, cylindrical, annulated bodies; body straight or gently bent but not twisted nor curved; both ends rounded, without apertures; sides smooth and distinct, nearly parallel; annulations numerous, fine, straight and closely spaced.

Dimensions. The holotype is 2.2mm wide, 24mm long, with 8-10 annulations per mm. of the length. Measurements of 8 specimens (Fig. 13) indicate a size range from 1.6 to 2.2 mm in width and from 16 to 24mm in length, suggesting an average width-length ratio of about 1:10.

Comments. Sinosabellidites huainanensis resembles the organic-walled tubes of the Late Vendian - Early Cambrian sabelliditids (Sokolov, 1965, 1967, 1972), which are represented by Sabellidites cambriensis Yan. from the Blue Clay of the basal Cambrian Baltic Stage on the Russian Platform. (Sokolov and Rozanov, 1981, place the basal "horizon" of the Blue Clay in the topmost Vendian).

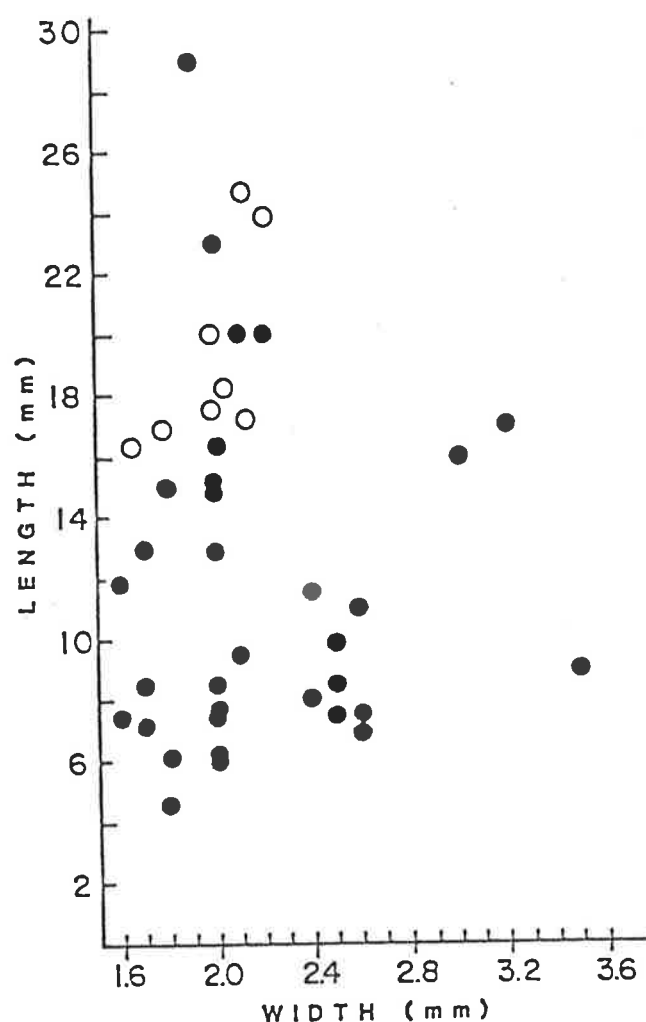


Fig. 13. Measurements of Sinosabellidites huainanensis Zheng and Tawuia sinensis Duan in the same assemblage from the late Precambrian Liulaobei Formation, Huainan Group, Mt. Bagongshan, Shouxian County, Anhui Province. The measured specimens of S. huainanensis, marked by open circles, were originally figured by Zheng Wenwu (1980, pl. 2, figs. 14, 16-20) and by Wang Guixiang (1982, pl. 1, fig. 9). The measurements of T. sinensis, marked by solid-circles are cited from Duan Chenghua (1982, fig. 6).

The specimens of Sabellidites (Plate 3) are always preserved as fragments of flattened, slender tubes and often found in abundance. Different tubes have constant diameters of 0.5 to 2.0, less commonly 2.8 to 3.0mm. Large fragments reach 70-120mm in length, without evidence of either tapering or closing. The outer surfaces of tubes are usually sculptured by fine, closely spaced cross wrinkles while the inner surfaces are always smooth. Sokolov (1967, 1972) interpreted Sabellidites as tubes of the Pogonophora, though others considered it to be probably sedentary annelids (Korkutis, 1966, 1981).

Sinosabellidites differs from Sabellidites and appears to represent compressions of worm-like bodies rather than tubes. The rounded ends and the apparently constant ratio between width and length of Sinosabellidites rules out the possibility of assigning it to the Family Sabelliditidae and interpreting it as pogonophorans. Its annulations can be seen on both the outer and inner sides of the membranous compressions (Plate 2:B). In Sabellidites the cross wrinkles are found only on the outer surfaces while the inner surfaces are commonly smooth.

The supposed metazoan origin of Sinosabellidites is questioned when it is compared with the accompanying macroscopic algal remains of Tawuia, including T. dalensis Hofmann and T. sinensis Duan. Both Sinosabellidites and Tawuia are black macroscopic ribbon-like compressions of elongate cylindrical bodies and occur at the same levels in the Liulaobei Formation. Sinosabellidites huainanensis has the shape and size range of T. sinensis (Plate 2:C; Fig. 13). The only difference between them in gross morphology is that Sinosabellidites has distinct fine annulations, which are absent in Tawuia.

When Tawuia was first described from the Precambrian Little Dal Group in the Mackenzie Mountains, northwestern Canada (Hofmann and Aitken, 1979), Hofmann referred Tawuia to the Group Vendotaenides Gnilevskaya and considered it to be "elongate compressions of undetermined affinities, probably of algae (Phaeophyta?) though possibly of metazoans". In the subsequent studies, the ribbon-like compressions of Tawuia and the discoidal compressions of Chuarua were interpreted as either macroscopic eucaryotic algae (Hofmann, 1981) or multicellular algae (Duan Chenghua, 1982) on the basis of the relatively large size and regular shape. I have recently discovered microscopic filamentous structures and tiny circular aggregations within the compressions of both Tawuia and Chuarua, and have suggested that they are possibly macroscopic colonies of algae analogous to the modern colonial blue-green algae Nostoc. (See Chapter 3).

However, the above interpretations of Tawuia as a kind of alga are difficult when applied to Sinosabellidites. There is no known analogue for this Tawuia-shaped annulated organism among the fossil and living algae. The gross morphology of Sinosabellidites is somewhat reminiscent of trichomes of oscillarian blue-green algae but Sinosabellidites is larger by two orders of magnitude and does not have cross walls within its hollow cavity (Plate 2:B1). Colonial algae may reach the size of Sinosabellidites but do not grow distinct and regular external annulations. No microscopic structures have yet been discerned in Sinosabellidites at up to 40 time magnification. The limited number of the specimens at hand does not allow preparation of peels and bioplastic transfers for more detailed analysis at higher magnification.

In summary, there remains much to be learnt about this organism. At the present stage of our knowledge it can not be ranked more precisely

than as "worm-like organism of uncertain affinities". Further studies may decide whether it has a rather close taxonomic relationship with Tawuia or possibly prove that it represents primitive animals, the oldest so far known.

Group B

Genus Pararenicola Wang, 1982

1982 Pararenicola Wang, p.11.

1982 Paleorhynchus Wang, p. 13.

Diagnosis. As for type species.

Type species. Pararenicola huaiyuanensis Wang.

Age and distribution. Late Precambrian (about 740 Ma, see Fig. 14), North China Platform.

Pararenicola huaiyuanensis Wang 1982

Plate 2:D-F; Plate 4:A-L.

1982 Pararenicola huainanensis Wang, p. 11, pl. 1, figs. 1,2,4,6,7.

1982 Ruedemannella minuta Wang, p.12, pl. 1, fig. 8, pl. 2, fig. 4.

1982 Paleorhynchus anhuiensis Wang, p. 13, pl. 1, fig. 3.

1982 Paleolina tortuosa Wang, p. 13, pl. 2, figs. 1 and 5.

Holotype. A7903 (Plate 2:D; refigured from the specimen of Wang Guixiang, 1982, pl. 1, fig. 1).

Material and preservation. Numerous specimens have been found. More than 50 specimens were available for this study. The fossils are small, black, carbonaceous remains of cylindrical bodies. Most specimens are transversely broken bodies due to fragmentation during sedimentation. They are often curved or twisted even in small fragments. Though most of them are preserved as compressions, deeply flattened between the laminae of the rocks, a few of them are three-dimensionally preserved and filled with the same matrix. Macroscopic algal remains of Chuararia and Tawuia

also occur in this formation but their occurrences are much less frequent than in the Liulaobei Formation.

Horizon and locality. Jiuliqiao Formation of Feishui Group, at Jiuliqiao, Shouxian County and northern slope of Mt Baiguashan of Huaiyuan County, Anhui Province.

Diagnosis. Small, black, elongate, cylindrical, hollow or compressed, membranous remains with numerous prominent annulations; anterior end slightly narrower and rounded, with first a few annulations curved toward a broad circular aperture (mouth), showing a large, long, irregular, proboscis-like structure in front; posterior end bluntly rounded, without an aperture; body often curved or twisted indicating considerable original flexibility; sides distinct and slightly constricted at the junctions of adjacent annulations in well preserved specimens; annulations contracted on the concave side and extended on the corresponding convex side; naturally preserved cross sections circular.

Dimensions. The holotype is a fragment, 3.5mm long, 1.2 mm wide, with 10-12 annulations per mm of the length. Most specimens are fragments commonly less than 8mm long and ranging in width from 1.0 to 1.8mm, and with 8-16 annulations per mm of the length, depending to some degree on contraction of the body. A nearly perfect specimen (Plate 4:H) is 9.5mm long and 1.2 mm wide in the middle portion. The preserved wall is less than 0.01 mm thick.

Comments. Pararenicola huainanensis represents most of the macroscopic worm-like body fossils in the Jiuliqiao Formation of the Feishui Group. The specimens exhibit a great range of morphological variation due to different stages of growth, flexibility of the body and its fragmentation and distortion during fossilization. The holotype (Plate 2:D) represents the frequently occurring fragments of curved and twisted bodies (Plate 4:E-G). The separation of "Paleolina tortusa Wang 1982" from the

holotype is impracticable because of the morphological intergradation of different specimens in this collection. The characters of the anterior end were not mentioned in the previous description but are now considered to be represented by "Paleorhynchus anhuiensis Wang 1982" (Plate 2:E). The characters of this supposed new genus and species correspond to those of many fragments of the body of Pararenicola huainanensis including those with a bluntly rounded posterior end (Plate 2:F), taking account of their width and characteristic annulations. Small specimens with curved body, rounded ends and fine annulations (Plate 4:J) which were named "Ruedemannella minuta Wang 1982" are here re-interpreted as possibly juvenile forms or small contracted bodies of Pararenicola huainanensis since larger and almost completely preserved specimens with similar features have been obtained (Plate 4:C,H). The generic name used by Wang was proposed by Howell in 1959 as a replacement of Bertiella Ruedemann 1925 (non Stiles and Hassall 1902). R. obesa Ruedemann is a somewhat similarly shaped and corrugated but much larger Upper Silurian worm (see Howell, 1962).

The morphological variation of the anterior end requires further comment. Specimen A7904 (Plate 2:E) displays a large, irregular, proboscis-like structure in the front; specimen P8202 a-b (Plate 4:A,B counterparts) contains a hook-shaped structure extending forward through the anterior aperture; and specimen P8207 (Plate 4:H) has nothing but a broad circular aperture at the anterior end. These differences are probably only due to preservation. Though the function of the preserved proboscis-like structure is not clear, it may be suggested that Pararenicola had within its anterior end a retractile proboscis-like structure, which could be preserved in various positions, distorted, or lost.

Several specimens are naturally preserved cross sections (Plate 4:K,L). They are circular in outline and show the membranous organic wall consisting of annulations and enclosing a wide inner cavity. One cross section (Plate 4:K) contains a tiny circular structure toward one side within the inner cavity but others do not.

Most specimens of this species, even in the case that the fragments are only a few millimeters long, are curved or twisted, indicating flexibility of the original body.

The substance of the annulated organic wall is carbonised and its original composition is not clear but probably represents a cuticle. Several specimens have been freed from the rock matrix by peels and bioplastic transfers, and examined in transmitted light. The prepared specimens are translucent, dark brown in colour and darker at the conjunctions of the adjacent annulations. No microscopic structures of potential significance were encountered.

A few specimens resembling this species have been recently reported by Chen Meng'e et al. (1982) from the equivalent of the late Precambrian Changlingzi Formation, Wuhangshan Group in the Fuxian district, southern Liaoning Province, northeastern China. The specimen previously illustrated (Chen Meng'e et al., 1982, fig. 1) is a curved fragment 4mm long, 1.3mm wide, with fine annulations. Reference in that report was to "Sabelliditidae - form fossils". They are here referred to Pararenicola huaiyaianensis as the previously illustrated specimen appears almost identical with a specimen in the present collection (Plate 4:F).

Pararenicola is generally smaller than Sinosabellidites from the Liulaobei Formation and differs from the latter in the variable outline

of the flexible body, the possession of an anterior aperture with a proboscis-like structure in the front, and the characters of more prominent, apparently elastic annulations. Fragments of Pararenicola were once misidentified as Paleolina and other supposed sabelliditids (Wang Guixiang, 1982; Chen Meng'e et al., 1982); however, more completely preserved specimens display the limited length and characteristic terminal features, distinguishing this taxon from the Sabelliditidae. The assignment of Pararenicola to the Arenicolidae (Wang Guixiang, 1982) cannot be accepted because it does not show regional differentiation along the body nor any sign of lateral appendages on the surface and differs markedly from the Triassic Archarenicola Horwood and the recent Arenicola Lamarck (see Howell, 1962, p. W163).

Pararenicola can at present only be classified as a worm-like animal of uncertain affinities. Its macroscopic size, flexible, elongate and cylindrical body, prominent and elastic annulations, possession of an anterior aperture demonstrate its metazoan origin and separate it from all known fossil and living algae. Its metazoan origin is further strongly evidenced by the naturally preserved cross sections because non-mineralized fossil algal bodies of originally cylindrical shape are not known to be preserved as fossils in this manner.

Genus Protoarenicola Wang, 1982

Diagnosis. As for type species.

Type species. Protoarenicola baiguashanensis Wang.

Age and distribution. Late Precambrian, North China Platform.

Protoarenicola baiguashanensis Wang, 1982

Plate 2:G

1980 ? Sabellidites spp. Zheng (undescribed), pl. 2, fig. 30.

1982 Protoarenicola baiguashanensis Wang, p. 11, pl. 2, fig. 3.

1982 Sabellidites sp. Wang, p. 14, pl. 2, fig. 2.

Holotype. A7906 (Plate 2:G; refigured from the specimen of Wang Guixiang, 1982, pl. 2, fig. 3).

Material and preservation. At least 3 specimens are known. Several fragments without ends may belong here. All are preserved as flattened black carbonaceous compressions on the bedding planes of laminated calcareous siltstone.

Horizon and locality. Same as Pararenicola huaiyuanensis.

Diagnosis. Body very narrow and slender, usually curved, consisting of numerous fine straight annulations, with uniform diameter through the length; sides distinct and smooth; anterior end conical, with a small distinct, ovate bulb in front.

Dimensions. The holotype is a fragment with well preserved anterior portion. It is 0.8 mm wide, more than 16mm long, with more than 12 annulations per mm. The front ovate bulb is 1.1mm wide and 0.6mm long. A larger fragment, resembling the holotype, is about 30mm long.

Comments. Protoarenicola baiguashanensis is distinguished from Pararenicola and Sinosabellidites by its very narrow and slender body,

with a ratio of width to length less than 1 : 20, and by the possession of a small, distinct, ovate bulb in the front. The latter character of the body also separates Protoarenicola from the fragments of Sabellidites tubes.

Some of the specimens that were found at the same stratigraphic level and referred by other names by previous authors are now regarded as probably conspecific with P. baiguashanensis. The only specimen of "Sabellidites" spp. figured by Zheng Wenwu (1980, pl. 2, fig. 30) is essentially similar to the holotype of P. baiguashanensis but its small conical anterior end is attached to a comparatively large elliptical (3 x 1.2mm) carbonaceous structure which appears like a deformed specimen of Chuarua. That rather strange appearance is probably due to preservational accident. Additionally, a few specimens that were referred to "Sabellidites sp." by Wang Guixiang (1982, pl. 2, fig. 2) are poorly preserved fragments, which are from 10 to 15mm long, about 1mm wide and finely annulated. They are very similar to body portions of P. baiguashanensis.

Structures showing the combined characters of a millimetric circular disc (cf. Chuarua) attached to a single ribbon-like or rod-like compression are known from the Suket Shale Formation, Semri Group, Vindhyan Supergroup in central India (Sahni and Shrivastava, 1954). A recent collection demonstrates that those structures possibly resulted from the closely positioned specimens of discoid Chuarua (= "Fermoria") and ribbon-like Tawuia (Mathur, 1983). Those ribbon-like structures, like typical Tawuia, lack any sign of annulations on the surface and can be separated from Protoarenicola. Also from the Suket Shale Formation, filamentous remains called Vindhyania Mathur 1983 have a reported size range 6-12mm long and 0.5-1mm wide, and appear like the main body of

Protoarenicola but again they differ in the absence of annulations and terminal features.

Unnamed "macroscopic microfossils" recently described by Peat (1984) from the late Precambrian Longmyndian Supergroup, Shropshire, England, include some enigmatic "nematomorph" carbonised structures, with a reported maximum size up to 0.155mm wide and 1.52mm long. Some of them are transversely striated and look, as figured (Peat, 1984, fig. 2a), somewhat similar to the main body of Protoarenicola at first glance. Those "nematomorph" structures were obtained from thin sections cut at a low angle to the bedding planes. Peat (1984, p. 21) tentatively interpreted them as "the organic lining of a metazoan dwelling tube or burrow" considering that they are "wider than the sheaths of known living "cyanobacteria", and are "associated with trace fossils of similar size".

Wang Guixiang (1982) referred Protoarenicola, together with Pararenicola, to Arenicolidae and interpreted its small front ovate bulb as proboscis. This small ovate structure may be analogous to the prostomium and pharynx of an arenicolid worm though there could be other possibilities; however, the main body of Protoarenicola is obviously different in shape and characters from Arenicolidae. Together with the better characterised Pararenicola, Protoarenicola is considered to be a second genus of "worm-like animals of uncertain affinities".

TIME RANGE AND STRATIGRAPHIC CORRELATION

The standard subdivision of the Upper Precambrian in China (Wang Yuelun ed., 1980; confirmed by the Geological Society of China in 1982; Huang Jiqing, 1983) suggests that the Upper Proterozoic of China consists of two major subdivisions, namely the Qingbaikou System (1000-800Ma) and

the Sinian System (*sensu stricto*, 800–600 Ma). The Qingbaikou System is represented by the Qingbaikou Group, which is the youngest major unit of the Jixian "Sinian" section in northern China and dated at the top as older than 850 Ma (Zhong Fudao, 1977; Chen Jinbiao *et al.*, 1980). The Sinian System is represented by the Yangtze Gorge Sinian section in southern China and the base is dated as younger than 800 Ma (Zhao Ziqiang *et al.*, 1980).

Based on the recent investigation and data presently available the time range of the continuously deposited Huainan and Feishui Groups falls in the interval of 900–700 Ma. The Huainan Group is comparable with the Qingbaikou Group in the Jixian section, northern China, and the Feishui Group is possibly older than the Nantuo Tillite in the Yangtze Gorge section, southern China. This sequence may link up or partially fill the gap between the two stratotype sections that are geographically and stratigraphically separated. This conclusion is illustrated by Fig. 14, and the evidence for it is as follows:

1. The Huainan Group is unconformably underlain by the Fengyang Group gneisses and schists, which were metamorphosed about 1650 Ma ago (K–Ar) and intruded by pegmatitic veins about 895 Ma ago (from Yang Qinghe *et al.*, 1980). The lower limit of the Huainan Group is therefore younger than 900 Ma.

2. The Huainan Group (the Bagongshan and Liulaobei Formations) is comparable with the Jingeryu Formation of the Qingbaikou Group in the Jixian section, northern China, and the Xihe Group (the Diaoyutai and Nanfen Formations only, redefined by Zhong Fudao, 1977) in the Fuxian district, southern Liaoning Province, northeastern China. These sequences are distributed on the North China Platform. The compared

CORRELATION CHART OF THE UPPER PRECAMBRIAN IN CHINA

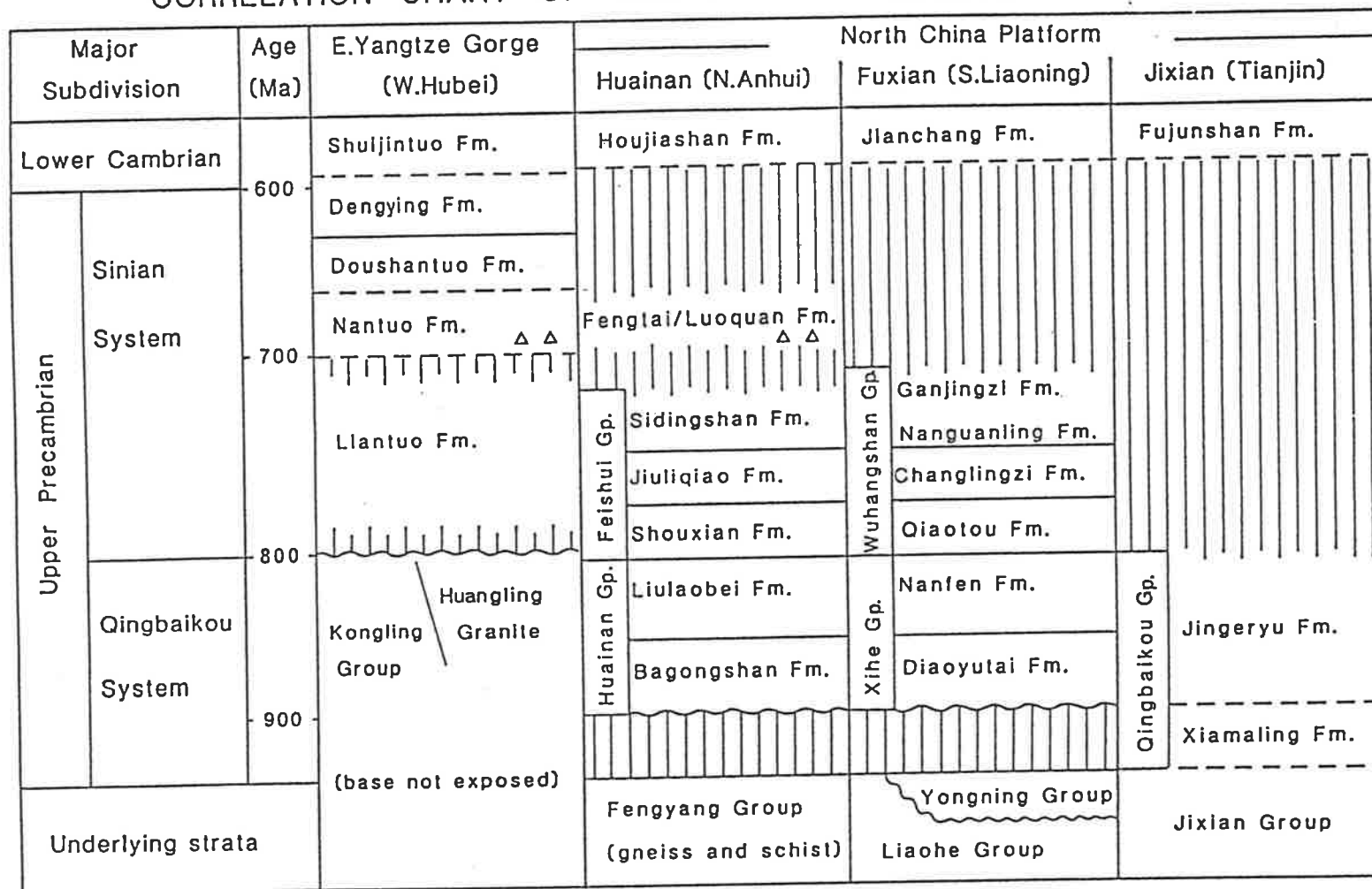


Fig. 14. Correlation chart of the Upper Precambrian in China, showing the possible stratigraphic relationship of the sequence in the Huainan district with the key sections in the Eastern Yangtze Gorge, southern China and on the North China Platform. Age indications given in the text.

strata are very similar in lithological characters and have either an unconformity or disconformity at the base, indicating that they were possibly deposited during the same late Precambrian transgression though the base may be diachronous. This correlation has been supported by the common occurrence of Chuaria circularis Walcott (Zheng Wenwu, 1980; Duan Chenghua, 1982), and further confirmed by a Rb-Sr whole-rock isochron of 840 Ma on the shales of the Liulaobei Formation (from Wang Guixiang, 1982).

3. The equivalent of the Feishui Group is missing within the disconformity between the Qingbaikou Group and the overlying Lower Cambrian in the Jixian section. The correlation of the Feishui Group with the Wuhangshan Group in the Fuxian district of southern Liaoning is based on the similar stratigraphic relationship, sedimentary characters and stromatolite assemblages. This correlation is now confirmed by the presence of Chuaria circularis Walcott and worm-like body fossils resembling Pararenicola huaiyuanensis in the Changlingzi Formation of the Wuhangshan Group (Chen Meng'e et al., 1982).

Stromatolites in the Jiuliqiao and Sidingshan Formations, Feishui Group have been identified by Cao Ruiji and Zhao Wenjie (in Yang Qinghe, et al., 1980), including morphological groups Tungussia, Anabaria, Boxonia, Conophyton, Gymnosolen, Georginia, Inzeria, Jurusania, Kussiella, Linella, Minjaria, etc. The general features of this stromatolite assemblage are commonly considered to be of Late Riphean aspect.

A few radiometric datings by K-Ar method on glauconites have been obtained from the Feishui Group, (from Wang Guixiang, 1982): 749.8 Ma for the Shouxian Formation and 738.5 Ma for the Jiuliqiao Formation, in which abundant worm-like fossils represented by Pararenicola huaiyuanensis and

Protoarenicola baiguashanensis occur. These figures probably indicate only the minimum ages of the dated formations on account of the potential loss of argon.

4. The Feishui Group is older than the late Precambrian Luoquan Tillite, which is distributed along the southern margin of the North China Platform (Wang Yuelun et al., 1982). In the Huainan district, the Sidingshan Formation is disconformably covered by the Fengtai conglomerate of glaciogene drop-stone facies. In the westernly adjacent Huoqiu-Gusi district on the border between Anhui and Henan Provinces, the Sidingshan Formation is disconformably overlain by the Luoquan Tillite (Li Yinyun et al., 1977; Mu Yongji, 1982; Ren Yunshen, 1982). Despite facies change between glaciogene diamictite and typical tillites, the Fengtai Conglomerate and the Luoquan Tillite are related to the same glaciation.

The distributions of the Luoquan Tillite and the Nantuo Tillite are separated by the Qinling-Dabie tectonic zone and there is no direct evidence to prove their stratigraphic relationship. It seems appropriate to refer both of them to a single late Precambrian glaciation, probably the Varangian (Chumakov, 1981). Wang Yuelun et al. (1980, 1982) and Chen Jinbiao et al. (1981) proposed a latest Precambrian age for the Luoquan Glaciation and placed the Luoquan Tillite on the same level as the Dengying Formation in the top of the Yangtze Gorge Sinian section. Liu Hungyun et al. (1980) and Mu Yongji (1982) disagreed with their proposal and compared the Luoquan Tillite with the Nantuo Tillite. They demonstrate a significant disconformity between the Luoquan Tillite and the regionally overlapping Lower Cambrian and show that the equivalents of the Doushantuo and Dengying Formations are mostly missing within the disconformity.

5. The supposed "Cyclomedusa" from the top of the Changlingzi Formation, Wuhangshan Group in the Fuxian district, southern Liaoning Province (Xing Yusheng and Liu Guizhi, 1979) previously influenced the stratigraphic correlation and age-determination of the equivalent sequence (the Feishui Group) in the Huainan district (Xing Yusheng, 1976, 1980; Wang Yuelun et al., 1980; Chen Jinbiao et al., 1981). The supposed "Cyclomedusa" from southern Liaoning has been critically re-examined in conjunction with the true medusa Cyclomedusa in the Ediacara faunal assemblage of South Australia (see Chapter 4; Sun Weiguo, in press), and has been proved to be pseudofossils made by upwards escaping gas and/or fluids through single vertical channels (in agreement with Glaessner and Daily, 1979, unpublished, and Glaessner, 1984).

6. For the time range of the Huainan-Feishui Groups to be confirmed to the interval 900-700 Ma, significant evidence is the presence of both Chuaria Walcott and Tawua Hofmann in the Liulaobei and Jiuliqiao Formations (Zheng Wenwu, 1980; Duan Chenghua, 1982). The Chuaria - Tawua macroscopic fossil assemblage was initially described from the late Precambrian Little Dal Group in the Mackenzie Mountains, northwestern Canada (Hofmann and Aitken, 1979). The Little Dal Group is unconformably covered by the basal Windermere tillites of the Rapitan Group. Armstrong et al. (1982) dated the diabase intruding the Little Dal Group by the Rb-Sr whole rock isochron method and concluded that the Little Dal Group is older than 770 Ma.

SIGNIFICANCE OF THE HUAINAN MACROSCOPIC FOSSIL ASSEMBLAGE

The Upper Precambrian in the Huainan district consists mainly of two continuously deposited shallow water marine sedimentary cycles, the

Huainan and Feishui Groups. This sequence is younger than 900 Ma, older than 700 Ma, and predates the late Precambrian Luoquan glaciation. The occurrences of abundant and varied macroscopic organisms in this sequence are confined to two stratigraphic formations. The older is the Liulaobei Formation of the Huainan Group and the younger the Jiuliqiao Formation of the Feishui Group. The two fossiliferous units are separated by the non-fossiliferous Shouxian Formation (high-energy intertidal sandstone) at the base of the Feishui Group. The whole late Precambrian Huainan macroscopic fossil assemblage may be called the Chuaria-Tawuia assemblage. These two kinds of macroscopic colonial bodies of algae are amazingly abundant in the Liulaobei Formation but become much less frequent in the Jiuliqiao Formation. Based on the macroscopic worm-like body fossils, two subassemblages can be recognised. In the Liulaobei subassemblage, Sinosabellidites, a worm-like organism of questionable metazoan origin, occurs in lesser quantity. It resembles the associated Tawuia but differs in having regular fine annulations on the enclosed cylindrical body. In the Jiuliqiao subassemblage, the first occurring worm-like animals of Pararenicola and Protoarenicola are dominant. They are apparently more advanced than Sinosabellidites in their more flexible bodies, more prominent and elastic annulations, possession of an anterior aperture and/or a differentiated front apparatus. Their general configurations and appearances tend to support the view of their metazoan origin, although their systematic positions are difficult to clarify in the light of the classification of the living worms. The palaeontological discoveries from the time interval represented by the Liulaobei stage, about 850 Ma ago, to the Jiuligiao stage, about 740 Ma ago are considered to have the potential of extending our knowledge about the oldest multicellular animals and the early evolutionary diversification of the Metazoa. As a matter of stratigraphic procedure, stages are given the same geographic names as the equivalent formations.

It is only in the last five years that macroscopic fossil assemblages consisting of Chuarina and Tawuia have been successively described from Canada (Hofmann and Aitken, 1979), China (Zheng Wenwu, 1980; Duan Chenghua, 1982), Svalbard (Knoll, 1982) and India (Mathur, 1983). Data available at present indicate that all these occurrences may fall in a time interval approximately from 900 Ma to 700 Ma, and they are either stratigraphically below or correlationally older than the regional late Precambrian tillites on each continent. The Huainan assemblage ("The Huainan Biota", Zheng Wenwu, 1980) of the North China Platform is particular in the association of diverse worm-like organisms. Sinosabellidites, Pararenicola and Protoarenicola were contemporaneous with and adapted to the same living and/or preservational conditions as Chuarina and Tawuia. Further investigations may prove that the macroscopic worm-like body fossils first found in the Huainan district (Zheng Wenwu, 1980; Wang Guixiang, 1982) may also have an extensive distribution, particularly in the successions where the Chuarina - Tawuia assemblage has already been found.

Apart from the enigmatic Sinosabellidites, both Pararenicola and Protoarenicola are claimed to be the oldest multicellular animals so far discovered in the world and the first reliable evidence for the pre-Ediacarian evolutionary history of the manifest metazoan life. Their general simple configurations lack sufficient diagnostic characters to show their possible relationship with recent annelids or other worms but, as expected, demonstrate the relatively primitive nature of these late Precambrian fossil Metazoa.

While a majority of scientists (Cloud, 1968, also in Cloud and Glaessner, 1982; Margulis, 1970; Schopf et al., 1973; Knoll and Barghoorn, 1975; Stanley, 1976) considered that the early diversification

of the Metazoa could not have started until about 700 Ma ago or could have been triggered by the warming of the atmosphere after the late Precambrian glaciations, Glaessner (1972, 1983, 1984) inferred a prolonged evolutionary process leading to the appearance of the Ediacarian faunal assemblages and proposed that the beginning of that process might be 1000 Ma ago. The relatively high level of the metazoan diversification reached by the Ediacarian faunal assemblages indicates that they "do not represent the earliest Metazoa" (Glaessner, 1984, p. 30). This latest point of view is now supported by the discoveries of the primitive worm-like body fossils from the Huainan district, North China Platform and may be proved by further investigations in China and elsewhere.

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CHAPTER 3

PALAEONTOLOGY AND BIOSTRATIGRAPHY
OF LATE PRECAMBRIAN MACROSCOPIC COLONIAL ALGAE:
CHUARIA WALCOTT AND *TAWUIA* HOFMANN

ABSTRACT

Chuaria Walcott 1899 and Tawuia Hofmann 1979 are among the oldest known macroscopic organisms. These previously enigmatic fossils have been studied in detail based on abundant well preserved specimens from the late Precambrian (900-700 Ma) strata on the North China Platform. With the aid of improved techniques, this study initially discovered filamentous cellular structures in the small circular discoidal carbonaceous compressions of Chuaria. This late Precambrian fossil is now interpreted as analogous to the spherical colony of the living filamentous bluegreen alga Nostoc in shape, size range and general configuration. Tawuia is represented by relatively large, elongate, ribbon-like, carbonaceous compressions with characteristic rounded ends, and is considered to have a very close taxonomic relationship with the accompanying Chuaria. Both genera are referred to the Family Chuariaceae Wenz (1938, nom. corr.), which is redefined as a group of planktonic colonial filamentous algae and tentatively placed in the Order Nostocales Geitler 1925.

The global distribution of Chuaria is demonstrated by its occurrence in the U.S.A., Canada, Sweden, Svalbard, Iran, India, China, Argentina and probably in western Africa and elsewhere. Most of these occurrences

are bracketed within the time range 1000 - 700 Ma. Considering that all the previously reported occurrences of Chuar were described without finding potentially preserved cellular structures and that separation of Chuar from some large microscopic sphaeromorphid acritarch forms can be confused by similar gross morphology and partially overlapped size range, using Chuar as an index fossil is possible but practically difficult. However, the distinctive Chuar - Tawuia macrofossil assemblage, with its recently known occurrence in Canada, China, Svalbard and India, has proved to be a significant, valid and convenient biostratigraphic index for the global correlation of the Late Riphean, predating the Varangian glacial event and the appearance of the Ediacara-type metazoan assemblages.

INTRODUCTION

Chuar Walcott 1899, represented by millimetric, circular, discoidal, carbonaceous compressions, is one of the oldest known macroscopic body fossils. It has been found worldwide in late Precambrian sediments. In Canada, China, Svalbard and India, Chuar has been recently found together with relatively large, elongate, ribbon-like carbonaceous compressions of Tawuia Hofmann 1979. Studies of Chuar and Tawuia are important, not only in understanding the evolutionary history of a major group of Precambrian algae, but also in recognizing their potential significance as a biostratigraphic index for international upper Precambrian correlation.

RESEARCH HISTORY

Walcott (1899, pp. 234-5; pl. 27, figs. 12 & 13) originally described Chuar circularis, the type species, from what is now known as the late Precambrian Chuar Group at the Kwagunt Valley in the Grand Canyon, Arizona, U.S.A. He considered these discoidal fossils as compressed shells of a discinoid brachiopod on account of more or less concentric wrinkles often occurring on the discoidal surfaces.

Prior to Walcott's description, specimens referable to Chuar had already been found from the Grand Canyon by White (Powell, 1876) and from the late Precambrian Visingsö Formation in southern Sweden by Wiman (1894). Fossils appearing like Chuar were successively found in late Precambrian sequences in several other regions and described under different names.

Ford and Breed (1973b) made a comprehensive review on the type

material of Chuaria circularis and various Chuaria-like forms.

According to them, Chuaria had been regarded as an inorganic structure, a dubiofossil of unknown origin, a brachiopod, a gastropod, a chitinous foraminiferid, a hyolithid operculum, a trilobite egg, a juvenile medusoid, an alga, or an acritarch. Ford and Breed considered Chuaria to be algal in origin, in agreement with Howell (1956), Glaessner (1966) and Cloud (1968), and referred to it as an unusually-large planktonic sphaeromorphid acritarch belonging to the Family Leiosphaeridae Eisenack 1959. They included C. wimani Brotzen 1941 from Sweden, the species of Fermoria Chapman and Protobolella Chapman 1935 from India and several other questionable Chuaria-like forms in a single species, C. circularis, on the basis of their morphological similarities, particularly in size and shape. They proposed an arbitrary lower size limit at 0.5mm in diameter for Chuaria in order to separate it from various acritarch forms which are generally smaller. For the first time, they pointed out the potential of Chuaria as a stratigraphic index fossil for the rocks from 1,000 Ma to the beginning of Cambrian.

Ford and Breed's report stimulated worldwide investigation and discussion on the palaeontological and stratigraphic significance of Chuaria. A crucial problem encountered in the discussion was that knowledge of Chuaria was still limited to the gross morphology of compressed specimens. As different authors had their own criteria for identification, on the one hand a number of new names have been erected for the genus and species of Chuaria circularis, on the other, many heterogeneous forms have been assigned to this taxon. In fact, the term Chuaria has become a morphological group (Hofmann, 1977; Cloud, 1983) to which Precambrian discoidal structures of different origins were referred. Without critical discrimination, forms with this morphology are found to vary in diameter from less than 0.1 mm (Vidal, 1974, 1976)

to more than 5 mm (Ford and Breed, 1973b) and even up to 44 mm (Hofmann, 1977; Ford and Breed, 1977) and range in age from about 1,800 Ma (Hofmann and Chen, 1981) to the beginning of Cambrian (Ford and Breed, 1973b; Hofmann, 1977; Xing Yusheng *et al.*, 1984).

A significant new phase in studies of Chuar was marked by discoveries of the Chuar-Tawu macrofossil assemblage initially from the late Precambrian Little Dal Group in northwestern Canada (Hofmann and Aitken, 1979) and subsequently from the upper Precambrian in northern China (Zheng Wenwu, 1980; Duan Chenghua, 1982), Svalbard (Knoll, 1982) and central India (Mathur, 1983).

Hofmann (in Hofmann and Aitken, 1979) at first included Tawu, type species T. dalensis Hofmann 1979, in the Family Vendotaenidae Gnilevskaya 1971 and regarded Chuar as a sphaeromorphid acritarch. Hofmann (1981) then hypothesized that both Chuar and Tawu could be eucaryotic algae and probably represented an alternation of generations of the same organism. Duan Chenghua (1982) assumed that both Chuar and Tawu could be advanced multi-cellular algae (in agreement with Zheng Wenwu, 1980) and supposed that Tawu was probably related to Chuar due to a "morphological change" in the process of evolution. On this basis, Duan (1982, p. 58) referred both Chuar and Tawu to the Family Chuariaceae Wenz 1938 (*nom. corr.*) with an emended definition as multicellular algae, rather than gastropods as Wenz (1938) had previously suggested. Duan (1982, p. 67) further interpreted that this family "may have had some evolutionary relationship with the later forms of Vendotaenia".

Without any accompanying explanation, Tappan (1980) placed Chuar in the Family Leiosphaeridiaceae under the Order Pyramimonadales (green

algae), and Surech and Sundra Raju (1983) hinted that Chuararia was perhaps a colonial alga like Volvox.

It should be noted that all the previous interpretations of Chuararia and Tawuia were speculations based on gross morphology, mainly size and shape of compressions. After almost one century of investigations, the original configuration and systematic affinities of Chuararia remained uncertain until the present study determined its internal structures and compared it with the colonies of the living filamentous bluegreen alga Nostoc Vaucher 1803.

OCCURRENCES AND STRATIGRAPHY

This study was based on abundant well-preserved specimens recently collected from late Precambrian strata, about 900-700 Ma old, in the Huainan and Fuxian districts on the North China Platform.

Following the discoveries by Zheng (1980), Duan (1982) and Du Ruling (1982), it has been known that Chuararia is widely distributed in late Precambrian shallow, marine, fine-grained clastics on the North China Platform (Fig. 15). The common occurrence of Chuararia provides important evidence for the stratigraphic correlation of the late Precambrian sequences over the vast North China Platform (Fig. 16).

In the Jixian section (Locality 1, Fig. 15), the stratotype for the upper Precambrian of northern China, Chuararia occurs in the shales of the middle Jingeryu Formation, Qingbaikou Group (Duan, 1982), which is the top unit of the section and covered by the Lower Cambrian Fujunshan Formation with a sedimentary break in between. Glauconites from the middle and top parts of the Jingeryu Formation have been dated by the

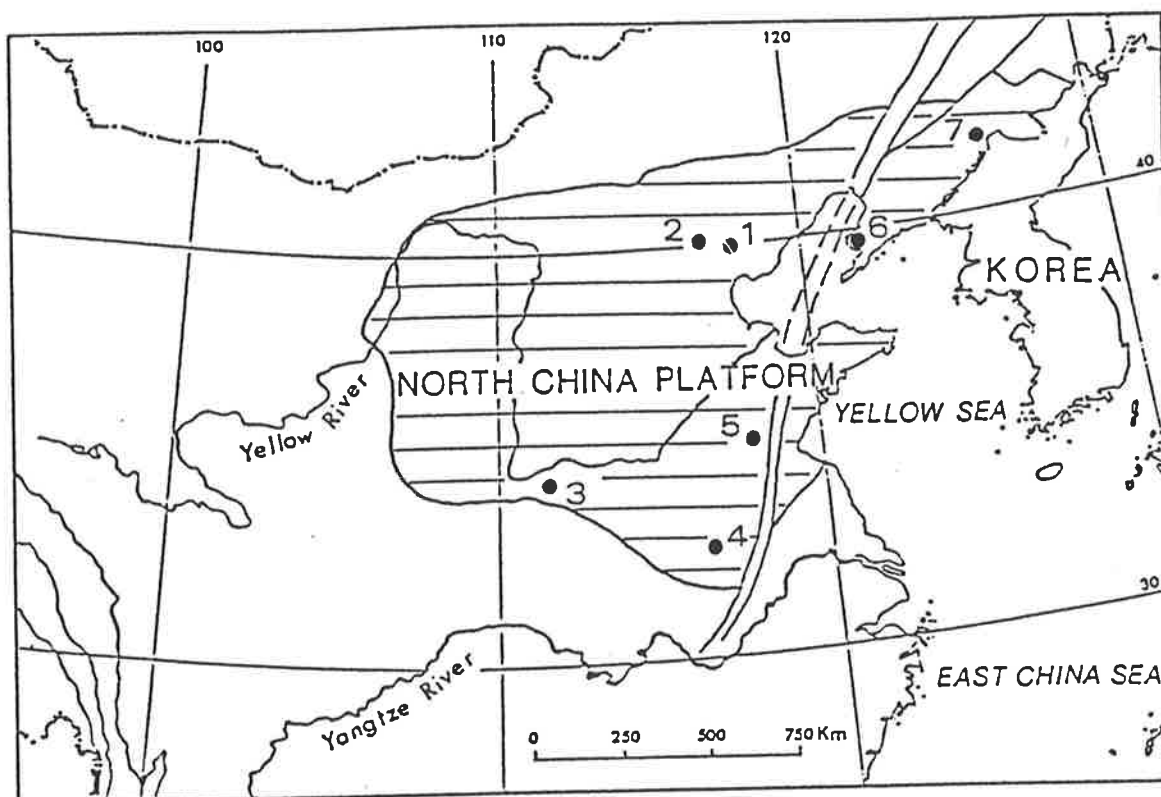
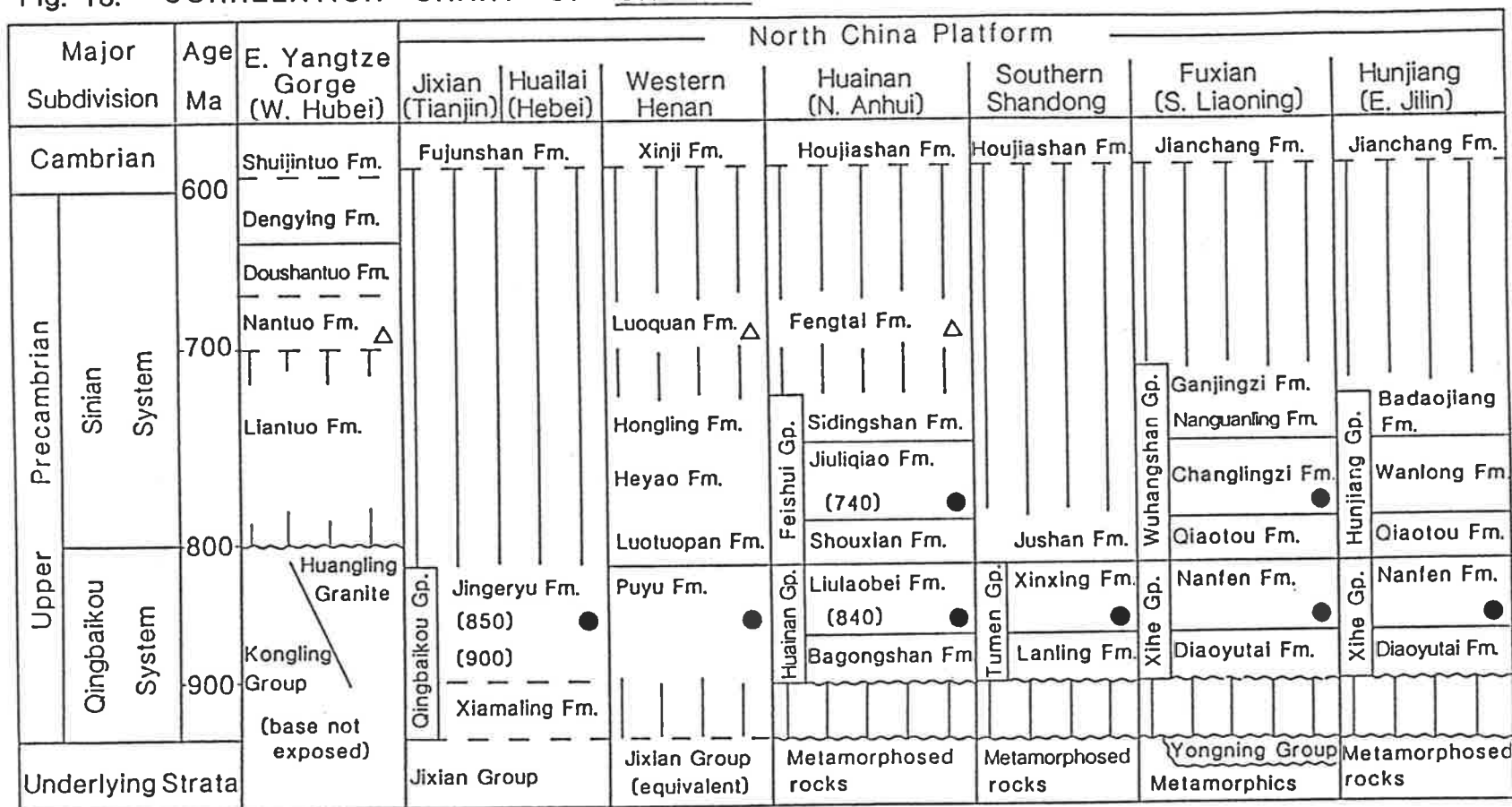


Fig. 15. Locality Map showing the distribution of Chuarina circularis Walcott on the North China Platform. 1. Jixian, Tianjin; 2. Huailai, Hebei Province; 3. western Henan Province; 4. Huainan, northern Anhui Province; 5. southern Shandong Province; 6. Fuxian, southern Liaoning Province; 7. Hunjiang, eastern Jilin Province.

Fig. 16. CORRELATION CHART OF CHUARIA - BEARING SECTIONS IN CHINA



K-Ar method at about 900 Ma and 850 Ma respectively (Zhong Fudao, 1977; Chen Jinbiao et al., 1980).

The Chuar-bearing strata on the North China Platform are best represented by the late Precambrian sequence in the Huainan district, northern Anhui Province (Locality 4, Fig. 15). This approximately 2,000 m thick sequence is confined at the base by the unconformably underlying Fengyang Group metamorphic complex and at the top by the disconformably overlapping Lower Cambrian Houjiashan Formation. This sequence consists mainly of two continuous marine sedimentary cycles, namely the Huainan Group (older) and the Feishui Group (younger), and a disconformable top unit, the Fengtai Formation. The Huainan Group comprises two rock formations. The lower is the Bagongshan Formation, consisting of supratidal and intertidal quartz sandstone with basal conglomerate. The upper is the Liulaobei Formation, consisting of neritic shales and alternations of siltstone, shale and laminated argillaceous limestone. The Feishui Group is made up of three formations. The lower is the Shouxian Formation with intertidal feldspathic sandstone and calcareous, glauconitic sandstone; the middle is the Jiuliqiao Formation composed of subtidal argillaceous limestone with stromatolites and calcareous siltstone interbeds; the upper is the Sidingshan Formation built by intertidal carbonate deposits, mainly stromatolitic dolomite with chert concretions and layers. The Fengtai Formation consists of conglomerate and associated dropstone facies, indicating a glaciogenic origin for parts of this formation. I recently restudied this sequence and presented a detailed report in Chapter 2 (Sun Weiguo et al. in press).

Abundant specimens of various macroscopic organisms, including Chuar, Tawuia and some worm-like fossils, have been found in the Liulaobei and Jiuliqiao Formations in the Huainan district (Zheng, 1980;

Yang Qinghe et al., 1980; Duan, 1982; Wang Guixiang, 1982). This assemblage, initially called "the Huainan biota" by Zheng Wenwu (1980), has been re-investigated recently and named the Chuarua-Tawuia macrofossil assemblage (see Chapter 2; Sun Weiguo et al., in press). Chuarua and Tawuia are abundant in the greenish grey shales and laminated calcareous siltstone at many levels in the middle and upper parts of the approximately 930 m thick Liulaobei Formation, but they are much less frequent in the laminated calcareous siltstone and argillaceous limestone of the 26 - 45 m thick Jiuliqiao Formation. The two fossiliferous units are conformably separated by the sandstone of the Shouxian Formation, in which no macroscopic organic remains are preserved, presumably because of the high energy sedimentary environment and coarser sediment grain size.

The time range represented by the Huainan-Feishui Groups has been estimated to be approximately 900-700 Ma. (see Chapter 2; Sun Weiguo et al., in press). The Huainan Group is correlated with the Jingeryu Formation, Qingbaikou Group in the stratotype Jixian section (Fig. 16). The Feishui Group is completely missing in the Jixian section. The Fengtai Formation is comparable with the known late Precambrian Luoquan Tillite, which is distributed along the southern and western margins of the North China Platform. As shown in Fig. 16, the Luoquan Tillite may be compared with the approximately 700 Ma old Nantuo Tillite on the Yangtze (Southwest China) Platform, but the stratigraphic relationship between the two tillites remains uncertain because the North China and Yangtze platforms are separated by the Qinling-Dabie Tectonic Zone (see Chapter 2; Sun Weiguo et al., in press).

Radiometric datings indicated that (a) the unconformably underlying Fengyang Group schists and gneisses were intruded by pegmatitic veins

about 895 Ma ago (K-Ar, from Yang Qinghe et al., 1980); (b) the middle part of the Liulaobei Formation, Huainan Group, is about 840 Ma old (Rb-Sr whole rock isochron on shales, from Wang Guixiang, 1982); and (c) the Jiuliqiao Formation, Feishui Group is about 740 Ma old (K-Ar age on glauconites, from Wang Guixiang, 1982). These quoted ages are regarded as valuable reference but need to be further refined.

In the Fuxian district, southern Liaoning Province (Locality 6, Fig. 15), the sequence comparable to the Huainan-Feishui Groups are the Xihe-Wuhangshan Groups. Abundant specimens of Chuarina have been found, without accompanying Tawuia, in the greenish grey or yellow green shales and laminated siltstone of the Nanfen Formation, the upper part of the Xihe Group (Zheng, 1980; Duan, 1982). A few specimens of C. circularis have been found more recently in the Changlingzi Formation, the middle part of the Wuhangshan Group (Chen Meng'e et al., 1982). The fossiliferous Nanfen and Changlingzi Formations are separated in a continuous sequence by the non-fossiliferous sandstone of the Qiaotou Formation. The time range of this sequence is inferred by its correlation with the Huainan-Feishui Groups in the Huainan district.

MATERIAL

Material available for the present study includes numerous specimens of Chuarina and more than 20 specimens of Tawuia, numbered with a prefix A82-, from the Liulaobei Formation, Huainan Group and the Jiuliqiao Formation, Feishui Group of the Huainan district, and more than 300 specimens of Chuarina, numbered with a prefix L79-, from the Fuxian district (see Figs. 15-16).

All the specimens figured in this paper will be deposited at Nanjing

Institute of Geology and Palaeontology, Academia Sinica, Nanjing, China.

RESEARCH TECHNIQUES

Specimens of Chuarua and Tawuia are black, macroscopic, membranous and carbonaceous (carbonized) compressions. Observations of compressions on the rock surfaces can be improved by wetting the surfaces with water, alcohol or liquid paraffin and examining the fossils under a stereoscopic binocular microscope. Nevertheless, such observations are confined to the gross morphology of the compressed bodies. No microscopic cellular structures can be seen with this technique because the surface specimens are opaque. Many previous authors did not carry their analysis beyond this stage.

Scanning electron microscopy (Plate 5 : C,D), adds little to our knowledge as the organisms were intensely crushed and compacted into membranous compressions which now exhibit merely the outline, wrinkles, folds and shrinkage cracks of secondary origin. The compressed surface was deformed further by compaction against sand and silt grains in the rock matrix. Several specimens were examined with the SEM up to X1,000, but no structures of particular interest were discerned.

The chemical composition of Chuarua compressions has been tested with HCl, HF and other acids by Eisenack (1966) and with the electron probe by Jarosewich (Ford and Breed, 1973b, p. 544). The results, agreed by the present study, indicate that Chuarua compressions are acid-resistant and dominantly carbonaceous. However, the origin of Chuarua cannot be decided in this way, because various organisms, both plants and soft parts of animals, can also be carbonized (Walcott, 1919, p. 220).

The palynological method, by which microscopic fossils such as acritarchs can be obtained through the process of acid maceration, is not satisfactory for the present material. This method has been described in detail and used in studies of Chuar by Vidal (1974, 1976). The problem is that macroscopic, membranous compressions of Chuar are delicate and easily broken into small fragments when the rock samples are dissolved in acid. They are further damaged during acid changing, washing, sieving and centrifuging, etc. According to Vidal (1974, 1976), the residue contains abundant very small vesicles, mostly ranging 0.09 - 0.2 mm in diameter. Those are without any known cellular structure and are difficult to separate from accompanying sphaeromorphid acritarchs, such as Leiosphaeridia (see Lindgren, 1981). Thus their identification with the macroscopic compressions on the bedding planes is uncertain.

Chuar, Tawua and other macroscopic membranous carbonaceous compressions can be studied in detail by making cellulose acetate sheet peels or bioplastic transfers. The carbonaceous compressions, which are resistant to HF and HCl, can be freed from the rock surfaces and embedded directly in either a cellulose sheet or a bioplastic film without damage and alteration of the membranous organic remains. As the cellulose sheet and bioplastic film are as transparent as a glass slide, they can be mounted and examined with transmitted light at high magnification. Well preserved and appropriately prepared specimens show microscopic details of the compressions, which provide reliable evidence for the interpretation of the origin and systematic affinities of Chuar and Tawua.

Ford and Breed (1973b, pl. 61, figs. 6 and 7; pl. 62, figs. 1 and 4) illustrated a few peels of Chuar, examined them at magnifications just up to X40, and they did not find any detailed structures.

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The standard process of making peels has been demonstrated by Stewart and Taylor (1965, pp. 224-247). Making peels normally needs a surface which has been ground and polished. In the present study, each peel was made for an individual compression or a small cluster of them at the place where the bedding plane of the shale or laminated siltstone was comparatively smooth, because the compression is extremely thin and delicate and the surface cannot be ground and polished.

The technique of making bioplastic transfers has been improved and introduced by Banks (in Banks et al., 1972, pp. 19-21) in the study of carbonaceous compressions of a Devonian plant. Banks' method was modified for the present study. The selected rock specimens were small, very thin pieces of shale or laminated siltstone, each with one or several individual compressions on a bedding surface. The surface with compressions on it was covered with a 0.5 - 1 mm thick layer of bioplastic. When the bioplastic became completely dry, the specimen was macerated with 40 percent HF until all the extraneous rock was dissolved. This process must be carried out carefully in a fume cabinet. Eventually, a thin, transparent, bioplastic film was obtained with the organic membrane of the compressions completely embedded on the lower side of the bioplastic transfer.

To remove all sediment grains and possible chemical products from the surfaces of prepared specimens, the peels and bioplastic transfers were further treated by (1) washing them with distilled water; (2) placing them for periods of several to thirty minutes in baths of concentrated HCl both before and after each treatment with HF; (3) thoroughly washing them several times.

The transparency of the separated organic membrane embedded in either

peels or bioplastic transfers varies from opaque to resinous, depending on the density and thickness of each compression. The specimens which are translucent are suitable for study at high magnification (Plate 6 : G.H). Some of the specimens which are opaque or dark brown were treated with concentrated HNO_3 saturated with crystals of KClO_3 but their transparency was not improved effectively.

In the course of this study, more than 50 peels and 20 bioplastic transfers were prepared. Most of them were mounted individually between a glass slide and a cover slip with mounting medium of either glycerine jelly or canadabalsam. Several bioplastic transfers which were slightly thicker than 1 mm were placed in flat-bottom transparent dishes, wetted with distilled water when examined under a transmitted light microscope. The mounted specimens were examined at magnifications up to X400 and the unmounted up to X100.

The bioplastic used for this study is ESCON EX 80 with one percent of M.E.K.P. Catalyst, both produced by Escon Chemicals Pty. Limited, Sydney, Australia.

SYSTEMATIC PALAEONTOLOGY

Subkingdom	Algae
? Division	Cyanophyta Smith, 1938
? Class	Cyanophyceae Sachs, 1874
? Order	Nostocales Geitler, 1925
Family	Chuariaceae Wenz, 1938
(nom. correct. Duan Chenghua, 1982 (<u>nom. transl. ex</u> Chuariidae Wenz, 1938))	
<u>Type genus.</u>	<u>Chuar</u> Walcott, 1899

Diagnosis. (revised from Duan Chenghua, 1982, p. 58). Colonies of cellular filamentous algae; colonial bodies growing up to macroscopic size and varying from sphaeroidal to elongate cylindrical in different forms (usually preserved as carbonaceous compressions); trichomes uniseriate and unbranched; heterocysts indistinct or absent.

Genus Chuar Walcott, 1899

Type species. Churia circularis Walcott, 1899

Diagnosis. As for type species

Chuar circularis Walcott, 1899

Plate 5 : A-H; Plate 6 : A-H; Plate 8 : A-B, partim.

1899 Chuar circularis Walcott, pp. 234-5, pl. 27, figs. 12, 13.

1935 Fermoria minima Chapman, p. 115, pl. 1, figs. 1, 3.

1935 Fermoria granulosa Chapman, p. 116, pl. 1, figs. 2, 4; pl. 2, fig. 5.

1935 Fermoria capsella Chapman, p. 117, pl. 2, figs., 3-4.

1935 Protobolella jonesi Chapman, p. 117, pl. 1, figs. 5-6; pl. 2, fig. 1.

1936 Fermoria minima Chapman; Sahni, p. 446, pl. 43, figs. 1-4.

1941 Chuar wimani Brotzen, p. 260 (based on the unnamed specimens in Wiman 1894, pp. 109-113, pl. 5, figs. 1-5.

1963 "Problematica", Assereto, p. 502, fig. 2.

1966 Chuar wimani Brotzen; Eisenack, p. 52, fig. 1.

1969 Kildinella magna Timofeev, p. 14, pl. 6, figs. 4, 5.

1969 Trachysphaeridium vetterni Timofeev, p. 21, pl. 6, fig. 3.

1970 Kildinella magna Timofeev, p. 158, pl. 1, figs. A, B.

1972a Chuar circularis Walcott; Ford and Breed, p. 17, pl. 1, figs. 1-6; pl. 2, figs. 1-4.

- 1973b Chuararia circularis Walcott; Ford and Breed, p. 539, pl. 61, figs. 1-7; pl. 62, figs. 1-6; pl. 63, figs. 1, 2, 4.
- 1974 Chuararia circularis Walcott; Vidal, p. 7, pl. 1, figs. 3-6 (partim).
- 1976 Chuararia circularis Walcott; Vidal, p. 18, figs. 8A-H, (partim).
- 1977 Chuararia circularis Walcott; Hofmann, p. 3. figs. 2a-j.
- 1977 Fermoria - disc-like remains type 1-6, Maithy and Shukla, p. 183, pl. 5, figs. 35-40.
- 1977 Tasmanites vindhyanensis Maithy and Shukla, p. 182, pl. 4, figs. 32, 33.
- 1979 Nucellosphaeridium spp. Hofmann (in Hofmann and Aitken), p. 156, figs. 12 A-C.
- 1979 Chuararia circularis Walcott; Hofmann (in Hofmann and Aitken), p. 157, figs. 13 K-M.
- 1979 Morania ? antiqua Fenton and Fenton; Hofmann (in Hofmann and Aitken), p. 160, partim.
- 1979 Shouhsienia shouhsienensis Xing, no description, pl. 12, figs. 6, 7.
- 1979 Chuararia circularis Walcott; Xing Yusheng, no description, pl. 12, fig. 9.
- 1980 Chuararia circularis Walcott, Zheng Wenwu, p. 59, pl. 1, figs. 1, 2; pl. 2, figs. 14, 15, 34.
- 1980 Chuararia annularis Zheng, p. 60, pl. 1, figs. 5, 6.
- 1982 Chuararia circularis Walcott; Duan Chenghua, p. 59, figs. 3 A-J; figs. 5 A-J, O-P.
- 1982 Chuararia circularis Walcott; Knoll, pl. 2, fig. 1; pl. 4, figs. ? 7, 13.
- 1982 Chuararia circularis Walcott; Du Rulin, p. 2, figs. 1-3.
- 1982 Chuararia cf. circularis Du, p. 2, fig. 4.
- 1983 Chuararia circularis Walcott; Suresh and Sundra Raju, pp. 81-2, fig. 2. 1-5.
- 1983 Chuararia circularis Walcott; Mathur, pp. 363-4, figs. 1A.

1983 Chuar fermorei Mathur; pp. 363-4, fig. 1B.

1983 Chuar olavarriensis Baldis et al.; pp. 78-9, pl. 1, figs. k, 3, 10.

1984 ? Chuar circularis Walcott; Amard and Affaton, p. 979, fig. 3a-e.

Type Material. The type material from what is now known as the Kwagunt Formation, Chuar Group, in the Kwagunt Valley, Grand Canyon, Arizona, is catalogued under U.S. National Museum No. 33800. Walcott (1899) did not designate a holotype but figured two type specimens. The specimen of Walcott's fig. 12 was designated as a lectotype by Ford and Breed (1973b, pl. 61, fig. 1). Some supplementary specimens from the type locality were collected and figured by Ford and Breed (1973b, pl. 61, figs. 2-6; pl. 62, fig. 1).

Diagnosis (revised from Ford and Breed, 1973b, p. 539). Black, circular to oval, discoidal, membranous, carbonaceous compressions, millimetric in diameter; periphery distinct and smooth; concentric and/or irregular wrinkles and folds usually shown on the discoidal surfaces due to collapsing and crushing of the originally spheroidal bodies.

Organic films of compressions varying from opaque to translucent resinous yellow; internal structures consisting of numerous, densely compacted, entangled filaments; filaments without distinct sheaths; trichomes uniseriate, unbranched, 1-2 μ m wide and each composed of a bead-like chain of granular cells; in some cases, colonies also containing one or more tiny circular bodies (daughter colonies), varying from less than 0.1mm to 0.5mm in diameter (Note: these microscopic diagnostic characters have not yet been found in the type material).

Age and distribution. Late Precambrian, commonly between 1,000 and 700

Ma old; the U.S.A., Canada, Sweden, Svalbard, Iran, India, China, Argentina and probably W. Africa.

Description. Specimens of C. circularis from the Huainan and Fuxian districts, North China Platform, are very similar to the type material from the Grand Canyon. In addition to the diagnostic characters, some other interesting features are described here.

Colonial bodies have been reduced to discoidal membranous compressions and carbonised. They are compacted either between the bedding planes or parallel to the lamination within the rock. Most of them are circular but some are oval in outline because of morphological variation and preservational alteration. Most, if not all, individual compressions show counterparts with black organic membrane on each of the rock surfaces when the rock is split along or parallel to the bedding planes (Plate 5 : A). On the bedding planes, the compressions are randomly scattered or are preserved in clusters (Plate 5 : A - C,E; Plate 6 : A,B). Overlapping is not an unusual phenomenon when the compressions are very crowded, but it involves only the marginal parts of the adjacent compressions (Plate 5 : B; Plate 6 : A,C).

Most, but not all, compressions display wrinkles and folds in their surfaces. More or less concentric wrinkles are always limited to the marginal areas (Plate 5 : B,C). Irregular wrinkles and folds may occur over surfaces (Plate 6:B). The surfaces of most compressions have been deformed to varying degrees by the sand and silt grains in surrounding rock matrix during compaction and diagenesis.

Measurements of hundreds of specimens provide a broad size range of this species (Figs. 17,18), continuously from 0.2mm to 4.5 - 5mm in

diameter but commonly in the range of 0.5 - 3mm.

In vertical sections (Plate 5 : F-H), compressions within the rock matrix are represented either by a very flattened lensoid, totally less than 0.1 mm thick, or by an irregular composite line with two thin layers which have been intensely compacted together with little sediment-infilled space in between.

The organic films of compressions are commonly no more than 0.01 mm. thick. High-magnification study under a transmitted light microscope reveals that these organic films, now embedded in the peels and bioplastic transfers, consist of numerous entangled microscopic filaments (Plate 6 : G-H). They are darker than their organic matrix. They do not have distinct sheaths. Individual filaments are uniseriate, unbranched trichomes, each of which comprises a bead-like chain of flattened circular or granular cells, commonly 1 - 2 μ m wide. There is no clear distinction between the component cells. As the cells are altered by compaction, shrinkage and diagenesis, it is impossible to decide whether heterocysts exist in these trichomes.

Some of the compressions have one or several tiny circular or ring-shaped flattened bodies inside (Plate 6 : B,C). They are always darker than the surrounding area on the discoidal surfaces. They vary in diameter from less than 0.1 mm to about 0.5 mm. These enclosed bodies are very similar to independent small circular compressions scattered on the same rock surfaces (in Plate 5 : A,B). As these enveloped tiny bodies contain very dense organic remains and are usually almost opaque, no distinct structures can be easily recognized within them, but one specimen (Plate 6 : E) indicates that they are also composed of microscopic filaments.

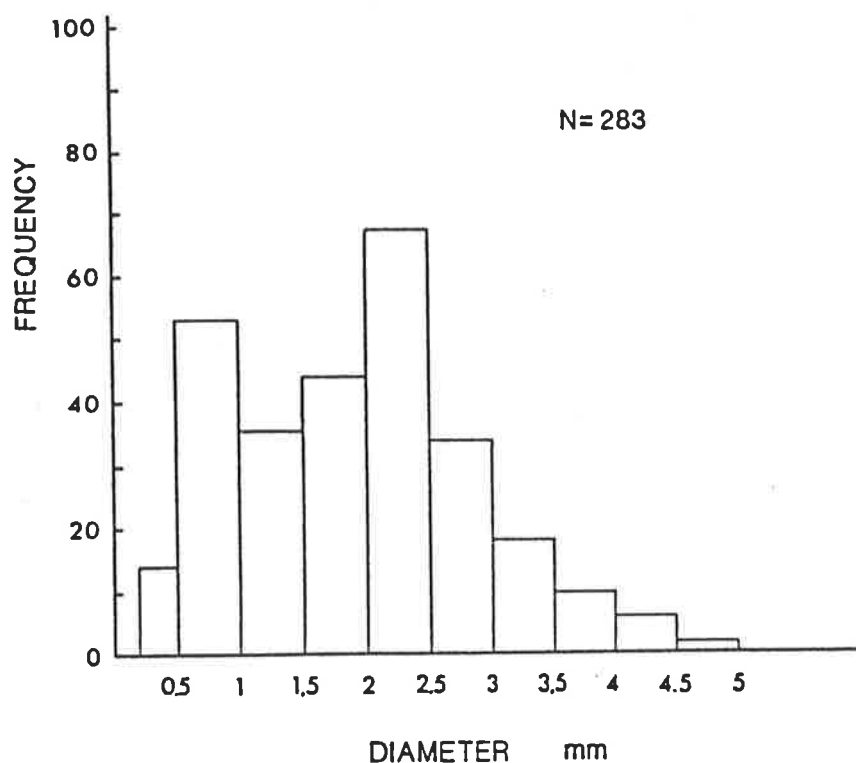


Fig. 17. Size distribution of Chuaria specimens from the Liulaobei Formation, Huainan Group, Huainan district.

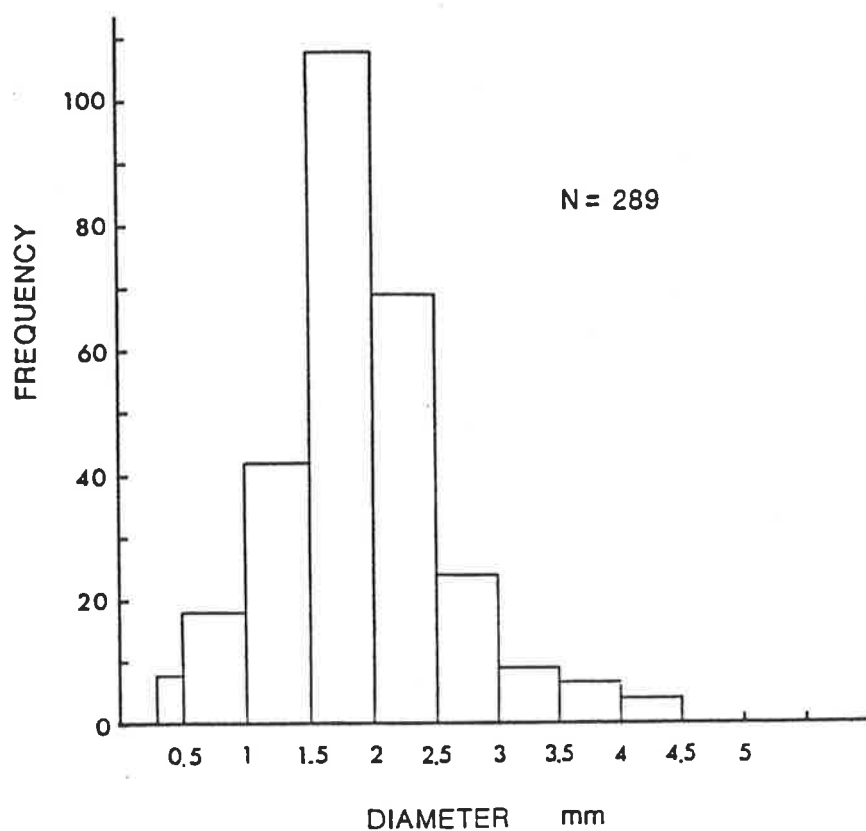


Fig. 18. Size distribution of Chuaria specimens from the Nanfen Formation, Xihe Group, Fuxian district.

Interpretation. The gross morphology and microscopic structures of Chuarina now become understandable with the aid of a comparison between it and the colony of a living filamentous bluegreen alga Nostoc Vaucher 1803, especially N. microscopicum Carm (1833) ex Born. et Flah. 1888.

N. microscopicum is a cosmopolitan aquatic species, which has been found in modern marine habitats (Chapman V.J., 1956; Humm and Wick, 1980). The colonies of this species are spherical or ellipsoidal, either solid or hollow, ranging from about 1 mm to 10 mm but seldom larger, soft but with a firm outer membrane; the filaments are numerous and loosely entangled within the gelatinous matrix; the sheath of each filament is more or less distinct, yellowish; individual trichomes are bead-like, uniseriate, unbranched, commonly 5 - 8 μ m broad; vegetative cells are spherical; heterocysts are intercalary, nearly spherical, only about 7 μ m in diameter; akinetes are 6 - 7 μ m broad and 9 - 15 μ m long (Chapman V.J., 1956, pp. 360-362; Desikachary, 1959, pp. 374, 387-388; Bold and Wynne, 1978, p. 55, fig. 2 - 26a, b; Bold et al., 1980, p. 29, fig. 2 - 27 a-c).

To facilitate the present study, Professor H.B.S. Womersley offered me about 20 Nostoc balls, which were collected from an unnoted South Australian habitat many years ago and preserved in a liquid for student use.

These Nostoc colonies (Plate 7 : A) are spherical and range from less than 1 mm to 15 mm but commonly several millimeters in diameter. They appear very similar to N. microscopicum but differ in their more numerous, more densely entangled, thinner (3-4 μ m) trichomes (Plate 7 : B,D,F). When a Nostoc ball is gently and gradually crushed between a glass slide and a cover slip, a circular to oval, discoidal, very thin

compression with more or less concentric and irregular wrinkles and folds is formed (Plate 7 : B,D,F). Such an experimentally made compression of Nostoc is analogous to Chuararia specimens.

Some of these Nostoc balls contain one or a few daughter colonies inside (Plate 7 : C). These small, slightly darker coloured, spherical, enclosed bodies contain the same kind of filaments as those in the surrounding gelatinous matrix within the mature colonies. Phycologists have found that in some species of Nostoc, the development of the trichomes to form a mature aggregate (daughter colony) takes place entirely within a matrix with a firm pellicle and thus the aggregate has a fixed shape (Bold and Wynne, 1978, p. 56). When a Nostoc ball is flattened, the daughter colonies become flat thickened discs or dark rings if broken within the experimentally made compressions.

Moreover, according to a palynological analysis by Dr. A.H. Knoll (pers. comm., June 29, 1983), the fossiliferous shales of the Liulaobei Formation also "contain a large number of small ($\sim 10 \mu\text{m}$) unicells (Myxococcoides) and small filaments (Taeniatum), along with occasional corroded specimens of larger acritarchs"; the analysed microbiota "does little to constrain ages, but does suggest that the deposits formed in a very near-shore environment."

In summary, the late Precambrian Chuararia can be compared with the living colonies of the filamentous bluegreen alga Nostoc in size, shape, general configuration and probably living habit. Almost all characters of a Chuararia can be found in experimentally compressed Nostoc balls. The remaining problem is whether the trichomes of Chuararia had heterocysts, which are characteristic of the nostoccean trichomes. The present material does not allow me to reach a clear answer because the

trichomes have been densely compacted and their component cells have been altered, dehydrated and shrunken, showing no significant differentiation among them. On account of the present knowledge and its uncertainties, it seems appropriate to maintain Chuariaceae as a separate family and place it, parallel to the living Nostocaceae, under the Order Nostocales.

Discussion. Prior to the present study, the identification and interpretation of Chuararia were based on the gross morphology and preservational characters of compressed specimens. The microscopic filamentous structures discovered in the present specimens have not yet been found or recognized within the type or other material. Hence, the assignment of the present material to Chuararia circularis needs to be confirmed or perhaps revised, depending on possible discoveries of cellular structures in the type material.

Many confusing problems have been indicated in current studies of C. circularis concerning its diagnosis, synonymy, systematics and stratigraphic distribution (Ford and Breed, 1973b, 1977; Vidal, 1974, 1976; Hofmann, 1977; Duan Chenghua, 1982; etc.). Although a comparison between the forms likely referable to this taxon on the level of the potentially preserved cellular structures is impossible at present, a proper understanding of the essential morphological characters of typical Chuararia specimens is certainly helpful to restrict the possible mistakes and confusion to a minimum.

1. Compressions

Specimens of Chuararia are algal remains reduced to carbonaceous (carbonized) compressions of micrometric thickness with little relief because of compaction.

At least two forms which were previously referred to C. circularis by Ford and Breed (1973b, 1977), Hofmann (1977) and Duan (1982) are not carbonaceous compressions and thus their assignments to Chuararia are questionable.

One is represented by discoidal structures, up to 3mm in diameter and bearing concentric wrinkles, in the late Precambrian Hector Formation of Alberta, Canada. The specimens were initially regarded as brachiopod-like fossils by Allan (1913), later considered to be problematic fossils comparable with Chuararia by Hofmann (1971) and then described to be "Chuararia sp. cf. C. circularis" by Gussow (1973). These specimens differ from Chuararia by their lack of the carbonaceous film and by their pronounced relief on the rock surfaces. Vertical sections (Gussow, 1973 p. 110, text-fig. 2D) indicate that these structures are made up of thick biconvex lenses of clear chlorite. Gussow explained the absence of the organic film as due to replacement by chlorite and carbonization under high temperatures at great depth of burial. That explanation is not convincing because Chuararia is preserved as carbonaceous compressions in the type section and many other late Precambrian sequences which were covered by thousands of meters of younger strata. Carbonized organic remains are chemically stable and unlikely to be replaced by chlorite. Judging from Gussow's description, there is no clear evidence for an algal origin of these Chuararia-like structures but it seems possible that they are diagenetic in origin. Hofmann's former opinion (1971, 1972) is worth consideration as the specimens from the Hector Formation cannot be classified more clearly than as dubiofossils.

The other is represented by small, circular, wrinkled casts and moulds of flattened impressions, 3 - 6mm in diameter, from the very late

Precambrian Central Mt. Stuart Beds of central Australia (Wade, 1969, pl. 69, fig. 5 - 7). Hofmann (1971, 1977) noted their superficial similarity to Chuaria notwithstanding their pronounced relief and lack of a carbonaceous film. Ford and Breed (1973b) referred them to C. circularis, based on an examination of latex casts (Pl. 63, fig. 3). The photographs and latex casts may give a false impression. I have re-examined Dr. M. Wade's figured material at the South Australian Museum, including specimens F16468, F16471 and F16472, and checked specimens from the same locality collected by Dr. M.R. Walter. In agreement with Wade (1969, p. 359 and the explanation of her plate 69), my conclusion is that these small circular structures are very likely isolatedly preserved gonads ("nuclei", Wade) of the medusoid Hallidaya brueri Wade (1969, text-fig. 4, Pl. 69, figs. 1 - 5) frequently occurring in the same beds, or probably minute medusoid fossils, but definitely not algal remains of Chuaria.

2. Size Range

Compressions of Chuaria are typically macroscopic in size. They were originally spheroidal in shape and grew to macroscopic size.

Vidal (1974, 1976) disagreed with Ford and Breed (1973b) in applying size limits, from 0.5 to 5 mm to identification of Chuaria. In his study of the Visingsö acritarch assemblage, Vidal obtained numerous microscopic Chuaria-like specimens by acid maceration. Most of his specimens are in size range 0.09 - 0.2 mm and some fragments have estimated diameters up to 3 mm. Vidal supposed that the size distribution of Chuaria was polymodal and the variation of the discs depended on the grain size of the rock matrix.

Ford and Breed (1977) agreed with Vidal and accepted some other microscopic forms as C. circularis. Hofmann (1977) also supported Vidal's proposal. He described 38 Chuarina specimens, ranging from 0.13 to 2.33 mm in diameter, from the Red Pine Shale, Utah, and considered that their size distribution was polymodal.

In conflict with Vidal's proposal, Duan (1982) joined Maithy and Shukla (1979) who suggested that the use of Chuarina (= "Fermoria") must be restricted to macroscopic discs occurring on rock surfaces, and that microscopic specimens found in acid residues should be excluded from Chuarina. For this and other reasons, Duan Chenghua did not accept "C. wimani" as Chuarina.

The millimetric size range in diameter, in my opinion, should be taken as a practical, convenient criterion to distinguish Chuarina from various acritarch forms, particularly those which are usually referred to unicellular Leiosphaeridia (see Lindgren, 1981). The size range from 0.5 to 5 mm in diameter covers most specimens assigned to Chuarina. A size range can only represent the common size distribution of the majority of measured specimens. It is not surprising, therefore, that a minority of specimens in a collection may fall outside such a size range if juveniles and morphological variants are included.

Vidal's proposal is not accepted here. It was based only on specimens obtained by acid maceration, a technique suitable for various microscopic acritarchs but not for macroscopic carbonaceous compressions of Chuarina (see p. /00). The hypothesis of polymodal size distribution fails to explain why it should have occurred during the growth of this organism. The supposed gaps between the adjacent size modals, as demonstrated by Hofmann's 38 specimens from the Red Pine Shale, are

expectably filled by supplementary specimens from the same assemblage. In the present collections from the North China Platform, abundant specimens show a broad, continuous size distribution from 0.2 - 0.3 mm. to 4.5 - 5 mm in diameter (Figs. 17,18). The supposed relationship of the size variation of Chuar specimens to the grain size of the rock matrix is denied by the observation that specimens of Chuar of varying size are frequently seen side by side on the same bedding plane (Plate 5 : A,B) and also by the fact that small circular discoidal compressions of Chuar and relatively large ribbon-like compressions of Tawuia are often preserved together (Plate 8 : B).

The species C. circularis present in the Visingsö Formation of southern Sweden is represented by the millimetric carbonaceous compressions which were first found and figured by Wiman (1894, PP. 109-113, Pl. 5, figs. 1 - 5), compared with the type material from the Grand Canyon by Walcott (1899, p. 235), called C. wimani by Brotzen (1941, P. 260), restudied by Eisenack (1966), repeatedly named under Kildinella magna and Trachysphaeridium vetterni by Timofeev (1969; etc.) and eventually referred to C. circularis by both Ford and Breed (1973b; etc.) and Vidal (1974, 1976; etc.). However, the assignment of numerous microscopic Chuar-like specimens in Vidal's material to Chuar, together with the difficulty in separating possible microscopic juveniles of Chuar from the various accompanying acritarch forms of Leiosphaeridia when their detailed original structures are unknown, remains inconclusive.

Thus, presently it seems desirable that the forms described as Chuar on the basis only of microscopic specimens, no matter whether they are surface specimens or those obtained by acid maceration, should be excluded from Chuar because they are different from the type

material at least in size range and their separation from the accompanying acritarch forms of the Leiosphaeridia group is as questionable as their forced assignment to Chuarina. The involved problematic microscopic forms include the small "sporomorphs" described from the Brioverian of France by Roblot (1964; Ford and Breed, 1973b, P. 537, 542), Kildinella jacutica, Trachysphaeridium vetterni, T. lachandinum and T. maicum described from the upper Precambrian of Siberia by Timofeev (1969, 1970; Ford and Breed, 1973b; Hofmann, 1977, Table 1), and the supposed Chuarina (in sense of Vidal, 1976) from Finland (Tynni and Bonner, 1980).

Probably also involved in this case are specimens described as C. circularis by Amard and Affaton (1984) from the late Precambrian Penjari Formation in the Volta Basin (Upper Volta and Benin), western Africa. Those specimens are carbonaceous compressions which appear like C. circularis but are very small, ranging from 0.3 to 0.78 mm and commonly 0.4 - 0.6 mm in diameter. Their assignment to C. circularis requires further investigation.

On the other hand, both Ford and Breed (1977) and Hofmann (1977) regarded Beltanelloides sorichevae Sokolov 1965 to be referable to C. circularis despite its much larger size from 5 to 44 mm in diameter. This Vendian problematic form has been found from different localities on the Russian Platform (Sokolov, 1973) and also from Spain according to Brasier et al. (1979). The former interpretation of this form as a medusoid (Sokolov, 1973, P. 206, fig. 5) was found to be incorrect (Glaessner, 1983). Its assignment to C. circularis is strongly challenged by its much larger size, mass accumulation of imprints and the pronounced positive relief on the upper bedding planes. A vertical section may be helpful in revealing its origin but no such sections have

been figured as yet.

3. Wrinkles

Most of the recent authors, represented by Cloud (1968), Ford and Breed (1973b) and Hofmann (1977), have reached a consensus that the concentric or irregular wrinkles were formed due to crushing of the originally spheroidal bodies of Chuarua.

Duan (1982) proposed that Chuarua was possibly a simple circular disc still preserved in its original form with more or less ring-shaped wrinkles in the marginal areas. He interpreted the irregular wrinkles in the central parts as due to flattening of the central elevation.

Zheng (1980) further suggested the use of ratio between the width of the wrinkled marginal zone and the radius of the whole disc for the specific identification of Chuarua.

The present study of Chuarua, with a comparison between the compressions of Chuarua and the experimentally flattened Nostoc colonies, confirms that the shape and arrangement of the wrinkles are not persistent but vary greatly from one specimen to another; the wrinkles are of mechanical origin, caused by the collapsing, shrinkage and crushing of the originally spheroidal bodies; and the existence of the wrinkles attests to a relatively thin but firm outer limiting membrane of the individual bodies.

Therefore, the development and arrangement of wrinkles should not be taken as a criterion for specific identification of Chuarua. The

establishment of new species, including C. annularis Zheng (1980) and C. cf. circularis Du (1982), both from the North China Platform, C. olavarriensis Baldis et al. (1983) from Argentina and C. fermorei Mathur (1983) from India, is regarded as unwarranted. Their separation from C. circularis cannot be accepted because of preservational variations. For the same reasons, Ford and Breed (1973b) have assigned the species of Fermoria and Protobolella (Chapman, 1935) to the monotypic species C. circularis.

4. Some problematic forms

Brasier et al. (1979) described a problematic form under the name Chuarua from the late Precambrian Pusa Shale of Spain. The specimens are long, convoluted chains, up to 80 mm long, apparently constructed of conjoined discs in the size range of 0.27 - 0.32 mm in diameter and also isolated discs of similar size on the bedding planes. However, these discs are significantly smaller than typical Chuarua and their occurrence in chains also suggests that the assignment to Chuarua is doubtful.

Hofmann and Chen (1981) reported the occurrences of carbonaceous megafossils of Chuarua and Tyrasotaenia Gnilevskaya from the 1,900 - 1,700 Ma old Changcheng Group, the oldest major unit in the stratotype Jixian section (locality 1, Fig. 15) of the North China Platform. The poorly preserved specimens of the supposed Chuarua are circular to ovate in outline, with or without faint wrinkles and ranging from 0.2 to 1.3 mm in diameter; and those of the supposed Tyrasotaenia are black fragmentary ribbons ranging in width from 0.07 to 0.23 mm and in length from 1.4 to 6.5 mm. I studied the Jixian section in 1977, led by the late Professor Wang Yuelun and his colleagues. Small, black or dark brown, irregular and membranous fragments occur frequently on the bedding planes of dark coloured silty shales in the Chuanlinggou Formation and

the muddy dolomites of the lower Tuanshanzi Formation, Changcheng Group (see Chen Jinbiao et al., 1980, p. 65). The origin of the black, possibly carbonaceous, fragmentary films is considered to be most likely inorganic. The specimens described as megafossils by Hofmann and Chen (1981, p. 446) were found and selected from abundant millimetric scraps of carbonaceous films. Their similarities in size and shape to either Chuarina or Tyrasotaenia are regarded here as accidental. The conclusion that those specimens might represent the oldest macroscopic organisms and were probably of eucaryotic origin (Hofmann and Chen, 1981, p. 447) is questionable. By the way, the confirmed occurrence of Chuarina in the Jixian section is in the Jingeryu Formation, Qingbaikou Group, the top major unit of the section (Duan, 1982; Fig. 16). The Qingbaikou Group is some 7,000 meters higher and about 1,000 Ma younger than the Changcheng Group (Zhong Fudao, 1977; Chen Jinbiao et al., 1980).

Xing Yusheng et al. (1984, P. 157, tables 1, 2) mentioned the occurrences of Chuarina, Shouhsienia Xing and Vendotaenia Gnilovskaya in the Jiucheng Member, Yuhucun Formation of the Wangjiawan section, Jinning County, Yunnan Province, southern China. The Wangjiawan section is one of the reference sections for the Precambrian - Cambrian boundary and is located only 20 km. from the Meishucun section, which is currently favoured for the global Precambrian - Cambrian boundary stratotype. The Yuhucun Formation is equivalent to the middle and upper parts of the youngest Precambrian Dengying Formation in the stratotype Eastern Yangtze Gorge section (Fig. 16). The Jiucheng Member, an equivalent to the Shibantan Member in the middle of the Dengying Formation, is considerably higher than the about 700 Ma old Nantuo Tillite and only slightly below the proposed Precambrian - Cambrian boundary. I studied all the sections mentioned above in 1982, with the guidance of local geologists. Abundant, irregular, ribbon-like, carbonaceous compressions of

Vendotaenia were found in the Shibantan Member and its equivalents; but I did not find any specimen which could be referable to Chuarina. Further comment cannot be made until Xing Yusheng and others publish their findings.

5. Possible cellular structures

The cellular structures inside Chuarina were unknown before this investigation. A few of the previous authors found some microscopic structures in Chuarina or Chuarina-like fossils but interpreted them in other ways rather than as cellular structures.

Vidal (1974, P. 7, pl. 1, figs. 3 - 6) found that "numerous, more or less spherical blister-shaped cavities can be observed inside the cell wall" of Chuarina from the Visingsö Formation of southern Sweden. He regarded Chuarina as a unicellular acritarch and explained the observed microscopic cavities, mostly 1 - 2 μ m in diameter as he figured, to many aggregates of pyrite crystals developed within the body. Those assumed "pyrite crystal cavities" appear somewhat similar in size, shape and, probably, arrangement to the component cells of trichomes found in the Chuarina specimens of the present material (Plate 6 : G.H). No pyrite crystals exist in the present specimens from the North China Platform. It seems possible that the microscopic cavities observed by Vidal may be altered cells of entangled trichomes, which have been intensely compacted. A similar problem has been encountered by Walcott (1919, P. 221) in his study on the Middle Cambrian colonial alga Morania. He noted that it was difficult for him to conceive of strings of pyrite balls being assembled in curved lines of varying configuration unless there were organic structures which gave them form and direction.

Maithy and Shukla (1977, P. 183, figs. 35 - 40) described six types of macroscopic, circular, wrinkled, discoidal, carbonaceous compressions, ranging from 0.5 to 3 mm in diameter, from the Suket Shales of India. They referred all of them to Fermoria, a synonym of Chuar. Another form, Tasmanites vindhyensis (Maithy and Shukla, 1977, P. 182, pl. 4, figs. 32, 33), in the same Suket assemblage, was described as follows: the discoidal surface, 0.5 - 1.2 mm in diameter, "covered with numerous puncta or pores with thick border, uniformly distributed over the entire surface". This latter form differs from typical Tasmanites in its larger size and single layered wall, as the authors recognized. The problem is that the described puncta and pores are possibly not structures of the original outer membrane but could be the enveloped cellular structures which have been compacted together with the outer membrane, showing impressions on the surface of the composite organic film. In fact, T. vindhyensis cannot be separated from Chuar, especially the author's "Types 1 and 2 of Fermoria", and the figured material can be compared with an experimentally compressed colonial body of the modern Nostoc (Plate 7 : B, G,H).

Zheng (1980) found that some of his Chuar specimens from the Liulaobei Formation, Huainan district, have one or more tiny circular or ring-shaped structures on the discoidal surfaces. He interpreted them as flattened surface ornaments. They are here reinterpreted as daughter colonies originally enveloped within the bodies (Plate 6 : B,C,E).

Discoidal carbonaceous compressions which appear like the accompanying specimens of Chuar in general and contain one or a few small circular bodies inside have been found elsewhere, such as "Trachysphaeridium vetterni" (= "C. wimani") from the Visingsö Formation of Sweden (Timofeev, 1969), "the Type-4 of Fermoria" from the Suket

Shales of India (Maithy and Shukla, 1977, p. 183, fig. 38) and Nucellosphaeridium spp. from the Little Dal Group of Canada (Hofmann and Aitken, 1979, p. 156, figs. 12A, B, C). I agree with Vidal (1974) in referring the forms represented by T. vetterni to Chuararia circularis. The present study of Chuararia in conjunction with the living Nostoc indicates that the development of daughter colonies shows up in some but not all adult colonies.

6. Systematic affinities

As outlined earlier in this paper, previous speculations on Chuararia were based mainly on its macroscopic size and relatively regular shape but were not supported by any known cellular structure.

The discovery of numerous, densely compaced, filamentous trichomes within individual Chuararia bodies shows that Chuararia was not a unicellular acritarch nor an eucaryotic cell. The presumption of Chuararia as a Volvox-like colonial alga, whose component cells are not arranged in chains, is also disproved. The study of macroscopic spheroidal colonies of the living filamentous bluegreen alga Nostoc strongly indicates that the general shape and size are not always critical enough to distinguish the eucaryotic from the procaryotic algae.

As already interpreted in this paper, Chuararia can be regarded as a late Precambrian planktonic colonial alga and can be compared with the living Nostoc microscopicum in many aspects, including shape, size range and general configuration. Among the living algae, Nostoc seems the only form that can be chosen as a useful model for understanding of Precambrian Chuararia.

It should be noted that isolated filamentous trichomes of the nostocean - type have been found worldwide in sediments ranging from late Precambrian to the Recent (Schopf and Blacic, 1971; etc.).

Among the known fossil forms, the closest genus to Chuarua is Morania Walcott 1919 (p. 226, pls. 43-5, 47-50, 52, 58), represented by M. confluens, from the Middle Cambrian Burgess Shale in British Columbia, Canada. Although both Chuarua and Morania were described and erected by the same author, Walcott did not compare Morania with Chuarua because he diagnosed Chuarua as a brachiopod (1899) and Morania as a colonial alga (1919) respectively.

Both late Precambrian Chuarua and Cambrian Morania were macroscopic, membranous, carbonaceous compressions of colonial bodies consisting of filamentous trichomes, analogous to the living Nostoc. In gross morphology, Chuarua differs from Morania by its regularly circular (originally spheroidal) shape, comparatively smaller size, smooth and distinct margin and commonly occurring concentric or irregular wrinkles (due to crushing) on the discoidal surface. Regarding cellular structures, the filamentous trichomes of Morania, found in the thin sections cut parallel to the flattened surface of the membranous organic films (Walcott, 1919, pl. 43), are comparatively less numerous, larger in individual size and less densely compacted than in Chuarua. The component cells of trichomes in Morania are more or less circular, about 7 μ m in average diameter as measured from Walcott's plate 43, fig. 4, and are relatively larger and more prominent than those in Chuarua. The heterocysts in the trichomes of Morania were mentioned by Walcott in the description but not shown in the figures. The tiny circular bodies contained in some of Chuarua specimens are apparently absent in Morania according to Walcott's report.

In the past, several occurrences of Morania were reported from Precambrian strata but their attribution to Morania is questionable. "Morania antiqua" described by Fenton and Fenton (1937, pp. 149-150, pl. 2, fig. 5) from the Altyn Limestone of the Belt Supergroup in Montana is represented by poorly preserved carbonaceous films, which are irregular in shape and commonly 3-8 mm in size. Without known filamentous structures, not only is their assignment to Morania doubtful but also their organic origin. "Morania? antiqua" described by Hofmann (in Hofmann and Aitken, 1979) from the Little Dal Group of northwestern Canada involves specimens showing morphological characters transitional between typical Chuarina and Tawuia. This problem is discussed later in this paper.

Genus Tawuia Hofmann, 1979

Type species. Tawuia dalensis Hofmann, 1979

Diagnosis. As for type species.

Tawuia dalensis Hofmann, 1979

Plate 8 : A-C (partim), D-I.

1979 Tawuia dalensis Hofmann; in Hofmann and Aitken, p. 158, fig. 13A - I.

1979 Morania? antiqua Fenton and Fenton; Hofmann (in Hofmann and Aitken), p. 160; partim.

1979 ?Shouhsienia longa Xing Yusheng, no description, pl. 12, fig. 5.

1980 Tawuia striatia Zheng Wenwu, p. 63, pl. 1, fig. 28.

1980 Tawuia cf. dalensis Hofmann; Zheng Wenwu, p. 64, pl. 1, fig. 29.

1980 Tawuia spp., Zheng Wenwu, p. 64, pl. 1, figs. 24-27.

1980 Pumilibaxa huaiheiana Zheng, p. 61, pl. 1, figs. 9, 12, 32.

1980 Pumilibaxa proceriaxis Zheng, no description, pl. 1, figs. 7, 11, 13, 15.

1982 Tawuia dalensis Hofmann; Duan Chenghua, p. 63, figs. 5 K-N.

1982 Tawuia sinensis Duan, p. 63, figs. 3 K-Q, fig. 5 p (partim).

1982 Tawuia dalensis Hofmann; Knoll, pl. 3, figs. 12-14.

1983 Tawuia suketensis Mathur, p. 364, fig. 1D.

1983 Tawuia rampuraensis Mathur, p. 364, fig. 1E.

Diagnosis (revised from Hofmann, 1979, in Hofmann and Aitken, p. 157-8).

Black, elongate, ribbon-like, membranous, carbonaceous compressions of millimetric width and centimetric length; outline smooth and even; side parallel to slightly tapering; ends approximately semicircular; some (mature) bodies containing one or more tiny circular bodies inside, varying from less than 0.1 mm to more than 1 mm in diameter; surface smooth, without annulations; cellular structures of filamentous trichomes uncertain as yet.

Age and distribution. Late Precambrian, approximately 900-700 Ma old; Canada, China, Svalbard and India.

Description. Specimens of T. dalensis in the present collection are similar to Hofmann's type material from the Little Dal Group, Canada. The specimens of Tawuia occur frequently with Chuarina on some bedding planes and are preserved in the same way as membranous carbonaceous compressions (Plate 8 : B). The compressed bodies of Tawuia are either straight (Plate 8 : D-I) or curved, even U-shaped (Plate 8 : C) but never overfolded or twisted. A small compression is only 5mm long and 1mm wide (Plate 8 : H), representing a juvenile form. A big one, found and measured by Duan Chenghua (1982, fig. 6, "T. sinensis"), is 29mm long and about 2mm wide. Most specimens fall in the size range of 5-25mm in

length and 1.5-3mm in width. Like those of Chuarua, individuals of Tawuia consist of two organic films, which are either completely compacted or separated by an extremely thin layer of silt, with a total thickness less than 0.1mm (cf. Duan Chenghua, 1982).

Three compressed bodies have been freed from the rock surfaces by bioplastic transfers. One of them (Plate 8 : F) displays numerous, darker coloured, curved, entangled, filamentous structures compacted in the organic film of the compression. The individual filamentous structures are uniformly wide, between 10 and 20 μ m broad, but their margins are obscure and the filaments have been thickened by the surrounding organic matrix. High-magnification study under a transmitted light microscope finds that these filamentous structures are poorly preserved without distinct cellular structures. The other two compressions are almost opaque, containing abundant, densely compacted, organic material.

Some specimens contain one or many tiny circular bodies compacted in the organic films. As shown in Plate 8 : D, two compressed bodies are preserved together. One of them contains more than 20 tiny bodies, which are randomly distributed, either circular, ring-shaped or irregular, varying from less than 0.1 to 0.6mm in diameter; but the adjacent compression, although of a comparable size, does not contain those tiny bodies. Zheng Wenwu (1980; p. 64, pl. 2, fig. 29) noticed a specimen ("T. cf. dalensis") with a prominent tiny circular body, 0.7mm in diameter, in the middle portion and a larger disc, about 2mm in diameter, at one end of the compression.

Discussion. Occurrences of Tawuia have been recently found in Canada, China, Svalbard and India. Studies of Tawuia are still in a preliminary

stage. Since the specimens of Tawuia show a broad range of morphological and preservational variations, many problems have arisen in the current studies.

1. Identification

Xing Yusheng (1979, pl. 12, fig. 5) figured a macroscopic ribbon-like compression from the Liulaobei Formation, Huainan district. That specimen, named "?Shouhsienia longa" without accompanying description, appears very similar to the present material of T. dalensis, particularly the largest one in Plate 8 : B.

Zheng Wenwu (1980) described three species of Tawuia also from the Liulaobei Formation. The monotype specimen of T. striatia is U-shaped and differs from other Tawuia specimens in displaying a few longitudinal striations on the surface. The separation of this species from T. dalensis is questionable until further collections demonstrate that the longitudinal striations are not due to preservation. The only specimen of Tawuia cf. dalensis, as already mentioned, shows no substantial difference from T. dalensis. Tawuia spp. refers to many specimens, which were later called T. sinensis by Duan Chenghua.

Duan (1982) restricted the type species T. dalensis to the specimens of curved bodies only, represented by Hofmann's holotype, and erected a new species, T. sinensis, for those of straight, more regular, shorter (up to 30mm), narrower (commonly 1.6 - 3.5mm) bodies compared with Hofmann's paratypes of T. dalensis. However, at least two figured paratypes of T. dalensis (Hofmann and Aitken, 1979, fig. 13C and I, partim.) are similar to Duan's T. sinensis. The separation of T. dalensis from the type species is arbitrary. The difference between the

straight and the curved, even U-shaped, bodies of Tawuia are possibly preservational and therefore of no taxonomic significance.

Mathur (1983) erected two species of Tawuia based on the material from the Suket Shale of India. Both T. suketensis and T. rampuraensis share the size range of 4-14 mm in length and 1 -2.5mm in width. The only difference between them is that the body of the latter form is slightly tapering towards one end. None of them is distinguishable from the type species.

2. Separation from Chuaria

All known occurrences of Tawuia are accompanied by Chuarua in the same macrofossil assemblage. Typical specimens of Tawuia can be easily separated from those of Chuarua by their size and shape. However, there seemingly exists a morphological transition between the two forms and the distinction between them becomes difficult.

In the Little Dal assemblage, the specimens showing elliptical, ovate, or kidney shaped outlines and varying in size range from 2.9 x 4.0 to 6.6 x 11.0mm are those that were referred to the name "Morania ? antiqua" by Hofmann (Hofmann and Aitken, 1979).

In the Huainan assemblage, specimens like "M ? antiqua" were given various names, including "Shouhsienia shouhsienensis" by Xing Yusheng (1979) and "Ovidiscina bagongshanica", "Ellipsophysa axicula", "E. proceriaxis", "Nephroformia liulaobeiensis" and "Pumilibaxa huaiheiana" by Zheng Wenwu (1980).

All of the taxonomic names mentioned above are invalid because they refer to morphological and preservational variants of either Tawuia or Chuarua. Duan (1982) considered the oval-shaped compressions in his

collection as Chuar, and so did Ford and Breed (1973b, pl. 61, fig. 2). Knoll (1983, p. 275, fig. 3) studied Tawuia and Chuar in the Kapp Lord Formation of Svalbard, and referred to T. dalensis the specimens ranging from elliptical compressions a few millimeters in length to elongate ribbon-like compressions more than 20mm long. Knoll's collection of Tawuia apparently includes both Tawuia and unseparated Chuar, and his diagram of size distribution, like that presented by Hofmann (in Hofmann and Aitken, 1979, fig. 15), demonstrates that it will be too arbitrary to separate a distinct taxon between Chuar and Tawuia based only on size and shape.

In the present collection, the morphological transition is shown by the specimens in Plate 8 : A,B, which demonstrate a continuous morphological variation from small circular Chuar to relatively large, elongate, ribbon-like Tawuia among specimens preserved together. Practically, it seems reasonable to regard the oval to short elliptical specimens as Chuar and assign the elliptical or more elongate specimens to Tawuia following a comparison of them respectively with the typical specimens in the same assemblage. However, this is not a satisfactory solution as there will always be uncertainty for elliptical forms intermediate between the two. Such a dilemma is only confined to consideration of the Chuar-Tawuia assemblage and does not arise for communities in which C. circularis is the sole macroscopic species, as in the case of the Chuar Group in the Grand Canyon and the Nanfen Formation in the Fuxian district, where C. circularis is known in great abundance without accompanying Tawuia.

3. Affinities

Hofmann (in Hofmann and Aitken, 1979) related Tawuia to the group Vendotaenidae and noted that it could be either algal (Phaeophyta?) or probably metazoan. He subsequently considered that both Chuar and

Tawuia could be eucaryotic algae and that they probably represented "an alternation of generations of the same organism" (Hofmann, 1981).

Duan Chenghua (1982) considered both Chuarua and Tawuia as advanced multicellular algae. He inferred that Tawuia was related to Chuarua through the intermediate oval type (still identified as Chuarua) "as a morphological change in the process of evolution". He also regarded that the Family Chuariaceae, including Chuarua and Tawuia, "may have had some evolutionery relationship with the later forms of Vendotaenia".

Tawuia is very closely related to Chuarua but, in my opinion, very different from Vendotaenia. The evidence for the close relationship between Chuarua and Tawuia consists of not only their macroscopic size, apparent or superficial morphological transition, accompanying occurrences and similar preservation but more importantly their comparable gross configuration.

Duan (1982) supposed that Tawuia could be originally ribbon-shaped. His interpretation is in conflict with the observation that the bodies were not twisted or folded over themselves and did not develop wrinkles caused by constriction on the concave sides when the bodies were curved or bent. It seems reasonable to deduce that the body of Tawuia was originally soft but resilient, elongate, cylindrical and enclosed by a thin, smooth but relatively firm, outer membrane (cf. Hofmann and Aitken, 1979). Although the definite cellular characters of the enveloped filamentous trichomes of Tawuia remain to be investigated, the contained tiny circular bodies, including the "terminal discs" (Hofmann and Aitken, 1979; Zheng Wenwu, 1980), can be compared with those found in Chuarua and therefore can also be interpreted as daughter colonies, which are here

considered as another evidence for the relationship between the two forms.

Tawuia may have evolved from Chuarua. They both had a daughter colony stage at the beginning of the growth of a colony. The generic difference between them is that the body of Tawuia has a distinct growth pattern, growing markedly in length with only a little increase in diameter (cf. Knoll, 1982). The evidence for this is demonstrated by the specimens of figs. E-H in Plate 8.

The difference between Tawuia and Vendotaenia is conspicuous. Specimens of Vendotaenia from the Upper Vendian on the Russian Platform and those from the stratigraphically equivalent Dengying Formation on the Yangtze Platform are ribbon-like carbonaceous compressions that are irregular in shape, usually twisted and over folded, and without rounded ends. There is no evidence indicating an originally cylindrical body of Vendotaenia. Well preserved specimens of Vendotaenia often show longitudinal striations within the organic film. A recent microscopic study by Gnilevskaya (1983, pp. 46-9) indicates that Vendotaenia is a multicellular alga, possibly of brown algae, with longitudinally arranged cells and sporangia. Whether Vendotaenia is a brown or a green alga requires further discussion; however, it is certainly not a colonial alga and its relationship with Tawuia, if any, must be remote.

Moreover, in its shape and size Tawuia appears more like Sinosabellidites Zheng 1980 than any other known fossil and living organism. Both Tawuia and Sinosabellidites occur in the Liulaobei Formation and the only difference between them in gross morphology is that Sinosabellidites possesses numerous, fine, straight, closely spaced annulations on the surface. Recent studies (Glaessner, 1983; Sun Weiguo *et al.*, in press; see Chapter 2) find that Sinosabellidites only superficially resembles tubes of Late Vendian - Early Cambrian

Sabelliditida and its enclosed cylindrical body with rounded ends excludes any relationship to the Pogonophora. No filamentous structures or contained small circular bodies have been found in Sinosabellidites. At present, Sinosabellidites is temporarily classified as a worm-like organism of uncertain origin (see Chapter 2; Sun Weiguo et al., in press).

BIOSTRATIGRAPHIC SIGNIFICANCE

Ford and Breed (1973b) noted the potential of Chuar as a stratigraphic index fossil of "the Upper Riphean" ranging from 1000Ma to the beginning of the Cambrian. This concept has been widely accepted (Hofmann, 1977; etc.).

The biostratigraphic significance of Chuar needs to be reassessed for two reasons. First, the previous conclusion was based on many Chuar-like forms which cannot be accepted in a stricter definition of Chuar and, secondly, geochronological data accumulated in recent years make it possible to define the time range of Chuar more precisely.

The term Late Riphean refers to the late Precambrian from less than 1,000 Ma to the beginning of the Vendian (sensu stricto), the base of which is represented by the late Precambrian Varangian tillites and considered to be more or less younger than 700 Ma (Chumakov and Semikhatov, 1981; Glaessner, 1984).

Following a critical review through the discussions of this paper, the global distribution of Chuar is represented by the confirmed occurrences (Fig. 19), among which the Chuar - Tawuia macrofossil assemblage has been found in Canada, China, Svalbard and India. Most of these Chuar occurrences fall in the time range of 1,000 - 700 Ma, i.e.



Fig. 19. Worldwide distribution of Chuarina circularis Walcott. 1. Grand Canyon, Arizona (type locality); 2. Utah; 3. northwestern Canada; 4. southern Sweden; 5. Svalbard; 6. northern Iran; 7. central India; 8. North China Platform; 9. Argentina; 10. West Africa.

Late Riphean. They are either stratigraphically succeeded by, or by correlation are older than, the regionally latest Precambrian tillites, such as the basal Windermere (Rapitan) tillites in North America, the Varangian tillites in Europe, and the Nantuo tillites in Asia, although this is probably not so in Africa (Fig. 20).

1. In the Grand Canyon area, Arizona, U.S.A., the type Chuar-bearing section is the Chuar Group. According to Ford and Breed (1969, 1972, 1973a), this almost 2,000 m thick sequence consists, in ascending order, of the Galeros, Kwagunt and Sixtymile formations. Abundant specimens of Chuar occur in the shales of the upper part of the Kwagunt Formation. Rare specimens of Chuar also occur in the shales near the base of the Galeros Formation. The two horizons are separated by a 1,500 m thick continuous sequence, in which stromatolites including Inzeria, Baicalia, and Boxonia are developed.

The underlying Cardenas Lavas, which are separated by the Nankoweap Group and two unconformities from the base of the Chuar Group, have been dated by the Rb-Sr method at $1,079 \pm 70$ Ma (McKee and Noble, 1976). The unconformity between the Kwagunt Formation and the overlying Sixtymile Formation approximates the boundary between the Belt and the Windermere Supergroups, and the conglomerates of the Sixtymile Formation are believed to correlate with the Mineral Fork Tillite of basal Windermere age occurring in the adjacent area of Utah (Hintze, 1973; Ojakangas and Matseh, 1980; Young, 1981). At present, the best estimate of the time range of the Galeros and Kwagunt Formations is within the time range from 1,000 to 800 Ma, rather than 845 - 600 Ma (Ford et al., 1972) or 1,000 - 600 Ma (Hofmann, 1977) as previously considered for the Chuar Group.

2. In the Uinta Mountains, Utah, U.S.A., the Chuar described by Hofmann (1977) occurs at an undefined position within the Red Pine Shale,

the uppermost unit of the Uinta Mountain Group. This formation is up to 1,000m thick and has yielded a Rb - Sr whole rock isochron age of ca. 950 Ma (Crittenden and Peterman, 1975; Hofmann, 1977). Regional stratigraphic investigations have indicated that the Uinta Mountain Group represents the upper part of the Belt Supergroup (Young, 1981), and that the basal Windermere Mineral Fork Tillite, which occurs in other areas of Utah, is missing within the unconformity between the weathered top of the Red Pine Shale and the overlying Palaeozoic strata (Ojakangas and Matsch, 1980).

3. In the Mackenzie Mountains, northwestern Canada, the Chuar - Tawua assemblage occurs in the Basinal Formation ("sequence") of the lower part of the 1,600 m. thick Little Dal Group (Hofmann and Aitken, 1979). The strata of both Belt ("the older succession") and Windermere ("the younger successions") Supergroups are well developed in this district and provide the standard stratigraphic position of the Chuar - Tawua assemblage in a single, relatively complete, geologic column.

The Little Dal Group is unconformably overlapped by the Rapitan tillites of the basal Windermere Supergroup (Hofmann and Aitken, 1979). The diabase sills and dykes intruding the Little Dal Group have recently been given a Rb - Sr whole rock isochron age of ca. 770 Ma (Armstrong et al., 1982). It may represent the age of the Belt - Windermere boundary in this area, although the boundary was customarily calibrated at ca. 850 Ma. Hofmann and Aitken (1979) estimated the time range of the Little Dal Group to be 1,100 - 800 Ma. The stromatolite assemblage (Aitken et al., 1978) and the microbiota (Hofmann and Aitken, 1979) contained in this group tend to suggest a Late Riphean age, in agreement with Knoll (1982). The time range of the Little Dal Group may be between 1,000 and 800 Ma, considering a possible correlation between this group, the Chuar

Group in the Gand Canyon and the Red Pine Shale of the Uinta Mountains Group in Utah. In general, the occurrences of Chuarina in North America are all in the upper part of the Belt Supergroup.

4. In the district surrounding Lake Vättern, southern Sweden, Chuarina occurs in the Visingsö Formation, which is more than 1,000 m thick. Its base rests unconformably on the old crystalline basement, and its top is covered by Quaternary deposits. The late Precambrian Varangian tillites, which are widespread in northern Europe, are missing in this area. Radiometric datings suggest the time range of this sequence to be bracketed between 1060 - 985 Ma and about or more than 707 Ma (Vidal, 1979, 1981). This time range needs to be further refined.

Studies of the microbiota led Vial (1974, 1976, 1979) to the conclusion (Vidal, 1981, p. 16) that the Visingsö Formation yielded two distinctive acritarch assemblages, which are virtually identical with assemblages reported from Upper Riphean correlations and Vendian sequences on the Russian and Siberian platforms (Vidal, 1979) and in northern China (see Xing and Liu, 1973).

It should be noted that Vidal's definition of the Vendian is broader than that currently used by Russian geologists (Chumakov and Semikhatov, 1981). He defined the Varangian tillites as the middle major unit, rather than the basal unit, of the Vendian (Vidal, 1981, fig. 3). Furthermore, the acritarch assemblages described by Xing and Liu (1973) were collected from the late Precambrian Jixian section, the top of which is believed to be well below the level of the Nantuo Tillite (about 700 Ma old) and has been dated at about 850 Ma (Fig. 16). The acritarch assemblages of the Visingsö Formation are comparable with those in the middle and lower parts of the Murchisonfjorden Supergroup in the Svalbard

(Knoll, 1982). It seems probable that the whole Visingso Formation is pre-Vendian (pre-Varangian) and, therefore, Late Riphean in age.

5. In Nordaustlandet, Svalbard, the Precambrian Murchisonfjorden Supergroup provides another example that the Chuaria - Tawua macrofossil assemblage occurs well below the Varangian tillites.

According to Knoll (1982), this supergroup is a 6,000 m thick, folded but essentially unmetamorphosed, shallow marine sedimentary sequence. It has been divided into four groups, namely (in ascending order) the Franklinsundet, Colsiusberget, Roaldtoppen and Gotia Groups. The uppermost Gotia Group, containing a conspicuous tillite horizon of the Varangian glaciation, represents the Vendian, and the other three groups are Late Riphean in age judged from the acritarch assemblages. The occurrence of the Chuaria - Tawua assemblage is restricted to the Kapp Lord Formation within the Franklinsundet Group, which is more than 3,000 m below the horizon of the tillite and has been estimated to be 900 - 850 Ma old by Knoll (1982).

6. In the Elborz Mountains area, northern Iran, Chuaria occurs in the Chapoghlu Shale of the Soltanieh Formation (Assereto, 1963; Stocklin et al., 1964; Ford and Breed, 1973b). The late Precambrian tillites are absent in this area and radiometric datings are not available at present. The age of the Chapoghlu Shale and the position of the Precambrian - Cambrian boundary are uncertain.

Based on the sections described by Assereto (1963) and Stocklin et al. (1964), it is regarded herein that the Precambrian - Cambrian boundary in northern Iran is represented by the major regional disconformity between the Zaigun Formation and the overlying Lalun

Sandstone, which contains Cruziana and other tracefossils of Palaeozoic age. Perhaps the whole Vendian sequence is missing within the disconformity. The Chapoghlu Shale, which is about 1800m below the Lalun Sandstone and some 600m above the crystalline basement, is very likely Late Riphean in age.

7. In India, occurrences of Chuarina (including "Fermoria" and "Protobolella") have been found in the Suket Shale and its equivalents in the vicinity of Neemuch and Ramapura, Madhya Pradesh (Chapman, 1935; Ford and Breed, 1973b; see Hofmann, 1977, table 1) and in the Bhima Basin, Karnataka (Suresh et al., 1983). Mathur (1983) recently described the Chuarina - Tawuia assemblage from the Suket Shale in the Neemuch district.

The Suket Shale is the basal formation of the Kaimur Group and also of the Upper Vindhyan Supergroup (Chapman, 1935, p. 109; some Indian geologists referred this formation to the top of the Semri Group, Lower Vindhyan). Recent studies of the Vindhyan microbiotas (Naithy and Shukla, 1977) and stromatolite assemblages (Raha and Satry, 1982) consistently suggest a Late Riphean age for the Kaimur Group (including the Suket Shale). Glaucconites in the lower and upper Kaimur Group have been dated at 940 Ma and 910 Ma respectively (Tugarinov et al., 1965; see Crawford and Compston, 1970).

8. On the North China Platform, Chuarina is very widespread. In the Huainan district the Chuarina - Tawuia assemblage occurs in the late Precambrian Huainan - Feishui Groups whose time range is bracketed between 900 Ma and 700 Ma. The top of the Feishui Group is disconformably covered by the diamictites of the Fengtai Formation, an equivalent of the late Precambrian Luoquan Tillite, whose age is not certainly known but may be related to the same glaciation as the Nantuo Tillite on the Yangtze Platform.

9. From the vicinity of Olavarria, about 300 km northwest of Mar del Plata, Argentina, specimens of Chuarua have been reported from argillites at the top of the "Sierra Bayas Formation" by Baldi et al., (1983). This formation is considered as a facies variant of the La Tinta Formation in the Tandilia region (Leveratto and Marchese, 1983) which has been dated at 769 ± 12 Ma and 723 ± 21 Ma by the Rb-Sr whole rock method (Bonhomme and Cingolani, 1980). For reasons explained by Bonhomme and Cingolani, the age of 769 Ma is preferred as being closer to the period of sedimentation.

10. In the Volta Basin (Upper Volta and Benin), West Africa, a new occurrence of Chuarua was recently reported by Amard and Affaton (1984) in the middle of the 2000 m thick Pendjari Formation, which has been dated by the Rb-Sr whole rock method at 660 ± 8 Ma. Below the Pendjari Formation is the Kodjari Formation, which contains a tillite in its lower part. Above the Pendjari Formation is the disconformably overlying Cambrian Obosum Group, which contains the Sang Conglomerate of fluvio-glacial origin at its base (Trompette, 1981). If the identification of this Chuarua occurrence (see page 116) and the age of the Pendjari Formation are confirmed by further investigations, the stratigraphic age of Chuarua may possibly be extended into the Vendian.

CONCLUSIONS

Knowledge of late Precambrian macroscopic carbonaceous compressions of Chuarua and Iawuia has progressed from morphological interpretation and preliminary speculations into discovery of filamentous cellular structures which allow them to be interpreted as planktonic colonies of filamentous algae. The originally spheroidal colonies of Chuarua can be compared with colonies of the living filamentous bluegreen alga Nostoc, particularly N. microscopium, in shape, size range, gross configuration

and probably living habit. The originally elongate, cylindrical, rod-like colonies of Tawuia are considered to have a very close taxonomic relationship with Chuar. Regarded as a distinct genus, Tawuia differs from Chuar in that its colonies have a characteristic growth pattern, growing markedly in length with only a little increase in diameter.

The global distribution of Chuar is demonstrated by its occurrence in the U.S.A., Canada, Sweden, Svalbard, Iran, India, China, Argentina and probably in western Africa and elsewhere. Most of these occurrences are bracketed within the time range 1000 - 700 Ma. Considering that all the previously reported occurrences of Chuar were described without finding potentially preserved cellular structures and that separation of Chuar from some large microscopic sphaeromorphid acritarch forms can be confused by similar gross morphology and partially overlapped size range, using Chuar as a index fossil is possible but practically difficult. However, the distinctive Chuar - Tawuia macrofossil assemblage, with its recently known occurrence in Canada, China, Svalbard and India, has proved to be a significant, valid and convenient biostratigraphic index for the global correlation of the Late Riphean, predating the Varangian glacial event and the appearance of the Ediacara - type metazoan assemblages.

APPENDIX

Since the present paper was finished, the articles by Vidal and Ford (1985) and Du and Tian (1985) have appeared in the journal Precambrian Research. A brief review on these two articles is given in this appendix.

Vidal and Ford (1985) analysed the microbiotas in the late Precambrian Chuar Group in the Grand Canyon area, Arizona and the Uinta

Mountain group in Utah (see Figs. 19 and 20 of the present paper).

Concerning Chuarina, the authors did not provide any new information about macroscopic discoidal carbonaceous compressions that resemble Walcott's type material in both morphology and preservation; instead, they concentrated on microscopic compacted sphaeroids that were obtained by acid maceration from the rock samples. No cellular structures were found in their material, probably because the organic film was too dark after compaction and carbonization. The authors continued to regard Chuarina as an acritarch (Ford and Breed, 1973b, 1977; Vidal, 1976; Vidal and Ford, 1985). They revised the former diagnosis of Chuarina (Walcott, 1899; Ford and breed, 1973b), and re-described the monotypic species C. circularis as "Acid - resistant, extremely robust, single - walled vesicle, circular to subcircular in outline (originally spherical) after compaction. The external surface is psilate or chagrinata" (Vidal and Ford, 1985, p. 357). Taking possible morphological and preservational variations into account, the characters in their revised diagnosis can be shared by many sphaeromorphid acritarch forms. The authors tried to use "acid - resistant" feature as a criterion to separate Chuarina from non - Chuarina circular compressions preserved on bedding planes. However, Walcott's type material from the Grand Canyon and similar specimens from other localities confirmed in my present paper are preserved as acid-resistant carbonaceous compressions. They are compacted between the laminae or within the rocks of shales and siltstone. They can be freed from rock surfaces by making peels or bioplastic transfers after acid treatment and can be examined in transmitted light. As I already discussed in the present paper, Walcott's type material and his morphological description (not his interpretation of Chuarina as a brachiopod) should be maintained as the basis for identification of Chuarina at the present stage. The diagnosis of this fossil is expected to be complemented when the

potentially preserved cellular structures are discovered in the type material or resembling specimens from the type fossil locality.

Vidal and Ford noticed that the Chuar Group (excluding the Sixtymile Formation) in Arizona and the Uinta Mountain Group in Utah are older than 820 - 770 Ma and that the Visingsö Formation in southern Sweden has been recently dated at about 800 - 700 Ma. These data tend to support that most, if not all, globally distributed occurrences of Chuar fall in the time range approximately from 1000 - 700 Ma, i.e. Late Riphean, and thus predating the Varangian glacial event.

Du and Tian (1985) published a progress report on the macroscopic algal assemblage from the late Precambrian Qingbaikou Group in the Huailai district on the North China Platform (see Figs. 15 and 16 of the present paper). In addition to the data previously reported by Du Rulin (1982), Chuar and Tawuia are now known from the Qingbaikou Group. Although Du and Tian's paper leaves much room for further palaeontological study, their figured material provides new evidence to confirm the biostratigraphic significance of the Chuar - Tawuia macrofossil assemblage.

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CHAPTER 4

PRECAMBRIAN MEDUSOIDS:
THE *CYCLOMEDUSA* PLEXUS AND *CYCLOMEDUSA*-LIKE PSEUDOFOSILS

ABSTRACT

The medusoid fossils that were conventionally referred to Cyclomedusa Sprigg 1947 are among the commonest elements of the late Precambrian Ediacara metazoan assemblage in South Australia. Specimens showing varying degrees of similarity have been reported worldwide from Precambrian occurrences.

This study indicates that the fossils traditionally named Cyclomedusa are a morphological plexus consisting of heterogenous medusae. The type species C. davidi Sprigg and C. radiata Sprigg are considered as a single species because of differences due to preservation. C. davidi can be compared with a living hydrozoan medusa Aequorea in general configuration and an affinity with the family Aequoreidae is suggested for the typical Cyclomedusa. Spriggia Southcott 1958, which was once regarded as a synonym of Cyclomedusa, is now reinterpreted as a float-bearing chondrophore (hydrozoan colonial medusa). The newly described S. wadeae sp. nov. provides remarkable evidence for the amazingly conservative evolutionary history of the family Porpitidae. "C". plana Glaessner and Wade, 1966 may be also chondrophoran in affinity but its configuration remains uncertain.

A critical review on the supposed Cyclomedusa from the Upper Precambrian in southern Liaoning, China (Xing and Liu, 1979) demonstrates that they are Cyclomedusa-like pseudofossils made by upwards escaping gas bubbles and water currents. Therefore they can not be used for stratigraphic correlation. This example suggests the need for extreme caution in studies of various Cyclomedusa-like circular structures.

INTRODUCTION

Cyclomedusa Sprigg, 1947 is one of the commonest medusoid remains among various soft-bodied metazoan impressions in the late Precambrian Ediacara assemblage of South Australia (Sprigg, 1947, 1949; Glaessner, 1959; Glaessner and Wade, 1966; Wade, 1972; Glaessner, 1979, 1984). The referred specimens are discoidal impressions with a concentrically rugose surface which is typically but not always sculptured by numerous fine, simple, unbranched radial grooves. The original configuration and possible taxonomic position of these fossils have generated growing interest but so far no conclusive interpretation has been obtained (Glaessner, 1984). A crucial problem has long been that the subumbrellar features (or oral surfaces) of these frequently occurring medusae were unknown (Glaessner, 1979).

The simple appearance of Cyclomedusa has been frequently regarded as reflecting primitive characters of late Precambrian medusae and the genus has been treated as a morphological group to accommodate numerous enigmatic Precambrian circular structures similar only in their concentrically sculptured discoidal surface. On the basis of such an approach, Cyclomedusa has been reported world-wide, with occurrences in South Africa (Germs, 1972a); England (Ford, 1963); South Wales, UK (Cope, 1977); northern Sweden (Kulling, 1964; Strand and Kulling, 1972; Glaessner, 1979, P. A95); the western Ural (Bekker, 1977), Ukraine (Zaika-Novatskii et al., 1968), northern Russia (Fedonkin, 1981) and eastern Siberia (Sokolov, 1973) of the U.S.S.R; Newfoundland (Anderson, 1978) and the Wernecke Mts. (Hofmann et al., 1983) of Canada; and southern Liaoning Province of China (Xing and Liu, 1979). Except for the comparatively distinctive Australian form C. plana Glaessner and Wade 1966 also occurring in the Ukraine and northern Russia, the

identification of all other material from outside of Australia as Cyclomedusa is uncertain because of the absence of radial sculptures characteristic of material from the Ediacara assemblage.

At present, both typical Cyclomedusa and various Cyclomedusa - like occurrences are in need of a further palaeontological study evaluating their potential as significant index fossils for late Precambrian stratigraphic correlation. Great caution is necessary in separating Cyclomedusa - like pseudofossils from Cyclomedusa fossils. A mistakenly identified Cyclomedusa may result in an incorrect age-determination of the relevant Precambrian strata.

I recently examined and restudied about 200 Cyclomedusa specimens so far collected from the Flinders Ranges, South Australia. Results of this study provide new information on the configuration, classification and evolutionary affinities of this enigmatic group.

Taken as an example of Cyclomedusa-like pseudofossils, the supposed medusoids from southern Liaoning, China were critically examined, and their mechanical origin was demonstrated.

Repositories. Specimens with numbers prefixed 'F' or 'T' or without prefix are deposited in the collections of the Geology Department, University of Adelaide. Those prefixed 'P' are deposited in the South Australian Museum.

CYCLOMEDUSA PLEXUS

The Cyclomedusa plexus comprises the medusoid fossils that were conventionally referred to the genus Cyclomedusa Sprigg 1947 on the basis of their preserved morphological characters (Sprigg, 1947, 1949; Harrington and Moore, 1956; Glaessner, 1959; Glaessner and Wade, 1966; Wade, 1972; Glaessner, 1979, 1984; Jenkins, 1984). Specimens of this plexus occur in the Ediacara assemblage, at Ediacara Range and many other widely spaced localities in the Flinders Ranges, South Australia (Fig. 21). The richly fossiliferous strata are confined to the Ediacara Member of the Rawnsley Quartzite, Pound Subgroup, the latter comprising the youngest late Precambrian deposits in South Australia (Wade, 1970; Glaessner, 1971; 1979; Jenkins et al., 1983).

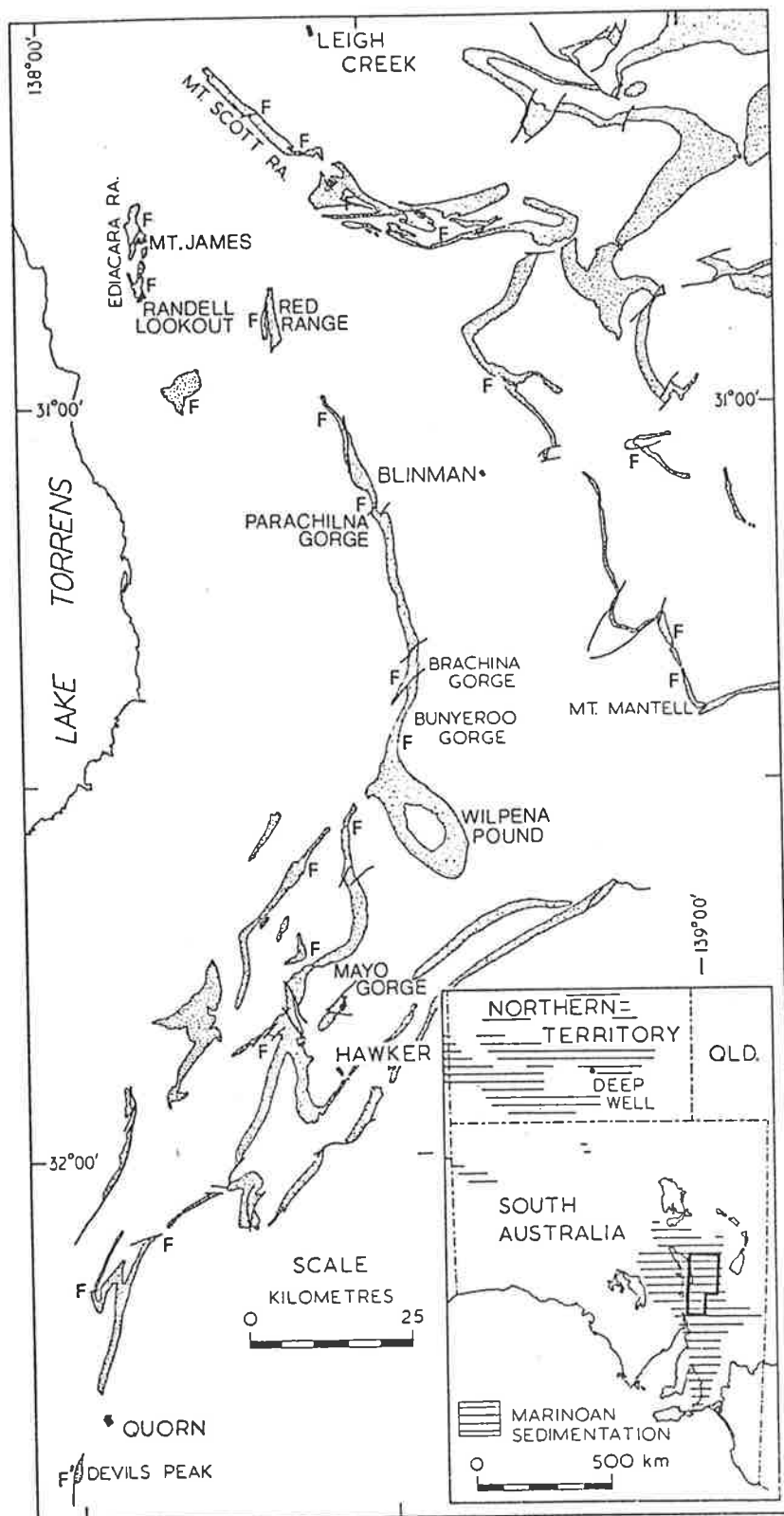


Fig. 21. Distribution of the late Precambrian Ediacara metazoan assemblage in South Australia. Larger map shows greater part of the Flinders Ranges with outcrop of the Pound Subgroup indicated by areas of stipple. Occurrences of the Ediacara assemblage marked by "F". Based on Jenkins and Gehling, 1978 and Jenkins, 1981.

Research history

Cyclomedusa was initially described by Sprigg (1947, p. 220-221) from a single incomplete specimen, the holotype of the type species C. davidi (Plate 9 : A). As he commented, "the form is highly problematical and possibly only represents the restricted central portion of a larger animal." Based on several better preserved specimens from the original locality at Ediacara, Sprigg (1949, p. 91-93) formally defined the genus Cyclomedusa as "Ex-umbrella sculptured by fairly prominent concentric grooves which may or may not extend to the margin, and numerous fine simple unbranched radial striations. The radial striations do not continue into the circular zone which may or may not contain a central nodular structure. The margin is simple and an epimarginal groove is present in well-preserved specimens." He chose specimen 2020 (Plate 9 : B) as a "hypotype" for C. davidi (Sprigg, 1949, p. 91, pl. 14, fig. 2, text-fig. 8-a) representing the forms in which 'prominent annular grooves extend to the margin.' Another species C. radiata was established for those with strongly developed radial grooves and an "outer zone essentially free of annular grooves." A large, incomplete specimen (2035) was named C. gigantea. He suggested that "the fossils (Cyclomedusa) may be discoid Scyphozoans, but such classification is too optimistic" (Sprigg, 1949, p.93).

Harrington and Moore (1956) placed Cyclomedusa under the heading "Medusae incertae sedis." They separated C. radiata from the genus and considered it, together with Tateana inflata Sprigg 1949, as "exumbrellar impressions" of Ediacaria flindersi Sprigg 1947.

Glaessner (in Glaessner and Daily, 1959) confirmed Sprigg's description and regarded Tateana as a synonym of C. radiata. Glaessner and Wade (1966) described C. plana and referred it to Cyclomedusa as a morphotypic species. They considered that separation of a genus Spriggia Southcott 1958 for C. annulata (Sprigg) (Plate 9 : E) from C. davidi was impracticable because of intergrading.

Wade (1972) placed Cyclomedusa under "Class Hydrozoa?" and interpreted it as an ancestral form of the Chondrophora, similar to Eoporpita Wade 1972, but without a float, and probably attached to the substrate by the aboral cone. Her speculation was based largely on a dubious specimen (Fl6720, Wade, 1972, p. 206, pl. 41, fig. 2), which has a damaged disc (Fl6720b) resembling a C. davidi but without radial sculptures, and a second juxtaposed specimen showing a mass of coarse, irregular, tubular casts (Fl6720a). She interpreted them as exumbrellar (aboral) and subumbrellar (oral) surfaces of Cyclomedusa respectively. No signs of similar tubular structures or their attachments have been found in any other Cyclomedusa specimens, and therefore, as she remarked, "until the oral surface of Cyclomedusa is definitely known, it will not be known whether it was allied to the chondrophores or merely a convergence "(Wade, 1972, p. 207).

Glaessner (1979, p. A94; 1984, p. 52-55) again placed Cyclomedusa under "Medusae of uncertain affinities" and noted "the oral surfaces of these commonly occurring medusae are unknown". In another paper (Føyn and Glaessner, 1979), he agreed with Wade (1972) that Cyclomedusa, including "Spriggia annulata", could be related to Chondrophora.

Jenkins (1984) isolated Tateana inflata and Spriggia annulata from the ill defined genus Cyclomedusa, and suggested using Tateana inflata to accommodate C. radiata. He considered both Tateana and Spriggia as floats of chondrophores.

It seems to me that C. radiata and T. inflata are specifically identical (cf. Glaessner, 1959) but their interpretation as chondrophoran floats is difficult because they lack the characteristic construction of annular chambers evidenced in most known fossil chondrophores (Stanley, 1982; Yochelson, et al., 1983). The speculation of a chondrophoran affinity for Spriggia is more acceptable.

Present knowledge

Our knowledge about the enigmatic Cyclomedusa plexus is growing with the accumulation of collections. Some recently obtained, well-preserved specimens greatly enrich our knowledge and show some important features that have not been recognized or preserved in the previously figured material. My findings concerning this morphological plexus are outlined as follows:

1. The formerly separated morphotypic species C. davidi and C. radiata are a single species, C. davidi Sprigg and their characters are respectively dominated by the exumbrellar and subumbrellar features due to different preservations and varying degrees of compression. The basic configuration of C. davidi is analogous to the living solitary hydrozoan medusae Aequorea Peron and Lesueur, together with which the typical Cyclomedusa may be referred to the Family Aequoreidae.

2. Spriggia remains a valid genus. The holotype of S. annulata has a discoidal float representing a porpitid chondrophore with a thick and fleshy marginal flange. A new species, S. wadeae sp. nov. is similar to

the living Porpita Linné, confirming the very conservative evolutionary history of the family Porpitidae from late Precambrian to the present.

3. The other forms in this plexus remain difficult to interpret because of their rare occurrence and poor preservation. Little can be added to the previous description of "C". gigantea and "C". plana. A comparison suggests that "C". plana is more like the aboral casts of Eoporpita than the typical Cyclomedusa represented by C. davidi.

4. Studies of the Cyclomedusa plexus, mainly Cyclomedusa and Spriggia, indicate that the diversification of hydrozoa had already reached a fairly advanced level at the time of emergence of the late Precambrian Ediacara metazoan assemblage, and that their basic patterns can be understood with the aid of modern fauna.

Systematic palaeontology

Phylum Cnidaria

Class Hydrozoa

Order Hydroida

Suborder Leptomedusae

Family Aequoreidae

Genus Cyclomedusa Sprigg, 1947

Type species. C. davidi Sprigg.

Diagnosis. As for type species.

Cyclomedusa davidi Sprigg, 1947.

Plate 9 : A-D; Plate 10 : A-B; Fig. 22 : A-B

1947 Cyclomedusa davidi Sprigg, p. 220, pl. 7, fig. 1.

1949 Cyclomedusa davidi Sprigg, p. 91, pl. 14, figs. 1, 2, and 4.

1949 Tateana inflata Sprigg, p. 86, pl. 11, figs. 1-2.

- 1956 Cyclomedusa davidi Sprigg; Harrington and Moore, in Moore, p. F153, figs. 2-3.
- 1956 Ediacaria flindersi Sprigg (partim); Harrington and Moore, in Moore, p. F74, figs. 60 (2-4).
- 1959 Cyclomedusa davidi Sprigg and Cyclomedusa radiata Sprigg; Glaessner, in Glaessner and Daily, p. 378.
- 1966 Cyclomedusa davidi Sprigg (partim, excluding Spriggia) and Cyclomedusa radiata Sprigg; Glaessner and Wade, p. 606.
- 1972 Cyclomedusa davidi Sprigg (partim); Wade, p. 204, pl. 41, figs. 3-5.
- 1972 Cyclomedusa radiata Sprigg; Wade, p. 205, pl. 41, figs. 1-2.
- 1979 Cyclomedusa davidi Sprigg (partim); Glaessner, p. A95, figs. 9-2 (c-d)
- 1984 Cyclomedusa davidi Sprigg and Cyclomedusa radiata Sprigg; Glaessner, p.52.
- 1984 Cyclomedusa davidi Sprigg and Tateana inflata Sprigg (= Cyclomedusa radiata Sprigg); Jenkins p. 97, pl. 1, figs. 4-5.

Holotype: T5 ("C. davidi"); 2037 ("C. radiata").

Paratypes (= Hypotypes, Sprigg, 1949) : 2020 and 2040 ("C. davidi"); 2010; 2032 and 2027 ("C. radiata").

Material and occurrence. About 200 specimens, some of which are fairly well-preserved; all the type specimens from Ediacara Range; additional specimens from many localities on the west flank of the main Flinders Ranges, particularly at, from south to north, the Devil's Peak near Quorn, Bunyeroo Gorge, Brachina Gorge, Red Range and Mt. Scott (Fig. 21). Most specimens occur in more or less convex relief on the bases of

weathered rock slabs from the Ediacara Member; a few are freshly exposed in situ also on the lower bedding plane surfaces.

Revised diagnosis. Umbrella radially symmetric, outline circular to subcircular, margin simple, entire and a distinct epimarginal groove present in some well-preserved specimens; diameter centimetric, up to 100mm or larger in maximum; exumbrella sculptured by several concentric rugae and grooves, the arrangement of which indicates an originally smooth, convex exumbrellar surface with a conically raised small centre; subumbrella displaying numerous, fine, simple, unbranched, radial grooves (radial canals), ranging from 50 to 100 and more in larger individuals arising from the base of central stomach represented by a ring around the centre and extending to the margin of the umbrella. As a result of compression, most individuals are preserved as composite moulds showing both concentric rugae and radial grooves of varying distinctness on the same surface.

Supplementary description. The relationship of the formerly separated "C. davidi" and "C. radiata" is linked up and demonstrated by a remarkable specimen also from Ediacara. As shown in Plate 10 : A, a-c, three individuals occur side by side on the base of a small quartzite slab (P 18279). Both P 18279a and P 18279b are of comparable size, about 40mm in diameter. P 18279a shows a smooth discoidal surface sculptured by several irregularly spaced concentric rugae, a prominent central knob and fine radial grooves faintly occurring in patches. It resembles a paratype of "C. davidi" (2020, Plate 9 : B). P 18279b is different from the adjacent P 18279a only in its outer portion which is flatter and sculptured by more distinct radial grooves, about 18 radial grooves per quadrant. It is apparently of the "C. radiata" form in the sense of Sprigg (1949). P 18279c is larger but otherwise indistinguishable from P 18279b, 68mm in diameter with about 30 radial grooves per quadrant. It

is almost identical to the holotype of "C. radiata" (2037, Plate 9 : C) and the only difference is that there are several slightly developed concentric rugae on its outer portion. Study of P 18279 indicates that separation of "C. radiata" from the type species "C. davidi" is arbitrary and they should be considered as a single species.

Specimen P 14176 (Plate 10 : B; C. davidi in Wade, 1972, pl. 41, fig. 4), about 90mm in diameter, shows a smooth but concentrically rugose exumbrellar surface. At a patch where a rock lamina moulding the exumbrellar surface has been weathered off, numerous prominent, closely spaced, fine, straight radial canals occur on a plane about 1mm below the exumbrellar surface and confined by the umbrellar margin. Careful observation indicates that very faint radial impressions also occur at places on the exumbrellar surface.

Specimen 2010 (Plate 9 : D; a hypotype of C. radiata in Sprigg, 1949, pl. 18, fig. 1) displays the subumbrellar surface of C. davidi. It is about 85mm in diameter and has a slightly depressed central area, about 10 mm across, which is delimited by a distinct, raised ring about 1mm wide. This ring is partially covered evidently by the material compressed from the other side through the central cavity to the subumbrellar side. More than 100 prominent radial grooves rise from the central ring and extend toward the margin. The marginal area shows a few weak near-concentric rugae. A rather smooth and undulose surface is exposed at places where the radially sculptured subumbrellar surface has been patchily exfoliated after weathering.

Interpretation. Specimens displaying typical features of the subumbrellar surface (Plate 9 : D) are rare. Most specimens show variable but distinct concentric rugae and radial grooves on the same

surface. The key to understanding the original configuration and extensive morphological intergrading of Cyclomedusa is the concept of "composite moulding". This form of preservation characterises many sorts of soft-bodied metazoan fossils and has been well explained by Glaessner and Wade (1966) and Wade (1968). Varying degrees of compression resulted in superimposition of impressions of exumbrellar and subumbrellar surfaces. The differing degree to which the preserved structures are evidenced depends not only on the preservation i.e. which side was settled downwards, but also on the intensity of compression. It may be proper to interpret the former distinction of "C. davidi" and "C. radiata" as preservational, dominated respectively by the exumbrellar and subumbrellar features of the same species.

Restoration. Specimens P 18279a and P 18279b (Plate 10 : A a-b; Fig. 22 : A-B) are a pair of ideal examples for the reconstruction of C. davidi. Based on their features and those of the type specimens, a diagrammatic reconstruction is presented in Fig. 22 : C.

C. davidi may have had a smooth, convex exumbrella which was thickened at the centre and formed a conically raised apex and thinned gradually towards the margin. The subumbrella may have been flat or slightly concave and had numerous fine, simple, unbranched, radial canals, which arose from the edge of a small, circular, ring-shaped mouth (or the margin of the central stomach) and extended towards the margin, along which a marginal circular canal may have been developed. There is no evidence for the preservation of a possible velum, which could be too rudimentary or delicate to be preserved, or simply undeveloped.

The umbrella was evidently filled with thick and stiff gelatinous substance. When the animal died and was quickly buried, the convex exumbrella gradually collapsed, dehydrated, flattened and forming

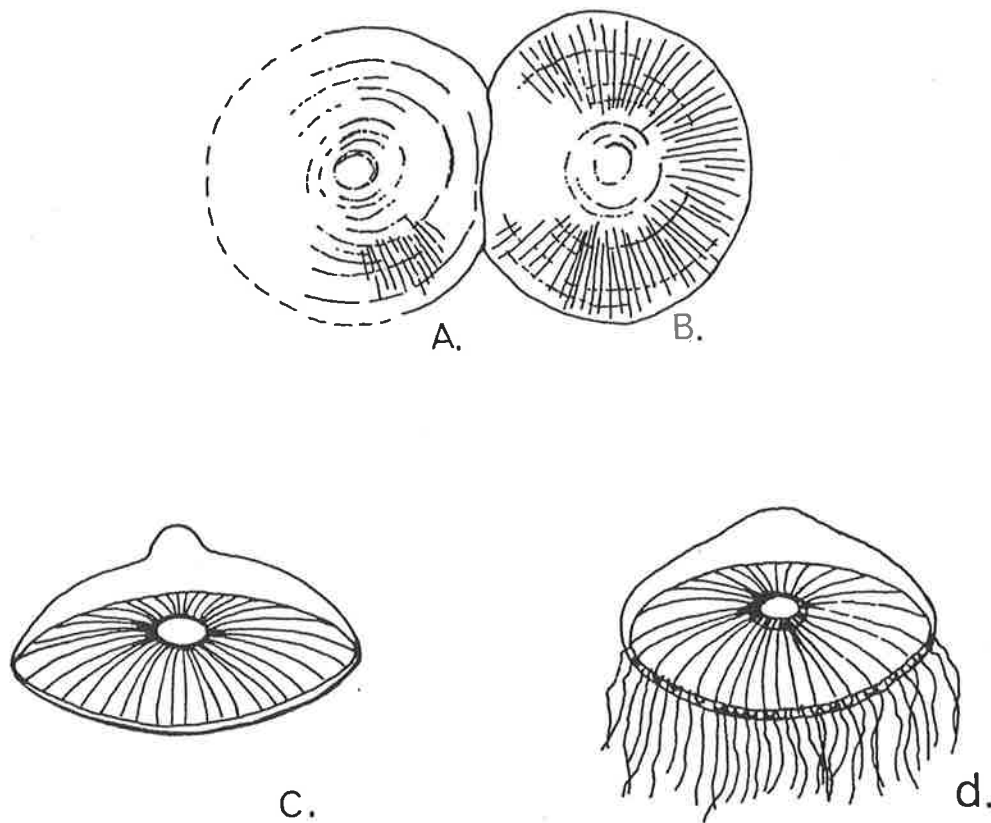


Fig. 22. Cyclomedusa davidi: A and B, diagrammatic sketches of specimens P 17279a and P 18279b (Plate 10 : A, a-b), xl, showing prominent concentric rugae when the remains are preserved as composite moulds dominated by exumbrellar features (A) or conspicuous radial grooves when they are preserved as composite moulds dominated by subumbrellar features (B); C, reconstruction of C. davidi, based on the combined features of A and B. D, Aequorea, a living hydrozoan medusa, for comparison, note the convex shape of the smooth exumbrella and numerous, fine, simple, straight radial canals extending from the base of stomach to the margin of the umbrella on the subumbrellar surface. (After Hyman, 1940).

concentric rugae and grooves. These concentric rugae may affect the originally flat subumbrella particularly in the central portion because of flattening. Their arrangement, like contours, may indicate the original shape of the umbrella. Some remains show that the convex exumbrella was obliquely compressed to a certain degree. Originally rather rigid radial canals resulted in radial grooves on the subumbrellar casts and formed similar but less distinct impressions on the exumbrellar surface due to compression.

Comparison. Spriggia, once thought to be synonymous with C. davidi, is again considered as a distinct genus referred to the Chondrophora based on recognition of its float and marginal flange (discussed next in this paper).

Among various medusoids in the Ediacara assemblage, Cyclomedusa seems more similar to Ediacaria Sprigg, 1947 (Sprigg, 1949; Glaessner and Wade, 1966; Wade, 1972). Both genera have a smooth exumbrella surface and a rather flattened subumbrella with a small circular mouth and numerous fine radial grooves. Cyclomedusa is usually smaller than Ediacaria and differs from it in the absence of the prominent annular furrow which subdivides the exumbrellar surface of Ediacaria into a slightly elevated, broad main disc and a surrounding zone. The radial grooves of Ediacaria are sometimes branched, and their distribution is mostly confined to the outer zone on the exumbrellar side and separated some distance from a small rounded mouth on the subumbrellar side. On account of these differences the two genera are considered distinct.

Affinity. The study of Cyclomedusa fossils in conjunction with the living medusae indicates that the Precambrian Cyclomedusa is analogous to the present Aequorea Peron and Lesueur, 1809 (Fig. 22 : D) in general

configuration, size range and characteristics of radial canals.

Preserved medusae of Aequorea were studied in the course of this work at the South Australian Museum.

Medusae of the family Aequoreidae are essentially characterized by their large number of radial canals and a considerable size reached by adult forms. The representatives of Aequorea may grow to 175mm or more in diameter. The umbrella is usually flatter than a hemisphere, saucer-shaped, with solid jelly which is thickest in the centre and thins gradually and evenly towards the margin. Both velum and ring canal are narrow. The radial canals are straight, unbranched, narrow but bearing a gonad along the most of the length of each radial canal, usually about 60 to 80 in number and sometimes more than 100 (Mayer, 1910; Hyman, 1940; Russell, 1953). The stomach is commonly broad and open, directly linked to the mouth in adult forms. The stomach is narrow and circular in some species, e.g. A. tenuis (Mayer, 1910, p. 332, figs. 190-191).

This comparison links Cyclomedusa to the same family as Aequorea and extends the evolutionary history of the order Leptomedusae (Hydrozoa) backwards to late Precambrian.

Order Hydroida

Suborder Chondrophorina

Family Porpitidae

Genus Spriggia Southcott, 1958.

Type species. S. annulata (Sprigg) Southcott, 1958.

Revised diagnosis. Discoidal body remains of a porpitiid, circular to elliptical in outline, moderately large, radially symmetric, consisting basically of an annularly chambered disc (float), a surrounding marginal flange and numerous marginal tentacles. Disc either flattened or

slightly raised toward the centre, having a very small circular central chamber surrounded by many conspicuous concentric grooves and rings (annular chambers), which are fine in the middle field and become coarser outwardly; oral surface, when known, distinct from aboral surface only by a small, prominent, circular, crater-shaped structure (central gastrozoid) enclosing the central chamber in its depressed bottom and bearing many fine radial processes (bases of oral tentacles) on its elevated rim. Marginal flange either broad and thick or narrow and membranous. Marginal tentacles fine, slender, extending radially outward below and outside the marginal flange.

Spriggia annulata (Sprigg) 1949

(Plate 9 : E; Fig. 23)

- 1949 Madigania annulata Sprigg (partim), p. 93-4, pl. 16, fig. 1.
- 1956 Madigania annulata Sprigg; Harrington and Moore, in Moore, p. F154, fig. 124.
- 1958 Spriggia annulata (Sprigg), Southcott (nov. gen; non Madigania Whitley, 1945), p. 59, fig. 3.
- 1959 Spriggia annulata Southcott; Glaessner, in Glaessner and Daily, p. 388.
- 1966 Cyclomedusa davidi Sprigg (partim); Glaessner and Wade, p. 606.
- 1972 Cyclomedusa davidi Sprigg (partim); Wade, p. 205.
- 1979 Cyclomedusa davidi Sprigg (partim); Glaessner, p.A. 94.
- 1979 Cyclomedusa davidi Sprigg (partim); Glaessner, in Foyn and Glaessner, p. 40, fig. 5c.
- 1984 Spriggia annulata (Sprigg); Jenkins p. 97, pl. 1, fig. 6.

Holotype. 2031

Material and preservation. Sprigg (1949) initially referred 4 specimens to this species (as Madigania annulata). Wade (1972) found that the three paratypes (2025, T9 and T14) are different from the holotype and referable to Brachina delicata Wade. This species is monotypic at the present. The holotype is preserved as a cast showing the aboral side in slightly convex relief on the base of a small quartzite slab. It was found in the Ediacara Member of Rawnsley Quartzite at the Ediacara Range.

Diagnosis. Annularly chambered disc slightly convex and with a small central papilla on aboral side; marginal flange flat, nearly as wide as the radius of the surrounded disc, showing numerous fine near-concentric wrinkles on the surface probably due to shrinkage. Oral surface unknown.

Redescription. As shown in Fig. 9 : E and illustrated in Fig. 23, the holotype is elliptical in outline and has a preserved maximum diameter of 75mm. Annularly chambered disc is 41 x 48 mm in size, slightly convex, with small conspicuous central papilla on aboral side. Central chamber circular, 2mm in diameter, enclosed by 9 or 10 fine, prominent, annular chambers each less than 1 mm wide and 3 or 4 outer chambers varying from 2 to 5 mm in width. Marginal flange is up to 18mm wide, generally flat but weakly marked by numerous extremely fine near-concentric wrinkles. Marginal tentacles are shown at a patch where the marginal flange has been damaged. They are preserved as numerous, fine, slender, gently curved, radial striae below the layer of the marginal flange, and some of them extend just outside the periphery of the marginal flange.

Discussion. S. annulata distinguishes itself from C. davidi by the existence of a marginal flange surrounding the annularly chambered disc

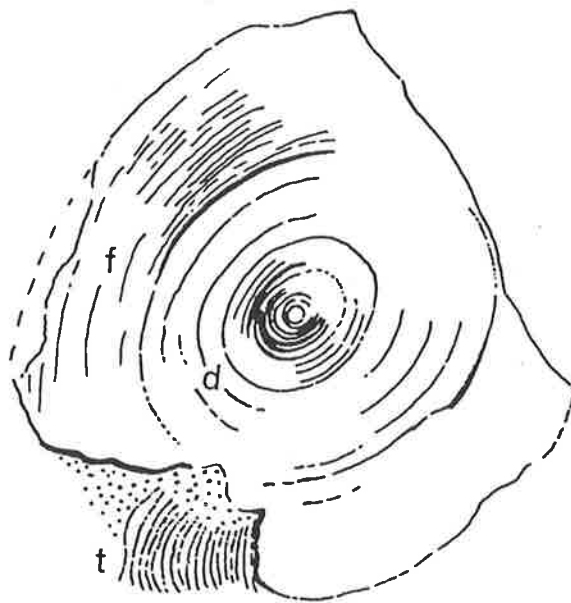


Fig. 23. Diagrammatic sketch of Spriggia annulata, 2031 holotype, as shown in Plate 9 : E, x 1: d, disc with many annular grooves and rings; f, marginal flange with numerous delicate fine wrinkles; and t, marginal tentacles, fine, slender, slightly curved, occurring beneath the marginal flange.

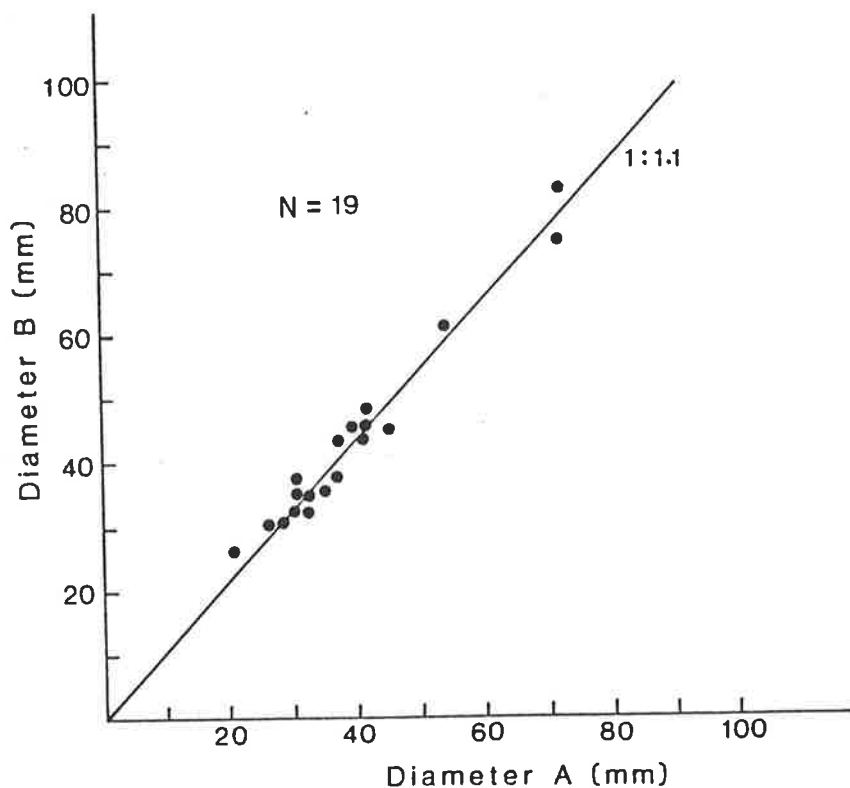


Fig. 24. Size distribution of Spriggia wadeae sp. nov., showing diameters of 19 discs (not including the width of marginal flanges). Mean diameter is 39mm.

and covering marginal tentacles, and by the absence of distinct radial grooves on the discoidal surface. On the exumbrellar sides of C. davidi, the concentric rugae are fewer, coarser, irregularly spaced and tend to be developed toward the extreme margin, without a flange.

The complete absence of radial grooves on the surface was initially taken as a criterion to separate Spriggia ('Madigania' Sprigg) from Cyclomedusa (Sprigg, 1949; Glaessner, 1959). This characteristic was subsequently questioned (Glaessner and Wade, 1966) because S. annulata also shows "radial lines" on a somewhat lower plane (Southcott, 1958). A careful re-examination indicates that the "radial lines" of S. annulata are impressions of marginal tentacles, which are delicate, slender, gently curved and extend below and outside the edge of the marginal flange. They are different from the distinct, straight, radial grooves of Cyclomedusa and can not be interpreted as gastrodermal radial canals.

S. annulata differs from Brachina delicata (Wade, 1972; Glaessner, 1979) in the presence of many fine rings in the middle field and the absence of small spatulate marginal lappets.

Discoidal remains of Kullingia concentrica Glaessner (in Føyn and Glaessner, 1979) from the Upper Vendian of northern Sweden were initially referred to Spriggia ("Madigania") annulata (Kulling, 1964; Strand and Kulling, 1972). Kullingia does not have a marginal flange and preserved marginal tentacles; its annular rings are more numerous, finer and evenly spaced on the discoidal surface. These characteristics justify separation of this Swedish species from Spriggia. Glaessner (in Føyn and Glaessner, 1979) interpreted Kullingia as an annularly chambered float similar to that of a living Porpita.

Spriggia wadeae sp. nov.

(Plate 11 : A-D,; Fig. 8 : A-C).

Holotype. 1099a.

Paratypes. 1099b, c, d, e, and f.

Etymology. Named after Dr. Mary Wade.

Material and occurrence. Wade (1972, p. 206) found 49 discoidal remains on one bedding plane in the Ediacara Member of Rawnsley Quartzite at Brachina Gorge and tentatively referred them to Cyclomedusa. The rock specimens numbered as 1080, 1081, 1090, 1094, 1095 and 1099 were afterwards collected by Wade and became available to this study. Several individuals are still preserved in situ (Jenkins, pers. comm.).

Preservation. About 30 discoidal remains occur as counterpart casts (Glaessner and Wade, 1966) in varying convex relief on the upper bedding plane of purplish, medium-grained, feldspathic sandstone slabs (1094 and 1099). Their impressions are preserved as external moulds (Glaessner and Wade, 1966) in slightly negative relief on the lower bedding plane of the overlying sandstone slabs (1080, 1081 and 1090). The counterpart surfaces are separated by a film of very fine silts, which allowed the detail of soft-bodied remains to be well preserved as impressions. Preservation of casts and external moulds of fine, conspicuous annular structures indicates that the remains were originally rigid and sufficiently resistant to withstand compaction of the embedding sediment. The fine laminations in the sandstone beds and the wavy bedding plane on which the discoidal remains are crowded suggest a shallow water environment and regular cycles of intertidal sedimentation (Jenkins et al., 1983). The medusae were possibly washed to and stranded on an intertidal flat, quickly covered by mud settling from suspended

material when the water current became temporarily quiet, and then buried by sand grains when the succeeding sedimentary cycle commenced. Due to the water current, the remains were buried in various attitudes, settling on the sedimentary substrate with the aboral surfaces either upwards or downwards. The remains, discs with a marginal flange, were preserved either flat (Plate 11 : Ac, B), or distorted only at the marginal flange (Plate 11 : Ab), or folded (Plate 11 : C). The holotype (Plate 11 : Aa) was overfolded, showing both sides of a annularly chambered disc which seems to have been relatively resilient. This is perhaps the only overfolded specimen of a 'medusoid' known in the Ediacara assemblage.

Diagnosis. Distinguished from the type species in that the disc is flattened or slightly depressed in the middle field, without a central papilla; annular chambers increase in coarseness outwardly and form a prominent edge of the disc in contrast to the membranous marginal flange; marginal flange varying from one half to one third as wide as the radius of the surrounded disc; marginal tentacles are more numerous and extremely fine, extending for a considerable distance outside the marginal flange; a small, circular, crater-shaped central gastrozoid is characterizing the oral surface which is otherwise identical with the aboral surface in showing distinct annular chambers.

Dimensions. Measurements on 19 specimens shown in Fig. 24, indicating a size range of the discs (not including the marginal flanges) from 20 to 80mm in diameter, but dominantly 25-45mm. The mean ratio between the shorter and longer diameters at 1:1.1, therefore almost perfectly circular.

Description. The holotype (Plate 11 : A a) has a conspicuous circular disc, 36mm in diameter and a membranous marginal flange, 4 or 5mm wide.

The whole disc is overfolded and both sides are consistently sculptured by many annular grooves and elevated rings, interpreted as corresponding to the annular chambers of the float (disc) in living chondrophores. As many as 8 rings can be recognised. The centre is covered by the overfolded portion. The outermost ring is the strongest, 3mm wide, and forms the prominent edge of the disc slightly raised with respect to the membranous marginal flange. Marginal tentacles are represented by numerous, very fine and slender, radial striae that emerge from the edge of the disc and occur as very faint impressions across the marginal flange. They extend for more than 20 mm outwardly. A few delicate creases across the discoidal surface evidently resulted from the overfolding of the disc and may be taken as evidence for the original existence of a layer of soft tissues (coenosarc) that enclosed the annularly chambered disc (float) and extended to form the marginal flange around the disc.

Both paratypes 1099b and 1099c (Plate 11 : A b-c) are discoidal remains presumed to show the aboral side. Their sizes and configurations are comparable with the adjacent holotype. The annularly chambered discs are flattened or slightly depressed in the middle fields and show a very small single circular chamber, 1 or 2 mm across, at each centre. The distorted marginal flange of paratype 1099b suggests that the flange could have been originally thin, and flexible on account of its membranous and delicate appearance.

The oral surface may be represented by paratype 1099d (Plate 11 : B). The flattened disc is subcircular in outline, 36-42mm in diameter and consists of a very small central chamber and 10 annular chambers. The outermost chamber forms the prominent edge of the disc. The inner chambers are thinner and seemingly collapsed; they are separated from

each other by distinct concentric ridges which are comparable with the annular grooves in the holotype. At the centre is a small, circular, crater-like structure, which is 10mm in diameter and shows the central chamber in its depressed bottom and bears numerous very fine, short, radial processes on its elevated rim. This crater-like structure is analogous to the central gastrozoid of a living chondrophore. Similar structures are seen in several specimens (Plate 11 : D).

Preservational variations are conspicuous in some instances. Paratype 1099e (Plate 11 : C) is of comparable size to Paratype 1099d (Plate 11 : B). Its outer portion is folded and its middle field is sculptured by very fine annular grooves and rings, more numerous than those of the latter. The presumed oral surface of another paratype (Plate 11 : B) is rather rough perhaps because of the decomposition of soft tissues that originally enveloped the disc.

Distinct radial sculptures are generally absent on either presumed oral or aboral surfaces of the discs. However, close examination indicates that faint, radial striae are occasionally present (Plate 11 : D). Their meaning is uncertain but they were possibly related to the vascular canals or radial strands of chondrophores, originally generated within the soft tissues, which were decomposed.

Comparison. S. wadeae differs C. davidi in the presence of more numerous, fine, delicate, annular grooves and rings consistently occurring on both sides of the disc, the existence of a marginal flange with preserved marginal tentacles, and the absence of a conically raised centre on the aboral side and distinct radial grooves on the oral side.

Both S. wadeae sp. nov. and the type species S. annulata share a basic configuration consisting of an annularly ridged disc, a surrounding marginal flange and many marginal tentacles. On account of this similarity, they are regarded as congeneric.

S. wadeae is separated from the type species by its more prominent discoidal float which is flattened or slightly depressed in the middle field without a raised central papilla, by its narrower membranous-appearing marginal flange and its more numerous, much longer and slender marginal tentacles. These differences are conspicuous in about 50 individuals and inferred as to be of specific significance. The type species is at moment represented by only one specimen and the features of its oral surface are unknown. The tentative specific separation of S. wadeae from the type species needs to be confirmed. It is worth noting that further studies may find a broader morphological and/or preservational variation range, which would suggest a conspecific relationship of S. wadeae with the type species S. annulata, as Dr. R.J.F. Jenkins and Professor M.F. Glaessner commented in discussion.

Reconstruction and affinity. As illustrated in Fig. 25, based on the holotype (A) and a paratype (B) and supported by many other specimens, the restored body of S. wadeae (C) shows striking similarity with the living Porpita (Fig. 26).

Porpita is a polymorphic colonial hydrozoan. A mature colony assumes a medusoid shape with a circular or elliptical outline and radial symmetry and consists dominantly of a flat disc-like coenosarc, from the underside of which hangs a large central gastrozoid with a mouth facing down, surrounded by a number of gonozooids and marginally flanged with numerous tentacles (tentacular dactylozooids). The coenosarc is composed of a well-developed, circular, rigid but flexible, annularly chambered

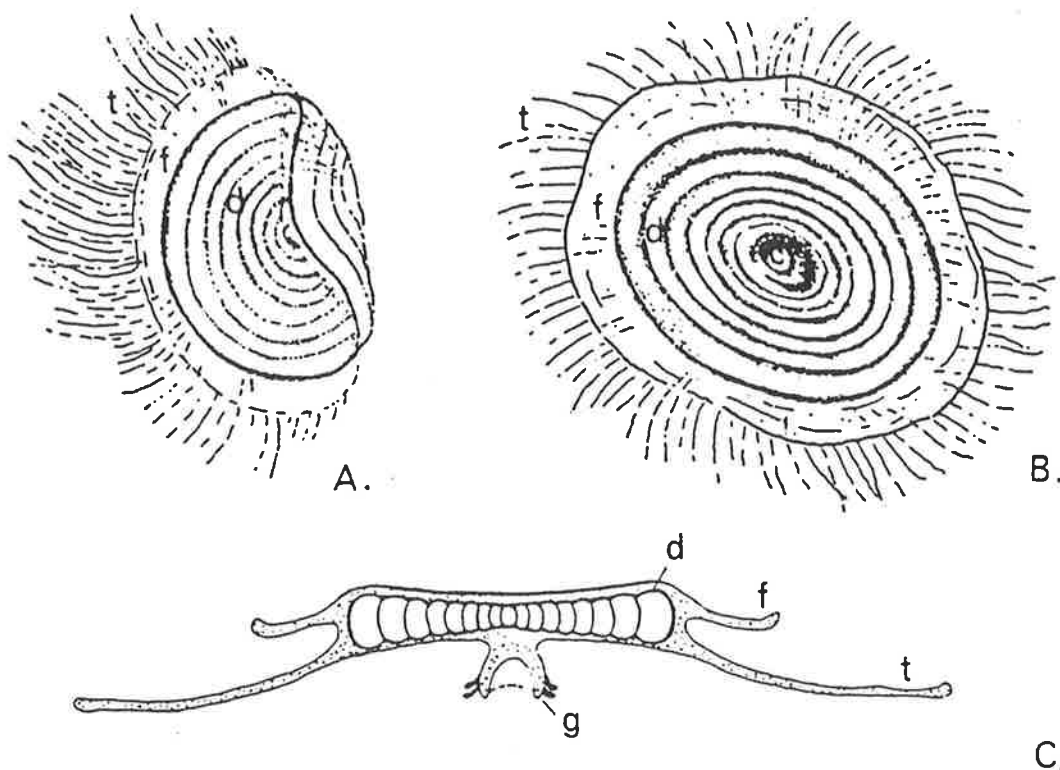


Fig. 25. *Spriggia wadeae* sp. nov. x 1: diagrammatic sketches of A, holotype (1099a) showing an overfolded body with annular grooves and rings on both sides of the disc, and B. a paratype (1099e) showing a flattened discoidal body, view of oral side, with a crater-shaped central gastrozoid; C. transverse section through the centre of a restored body, based on the combined features of A and B. d, annularly chambered disc; f, marginal flange; t, marginal tentacles; cg, central gastrozoid.

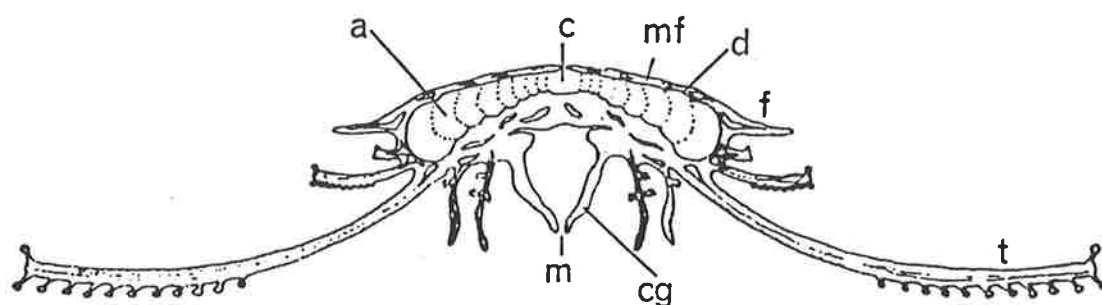


Fig. 26. *Porpita porpita*, a living chondrophore (Hydroida), transverse section through the centre: a, annular chambers; c, central chamber; cg, central gastrozoid; d, disc (float); f, marginal flange; g, gonozooids; m, mouth; mf, mantle flap; t, marginal tentacles (tentacular dactylozooids). (After Mackie, 1959).

float (disc, pneumatophore) which is completely covered by soft tissues, with a mantle flap and surrounded by a marginal flange (Hyman, 1940; Mackie, 1959). Numerous radiating vascular canals or muscle strands are embedded in the soft tissues and often seen on the mantle flap (see Hyman, 1940; Mackie, 1959). Because the float is chitinous and the only "hard" part of the colonial body, it is more likely to be preserved than the soft parts after death. These float-bearing animals are periodically driven onto modern beaches and stranded. Alternatively the rigid float may separate from decomposed soft tissues of a dead colony and may drift about for some time before finally becoming water-logged and sinking (Stanley, 1982).

Comparison of S. wadeae with Porpita suggest that the taxonomic position of Spriggia lies within the family Porpitiidae of Chondrophora.

The chondrophores, exemplified by Porpita and Velella in the living planktonic and pelagic fauna, were earlier referred as a major group to the Siphonophora (Hyman, 1940; or Siphonophorida, in Harrington and Moore, 1956) but they are more correctly assigned as a suborder, Chondrophorina, to the Order Hydroida (Fields and Mackie, 1971; Glaessner, 1979, 1984; Stanley, 1982; Yochelson et al., 1983). Both porpitiids and velellids are characterized by a discoidal annularly chambered float in the coenosarc. Velella is distinguished by a sail vertically raised at the centre and diagonally across the aboral surface. Porpita does not have a sail and neither did Spriggia.

Discussion. The similarities between the Precambrian S. wadeae and the living Porpita provide evidence for the very conservative evolution of the chondrophores with little change over 600 million years.

Besides Spriggia, three genera in the late Precambrian Ediacara assemblage, South Australia are considered to be of chondrophoran affinities.

Both Ovatoscutum (Glaessner and Wade, 1966) and Chondroplon (Wade, 1971) are preserved as casts or external moulds of chambered floats only. They are characterized by a bilateral symmetry, with an axis bisecting the disc, and therefore referred to a distinct family, Chondroplidae (Wade, 1971). They are different from radially symmetrical floats of the Porpitidae but probably related somewhat closer to Velellids (Yochelson et al., 1983; Glaessner, 1984) supposing that the axial furrow was corresponding to the base of the sail of a velellid.

Eoporpita Wade (1972) is preserved as casts and external moulds of both soft and "hard" parts of an ancient porpitud. It is distinguished from S. wadeae and the living Porpita by a slightly raised central dome on the mantle flap and several whorls of club-shaped, specialized tentacular structures (gonozooids and dactylozooids, Glaessner, 1979) encircling a single, large central cone (gastrozooid) on the oral side.

A few species of Palaeozoic porpituds and velellids are known (Harrington and Moore, 1956) and summarised in the recent studies by Stanley (1982) and Yochelson et al. (1983). Some of them, particularly the Devonian Plectodiscus, also show striking similarity to the living Chondrophores (Velella).

Modern biologists have noted the paucity in chondrophoran diversification (Edwards, 1966). Palaeontological studies indicate that the living chondrophores are relics, "living fossils", representing a very conservative evolutionary branch of the Metazoa.

Other species in the Cyclomedusa plexus

Some enigmatic forms remaining in the Cyclomedusa plexus, such as "C". gigantea, "C". plana, etc., show poor preservation or extensive morphological intergrading. They are not necessarily congeneric with C. davidi.

"Cyclomedusa" gigantea Sprigg, 1949

Comments. This species is represented principally by its holotype (2035 from the Ediacara Member, Ediacara Range; Sprigg, 1949, p. 93, pl. 15, fig. 2; Harrington and Moore, 1956, fig. 122-1; Glaessner and Wade, 1966, p. 606; Wade, 1972, p. 205; Glaessner, 1979, fig. 9-26). The specimen is incomplete, without a preserved margin. It represents a large medusoid with a radius of more than 67mm. It differs from C. davidi in its larger size, the presence of a wide, deep, annular furrow which subdivides the exumbrellar surface into a slightly elevated central platform and a surrounding zone, and more numerous (about 200) very fine radial striae on the discoidal surface. It somewhat resembles the main exumbrella of the newly described scyphozoan medusae Mawsonites randellensis Sun (in press, Chapter 5), which is characterized by many large prominent marginal lappets. Unfortunately, the incomplete preservation of "C". gigantea precludes any further comparison.

Stanley (1982) referred this species to the chondrophores without any explanation. Glaessner (1984) separates it from the list of the confirmed taxa of the Ediacara metazoan assemblage because of its poor representation and ill defined characteristics.

"Cyclomedusa" plana Glaessner and Wade, 1966

Comments. Eight specimens from the Ediacara Member, Ediacara Range, are

referred to this species. These include the holotype P13778 and paratypes P13779 and P13780 (Glaessner and Wade, 1966, p. 607, pl. 98, figs. 1-3). They are preserved as exumbrellar (aboral) casts with slightly convex relief on the lower surfaces of quartzite slabs. No additional specimens have been found in the Flinders Ranges and little can be added to the description given by Wade (1972). Specimens referable to this species are now known from the Upper Vendian in the Ukraine and northern Russia of the U.S.S.R. where they are described respectively by Zaika-Novatskii et al. (1968) and Fedonkin (1981).

This species is distinguished by a broad, flat disc (maximum known radius 12cm) surrounding a small central, concentrically rugose cone rarely over 1cm in radius. (Glaessner and Wade, 1966). It differs from the typical Cyclomedusa and Spriggia in its large generally flat disc which is almost free of concentric rugae except the small central portion, and its extremely fine radial striations on the surface.

The holotype (P 13778) and some paratype specimens resemble the aboral cast of Eoporpita medusa (P 14283, Wade, 1972, pl. 40, fig. 4) in size, general form of the disc and presence of numerous, faint radial striations. The only difference between "C. plana" and E. medusa is that the central cone of "C. plana" has a few concentric grooves while that of E. medusa forms a slightly elevated mound without concentric grooves. A paratype (P 13780, Glaessner and Wade, 1966, pl. 98 fig. 3) displays twinning centres (?overlapping specimens) and makes the comparison of "C. plana" with E. medusa more difficult. "C. plana" may be interpreted as aboral casts of thick, stiff mantle flap of a Eoporpita - like chondrophore but more information is needed to substantiate this speculation. Stanley (1982) referred it ("C. plana") to the fossil chondrophores without accompanying interpretation.

"Cyclomedusa" sp.

Referred to this morphotypic species are numerous small discoidal casts that are commonly less than 3cm in diameter and have a smooth surface deeply sculptured by a few near-concentric grooves. Specimens of this kind have been found at the Ediacara Range and many other localities in the main Flinders Ranges. They often occur in loose clusters and preserved in convex relief on the lower bedding planes of rocks in the Ediacara Member. One example is figured as C. davidi and interpreted as flattened casts of the aboral sides by Wade (1972, pl. 41, fig. 1). They resemble the holotype C. davidi (incompletely preserved) but do not have characteristic radial striations. It should be noted that paratypes of C. davidi (2040 of C. davidi and 2032 of C. radiata, Sprigg, 1949, pl. 14, figs. 3 and 4) are small specimens less than 3cm in diameter, but they show distinct radial grooves on the surfaces.

The typical Cyclomedusa has been compared with adult forms of the living Aequorea in general configuration. Studies of Aequorea (Mayer, 1910; Russell, 1953) indicate a great range of morphological variation between the juvenile and adult forms. The juvenile forms usually have a higher ratio between the height and diameter of umbrella and are often bell-shaped. With maturity the umbrellas gradually become saucer-shaped, lower in height relative to the diameter.

It is not impossible that many of these "C." sp. specimens might be juvenile forms of C. davidi and their convex fleshy umbrellas did not always allow probably weakly developed radial canals to be preserved as radial grooves on the exumbrellar surfaces. Other possibilities can not be excluded because many other medusoids, such as Ediacaria, Brachina, etc. occur in the same assemblage and their juveniles are generally unknown.

CYCLOMEDUSA-LIKE PSUEDOFOSSILS

In the description of Cyclomedusa by Sprigg (1947, 1949), prominent concentric rugae and numerous fine simple unbranched radial grooves were considered of equal significance in its diagnosis. However, the radial grooves which may be interpreted as radial canals are not always preserved on the concentrically rugose exumbrellar surfaces because of varying degrees of preservation. Without distinct radial grooves, a compressed umbrella of Cyclomedusa is difficult to separate from the annularly chambered discs (floats) of various chondrophores that accompanied Cyclomedusa in the same assemblage of the late Precambrian Ediacara Member of the Pound Subgroup, South Australia.

Various Cyclomedusa - like discoidal markings have been reported from many localities in other regions of the world, but in fact none of them demonstrates characteristic radial grooves of the genotype Cyclomedusa davidi. Therefore, the assignment to Cyclomedusa is questionable.

It must be noted that discoidal markings with concentric sculptures are not necessarily metazoan in origin, i.e. medusoids, floats of chondrophores, flattened discoidal holdfasts of pennatulids ("Charniodiscus" in Ford, 1958; Jenkins and Gehling, 1978; Glaessner, 1979). Some others, although Cyclomedusa - like or "medusiform", are known to be sedimentary structures related to algal activities, concretions, gas pits, etc.

Cloud (1968) and Glaessner (1969) appealed for greater efforts to be made in distinguishing Precambrian fossils from pseudofossils, particularly those commonly described medusoids.

Alf (1959) described some enigmatic discoidal markings with concentric rings from the late Precambrian Bass Formation, Grand Canyon, Arizona, U.S.A. and supposed that they were probably medusoid fossils. Later studies (Cloud, 1968, fig. 4B; Glaessner, 1969, fig. 2) indicate that they are not medusoid. Glaessner (1969) demonstrates the possibility that the questioned circular structures could have been made by gelatinous sheaths of algal colonies. This interpretation was accepted by Germs (1972) who described similar structures from the late Precambrian Nama Group of Namibia (Southwest Africa).

Vologdin (1964) studied some concentric structures from the Precambrian and possibly Cambrian in northern Siberia. He correctly recognized his specimens as colloidal mineral coneretions; however, as Germs (1972) pointed out, he mistakenly inferred that they were identical with Spriggia ("Madigania") annulata in the Ediacara assemblage of South Australia. Vologdin apparently missed Southcott's report (1958) in which "radiating lines at a somewhat lower plane" are noted as a significant feature of S. annulata.

Walter (1970) investigated several medusiform pseudofossils from the Precambrian Brockman Iron Formation, Western Australia. The material was first described as fossils by Edgell (1964). Although many of them show prominent regular concentric sculptures on the circular discoidal surfaces, they do not have distinct radial grooves characteristic of Cyclomedusa nor the marginal flange as seen in Spriggia. Polished sections and cross sections enabled Walter to interpret those concentric medusiform structures variously as pseudofossils due to diffusion and rhythmic precipitation of silica, or moulds and casts of nodules, or

structures of gelatinous algal colonies.

Cyclomedusa-like pseudofossils from southern Liaoning, China

Initially, my attention was drawn to the supposed Cyclomedusa - like structures from southern Liaoning Province, China, which have been used as palaeontological evidence for regional and international correlation.

The enigmatic circular structures from the top of the Changlingzi Formation (not the base of the overlying Nanguanling Formation as suggested by Xing and Liu, 1979) in the Precambrian Wuhangshan Group in Fuxian County, southern Liaoning Province, China (Chang, 1980) were first found by Liu Guizhi and her colleagues in 1975. The specimens were subsequently identified by Xing Yusheng (1976) as Cyclomedusa. With a further collection of some 50 specimens and 70 circular structures, Xing and Liu (1979, pp. 267-272, pls. 1-3) described and figured the material as medusoid fossils, including eight species of Cyclomedusa, one undertermined species of Planomedusites, two species of Medusinities and two species of Liaoningia Xing and Liu. On the basis of the supposed medusoid assemblage, the authors inferred that the Precambrian sequence from the "fossiliferous beds" upwards and below the disconformably overlying Cambrian in southern Liaoning Province could be Late Sinian in age (younger than the about 700 Ma old Nantuo tillite in the Yangtze Gorge section, southern China) and therefore approximately comparable in age with the Wilpena Group in South Australia, the Vendian in the U.S.S.R., and the Nama Group in Southwest Africa because of the common occurrence of Cyclomedusa.

Professor M.F. Glaessner and Dr. B. Daily in 1979 advised their Chinese colleagues that, according to their personal observations in the

field in May 1979 and examinations in the laboratory, the supposed Cyclomedusa from southern Liaoning are pseudofossils caused by rhythmic gas eruptions and the suggested stratigraphic correlation is doubtful (Professor M.F. Glaessner pers. comm. to Yang Kong (Chief Engineer, Geol. Survey of Liaoning), 21 August 1979; quotation and agreements in Chen Meng'e et al., 1982; Glaessner, 1984, p. 90).

However, the identification and stratigraphic correlation by Xing and Liu (1979) have been repeatedly cited in a number of articles and textbooks (Wang et al., 1980; Chen et al., 1981; etc.). The present situation requires an illustration of these Cyclomedusa - like pseudofossils.

The top of the Changlingzi Formation consists of grey, thin bedded, finely laminated, silty or muddy limestones and richly calcareous siltstones, indicating a quiet shallow water marine sedimentary environment, probably a lagoonal or intertidal mud flat. Numerous circular structures and many synaeresis cracks frequently occur on the bedding planes. The upper and lower bedding planes of a single bed, often about 10 mm thick or less, are correspondingly sinuously bent at places where the circular structures appear. This fact aroused my suspicions that their interpretation as impressions of originally soft-bodied medusoids was incorrect when I studied the Fuxian Precambrian stratigraphic section in October 1977. Dr. B. Daily examined my collections in Nanjing, 1978, and confirmed that they are not fossils but sedimentary structures. Contrary to their classification under many taxonomic categories given by Xing and Liu (1979), and in agreement with Glaessner and Daily, I conclude that the circular structures near the top of the Changlingzi Formation are all made by upwards escaping gas and/or fluids. Small gas pits, large gas pits and gas bubble bursts can be distinguished.

Numerous small gas pits, diameter less than 10mm and commonly 2-3mm, are closely dispersed over the upper bedding planes of concave epirelief (Plate 13 : D). Their casts filling the depressions are preserved as small mounds of convex hyporelief on the lower bedding planes of the overlying layers (Plate 13 : E). The significance of these small gas pits was apparently overlooked by the previous authors although they appear in almost all the figures of the supposed medusoids (Xing and Liu, 1979, pls. 1-3). In cross sections perpendicular to the bedding (Plate 13 : F), each pit is funnel-shaped. The conical depression of the pit has a single vertical channel extending downwards through thin laminae and forming a tiny projection on the lower bedding plane. The vertical channels, about 1mm wide, are well defined from the surrounding matrix, normally calcite - filled but hollow in weathered specimens. The sedimentary laminae in a thin slab are bent downwards. A single vertical channel may successively penetrate a few thin slabs, up to 20mm or more in accumulated thickness, and form tiny pits on each upper bedding plane.

Many larger gas pits, diameters ranging from less than 10mm to 60mm and commonly 10-30 mm, are frequently scattered among the numerous small gas pits on the bedding planes. There is no gap in the size range of the smaller and larger gas pits. They are crater-shaped, with a depressed centre surrounded by several elevated rings. The margins usually fade out into the bedding planes. Their casts (with reverse relief) are better preserved on the lower bedding planes of the overlying layers (Plate 12). They are superficially similar to the typical Cyclomedusa in having an irregular, central node, and concentric undulations of the discoidal areas. On the basis of the size of the markings and the number and arrangement of the concentric rings, they were arbitrarily separated and given various taxonomic names of medusoids by Xing and Liu (1979). However, cross sections (Plate 13 : A-C) indicate that these supposed medusoids are identical in nature with the associated small gas pits. They either have a large vertical channel through the centre or display

prominent distortion of the sedimentary laminae. The walls of the channels are often irregular but well defined from the surrounding matrix by darker brown material and merge into the laminae where the channels are eventually covered by the sedimentary layers.

The effects of gas bubble bursts are occasionally seen on the same bedding planes as gas pits. They are represented by faint circular markings, varying from 10 to 30 mm in diameter, with several ridges of approximately equal length radiating from a small centre. There is no regularity in the number and arrangement of the radial ridges in these structures, which were figured as Liaoningia and considered to be medusoid fossils by Xing and Liu (1979, pl. 3, figs. 6-10).

The process through which the gas pits and gas bubble bursts were formed in the top of the Changlingzi Formation may be inferred as follows. The gas was initially trapped in unconsolidated or semiconsolidated mud. The evidence is the distortion of the fine laminae in the rock. When the gas, probably together with water, escaped upwards through the sediment, the laminae were penetrated opening the channels, and tiny pits on the surface were produced. When bubbling ceased, the sediment surrounding the channels sagged down due to loss of support from the formerly upwards escaping gas bubbles. Larger gas bubbles that rose intermittently through the mud formed broader channels, caused stronger disturbance and their pulsating eruptions gave rise to concentric rings surrounding the vents on the depositional surface. Gas bubbles that were once just beneath the surface membrane of mud could result in radial gas bubble burst when they were eventually broken.

Concerning the generation of the gas bubbles, Professor M.F. Glaessner (pers. comm.) has suggested that the gas may have originated

from the decomposition of microscopic plant material which was most likely responsible for the thin dark-coloured layers and the dark colour of the sediment when finely disseminated. His interpretation may be supported by the fact that, as seen in cross sections (Plate 13 : A-C), the walls of the vertical channels are often dark brown coloured, indicating concentration of decomposed organic matter in the sediment.

On account of the density of numerous gas pits and bursts on particular bedding planes and fine lamination of the beds, I would like to add another possibility. The vertical migration of bubbles in the mud and their evidently vigorous eruptions may have been related to regularly rising and falling tides as seen on beaches today. When the tide is rapidly rising, the air in the fine soft sediments is trapped and forced to ascend through the mud or silts. This process repeats with the next tide.

Gas as a sedimentary and diagenetic agent has been discussed in detail by Cloud (1960). Various gas pit structures from sediments the Precambrian Belt Supergroup up to the present have been reviewed by Shrock (1948) and figured by Conybeare and Crook (1968). The small gas pits from the Changlingzi Formation, Southern Liaoning closely resemble those described from Cambrian sediments on Kangaroo Island, South Australia by Madigan (1928, p. 213, fig. 20); the larger gas pits, i.e. the questioned medusoids including the supposed Cyclomedusa, resemble those found on the modern beach (Plate 14) and those figured as pit-mound structures by Shrock (1948). The gas bubble bursts with radial cracks such as "Liaoningia", are similar to those figured from the Precambrian presumed lacustrine sediments in Zambia (Clemmey, 1978, fig. 5).

Cross sectioning proved to be a convenient and effective method in distinguishing genuine medusoid impressions from medusiform

pseudofossils, e.g. gas pit structures, concretions and concentric structures caused by algal activities. The method should be tried when various Cyclomedusa - like discoidal markings are found with both casts and counterpart moulds. Completely preserved holdfasts of fossil pennatulids often show evidence of detachment from the stalk of their frond-like main bodies. Medusoid fossils represented by Cyclomedusa and Spriggia are preserved as casts and moulds of their body impressions and, as I examined from the specimens damaged across the centre, do not show a verticle tube and other kinds of particular sedimentary distortions in the verticle sections.

The supposed Cyclomedusa and other medusoids from the top of the Changlingze Formation, southern liaoning, China, are thus demonstrated to be pseudofossils of mechanical origin, and therefore can not be used as an index for stratigraphic correlation.

Discussion of the chronostratigraphic position of the Precambrian Wuhangshan Group in southern Liaoning Province is beyond the scope of this report but will be made elsewhere (see Chapters 1-3). Data available at present indicate that the base of the Wuhangshan Group, i.e. the top of the conformably underlying Chuaria - bearing Xihe Group, is approximately equivalent to the top of the Qingbaikou Group (System) in the Jixian Sinian section, about 850 Ma (Zhong, 1976; Xing and Liu, 1979; Wang et al., 1980; etc.) The top of the Wuhangshan Group is still not well defined because it is disconformably overlapped by the Cambrian but it is very likely older than the late Precambrian Nantuo Tillite (700 - 740 Ma, Wang et al., 1980) in the Yangtze Gorge, southern China. No Precambrian glaciogenic deposits are known in southern Liaoning, northeastern China, but in adjacent North Korea, a comparable Precambrian sequence is disconformably separated from the Cambrian by the Pirandon

glaciogenic diamictites (Zhong, 1976; Chumakov, 1981; Harland, 1982). Studies of stromatolites also indicate a Late Riphean aspect for the Wuhangshan Group (Zhu, 1982). Therefore, the suggested correlation of the upper Wuhangshan Group with the Sinian above the Nantuo Tillite in southern China, the Wilpena Group in South Australia, the Vendian in the U.S.S.R. and the Nama Group in Namibia (Southwest Africa) by Xing and Liu (1979) is not acceptable.

Appendix

When this manuscript was completed I received a paper from China. In "A discussion about the 'medusa fossils' from Wuhangshan Group of Late Precambrian, Liaodong Peninsula, China", (Scientia Geologica Sinica, 1984, no. 1, pp. 51-57) Chen Meng'e considered that the supposed Cyclomedusa specimens (Xing and Liu, 1979) might be soft-sand deformation structures or probably trace fossils like Monocraterion. He doubted Wade's explanation (1968) on preservation of medusoids in the Ediacara fauna, and suggested to refer Cyclomedusa and some other 'medusa fossils' from Precambrian strata to "dubiofossils".

The discussion of the validity of the supposed Cyclomedusa from southern Liaoning is appreciated; however, to mix pseudofossils with genuine medusoid fossils and refer them altogether to "dubiofossils" or "pseudofossils", as Volgdin did in 1964, is a mistake.

For those who are doubting the existence of medusae in the late Precambrian Ediacara faunal assemblages, the new, remarkably well preserved specimens of Cyclomedusa davidi (Plate 10 : A, this Chapter) and a partially over-folded Spriggia wadeae (Plate 11 : A, this Chapter) will be among the best evidence to eliminate confusion and suspicions in this field.

Chen's paper strongly indicates, from an alternative point, the significance and necessity of the study on "Cyclomedusa plexus and Cyclomedusa-like pseudofossils".

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CHAPTER 5

LATE PRECAMBRIAN SCYPHOZOAN MEDUSA:
MAWSONITES RANDELLENSIS SP. NOV. AND ITS SIGNIFICANCE
IN THE EDIACARA METAZOAN ASSEMBLAGE, SOUTH AUSTRALIA

ABSTRACT

Mawsonites randellensis sp. nov. is described as a new medusa from the late Precambrian Ediacara metazoan assemblage, Ediacara Range, South Australia. The size and morphological complexity of this species are apparently of the scyphozoan grade. The characteristic three major zones and deeply cleft marginal lappets of this fossil form are similar to those of the living Coronatae but pedalium are not developed. This new species sheds significant light on the previously enigmatic Mawsonites Glaessner and Wade, and provides the basis for the erection of the Family Mawsonitidae under? Order Coronatae. The present study confirms the fairly advanced evolutionary grade reached by medusae during late Precambrian time (the Ediacaran or Ediacarian Period).

INTRODUCTION

The late Precambrian Ediacara metazoan assemblage is widely distributed over a large area of the Flinders Ranges, South Australia (Wade, 1970; Glaessner, 1971; Jenkins et al., 1983). It consists of a rich and varied assemblage of soft-bodied animal remains including mainly cnidarians, some annelids and arthropods, and a few unique forms (Glaessner and Wade, 1966). Among nearly 2000 specimens so far collected, "medusoids" comprise the majority of individuals as well as taxa. Following the initial work of Sprigg (1947, 1949), at least 10 genera and 13 species of medusoids have been recognized (Glaessner and Daily, 1959; Glaessner and Wade, 1966; Wade, 1971, 1972). Some additional unidentified medusoid specimens require better preserved material for their description and identification.

During a geological trip to the Flinders Ranges in 1981, with Dr. R.J.F. Jenkins, I found a fairly well preserved medusa in the float weathered from the late Precambrian Ediacara Member, Rawnsley Quartzite, Pound Subgroup at the southern end of Ediacara Range. It has a discoid main body and many prominent marginal lappets. Based on this specimen (the holotype) and two specimens previously collected by Dr. Jenkins from the same locality, a new scyphozoan species, Mawsonites randellensis sp. nov., is described. The new species sheds additional light on the previously monotypic genus Mawsonites Glaessner and Wade 1966, and provides the basis for the erection of the Family Mawsonitidae under ?Coronatae. Prior to this study the genus Mawsonites was placed under "Medusae of uncertain affinities" (Glaessner, 1979, p.A96).

SYSTEMATIC PALAEONTOLOGY

Class Scyphozoa

? Order Coronatae

Family Mawsonitidae nov.

Type genus. Mawsonites Glaessner and Wade (1966) emend.

Diagnosis. Outline circular; configuration radially symmetrical; main exumbrella subdivided by a distinct coronal furrow or a comparable structure into a more elevated central zone and the surrounding zone; marginal zone broad and deeply cleft into many prominent marginal lappets.

Genus Mawsonites Glaessner and Wade (1966) emend.

Type species. Mawsonites spriggi Glaessner and Wade, 1966.

1966 Mawsonites Glaessner and Wade, p. 607-8, pl. 99.

1979 Mawsonites Glaessner and Wade, p. A96.

Revised diagnosis. A mawsonitid medusa, large (maximum known radius 75mm), generally discoidal in form, characterised by three major concentric zones of about equal width and by many, large, deeply cleft lappets in the marginal zone. Exumbrellar surface either smooth (M. randellensis) or strongly sculptured by many large irregular bosses (M. spriggi).

Its characteristic configurational pattern and prominent marginal lappets distinguish it from all other fossil and living forms. This genus and the new family represented by it differ from the living Coronatae in lacking pedalia and from the living Semaestomeae in possessing a distinct annular groove (coronal furrow) which divides the main part of umbrella into two major zones.

Mawsonites randellensis sp. nov.

Plate 15 : A-C; Fig. 27

Material and occurrence. Three fragmentary specimens on small sandstone slabs; from the late Precambrian Ediacara Member, Rawnsley Quartzite, Pound Subgroup at Ediacara Range, South Australia.

Holotype. P24594.

Paratypes. P24595, P24596.

Repositories. South Australian Museum, Adelaide.

Etymology. Named for the occurrence of the holotype near Randell

Lookout, southern end of Ediacara Range.

Preservation. The fossils occur in convex hyporelief on the lower bedding surface of purplish stained, flaggy, medium grained quartzite (holotype) or medium to coarse grained arkose (two paratype specimens). They are preserved as positive composite moulds (Wade, 1968, p. 254), revealing dominantly exumbrellar features and possibly superimposed impressions of some major internal structures. This mode of preservation is similar to that of other medusoids in the Ediacara assemblage, and is described by Glaessner and Wade (1966) and Wade (1968).

Diagnosis. Moderately large (radius 75mm in holotype), circular, discoidal medusa, radially symmetrical, with three major concentric zones of about equal width. On exumbrellar side, inner zone occupied by a raised disc which is divided by a sharp concentric furrow into a circular centre and a surrounding ring sculptured by radial grooves; disc delimited from intermediate zone by a wide, deep annular groove (? coronal furrow); intermediate zone flattened and with a few concentric rugae and numerous fine radial striae; broad marginal zone deeply cleft into many large, prominent, radially elongate lappets of uneven size, 8-10 in one quadrant.

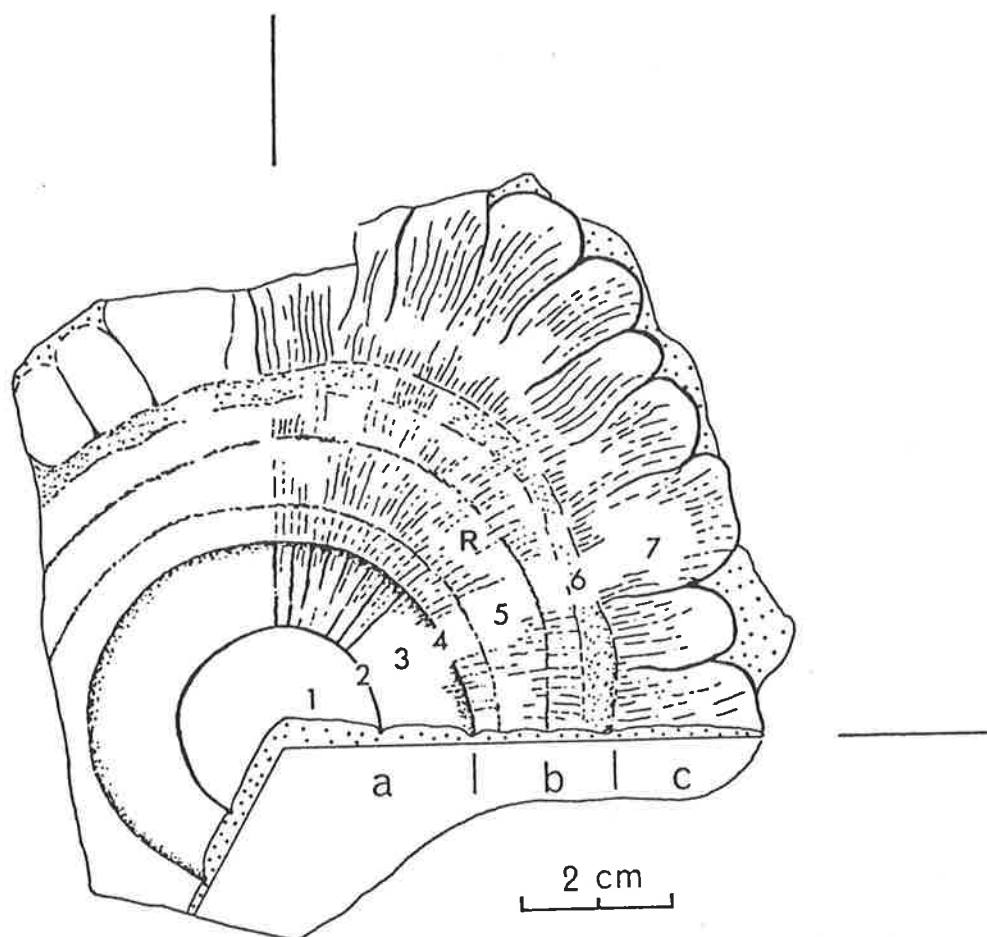


Fig. 27. Mawsonites randellensis sp. nov. Diagrammatic sketch, mainly based on holotype (Plate 15 : A); radial grooves shown on annular ring (3) of central disc (a) better preserved in a paratype (Plate 15 : B). Detail shown on one quadrant only. Zones a,b, and c, and surfaces features marked by numbers 1-7 and the letter "R" are explained in the text.

It resembles Mawsonites spriggi Glaessner and Wade in the possession of prominent marginal lappets, by which both species are distinguished from other medusoids of the Ediacara assemblage. It differs from the latter in its discoidal main part which has a generally smooth surface, without any sign of bosses, and a much more distinct marginal annular band delimiting it from the cleft marginal zone.

Description. The holotype (Plate 15 : A) is a fragment showing more than one quadrant of the exumbrella including the entire outline of the central disc. The maximum preserved radius is 75mm. Its morphology, as illustrated in Fig. 27, comprises three major concentric zones.

The central zone (a) is a raised disc, about 2-3 mm higher than the bedding plane and with a radius of about 25 mm. The central disc is further divided into a broad central circle (1) and a surrounding ring (3) by a sharp, deep, concentric furrow (2). The surface of zone (a) is weathered to varying degrees; however, very fine radial striae and coarser but fewer radial grooves can still be observed in places on the surrounding ring (3).

The outer edge of the central disc is confined by a conspicuous annular groove (4), which forms a slope dipping outwards along the central disc.

The intermediate zone (b), about 20 mm wide, is comparatively smooth. It is weakly ridged by three concentric rugae and crossed by numerous radial striae. The concentric rugae (5) are marked by fine, shallow, concentric furrows that are filled by thin films of silt a few grains thick. The radial striae (R) are very faint, fine, simple and unbranched, and number about 40-50 per quadrant. These radial striae may

fuse into those of the surrounding ring (3) of the central disc and apparently extend toward the extreme edge of the umbrella. They increase in number outward by interpolation.

The outer margin of the intermediate zone is delimited by a depressed annular band (6), varying in width from 2 to 4 mm. It is also partially covered by silt. Where the silt has been removed by weathering, its surface is smooth but traversed by very fine radial striae.

The marginal zone (c) is broad, about 22 mm wide. It is deeply cleft into many large, prominent, marginal lappets (7), about 9-10 lappets per quadrant. The lappets are radially elongate, tongue-shaped or sub-rectangular, bluntly rounded at the outer edge, sometimes overlapping at the sides, and of uneven size. Clefts that separate adjacent lappets extend from the vicinity of the marginal band (6) of the intermediate zone (b), mostly without connecting with it.

One paratype (Plate 15 : B) is a fragment representing an individual of similar morphology and size to the holotype. The preserved maximum radius is about 70 mm. The significance of this specimen lies in providing a better preserved central disc.

The central disc, about 20 mm in radius, is separated from the adjacent intermediate zone by a very conspicuous, deep, annular groove, about 2 mm wide and 1 mm deep. The annular groove is partially covered by sediment. The central disc, like that of the holotype, is further divided by a sharp concentric furrow into a central circle, 22 mm in diameter, and a surrounding ring, which is crossed by distinct, sharp, unbranched grooves, about 12 per quadrant. The ridges are delimited by radial striae like those on the surface of the intermediate zone.

As the surface of this medium - coarse grained arkose slab is rather rough and undulating at the edge, fine sculptures are largely obliterated; the marginal lappets are preserved in low relief but still clearly outlined.

The other paratype (Plate 15 : C) is represented by only about one quarter of the marginal zone. It shows 9 prominent marginal lappets. Fine radial striae are shown on the surface of the lappets, which are of similar size to those of the holotype.

Interpretation. Knowledge of Mawsonites randellensis is limited to the composite moulds of flattened exumbrellar sides. Because the features of the subumbrellar side are unknown, any attempt to restore its original morphology is possible only by inference. Nevertheless, a study of fossil medusoids in conjunction with living medusae may lead to a tentative interpretation for the structures described.

The umbrella was discoid and evidently had an elevated central dome, which has been compressed into the slightly raised central disc (zone a).

The circular central area (1), which is free of radial or concentric grooves, might delimit a presumed central stomach (within groove 2), which has been compressed with the exumbrellar apex and preserved as a composite mould.

Distinct radial grooves confined to the ring (3) surrounding the central disc may suggest some originally stiff internal radial structures, probably radial canals, extending outward from the base of the stomach. There is no indication of a ring canal.

The conspicuous annular groove (4) which horizontally divides the discoidal main part of the exumbrella into two major zones (a and b) seems analogous to the coronal furrow characteristic of the living Coronatae (Coronatida, in Harrington and Moore, 1956, p. F41).

The concentric rugae (5) on the intermediate zone (b) probably resulted from centripetal contraction or wrinkling when the medusoid body (umbrella) gradually dehydrated or subsequently collapsed due to compression. Additionally, their arrangement may indicate some soft internal tissues, such as muscle bands, which were originally distributed in annular zones. The depressed annular band (6) around the outer edge of the intermediate zone (b) is reminiscent of the coronal (or ring) muscle, a strong circular band occurring near the margin on the subumbrellar side of most scyphozoan medusae (Mayer 1910, p. 563, fig. 35; Hyman 1940, p. 503, fig. 162-C; 1956, p. F16). By its contractions the umbrella pulsates enabling the medusa to swim. The fossil medusa may have functioned similarly.

From their preservation as prominent lobate casts, the marginal lappets (7) evidently consisted of resilient fleshy material, projecting downwards from the margin of the discoidal main body and apparently free from each other. Most major groups of living scyphozoan medusae have a distinct marginal zone cleft into lappets (Mayer 1910, p. 501). Distinct marginal zones and deeply cleft marginal lappets are generally absent in hydrozoan medusae. But the Narcomedusae (Suborder Narcomedusia, in Harrington and Moore, 1956, p. F 68-73) may have a scalloped umbrellar rim divided by epidermal extensions of the tentacular base into "lappets", which are not free from each other but linked up in a ring of velum and thus differ from those of scyphozoan modusae.

Numerous fine, simple, unbranched radial striae (R) displayed on the holotype surface might be better interpreted on account of their delicate preservation as impressions of radial muscle strands shown on the surface after compression. Alternative interpretations may include superficial sculptures or fine radial canals but they are less likely. Fine superficial lineations can be easily distorted or destroyed when medusae dehydrate and shrink. They seem too numerous and too delicate to be related to radial canals.

Affinities. Considering its large size, conspicuous concentric zonation, large and deeply cleft marginal lappets, evidently of thick gelatinous substance, and developed muscles, M. randellensis may be regarded as an ancient free - swimming scyphozoan medusa.

The gross morphological pattern and the structures interpreted from the composite mould may suggest a probable affinity with the Order Coronatae for M. randellensis. Nausithoe Kolliker (Fig. 28) a common coronatan medusa, has a coronal groove subdividing the umbrella into a dome-like upper part (central zone) and a lower part (intermediate zone) and has a broad marginal zone deeply cleft into large lappets. If the exumbrella and subumbrella are compressed together, there may form a pattern like that of M. randellensis. Nausithoe is often small, below 50 mm in diameter, but some coronatan medusae, e.g. Atolla Haeckel grow to 150 mm in diameter (Mayer, 1910, p. 562). Marginal lappets of the living scyphozoan medusae are normally either all alike or variable in size but arranged in a regular pattern corresponding to the essential tetrameral symmetry of the umbrella. A few exceptions exist as noted by Mayer (1910, p. 584). The living swimming scyphozoan medusa, Dactylomedusa lactea (Mayer, *ibid.*, p. 584, fig. 369), has 34 marginal lappets. They vary considerably in both size and shape and develop in an irregular

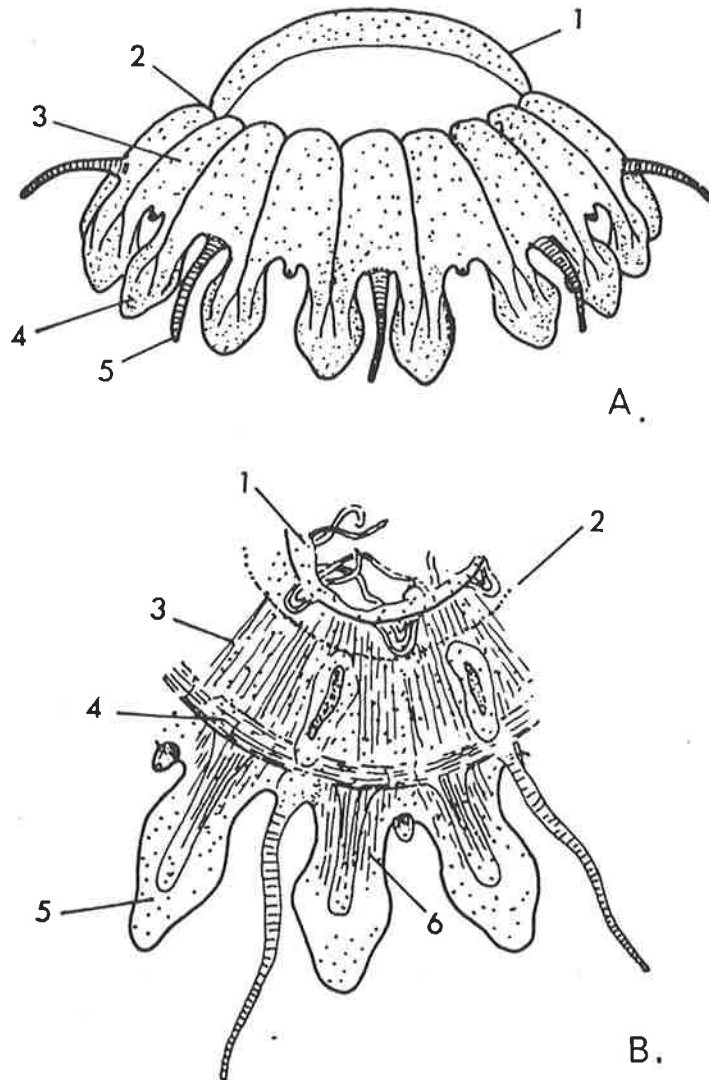


Fig. 28. Nausithoe punctata, a living scyphozoan medusa (Coronatae).
(After (a) Mayer, 1910, P.554, fig. 352; (b) Hyman, 1940, P. 502, fig. 162-C).

A. side view of exumbrella:

1. central dome, 2. coronal furrow, 3. pedalium, 4. marginal lappet, 5. tentacle.

B. subumbrellar view:

1. margin of central stomach, 2. corresponding position of coronal furrow, 3. radial muscle strands, 4. ring muscle band, 5. marginal lappet, 6. muscle strands in lappet.

pattern, ranging from 2 to 7 lappets per octant of an umbrella.

Tentacles and other appendages can be easily lost when the animal is dead and buried.

It is noted that M. randellensis apparently lack impressions of pedalia on its intermediate zone while the presence of pedalia is one of the diagnostic features of modern coronatan medusae (Mayer, 1910, p. 541; Hyman, 1940, p. 515; Russel, 1970, p. 27). The living Semaestomae lack pedalia and do not have a coronal groove.

Comparison. The holotype of M. spriggi (Plate 16; Glaessner and Wade, 1966, pl. 99, fig. 1) is of comparable size to the holotype of M. randellensis and is also preserved as an exumbrellar mould (Glaessner and Wade, 1966, p. 607; Glaessner, 1979, p. A96) with a broad marginal zone deeply cleft into prominent large lappets.

In striking contrast to the new species, the greater part of the surface of M. spriggi is strongly sculptured with arcs of many, large, irregular bosses that increase in size outwards from the outer part of a circular central area and merge into the cleft marginal zone. There is no consistent concentric band or groove to delimit the cleft marginal zone from the main part which bears bosses. A restudy of the holotype of M. spriggi (Plate 16) and comparison between it and the holotype of M. randellensis sp. nov. indicate that M. spriggi also has a basic pattern of three major zones and therefore the two species may be congeneric.

The structures as marked in Plate 16 are interpreted as follows.

The central zone (a) consists of a compressed conical centre (note compressions indicated by laterally displaced concentric grooves) (1)

separated by a sharp concentric furrow (2) from a surrounding ring (3) which has one or two arcs of small bosses. This zone is delimited from the rest by a distinct annular groove (4).

The intermediate zone (b) is sculptured by a few arcs of large, prominent, irregular bosses (5). Although the outer margin of this zone is not distinct, the outermost bosses occur in a circle (6).

The marginal zone (c) is deeply cleft into large, radially elongate lappets (7), of uneven size, with about 6-7 lappets per quadrant. The outer edge is largely weathered.

The three zones are (a) 15 mm, (b) 17 mm and (c) 30 mm wide respectively in radial direction. Therefore, the proportions are not very different from those of M. randellensis sp. nov. but the marginal zone is markedly wider.

The holotypes of M. spriggi and M. randellensis are both composite moulds with fairly well preserved surfaces. The former is characterised by many irregular bosses while the latter shows numerous fine radial striae.

In M. spriggi, the bosses, where less distorted, are arranged in alignment with the corresponding lappets and therefore, they cannot be imagined as representing rudimentary pedalia of the living Coronatae; their irregular shape, varying size and wide distribution over most of the discoidal main surface precludes consideration of them as originally internal structures, e.g. gonads. They may be interpreted as thickened, solid, irregular, wart-like ornaments inherently on the exumbrellar surface, analogous to those of some species of the living semaeostome Pelagia Peron and Lesueur (Fig. 29; Mayer, 1910, p. 571).

If that is the case, the boss-bearing exumbrellar surface of M. spriggi might have been too irregular and tough to allow the muscules, as interpreted for the new species, to be preserved as impressions on it. Because of compression, the bosses resulted in radial foldings to let some of the marginal clefts extend into the intermediate zone, as shown by the holotype, or they may even have obliterated the general pattern of zonation, as displayed by the paratypes (Glaessner and Wade, 1966, pl. 99, fig. 2; Glaessner, 1979, fig. 9-3), which should be regarded as morphological (preservational or ontogenetic) variants of M. spriggi.

The systematical position of the previously monotypic genus Mawsonites used to be uncertain (Glaessner and Wade, 1966; Glaessner, 1979, p.A 96; 1984, p.52).

The new species, M. randellensis sp. nov. contributes some significant characteristics to the diagnosis of the genus and suggests that the genus Mawsonites is one of the most advanced medusae in the Ediacara assemblage.

DISCUSSION

Mawsonites randellensis sheds additional light on the genus and shows a parallel development to other Scyphozoans. Its moderately large size, three distinct major zones and large, prominent marginal lappets display the fairly advanced evolutionary grade reached by the late Precambrian medusae.

Study of Mawsonites in conjunction with other medusoids occurring in the same assemblage indicates that the phylogenetic diversification of the living hydrozoan and scyphozoan medusae can be traced back for over 600 million years to the Ediacara assemblage (cf. Wade, 1972).

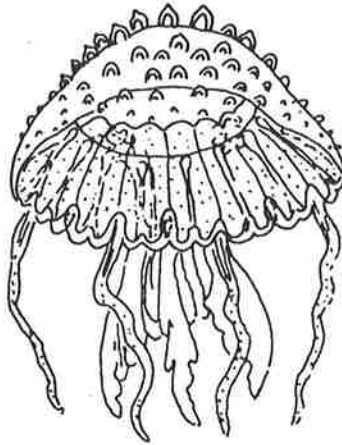


Fig. 29. Pelagia flaveola, a living scyphozoan medusa (Semaestomeae). Note the wart-like bosses on the exumbrellar surface. (After Mayer, 1910, p.575, fig. 364).

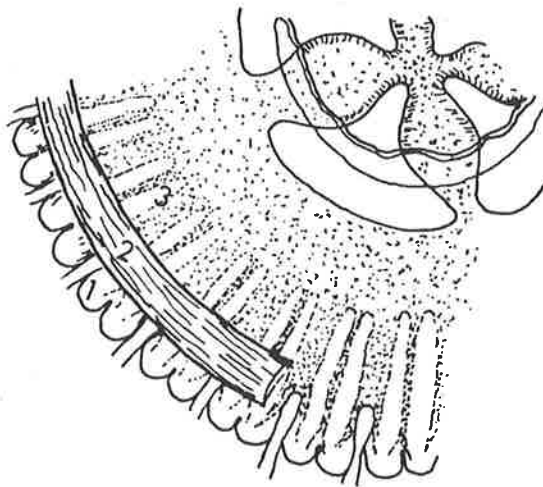


Fig. 30. Atolla bairdii, a living scyphozoan medusa (Coronatae), view of subumbrella: 1. small marginal lappet, 2. coronal muscle band, 3. radial canal. (After Hyman, 1940).

In this assemblage, the commonest medusoids are Cyclomedusa Sprigg, 1947 (Sprigg, 1949; Glaessner and Wade, 1966; Wade, 1972; Glaessner, 1979). Its gross pattern is typically of the "single-zone" form, which does not have a coronal furrow and a differentiated marginal zone. The arrangement of concentric rugae due to flattening indicates an originally smooth, convex exumbrella with a small prominent conical centre. Its numerous, fine, simple, unbranched radial grooves may be interpreted as radial canals extending from the base of a central stomach to the margin and shown on the surface because of composite moulding. The margin is generally simple and entire. Its size and general configuration are apparently similar to those of the living Aequorea Peron and Lesueur, a hydrozoan medusa of scyphozoan size and characterized by many, simple, commonly unbranched radial canals (see Chapter 4; Sun Weiguo, in press).

The largest form is represented by Ediacaria Sprigg 1947 (Sprigg, 1949; Glaessner and Wade, 1966; Wade, 1972; Glaessner, 1979). The maximum diameter is known approaching 50 cm (Wade, 1972). Its general pattern is of the double-zone form. The exumbrella is divided by a distinct annular groove into a broad, slightly elevated central disc and a surrounding ring. The subumbrellar side is similar to that of Cyclomedusa ("C. radiata" Sprigg, 1949; see Chapter 4, Sun Weiguo, in press) but differs in its radial grooves rarely entering the central portion, mainly confined to the outer portion, and occasionally branching toward the margin. The margin of the outer ring (zone) is smooth without clefts and lappets. The systematic position is uncertain (Wade, 1972; Glaessner, 1979). In spite of the very large size and a possible coronal furrow, it does not show any meaningful evidence for a possible scyphozoan affinity.

The scyphozoan medusa Brachina Wade 1972 (Glaessner, 1979), as shown in Plate 17, provides a transitional form between the double-zone, lappet-free Ediacaria and the triple-zone, lappet-prominent Mawsonites. The exumbrella (paratype, F17457, Plate 17 : B; Wade, 1972, pl. 42, figs. 4a and 4b.) appears like that of Ediacaria, divided by a conspicuous double-grooved ridge (? coronal furrow, Wade, 1972) into a slightly elevated central disc and a broad, rather flattened, surrounding zone. It is interesting to note that the periphery of the umbrella is weakly cleft into numerous, very small, marginal lappets (Plate 17 : C), 2-5 mm in size with approximately 30 lappets per quadrant (Wade, 1972, p. 211). On the subumbrellar side the presumed manubrium is small and conical; (Wade, 1972, pl. 42, fig. 5); in the holotype (F17343, Plate 17 : A; Wade, 1972, pl. 42, fig. 3.), numerous fine radial canals anastomose inwardly forming a wide ring complex around the stomach and extend outwardly attaining almost the outer edge where the spatulate lappets form a fringe. A broad annular band (Plate 17 : A-3) which continuously covers the median portions of the radial canals on the subumbrellar side was previously interpreted as a unique structure, an annular gonad (Wade, 1972, p. 209, p. 213). However, it is here alternatively regarded as evidence of a coronal muscle band. The general features of the subumbrella, except the complicated central mass partially due to preservational factors, are amazingly similar to those of a living coronatan medusa, Atolla bairdii Fewkes (Fig. 30; Mayer, 1910, p. 563, fig. 357-C; Hyman, 1940, p. 518, fig. 169-b). Numerous (128) small spatulate marginal lappets and a broad coronal muscle band are also seen in Rhizostomites admirandus Haeckel, a scyphozoan medusa in the Late Jurassic Solnhofen faunal assemblage, West Germany (see Harrington and Moore, 1956, p. F47, figs. 36-1 and 2) despite that the features from the coronal muscle band inward are obviously different. It is worth noting that Brachina, like Mawsonites randellensis, does not show pedalia on its

generally smooth exumbrellar surface but resembles the living Coronatae (Scyphozoa) in many other aspects including a coronal furrow, marginal lappets, radial canal system, a strong annular (coronal) muscle band and the absence of a ring canal.

The four discussed genera represent most of the discoidal medusoids so far known in the Ediacara assemblage. The increase of morphological complexity from the single-zone Cyclomedusa, the double-zone Ediacaria, the transitional Brachina, to the triple-zone Mawsonites form may indicate a possible evolutionary trend in the diversification of the late Precambrian medusoids (Fig. 31). The emergence and development of a prominent annular groove (coronal furrow), a differentiated marginal zone, many marginal lappets and a strong coronal muscle band are of considerable evolutionary significance. These structures enabled Brachina and Mawsonites to obtain a powerful capability of swimming and, together with other characteristics, suggest that the two more advanced genera can be regarded as ancestral Scyphozoa, with closer relationship to the living Coronatae.

Wade (in press) is to establish a subclass Vendimedusae to accommodate some non-tetrameral fossil medusae that show configurational complexity apparently of modern scyphozoan grade. The new subclass is based essentially on the new order and family represented by monotypic Brachina delicata. Based on Wade's work, Glaessner (1984, p. 52-54 and p. 116) suggested that Ediacaria flindersi may belong to the family Brachinidae on account of a coronal furrow dividing the disc.

The present study confirms Brachina to be the representative of a distinct family but disagrees on the inclusion of Ediacaria in the Brachinidae because of the lack of a differentiated marginal zone and

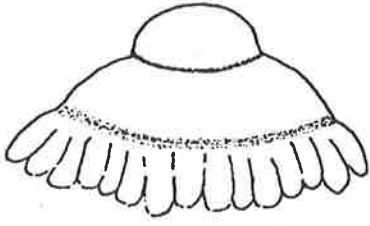
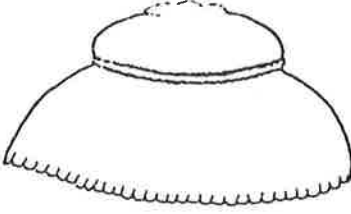
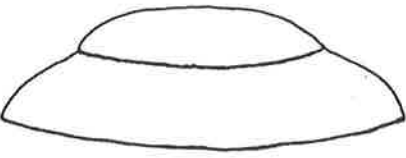
Representative	Affinity	Characters
 D. <i>Mawsonites randellensis</i>	Scyphozoa	Marginal zone
 C. <i>Brachina delicata</i>	Scyphozoa	Marginal lappets
 B. <i>Ediacaria flindersi</i>	uncertain	Coronal furrow
 A. <i>Cyclomedusa davidi</i>	Hydrozoa	Increase of morphological complexity

Fig. 31. Morphological diversification of medusae in the late Precambrian Ediacara metazoan assemblage, South Australia.

marginal lappets. It seems to me appropriate to classify the parallel families of Brachinidae and Mawsonitidae tentatively under "Order Coronatae" (or ? Coronatida, in Harrington and Moore, 1956), while the family represented by Ediacaria is here interpreted as a transitional group in the morphological diversification of medusae from the Hydrozoa to the Scyphozoa (see Fig. 31).

The oldest known remains of unquestionable Coronatae are those represented by Epiphyllina Kieslinger 1939 (Harrington and Moore, 1956, p. F42, fig. 31) from the Late Jurassic Solnhofen medusoid assemblage. Epiphyllina is essentially identical to the living coronatan medusae, showing conspicuous tetramerous symmetry and regularly developed pedalia and marginal lappets.

Simple radial symmetry, lack of pedalia and uneven size of marginal lappets may indicate the primitive characters of the ancestral coronatan medusae in the late Precambrian Ediacara assemblage. Considering the time interval of more than 450 million years between the Ediacara and Solnhofen assemblages, the prevalence of those primitive characters is understandable.

The inferred evolutionary tendency from the simple Cyclomedusa single-zone form to the advanced Mawsonites triple-zone form requires biostratigraphic proof. The medusoid fossils here discussed were found, in close association with many and varied other metazoan remains, in the Ediacara Member (Jenkins, 1975) of the Rawnsley Quartzite, late Precambrian Pound Subgroup. The Ediacara Member is less than 30 m thick at Ediacara and may reach a thickness of 112 m in the Flinders Ranges to the east (Wade, 1970; Jenkins et al., 1983). Zonation by fossils is not available for the Ediacara Member and therefore the sequence of the first occurrences of each kind of medusae can not be decided at the present

stage. Judging from the limited time span represented by the Ediacara Member, the diversification of the Scyphozoans must have commenced prior to the typical Ediacara assemblage (cf. Wade, 1972).

Repositories. Specimens studied in this paper are deposited in the collections of the South Australian Museum, Adelaide.

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CHAPTER 6

LATE PRECAMBRIAN PENNATULIDS (SEA PENS) FROM THE
EASTERN YANGTZE GROGE, CHINA: *PARACHARNIA* GEN. NOV.

ABSTRACT

Pennatulids preserved as membranous carbonised compressions from the Shibantan Member, Dengying Formation, Sinian System in the Eastern Yangtze Gorge, Hubei Province represent the first genuine discovery of the late Precambrian Ediacara-type metazoan remains in China. The specimens were initially referred to *Charnia* Ford 1958 and described as *C. dengyingensis* by Ding and Chen in 1981. Re-examination of the type material and comparison of it with other late Precambrian frond-like forms, particularly those from the Ediacara assemblage of South Australia and from the Charnwood assemblage of England, indicate that this Chinese species represents a distinct genus, *Paracharnia* gen. nov. Its characteristic polyp leaves individually free-standing on distinct leaf-stalks along the lateral sides of the median stem, resembling those of many living sea pens represented by *Pennatula*, contribute a significant feature to the Precambrian Charniidae Glaessner 1979. Its close association with abundant macroscopic algal remains of *Vendotaenia* sp. and its proximity to the overlying basal Cambrian small shelly fossil assemblages in the same succession emphasise its palaeontological and biostratigraphic significance.

INTRODUCTION

In November 1978, a fragmentary frond-like fossil was found by a Chinese geologist at Shibantan ($111^{\circ} 9'E$, $30^{\circ} 48'30"N$) on the western bank of the Yangtze River in western Hubei Province, China. The fossil locality is in the classic Eastern Yangtze Gorge 'Sinian System' section of J.S. Lee (1924) and occurs within the Shibantan Member, middle Dengying Formation. M.F. Glaessner and B. Daily were shown this specimen during their visit to China in May 1979. They suggested that it was not a trace fossil as previously supposed, but a body fossil of a pennatulid (sea pen). Subsequently Ding Qixiu and Chen Yiyuan obtained the other part of the first specimen and a piece of another fragmentary frond. These specimens were briefly described and referred to Charnia Ford 1958 as a new species, C. dengyingensis, by Ding & Chen (1981).

The significance of this discovery is considerable. On one hand, it represents the first find of genuine late Precambrian Ediacaran soft-bodied metazoans in China; on the other, as the specimens were found in a well known key section, about mid-way between the underlying Nantuo tillite and the overlying small shelly fossil assemblages in the topmost Dengying Formation, it provides important evidence for understanding the transition from the Precambrian to Cambrian in China. Because the original fossil-bearing outcrops have been flooded by the Yangtze River since construction of a new dam, the type material is especially significant for further study.

I re-examined C. dengyingensis at Hubei Institute of Geology, Wuhan, China during the trip to the Yangtze Gorges in October 1982; and compared it with other late Precambrian frond-like fossils, particularly those from the Ediacara assemblage of South Australia and from the Charnwood assemblage of England, at the Department of Geology, University of Adelaide, South Australia. These studies clarify that C.

dengyingensis substantially represents a distinct genus, Paracharnia gen. nov., in the Family Charniidae Glaessner 1979.

SYSTEMATIC PALAEONTOLOGY

Order Pennatulacea Verrill, 1865

Family Charniidae Glaessner, 1979

Genus Paracharnia gen. nov.

Diagnosis. Frond feather-like, narrow and elongate, almost uniformly wide through 2/3 of its length, distally tapering gradually to a narrowed apex; median stem wide and naked; polyp leaves or primary branches, apparently free-standing, relatively small, fusiform in shape, closely spaced on either side of stem; each polyp leaf joined to stem by a distinct leaf stalk and forming an angle of 50-80° with centre line of frond; secondary branches delimited by faint shallow furrows on one edge of individual polyp leaves.

Type species. Paracharnia dengyingensis (Ding & Chen 1981) emend.

Distribution. Late Precambrian of western Hubei, China.

Paracharnia dengyingensis (Ding & Chen 1981) emend.

(Plate : 18 A,B; Fig. 32).

Charnia dengyingensis Ding & Chen 1981, p. 55, pl. 5, Figs. 1, 2a-b.

Diagnosis. More than 60 polyp leaves on either side of stem; positions of leaf stalks alternate; up to 13 secondary branches on larger polyp leaves and fewer on smaller ones; secondary branches approximately perpendicular to upper edge of polyp leaf.

Holotype. Zn F0011, designated by Ding & Chen (1981) and deposited at Hubei Institute of Geology, Wuhan, Hubei Province, China.

Type horizon and locality. Late Precambrian Shibantan Member, middle

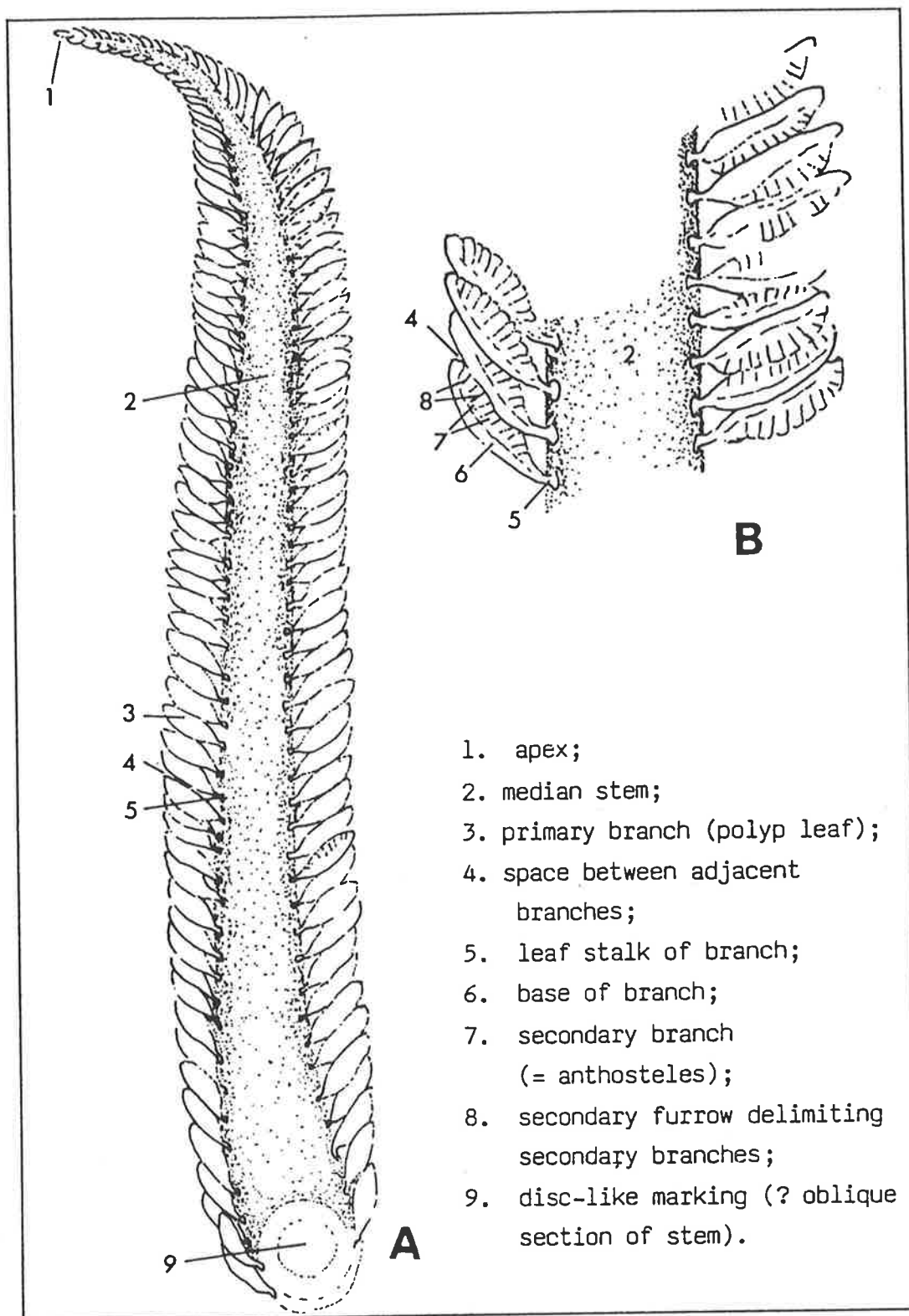


Fig. 32. Diagrammatic reconstruction and terminology of *Paracharnia dengyingensis*, based on re-examination of holotype: Fig. 32 A, x1, general appearance and major structures of frond, basically from Plate 18 : A; Fig. 32 B showing details of polyp leaves partially magnified from Plate 18 : A and Fig. 32A; note that formerly flexible ventral (upper) portions of polyp leaves were in some cases folded downwards because of flattening.

Supplementary description. The holotype, ZnF0011, is a detached frond and the second specimen, ZnF0012, (Ding and Chen, 1981, pl 5, fig. 2) is a fragment showing structures similar to the distal portion of the holotype. Both were found in situ on the weathered upper bedding plane surfaces in black, thin-bedded, organic-rich limestone. The well developed regular thin lamination suggests a quiet, sub-tidal marine sedimentary environment.

The holotype (Plate 18 : A, B; Fig. 32) is a narrow, elongate, feather-like frond, lying flat on its presumed ventral side. It is in slightly positive relief on the bedding plane. The frond is 24 cm long and up to 3 cm wide at about 1/3 of its length. The distal portion gradually tapers upwards to the apex which is bent, indicating original flexibility of the frond.

Closely spaced polyp leaves (primary branches) extend from either side of the median stem, which is wide and naked, occupying 1/3 width of the frond. It was evidently infilled by sediment and is preserved as a cast of the original structure. At the lower end there is a faint subcircular disc-like marking slightly smaller in diameter than the width of the stem. This marking suggests that the frond was folded over from a possible anchoring device to an originally upright stalk. The polyp leaves are preserved as black, film-like, organic compressions. Their colour contrasts with the pale surrounding surface of the weathered limestone. Their composition is not known. This unusual mode of preservation may provide an indication of the composition of the original tissues. Elsewhere Late Precambrian soft-bodied metazoan remains are commonly preserved as moulds and casts.

Some 60 polyp leaves are seen on either side of the stem. They are closely and regularly spaced and each extends from a short leaf stalk.

The relative positions of the leaf stalks on the opposite sides are apparently alternate. The edges of the frond are lobate, the outwardly convex portions corresponding to the terminal parts of the polyp leaves, the notches indicating spaces between them. The individual polyp leaves are usually fusiform in shape, about three times as long as wide, consisting of a relatively narrow, straight ridge extending from the leaf stalk (fused polyp base) and a blade-like portion bearing secondary branches (anthosteles). Some of the polyp leaves have been twisted through 180° along their length and most overlap to some extent because of flattening. The secondary branches are delimited by faintly developed furrows at approximately right angles to the edges of each polyp leaf. According to Ding and Chen (1981, p. 55), the larger polyp leaves may bear 13 secondary branches; fewer are present on the smaller ones.

In the mid-portion of the frond the stem is 8 - 10 mm wide, the interval between two adjacent leaf stalks is 2 - 2.5 mm; a single polyp leaf is 2.8 mm wide and up to 10 mm long (including the leaf stalk which is about 1 mm long); the angles between the polyp leaves and the stem of the frond are commonly 50° - 80° . Smaller, more crowded polyp leaves diverge from the narrowed distal part of the stem at more acute angles. Larger, loosely spaced ones appear in the proximal portion.

The appearance of distinct leaf stalks, the variable direction of twisting of the polyp leaves and the lobate margins of frond suggest that the polyp leaves were most likely free-standing from each other as in living sea pens.

Comparison and discussion. Ding & Chen (1981, p. 55) suggested that the present material could be compared with Charnia masoni Ford 1958 from the late Precambrian of Charnwood Forest, England, and Charnia -like fossils

from the Conception Group of southeastern Newfoundland, Canada (Anderson and Misra, 1968; Misra, 1969). They did not clarify the similarities and why they were considered to indicate generic identity; they mentioned some differences, such as the general shape, number and diverging angles of polyp leaves. They also hinted at a resemblance to Rangaea.

Re-examination of this Chinese species and comparison with other frond-like fossils from the late Precambrian in England, Australia, Southwest Africa, Canada and the U.S.S.R. indicate that it should be referred to the family Charniidae Glaessner 1979. Three genera have been ascribed to this family, namely Charnia, Charniodiscus and Glaessnerina. These genera are all represented by fusiform, foliate, single fronds with well defined secondary 'branches' showing serial divisions.

Ford described the frond-like Charnia (Ford, 1958, fig. 1) and disc-like Charniodiscus (Ford, 1958, fig. 2) from the late Precambrian of Charnwood Forest. He presumed that these two forms respectively represented by Charnia masoni and Charniodiscus concentricus, might be different parts of the same kind of organism and provided a diagrammatic composite sketch showing the possible association of a frond-like growth on a disc-like base (Ford, 1958, fig. 3; cited by Ding & Chen 1981, p. 54). Ford (1963) figured the entire specimen of the holotype of Charniodiscus concentricus showing a disc-like structure associated with a stalked frond which appears to be attached to the centre of the disc (Ford 1963, pl. 1, fig. a; Jenkins & Gehling 1978, figs 2 and 4; Glaessner 1979, p. A100, fig 2a). Ford included this frond in Charnia masoni, although he previously remarked that it differed in structure from the holotype of that species (Ford, 1958, pp. 213-214).

Subsequent research and comparison by Jenkins & Gehling (1978) demonstrated that the frond of Charniodiscus concentricus resembles Arborea arborea Glaessner 1959 from the Flinders Ranges, South Australia and differs markedly from the detached frond of the holotype of Charnia masoni. Jenkins & Gehling (1978, pp. 349-351) and Glaessner (1979) considered that Charniodiscus concentricus actually represents a genus and species separate from Charnia masoni, and recognised Arborea as a synonym of Charniodiscus.

The present material differs from Charnia in showing a wide stem to the frond rather than a zig-zag axial trace, and in its more numerous branches and generally more elongate form. The configuration of the branches is also markedly different in that they appear to be separate, free standing structures diverging from the stem at $60 - 80^{\circ}$ rather than complex fusiform elements forming an alternate sympodial pattern at an acute angle to the mid-line of the frond. Therefore the previous assignment of the present material to Charnia seems unjustified.

Specimens of Charniodiscus are frequent components of the Ediacara assemblage. Charniodiscus arboreus (Glaessner 1959) and Charniodiscus oppositus Jenkins 1979 are distinguished mainly on the basis of whether the secondary 'branches' are in alternate or opposite positions, respectively. In both species the fronds are usually large, broad, fusiform in shape, 2.5 to 4 times as long as wide and with a relatively wider dorsal track and a slightly narrower ventral track of the stem. One of the most diagnostic characteristics is that the polyp leaves appear to have been situated on a foliate base. Thus the frond has entire margins. Accordingly, the potential assignment of the present material to Charniodiscus is also eliminated.

Germ's (1973, p. 5) recognized essential differences between Rangaea Gürich 1929 from the Nama Group of Southwest Africa and forms from the Flinders Ranges formerly named Rangaea grandis and Rangaea longa Glaessner and Wade 1966. He suggested that the former be referred to a separate genus, Glaessnerina Germ's 1973.

Glaessnerina grandis, the type species, is superficially similar to Charnia. Germ's (1973) and Glaessner and Walter (1975) suggested that further study of Glaessnerina and Charnia may make it advisable to place them in the same genus. However, both Jenkins and Gehling (1978, pp. 356-357) and Glaessner (1979) have noted several differences, particularly in the detailed features of secondary branches.

Glaessnerina longa was referred to Charniodiscus by Jenkins & Gehling (1978, p. 351, p. 354). Glaessner and Walter (1975, p. 68; 1979, p. 386) maintained it in Glaessnerina. Recent study indicates that the differences between "G." longa, G. grandis, Charnia and Charniodiscus are possibly of generic significance. However at the present stage the placement of Charniodiscus longus according to Jenkins and Gehling (1978, pp. 356-357) is tentatively accepted.

The specimens referred to C. longus including the holotype P13777 (Glaessner and Wade 1966, pl. 100, fig. 4), paratypes P12716 (Glaessner 1959, p. 45, fig. 1), P12721 a-i, P12736, P12743 and a well preserved specimen (24593, Plate 19) have been restudied at the South Australian Museum and in the Department of Geology, University of Adelaide.

Both the present material of P. dengyingensis and C. longus comprise a long narrow flattened frond, gradually tapering distally, and with a prominent median stem, lobate frond margins and numerous polyp leaves.

Generally speaking, the present material is more similar to C. longus than any other known late Precambrian frond-like fossil. Nevertheless, some conspicuous differences between them are considered of generic significance. In C. longus, the ratio between the widths of the median stem and the whole frond is smaller, no more than 1:5 or even less; the polyp leaves are comparatively larger and there is evidence of their joining a foliate base which maintains their even separation. In some specimens, (e.g. holotype and specimen in Plate 19) the frond appears to be outlined by a curved array of irregular nodules that indicate a tendency of the outer terminal parts of polyp leaves to fan out and curve backwards.

Concerning the frond-like forms in the late Precambrian Conception Group of southeastern Newfoundland, Canada, one specimen figured by Anderson (1978, p.148, fig. 4) seems to be somewhat similar to the Chinese present material, especially in general outline and size. According to Anderson this remarkably long and narrow frond may represent a genus distinct from Charnia. I suggest its near affinity to C. longus. The Canadian specimen appears to be different from the present material in its very narrow, sharply defined median stem, broader polyp leaves and more acute angles between the polyp leaves and the stem, generally less than 35° .

The above comparison shows that the present material, which was formerly named Charnia dengyingensis, is conspicuously different from Charnia masoni, and also obviously distinct from Charniodiscus and Glaessnerina. It may be regarded as a representative of a new genus, to which the name Paracharnia is given.

Glaessner (1959, 1959a) referred the late Precambrian frond-like fossils, particularly those now known as Charnia, Charniodiscus,

Glaessnerina and Rangea, to the order Pennatulacea on the basis of their morphological resemblances to the living sea pens. His interpretation (Glaessner and Wade, 1966) has since been widely accepted and is confirmed by more recent studies (Jenkins and Gehling, 1978). It should be noted that this order includes living genera with polyps on separate polyp leaves (e.g. Pennatula) or on a common foliate base (e.g. Renilla).

It may be appropriate to consider the genera of the family Charniidae Glaessner 1979, including the new genus Paracharnia, as late Precambrian ancestors of the living Pennatulids. The family Rangeidae Glaessner 1979, represented by Rangea Gürich, seems to represent a unique group of ancient pennatulids. Rangea has so far been found only in the Nama Group of Southwest Africa. It is characterised by the presence of multiple fronds and distinctive lateral primary branches that are divided into small, chevron-shaped secondary branches (Pflug, 1970; Germs 1973, p. 5; Glaessner, 1979, p. A99).

BIOSTRATIGRAPHY AND CORRELATION

The definition and subdivision of the 'Sinian System' in the Eastern Yangtze Gorge section were established by J.S. Lee and Y.T. Zhao in 1924. This section is regarded as the stratotype for the late Precambrian in South China, particularly on the Yangtze Platform. It consists of four formations, namely the Liantuo Formation at the base and overlying Nantuo Tillite, Doushantuo and Dengying Formations. Recently Zhao Ziqiang et al. (1980) subdivided the Dengying Formation into four members that are, in ascending order, the Hamajing, Shibantan, Baimatuo and Tianzhushan Members (Fig. 33).

	Formation	Member	Thickness (m)	Section	Description
LOWER CAMBRIAN	Shuijingtuo				Black shale and siltstone, yielding trilobites: <u>Tsuniyidiscus</u> , <u>Hupei-discus</u> , <u>Sinodiscus</u> , etc. 573 Ma.(Rb-Sr)
					-----disconformity-----
	Tianzhushan		0.2		Black, sandy clastic phosphorite, yielding rich and varied small shelly fossils. 602 Ma.(Rb-Sr)
			2-3		-----disconformity----- Silty dolomite, yielding a few small shelly fossils. e.g. <u>Circotheca</u> , <u>Anabarites</u> , <u>Protohertzina</u> , etc.
	Dengying	Baimatuo	390		Greyish white, massive, siliceous dolomite with chert yielding: ? <u>Saarina</u> , ? Worms: <u>Sinotubulites baimatuoensis</u>
		Shibantan	148		Dark, thin-bedded, organic-rich limestone with chert, yielding: Metazoa: <u>Paracharnia dengyingensis</u> ; <u>Vendotaenia</u> sp., acritarchs.
		Hamaqing	135		Grey dolomite with chert, yielding acritarchs and oncolites.
	Doushantuo		230		Dark argillaceous limestone, dolomite and shale yielding acritarchs. 693 Ma (Rb-Sr) 700 Ma (Rb-Sr)
	Nantuo		64		-----disconformity----- Tillite and diamictite. 739 Ma (Rb-Sr)
					-----disconformity-----
UPPER PRECAMBRIAN (SINIAN)	Liantuo		102		Purplish feldspathic and tuffaceous sandstone and shale, yielding acritarchs.
	----- unconformity -----				
Sandouping Group					Schist intruded by Huangling Granite. Granite ages 805 Ma(K-Ar) 819 Ma(Rb-Sr)

Fig. 33. Diagrammatic section of the late Precambrian (Sinian) in the Eastern Yangtse Gorge area, W. Hubei Province, China. Not to scale.

Paracharnia dengyingensis appears in the middle of the Shibantan Member in black, thin-bedded, organic-rich limestone. This level is about 400 m stratigraphically above the weathered top of the Nantuo Tillite and nearly 500 m below the first small shelly fossil assemblage in the lower Tianzhushan Member.

The close association of Paracharnia with abundant macroscopic algal remains of Vedotaenia sp. (Plate 20 : A) in the Shibantan Member suggests a possible stratigraphic correlation of the main part of the Dengying Formation with the terminal Vendian Valдай Group on the Russian Platform and indirectly with the Pound Subgroup in the Adelaide Geosyncline of South Australia.

On the Russian Platform, the Ediacara-type soft-bodied fossils have been found dominantly in the Redkino Formation, and abundant Vendotaenia in the Kotlin Formation (upper) of the Valдай Group (Chumakov and Semikhatov 1981, p. 249; Rozanov and Sokolov 1982, p. 129). More than 30 species of metazoan fossils have been described from the Winter Coast locality on the White Sea (Fedonkin 1981; Chumakov and Semikhatov 1981, p. 249). Of these, about ten species and ten genera are common to the lower part of the Rawnsley Quartzite of the upper Pound Subgroup in South Australia (Jenkins, 1981, p. 184; Cloud and Glaessner, 1982, p. 217).

The Precambrian-Cambrian boundary in the Eastern Yangtze Gorge area has been set within the top of the Dengying Formation, i.e. at the base of the Tianzhushan (=Huangshandong) Member (Qian, 1977; Qian, et al, 1979; Chang, 1980; Zhao, et al, 1980; Xing, et al, 1982). In an evidently continuous and monofacial sequence, the first shelly fossil assemblage, characterised by Anabarites, Circotheca and Protohertzina, occurs in the lower Tianzhushan Member dolomite. The succeeding assemblage contains rich and varied shelly fossils of Hyolitha,

Hyolithelmites, Brachiopoda, Gastropoda, Monoplacophora, Conodontomorpha, Tommotiida, Chancellorida, Cambroscleritida, etc. in sandy clastic phosphorite layers of the upper Tianzhushan Member. These assemblages have been attributed to the basal Cambrian Meishucun stage represented in the Meishucun section at Jinning County of Eastern Yunnan Province. Disconformably above is the Shuijingtuo Formation with black shales containing Early Cambrian trilobites and bradoriids from its base upwards.

Compared with the Precambrian-Cambrian boundary sections on the Siberian Platform in the U.S.S.R., the Tianzhushan Member embraces both the 'Nemakit-Daldyn Horizon' and the Tommotian Stage. It is interesting to note that a Charnia-like pennatulid frond, Glaessnerina ('Rangea') sibirica (Sokolov, 1973, p. 209, fig. 3; Glaessner, 1979, p. A100, fig. 1) was found in the middle Yudoma Group, i.e. the Khatyspit Formation of the Olenek uplift. The biostratigraphic position of G. sibirica is very similar to that of Paracharnia in the Yangtze Gorges, China. Furthermore, according to Z.A. Zhuravleva (in Rozanov and Sokolov 1982, p. 127) the "Lower parts of the Dengying Formation (the Hamajing and Shibantan Members - noted by the author) contain a typical Yudoma assemblage of microphytolites". It seems likely that the Chinese Dengying Formation is approximately comparable with the Yudoma Group in Siberia. Equivalents of the Nantuo Tillite are missing on the Siberian Platform.

GEOCHRONOLOGY

A number of radiometric datings suggest that the Nantuo glaciation probably took place in the time span from 740 Ma to 700 Ma. and the age limit of the Precambrian-Cambrian boundary, i.e. the base of the

Tianzhushan Member, may be defined at about 615 Ma. (Wang et al., 1980; Zhao et al., 1980; Chen et al., 1981; Xing et al., 1982). This geochronological scale (disputed by Odin 1982) has been essentially supported by Compston & Zhang (1983). They selected and dated illite, and carbonate-bearing shales, as total rock samples by the Rb-Sr isochron method, and obtained well defined results of 700 ± 50 Ma in the upper Doushantuo Formation, 602 ± 15 Ma in the Tianzhushan Member (upper part - author's note) and 573 ± 7 Ma in the lower Cambrian Shuijingtuo Formation. Therefore, the age of the Paracharnia-bearing Shibantan Member is loosely bracketed between 700 Ma and 600 Ma. It is apparently consistent with Glaessner's previous conclusion that "the known age range of the Ediacara fauna lies between 680 to 700 Ma and 590 to 600 Ma" (Glaessner 1971, p. 512), and seems to be in agreement with current knowledge that most Ediacara-type faunal assemblages in different regions tend to fall in the age range from 640 Ma up to the beginning of Cambrian (Glaessner 1979: A 86).

CONCLUSIONS

1. This paper confirms the presence of a frond - like pennatulid 'Charnia' dengyingensis (Ding & Chen 1981) in the Late Precambrian (Sinian) Dengying Formation, eastern Yangtze Gorge, W. Hubei. It represents the first genuine discovery of Ediacara - type metazoan remains in China.
2. The restudy of this fossil defines it as the type species of a distinct genus, Paracharnia gen. nov.

- 3 The new genus differs from Charnia, Charniodiscus, Glaessnerina and other fossil pennatulids in its elongate outline, relatively wide median stem and many small polyp leaves which are individually free-standing on distinct leaf-stalks, not linked to a common foliate membrane. Its separate polyp leaves, resembling those of many living sea pens represented by Pennatula, contribute a significant feature to the family Charniidae.
4. The close association of Paracharnia with macroscopic algal remains of Vendotaenia sp. and its sequential relationship with the successive basal Cambrian shelly fossil assemblages indicate a possible international biostratigraphic correlation of the Chinese Dengying Formation with the Russian Valday Group, Siberian Yudoma Group and the South Australian Pound Subgroup.
5. The study of Paracharnia predicts a prospective future discovery of Ediacara-type faunal assemblages in China, particularly on the Yangtze Platform.

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Plate 1

Dropstone structures in the late Precambrian Fengtai Formation conglomerate, Mt Houjiashan, Fengtai County, near Huainan City, Anhui Province.

A. Outcrops; B. weathered surface; and C. polished surface, showing the laminae of silty matrix distorted by scattered pebbles. Both specimens are deposited at Anhui Institute of Geological Sciences.

Plate 1

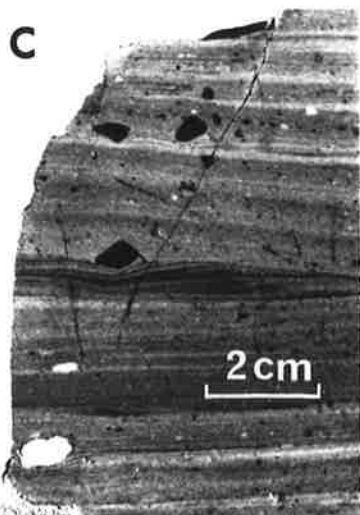
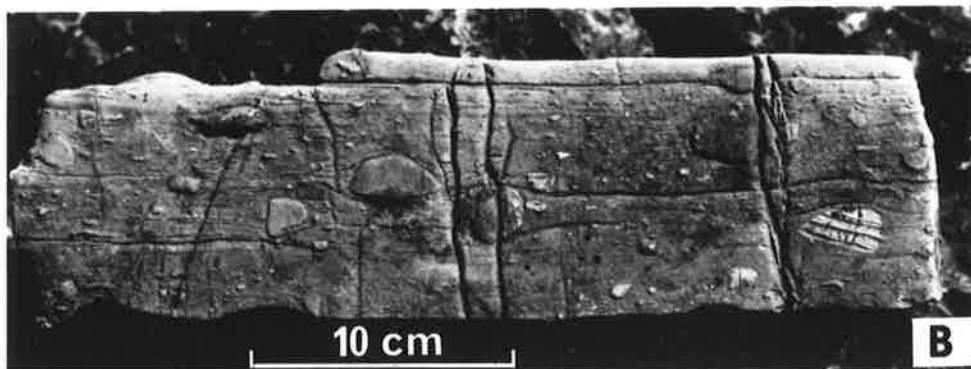


Plate 2

Late Precambrian macroscopic worm-like body fossils from the Huainan district, Anhui Province, China.

The scale bar represents 10mm on A1, B1 and C1; 3mm on A2, B2 and C2; 1.5mm on D,E and F; and 5mm on G;

A-B. Sinosabellidites huainanensis Zheng, from the Liulaobei Formation, Huainan Group; A1. holotype (62030, Geol. Dept., Hefei Multitechnological Univ.); A2. enlarged from A1, showing the detail of annulations; B1. A7091, previously designated as the holotype of "Huainanella cylindrica Wang 1982"; B2. enlarged from B1, showing two layers of the annulated compression and the flattened inner cavity filled by sediment;

C. "Tawuia sinensis" Duan, from the Liulaobei Formation, Huainan Group : C1. P8201, ribbon-like compression resembling Sinosabellidites; C2. enlarged from C1. without annulations.

D-F. Pararenicola huaiyuanensis Wang, from the Jiuliqiao Formation, Feishui Group; D. holotype, A7903, fragment of a twisted body; E. A7904, previously designated as the holotype of "Paleorhynchus anhuiensis Wang 1982", here re-interpreted as the anterior end of Pararenicola huainanensis, showing a large, irregular, proboscis-like structure in the front and a few annulations curved toward a broad circular anterior aperture (mouth); F. A7905, fragment of posterior part with bluntly rounded end;

G. Protoarenicola baiguashanensis Wang, holotype, A7906, from the Jiuliqiao Formation, Feishui Group, showing a slender annulated body with a small distinct ovate bulb at the anterior end.

Plate 2



A1



A2



D



E



B1



B2



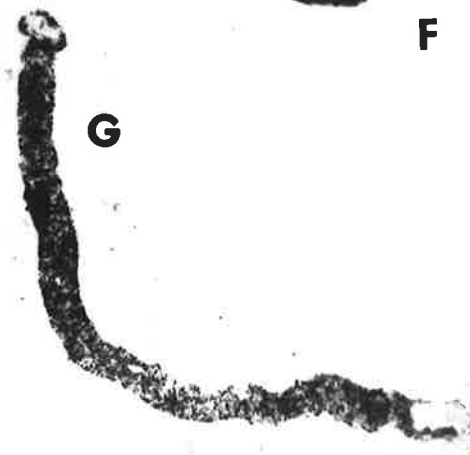
F



C1



C2



G

Plate 3

Sabellidites cambriensis Yanishevsky, from the Blue Clay, Lower Cambrian Baltic Stage, Leningrad district, Russian Platform : A. a borehole sample, showing abundant fragmentary tubes of Sabellidites; B. showing elongate tubes of constant width; C and D, SEM photographs showing detail of cross wrinkles on the exterior surfaces, photographed at the University of Adelaide. The specimens were presented by Professor M.F. Glaessner.

Plate 3

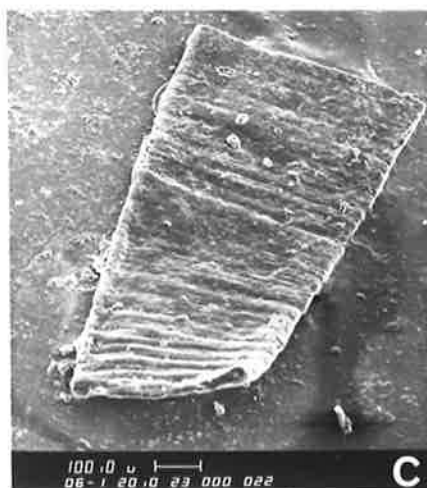
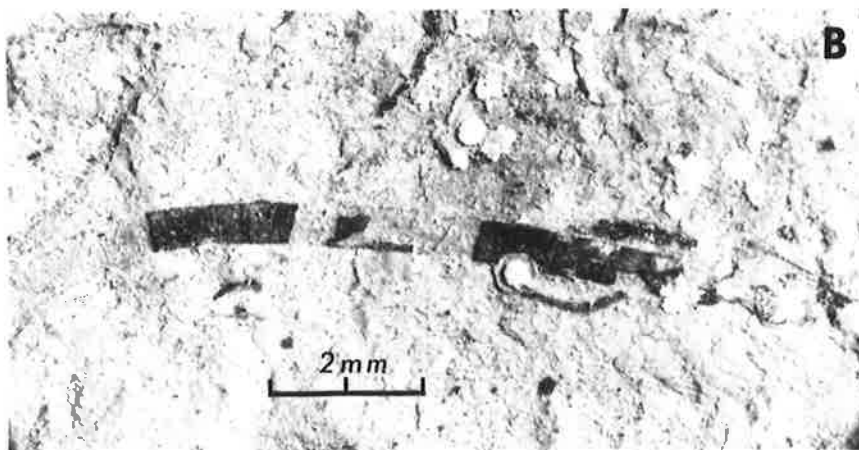
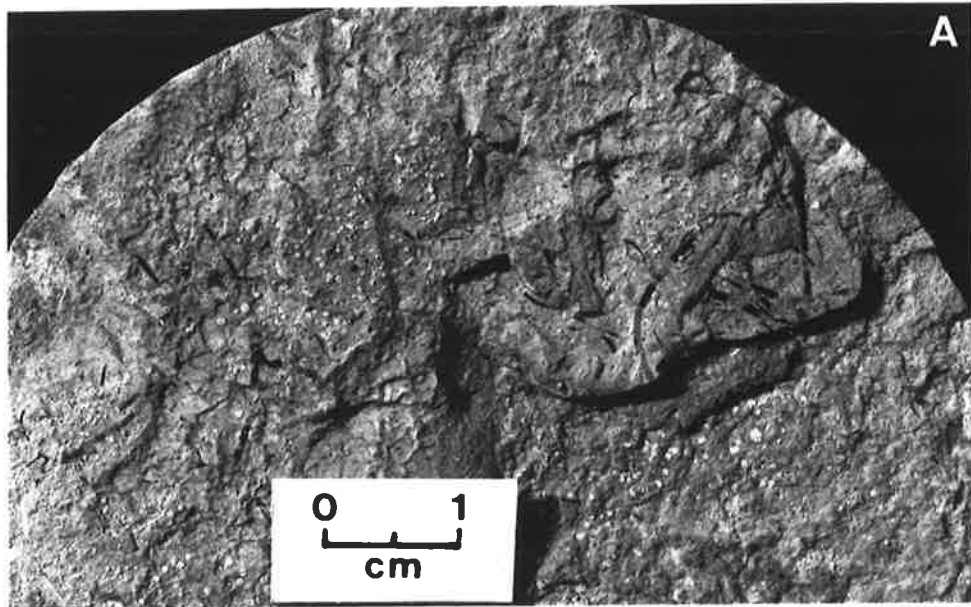


Plate 4

Pararenicola huaiyuanensis Wang, from the late Precambrian Jiuliqiao Formation, Feishui Group, Huainan district, Anhui Province, China. Scale bar represents 2mm for all.

A and B, P8202 a-b, counterparts of a fragment with anterior end, showing a possibly retractile proboscis-like structure in the front;

C. P8203, body curved and incompletely preserved;

D. A7907, fragment of a curved and twisted body, previously designated as the holotype of "Paleolina tortuosa Wang 1982";

E-G. P8204-6, fragments of curved bodies; H. P8207, body nearly complete, showing a broad circular aperture (mouth) in the front;

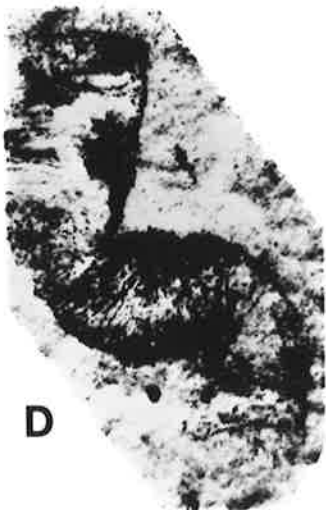
I-J. A7907-8, both previously described as "Ruedemannella minuta Wang 1982", here referred as juvenile forms or small contracted bodies of Pararenicola huaiyuanensis;

K-L. A7909 and P8207, naturally preserved cross sections on bedding planes, each showing a few annulations and a broad cavity, a small circular structure of uncertain significance seen inside K is not present in L.

Plate 4



J



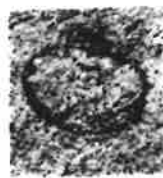
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K



I



L

2mm



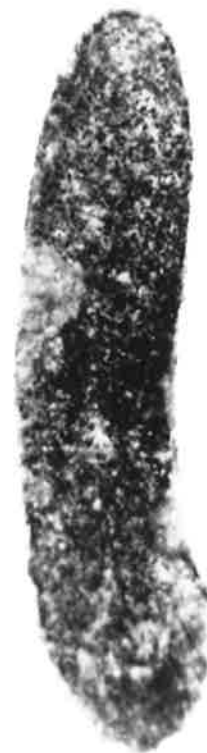
E



F



G



H

Plate 5

Chuaria circularis Walcott, showing appearance and preservation of the material from the upper Precambrian on the North China Platform.

Specimens in A-B are from the Liulaobei Formation, Huainan district; those in C-H are from the Nanfen Formation, Fuxian district.

A. A8251 a, b, silty shale split along and parallel to the bedding showing individual Chuaria compressions on the counterparts;

B. A8251 b, enlarged from 1b. Note the size range and preservational alteration. Some compressions are only partially exposed;

C-D. SEM images. C. a circular compression on the silty shale surface of sample L7931, showing concentric wrinkles and granular appearance of the surface due to compaction against the silty matrix; D. enlarged from the framed area in C, showing shrinkage cracks and wrinkles of the organic film. (A silt grain is attached to the wrinkle in the upper part of the picture).

E. L7901, specimen on a siltstone bedding plane.

F-H. Vertical sections of compressions within laminated siltstone, showing the variation resulting from different degrees of compaction.

F. L7922 a; G. L7922 b; H. L7923 a. The 1mm scale in F also applies to G and H.

Plate 5

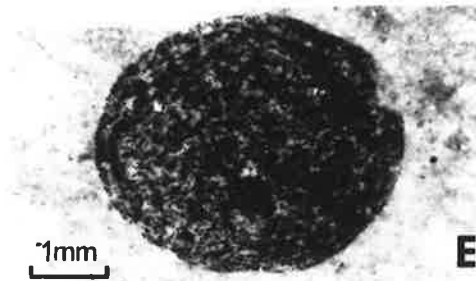
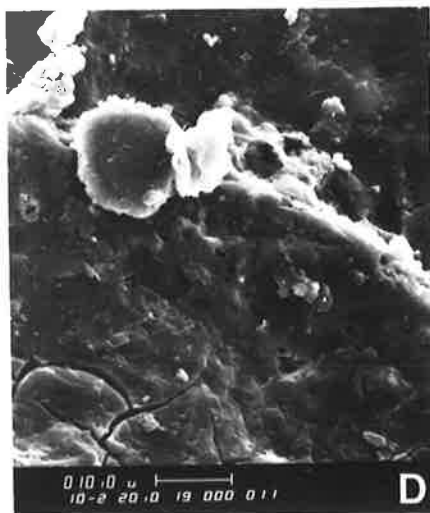
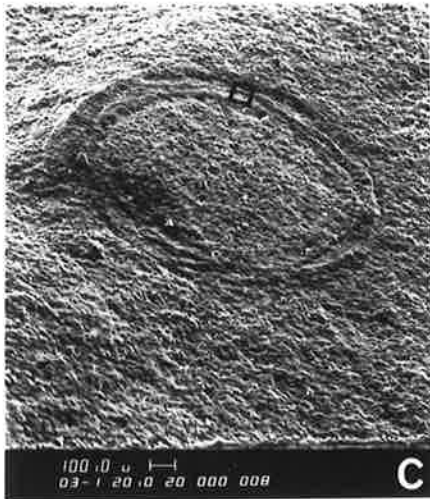
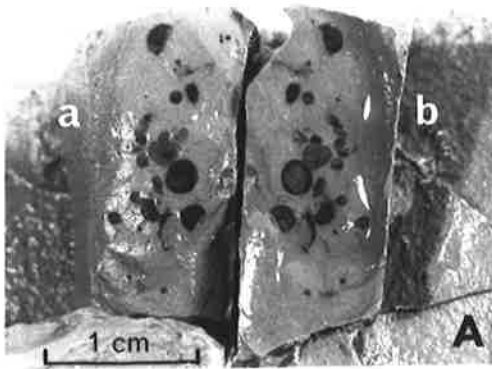


Plate 6

Chuarina circularis Walcott, demonstrating detailed structures in specimens from the Liulaobei Formation, Huainan district.

A. A8250, a cluster of compressions on a silty shale surface, showing variation in size and shape and in some cases overlapping of the margins of adjacent compressions.

B. Bioplastic transfer of A8252, showing strongly wrinkled and folded surface and a small circular body inside (left side of photograph).

C. Peel of A8215 a, showing two overlapping compressions, left one with two small circular bodies and right one with many more inside.

D. Enlarged from B, showing dark coloured wrinkles and folds of the outer membrane of an originally spheroidal body. Scale bar 250 μm .

E. Enlarged from the central area of the compression on the right of C, showing more detail of the enveloped small circular bodies. Note the obscure filamentous structures of the small body, marked by f. Scale bar 250 μm .

F. Peel of A8215 b, showing a circular compression with wrinkled and folded surface.

G. Membranous carbonaceous compression composed of numerous, densely compacted, entangled filaments with uniseriate, unbranched trichomes; microphotograph ($\times 450$) in transmitted light, taken from the lower left marginal area of the peel in F. Scale bar 50 μm .

H. Re-enlarged from the middle portion of G, showing more detail of the filamentous structures. Scale bar 50 μm .

Plate 6

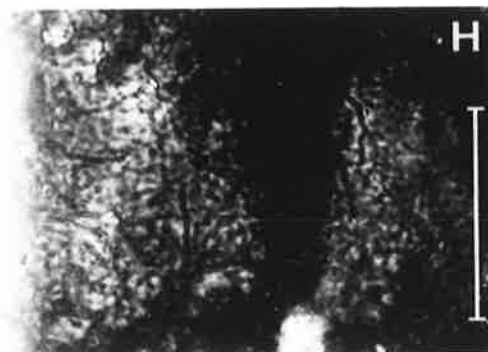
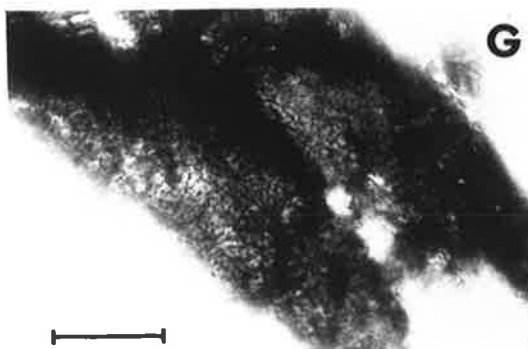
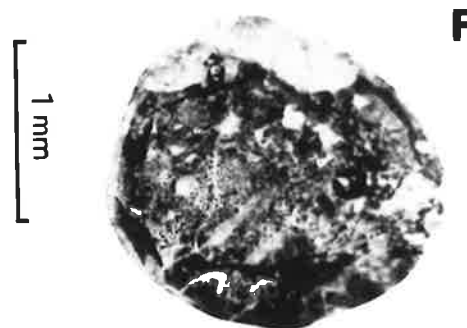
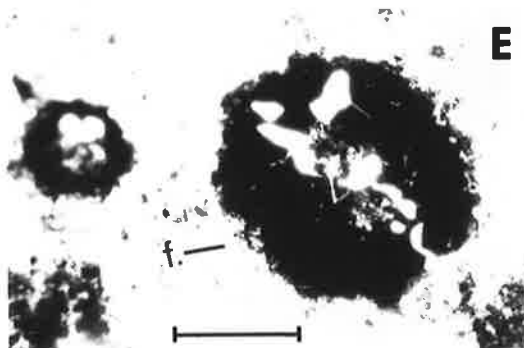
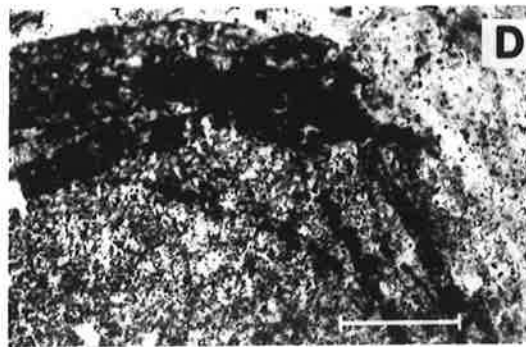
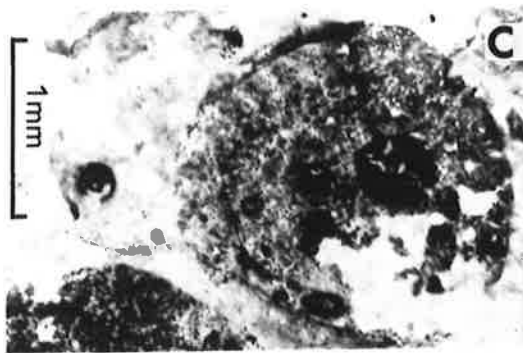
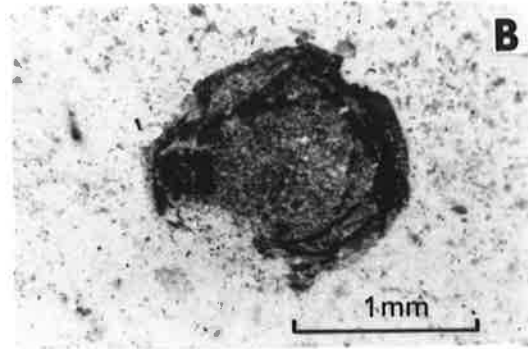
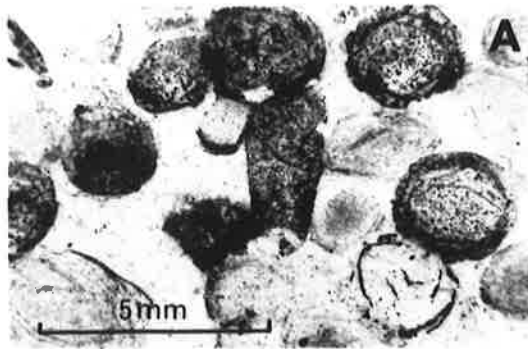


Plate 7

Nostoc sp., spheroidal colonies of a living filamentous bluegreen alga, from a beach in South Australia, studied for comparison with Chuararia.

A. Shape and size range of Nostoc balls. Two smaller bodies remaining spheroidal, the others collapsed and folded.

B. A Nostoc ball, 1.8 mm in diameter, now flattened and mounted between a glass slide and a cover slip.

C. A flattened and mounted Nostoc ball, showing two spheroidal daughter colonies (a, b) enveloped within the ball.

D. Development of wrinkles and folds of a flattened Nostoc ball. Scale bar 250 μ m.

E. Enlarged from Cb, showing the daughter colony with a thickened limiting membrane and numerous entangled fine filaments, same as those outside the daughter colony and within the ball. Scale bar 250 μ m.

F. Enlarged from the lower left part of B, showing concentric wrinkles developed towards the periphery when the Nostoc ball was gradually flattened. Scale bar 250 μ m.

G-H. A Nostoc ball consisting of numerous entangled filaments and a very thin common outer membrane. Each filament is composed of an indistinct sheath and a uniseriate, unbranched, bead-like trichome. Heterocysts are often terminal and only slightly larger than the vegetative cells.

Microphotograph (x450) in transmitted light, scale bar 50 μ m.

Plate 7

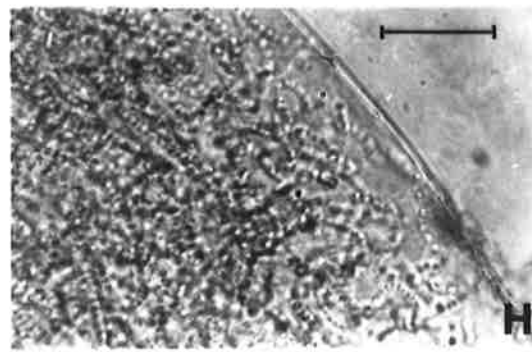
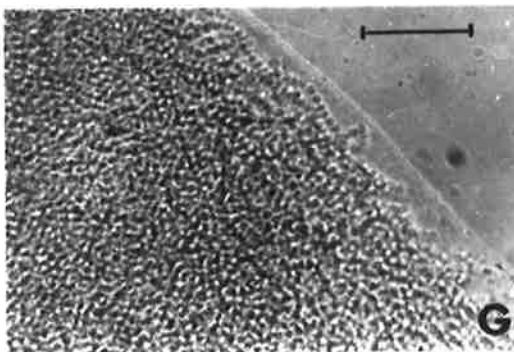
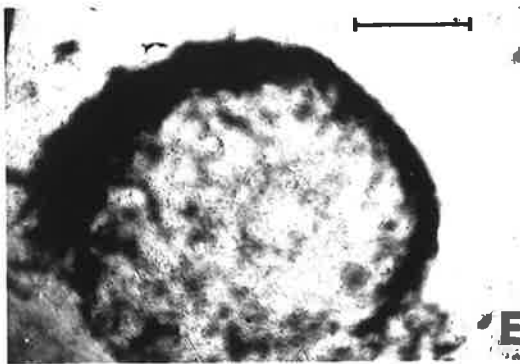
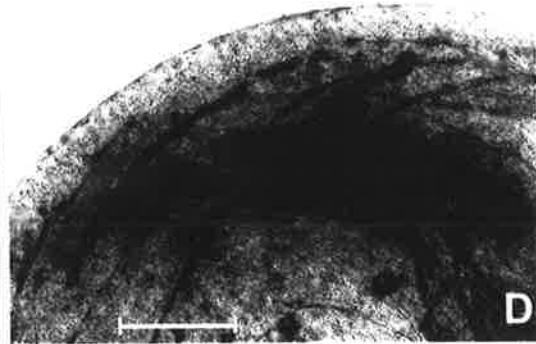
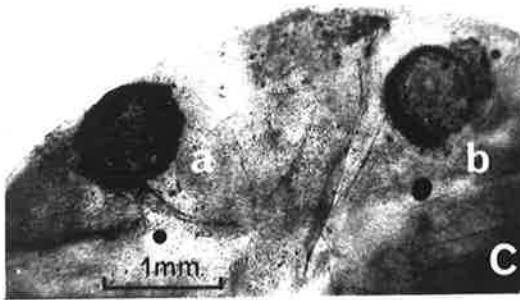
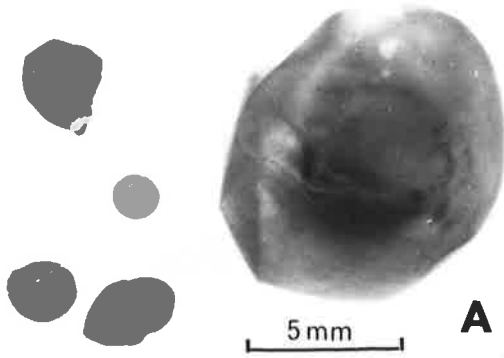


Plate 8

The Chuarua - Tawuia macrofossil assemblage from the Upper Precambrian, Huainan district, North China Platform. All figured specimens from the Liulaobei Formation, Huainan Group except that in C, which is from the Jiuliqiao Formation of the Feishui Group. 1 cm scale refers to E-H.

A. A8210, showing size range and morphological variation of a cluster of Chuarua compressions on a silty shale surface. Note four elongate elliptical forms on the right of the picture, which are probably small bodies of Tawuia.

B. Bioplastic transfer of A8253, showing compressions of small circular discoidal Chuarua and relatively large elongate ribbon-like Tawuia.

C. A8276, showing a curved compression of Tawuia dalensis Hofmann with a small Chuarua-like disc adjacent to one end, on a bedding plane of argillaceous limestone.

D. A8254, showing two individual compression of Tawuia dalensis on a bedding plane of silty shale. Note that the left one (a) encloses many small circular bodies but the right one does not.

E. A8218 a, showing a Tawuia dalensis compression which is still partially covered by the overlying layer of siltstone in its middle part.

F. A8213, Tawuia dalensis ("T. sinensis" Duan), showing numerous obscure filamentous impressions on the surface of the compression.

G. Enlarged from Db.

H. A8255 b, showing a small (juvenile) form of Tawuia.

I. Enlarged from D a, showing the enveloped small circular bodies.

Plate 8

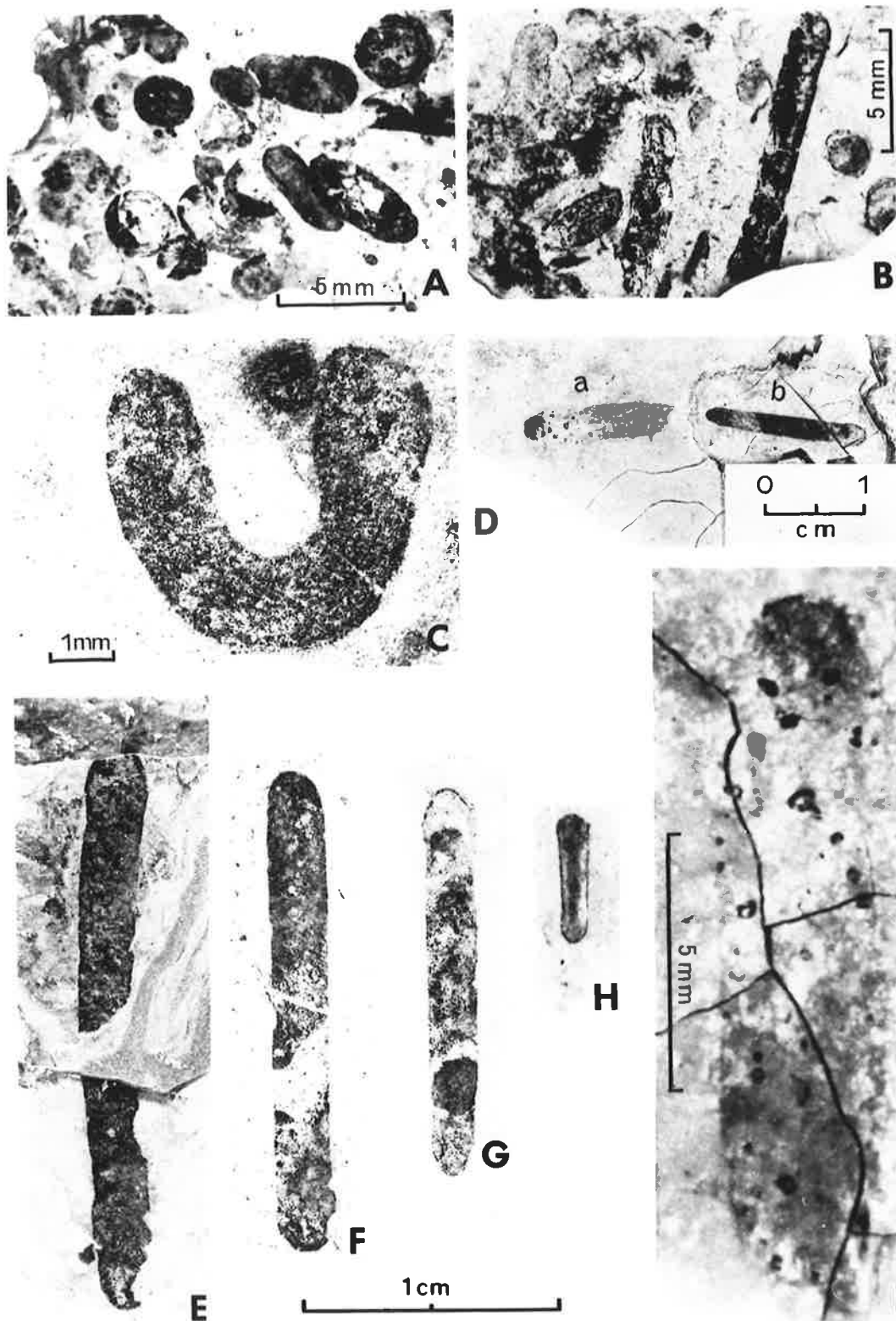
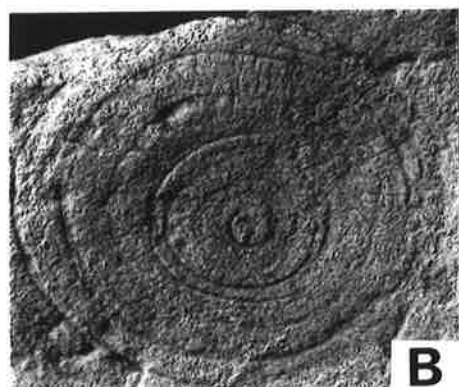
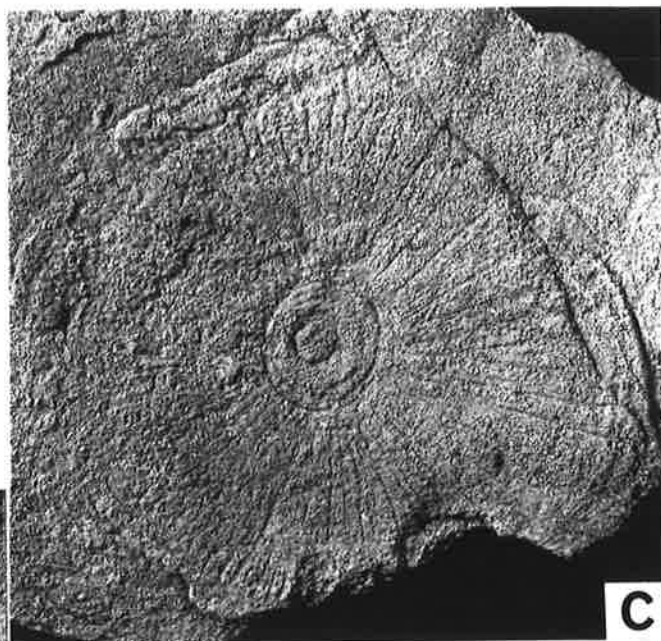
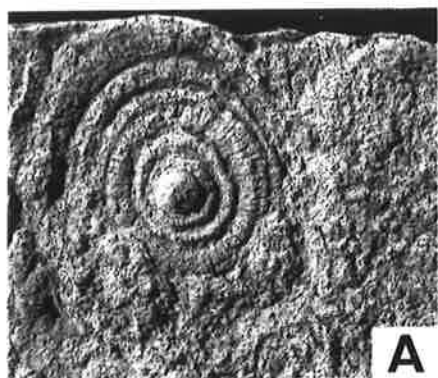


Plate 9

Cyclomedusa plexus; specimens preserved as casts on lower surfaces of sandstone or quartzite slabs; from the Ediacara Member of Rawnsley Quartzite, late Precambrian Pound Subgroup; Ediacara Range, Flinders Ranges, South Australia. Scale: 2cm for all.

- A. T5, holotype of C. davidi, composite mould dominated by exumbrellar features; outer portion incompletely preserved;
- B. 2020, paratype of C. davidi, with a complete subcircular outline; fine radial grooves patchily occurring on the concentrically rugate exumbrellar surface due to composite moulding;
- C. 2037, holotype of formerly separated "C. radiata", here reinterpreted as a composite mould dominated by subumbrellar features of the same species as C. davidi;
- D. 2010, paratype of formerly separated "C. radiata", here reinterpreted as a cast showing subumbrellar surface of C. davidi; showing a ring-shaped mouth (or margin of central stomach) and numerous strong radial grooves extending from the mouth towards the extreme margin; at a patch (lower right in the figure along the margin) where the subumbrellar surface has been exfoliated, a smooth, undulated surface (exumbrella) exposed;
- E. Spriggia annulata (Sprigg), 2031, holotype. Reinterpreted as an aboral surface showing an annularly chambered disc (float) with a small central papilla; a thick, wide, marginal flange with very fine concentric wrinkles, and at a patch (lower on the left in the figure) where the layer of marginal flange has been weathered off, numerous, fine, slender, gently bent, radial striae (marginal tentacles) extending below and just outside the flange, different from radial grooves of C. davidi.

Plate 9



2 cm

Plate 10

Cyclomedusa davidi Sprigg (1947); preserved as casts on lower surfaces of quartzite slabs, from the Ediacara Member of Rawnsley Quartzite, Ediacara Range. Scale: 5cm for both figures.

A. P 18279, showing three individuals; a. a composite mould dominated by exumbrellar features; b and c, composite moulds dominated by subumbrellar features. This specimen indicates that the formerly separated C. radiata is conspecific with the type species C. davidi;

B. P 14176, exumbrellar side; at a patch (on the right in the figure) where the layer of exumbrellar surface has been weathered off, numerous, straight, closely spaced, radial striae (radial canals) are shown on a plan beneath the exumbrellar layer and confined by the umbrellar margin.

Plate 10

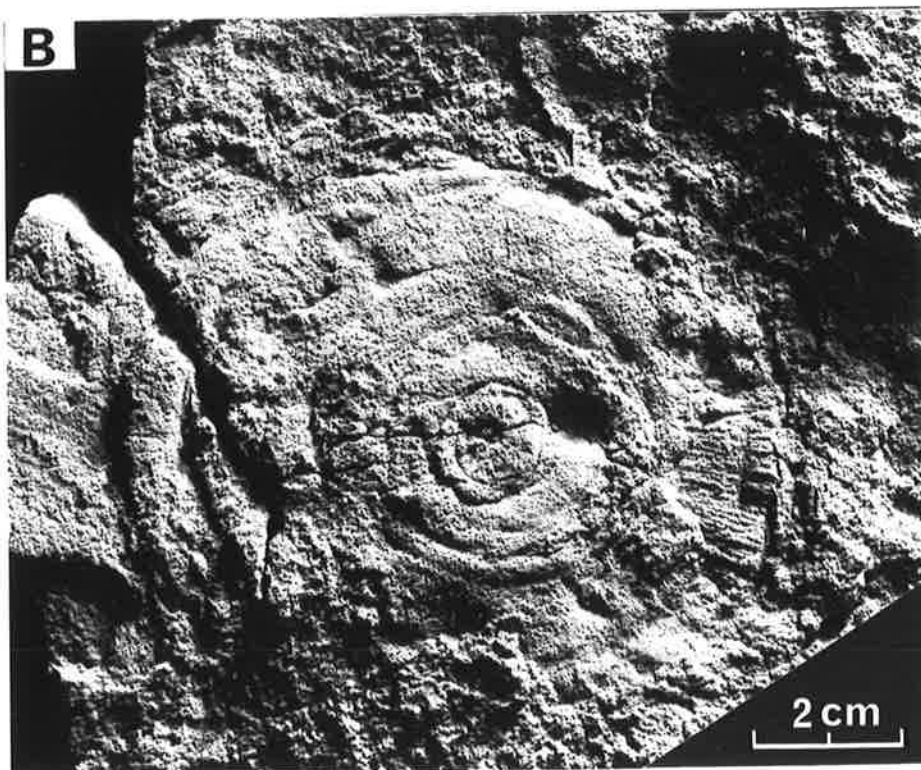
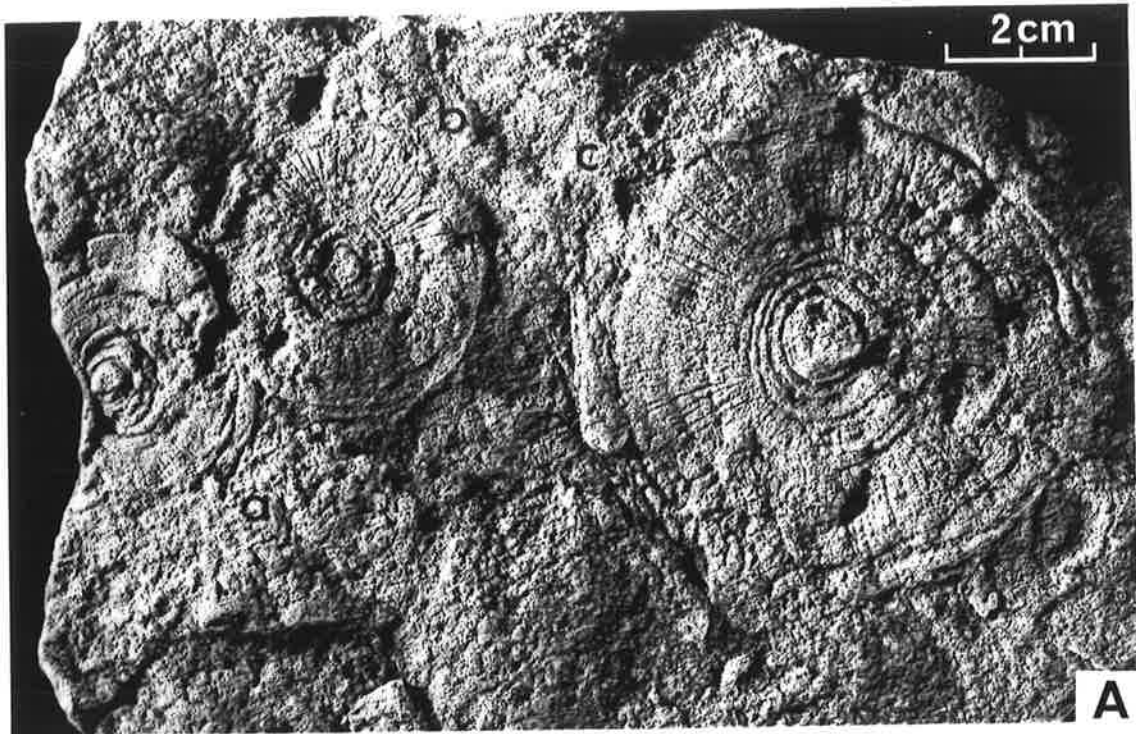


Plate 11

Spriggia wadeae sp. nov.; discoidal bodies preserved as casts of generally convex relief on a single bedding plane of a sandstone layer and their counterpart moulds (not figured here) on the lower bedding plane of the overlying layer; from the Ediacara Member of Rawnsley Quartzite, Brachina Gorge, Flinders Ranges. Scale: 5cm for all.

A. a, 1099a, holotype, an overfolded disc with distinct annulation of chambers displayed consistently on both sides; marginal flange membranous; marginal tentacles numerous, long, slender but too faintly preserved to be shown clearly by this figure. b, 1099b, paratype, aboral side, a flattened disc with a distorted marginal flange. c, 1099c, paratype, aboral side, disc very flattened, with fairly distinct impressions of marginal tentacles across and outside the marginal flange; a patch (lower along the margin) indicating that the remains had been compressed into a film and embedded by very fine silts;

B. 1099d, paratype, oral side, normally flattened, showing prominent annular chambers, a crater-like central gastrozoid with many short, fine radial processes (?bases of oral tentacles) on the ridge, the central chamber occurring in the bottom of central gastrozoid, membranous marginal flange and remains of marginal tentacles;

C. 1099e, paratype, ?aboral side, flattened disc showing very fine annulation sculptures perhaps due to alteration of annular chambers; marginal flange folded;

D. 1099f, paratype, the biggest known; oral side, surface rough probably due to shrinkage and decomposition of soft tissues, central gastrozoid prominent.

Plate 11

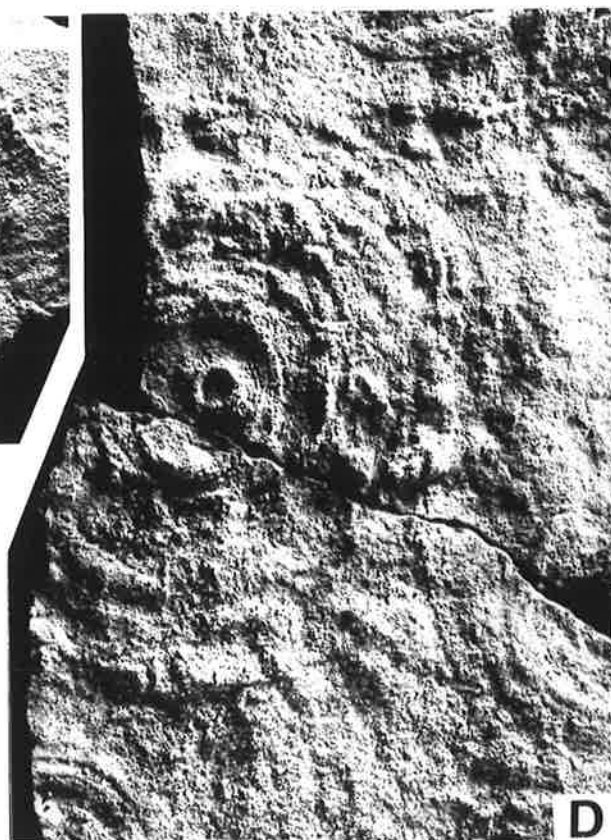
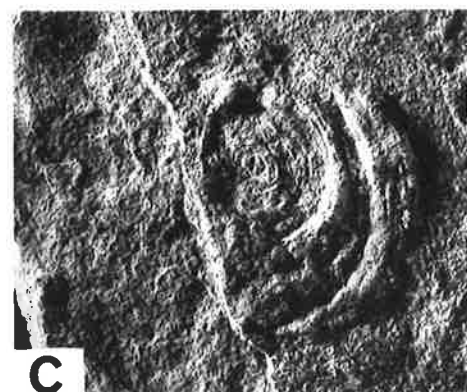


Plate 12

Cyclomedusa-like pseudofossils from the top of the Precambrian Changlingzi Formation, Wuhangshan Group, near Fuxian Country, southern Liaoning Province, China.

Lower bedding plane of a thin bedded muddy limestone slab showing many centimetric circular structures (the supposed Cyclomedusa) and numerous millimetric tiny mounds, which are casts of large and small gas-pit structures formed on the upper surface of the underlying layer.

Plate 12

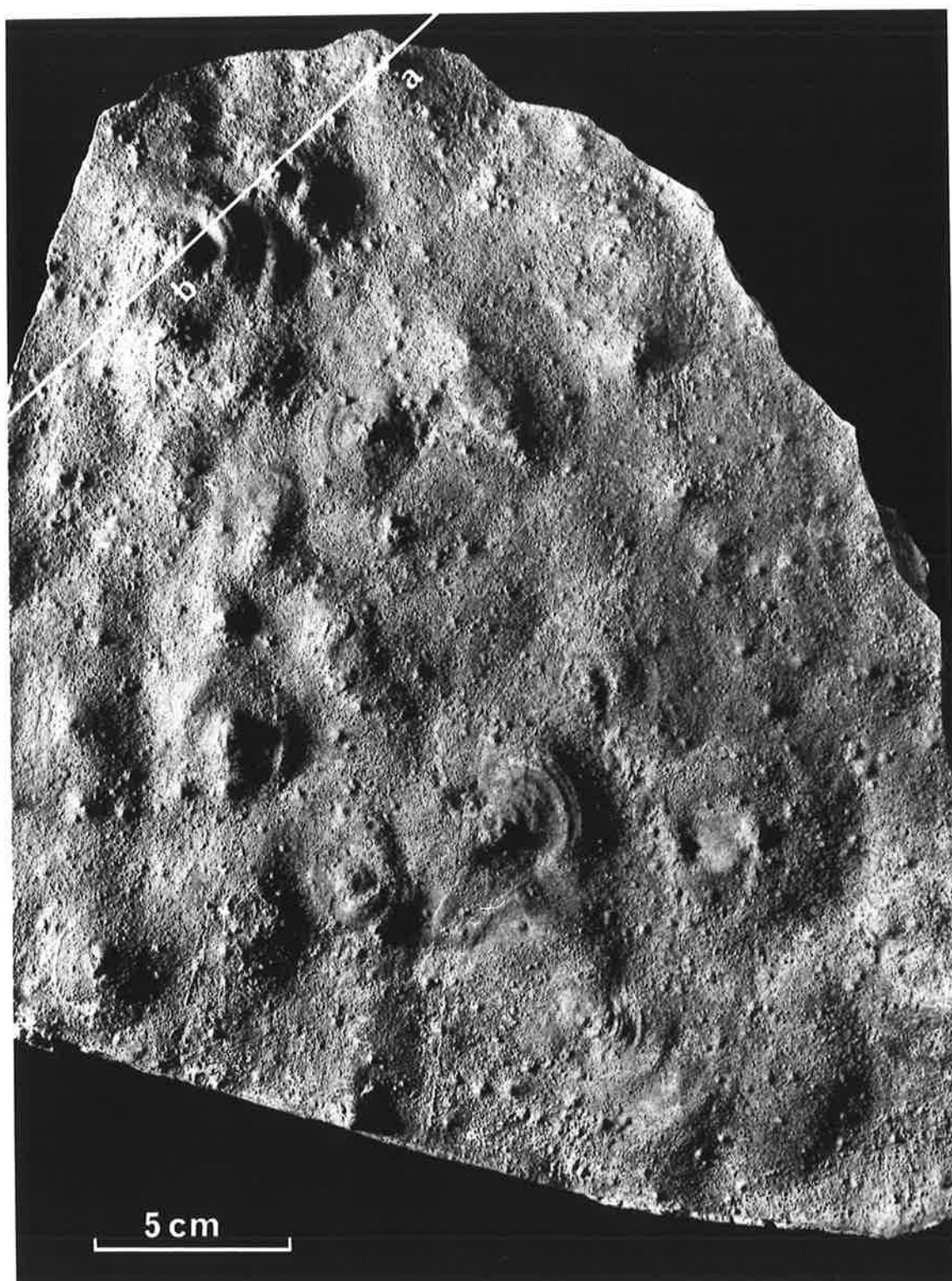


Plate 13

Cyclomedusa-like pseudofossils from southern Liaoning, China. Scale bar on each figure represents 1 cm.

A. Cross section a-b, position as shown in Plate 12, showing a prominent central vertical channel (on the left) within a Cyclomedusa-like structure, and distinct distortion of sedimentary laminae caused by casting of large gas pits (on the right);

B-C. Cross sections showing the detail of the vertical channel and distorted thin laminae of the Cyclomedusa-like structures : B. enlarged from A-a; C. thin section of the structure shown between a. and b. in Plate 12;

D-F. Small gas pits: D. showing numerous gas pits on the upper surface; E. tiny casts of gas pits on the lower surface of the overlying layer; F. cross section, showing a calcite-filled vertical channel through the centre of a gas pit and curved laminae.

Plate 13

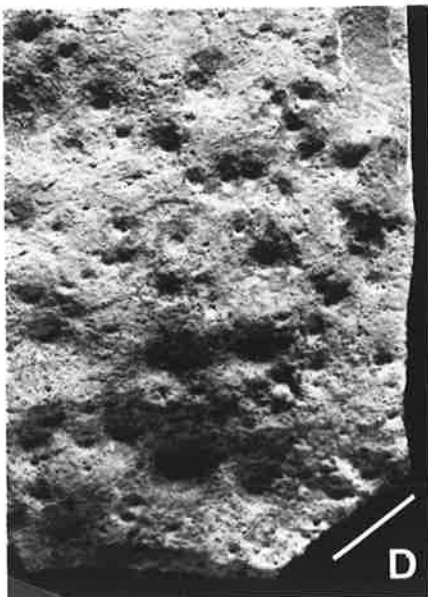
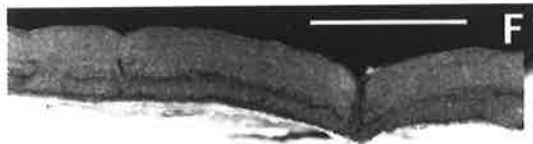
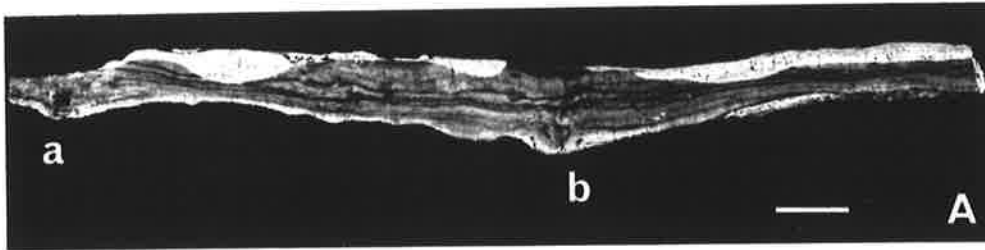


Plate 14

Gas-escape features in the sandy intertidal zone, beach adjacent to the Murray River mouth, Goolwa, South Australia; scale of coin equals 29mm.

(Photos by courtesy of Dr. B. Daily).

A. Collapsed gas-pit structures showing concentric ridges surrounding a central hollow tube; a non-collapsed gas-bubble structure lower in the picture; several small gas pits conspicuous on the same surface; flow lineations caused by swash retreating seawards;

B-C. Isolated and twinned collapsed gas-pit structures.

Plate 14

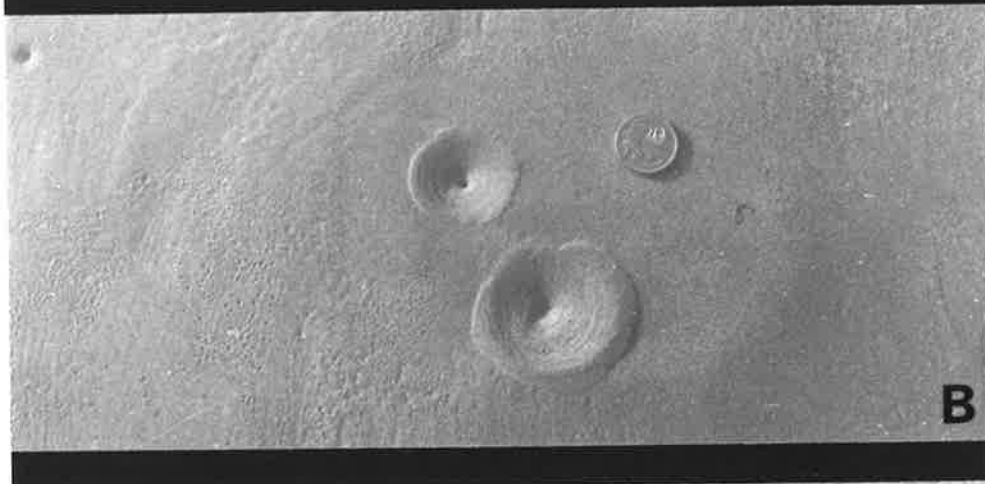


Plate 15

Mawsonites randellensis sp. nov. All preserved in convex relief on the depositional lower bedding surfaces of sandstone slabs; from the late Precambrian Ediacara Member, Rawnsley Quartzite, Pound Subgroup at Ediacara Range, South Australia. Scale 2cm for all;

- A. Holotype, P24594; positive composite mould of exumbrellar side. The surface of the central area is weathered to varying degrees;
- B. Paratype, P24595; positive composite mould of exumbrellar side. It shows a central disc better preserved than that of the holotype;
- C. Paratype, P24596; showing a fragmentary marginal zone. The arrangement of the marginal lappets is markedly distorted.

Plate 15

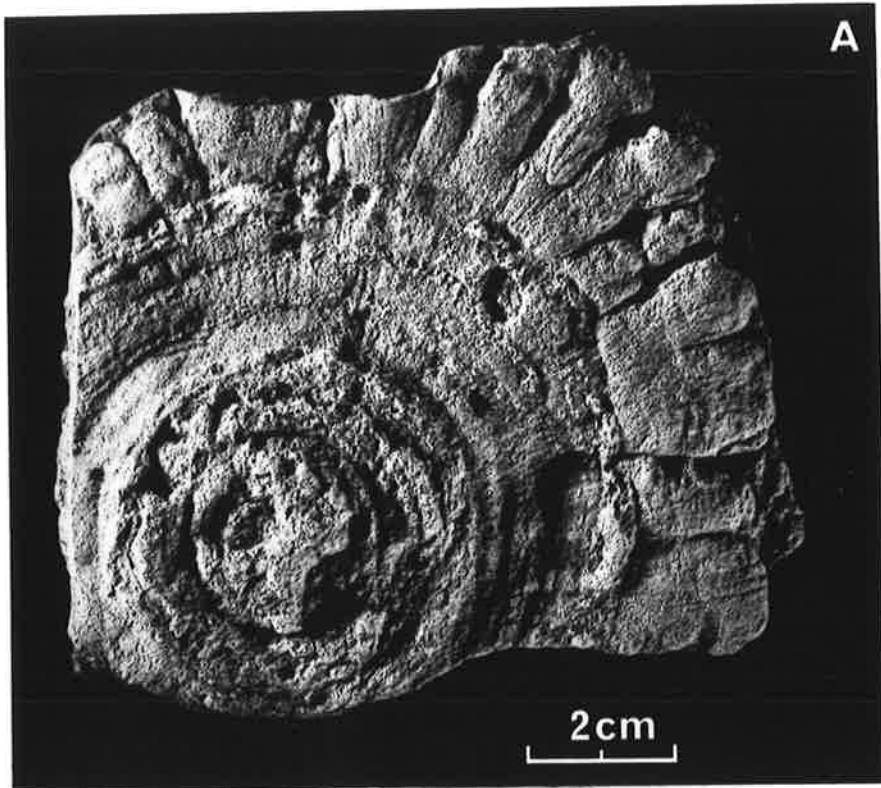


Plate 16

Mawsonites spriggi Glaessner and Wade, 1966, holotype, F17009, from Ediacara Range. Structures as numbered in the figure are explained in the text. Numbers (1-7) and letters (a,b, and c) refer to the equivalent features in Fig. 27.

Plate 16

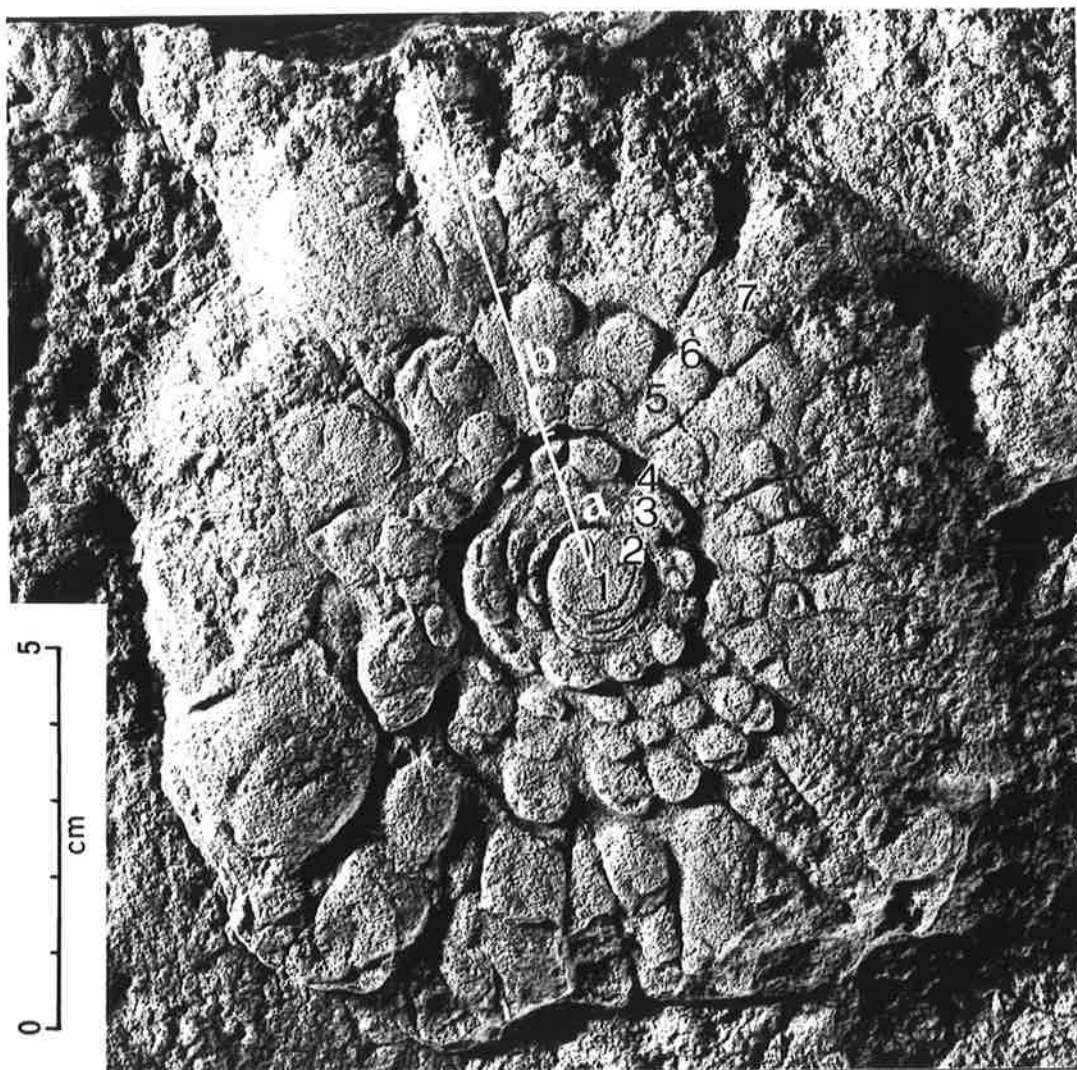


Plate 17

- A. Brachina delicata Wade, 1972. holotype, Fl7343, from Brachina Gorge, subumbrellar side, showing 1. very small marginal lappets, 2. radial canals, and 3. prominent coronal muscle band;
- B. Brachina delicata Wade, 1972. paratype, Fl7457, from Ediacara Range, exumbrellar side, showing 1. central disc, 2. double-grooved ridge (? coronal furrow), 3. surrounding zone, and 4. very small marginal lappets;
- C. Detail of marginal lappets in the marked portion of B.

Plate 17

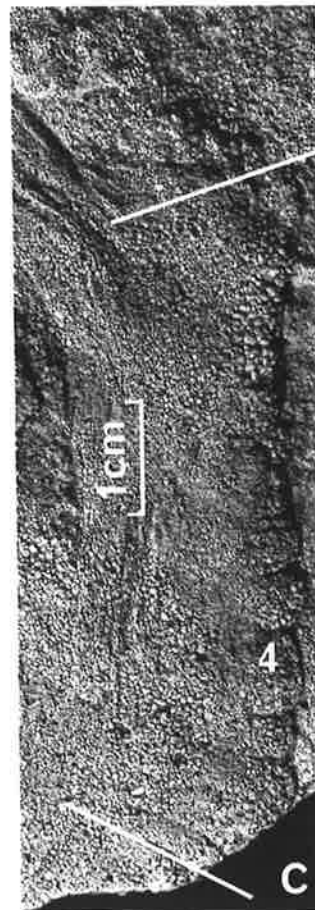
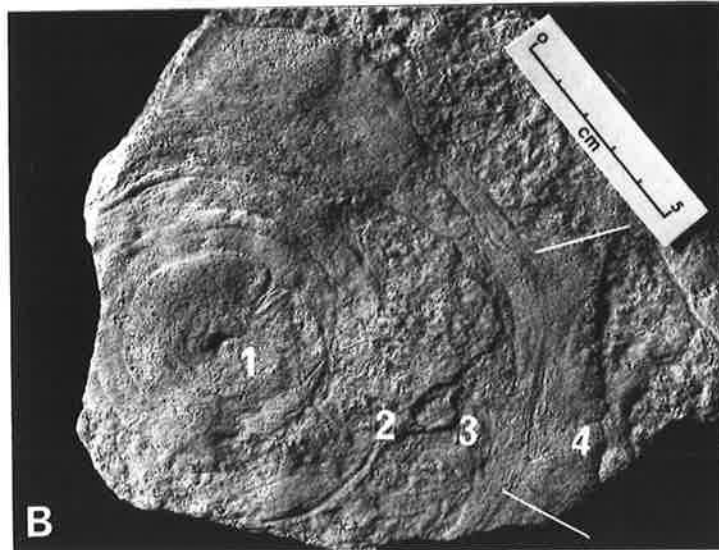


Plate 18

Paracharnia dengyingensis: A. holotype ZnF0011, from the Late Precambrian Shibantan Member of the Dengying Formation in the Eastern Yangtze Gorge, Hubei Province, China (by courtesy of Ding Qixiu of Hubei Institute of Geology). The scale is 2 cm long. B. Gross morphology of the holotype, tracing from A.

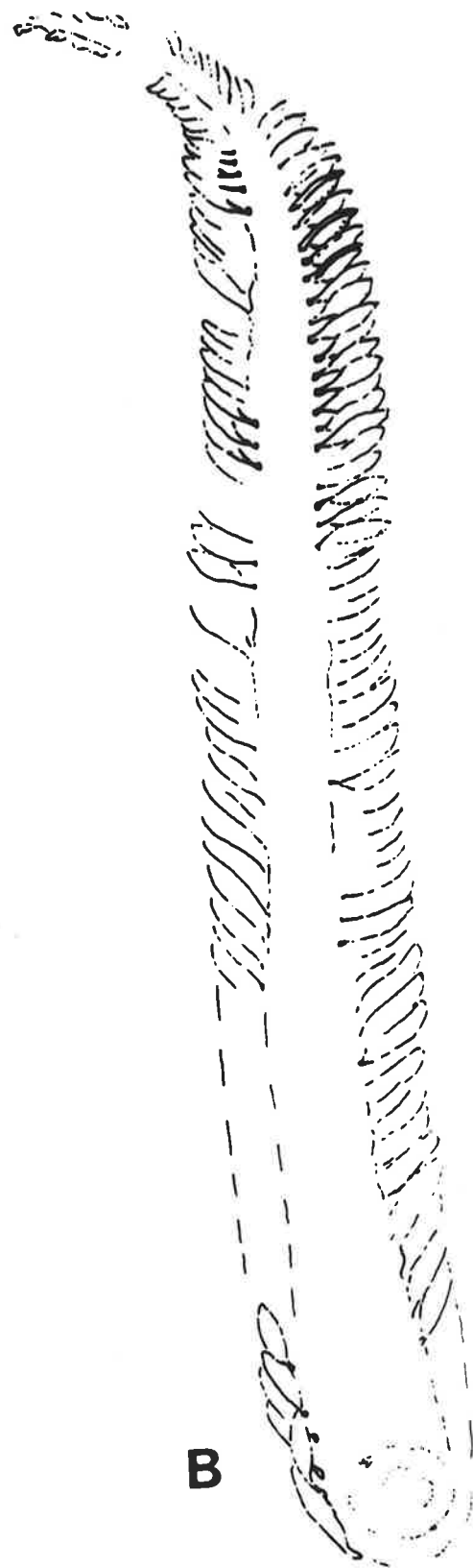
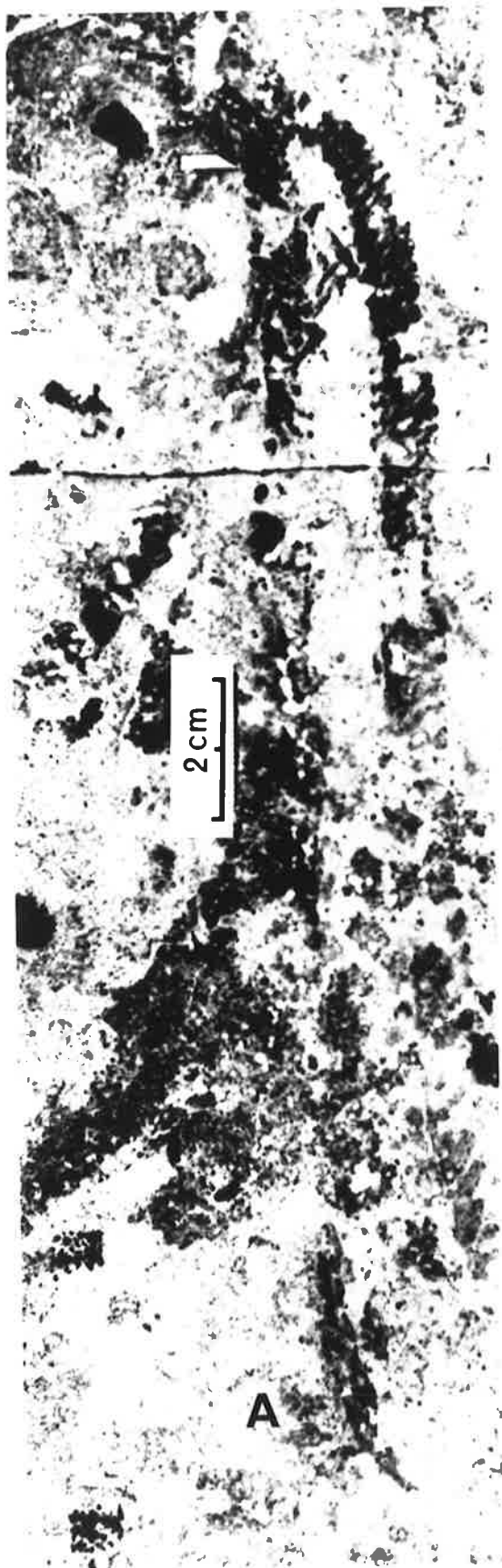


Plate 19

Charniodiscus longus (Glaessner and Wade 1966). 24593, from the lower part of the Rawnsley Quartzite, Pound Subgroup (Late Precambrian) in the Flinders Ranges, S. Aust. Preserved as composite mould with dominantly ventral aspect showing a long narrow frond with many polyp leaves joined by base to both sides of a prominent median stem.

Plate 19

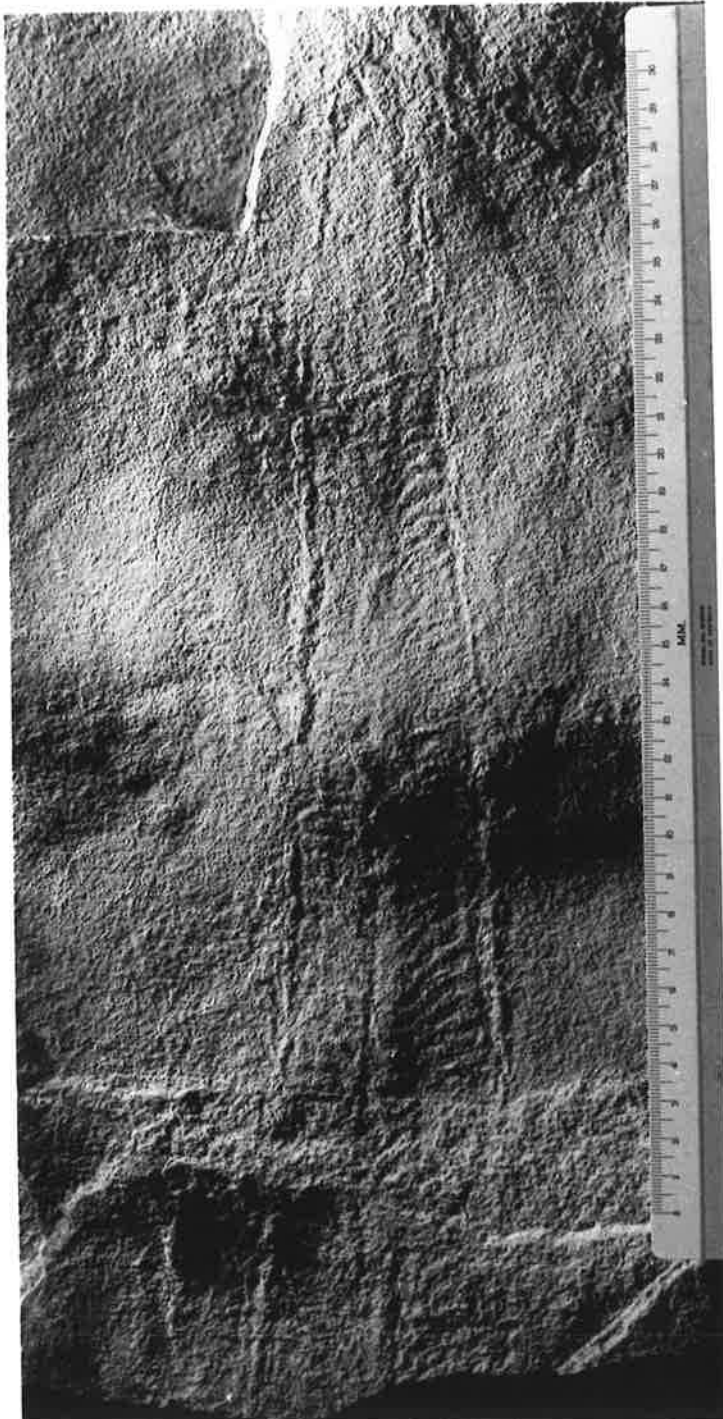


Plate 20

- A. Vendotaenia sp., Zds - 1a, x5, from the late Precambrian (Sinian) Shibantan Member, Dengying Formation at Shibantan in the Eastern Yangtze Gorge, W. Hubei, China;
- B. Sinotubulites baimatuoensis Chen 1981, silicified tubular fossils, from the late Precambrian (Sinian) Baimatuo Member, Dengying Formation at Shibantan in the Eastern Yangtze Gorge. (Specimen YG-96-2, by the courtesy of Qian Yi).

Plate 20

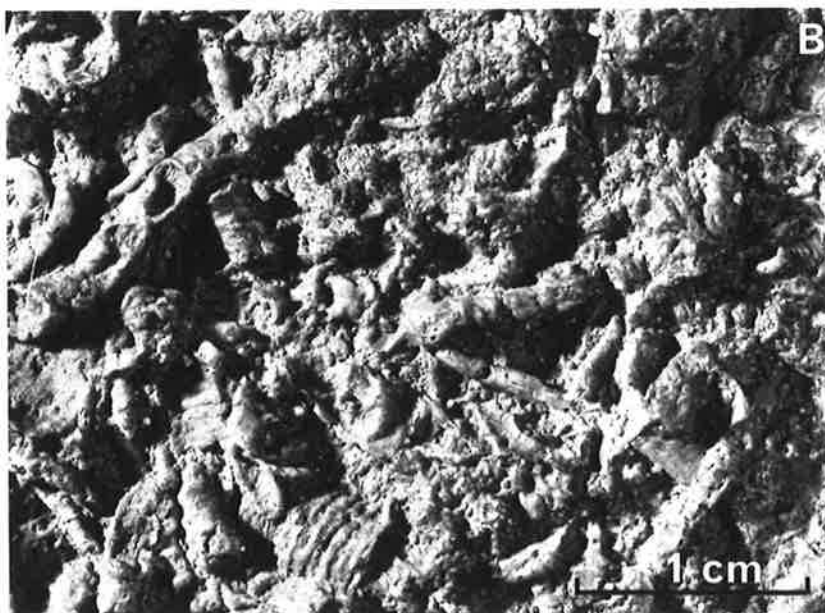
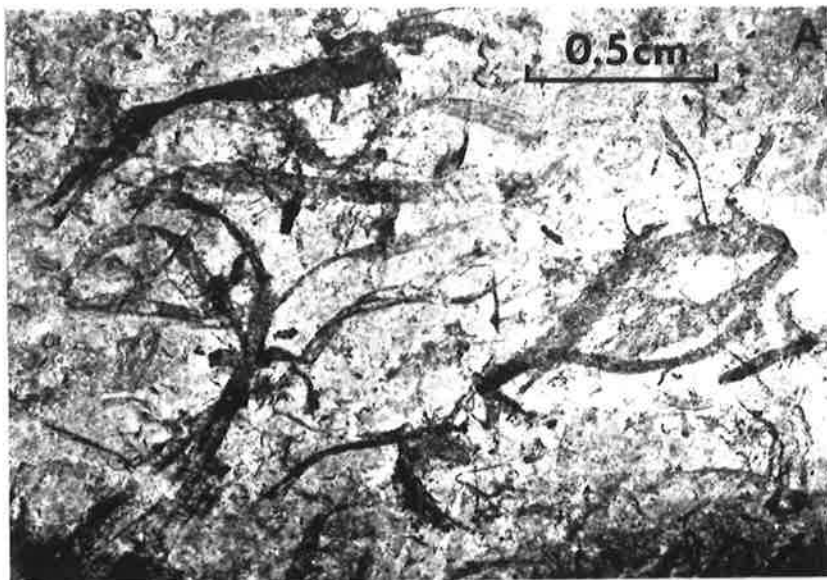


Plate 21

Basal Cambrian trace fossils:

- A. Didymaulichnus miettensis Young 1971, molluscan trails, on a lower bedding surface, from the Zhongyicun Member, topmost Dengying Formation, in the Meishucun section, eastern Yunnan Province, China. Specimen T82-1, by the courtesy of Qian Yi;
- B. D. miettenensis, on a lower bedding surface, from the Box Hole Formation (middle part of the 'Arumbera Sandstone'), at Cyclops Well, Central Australia. Scale : lens cap 65 mm in diameter.
- C. Plagiogmus arcuatus Roedel 1929 (large burrow above the lens cap) and some other sinuous trails, on a upper bedding surface, from the Allua Formation (upper part of the 'Arumbera Sandstone'), in the Ross River Gorge, Central Australia.

Plate 21

